3RD ANNUAL SOLAR AND BIOMASS WORKSHOP

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U.S. DEPARTMENT OF ENERGY SOLAR THERMAL COOPERATIVE PROGRAM IN ENERGY RD&D

by

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This conference affords the opportunity on behalf of the Department of Energy's Solar Thermal Program to recognize the outstanding contribution in successfully conducting the cooperative program between DOE and USDA. This program initiated through a Memorandum of Understanding in April, 1977, formalized a working relationship to mutually support Research Development, and Demonstration programs in the reduction of energy consumption, increased energy efficiency, and substitution of renewables for scarce forms of energy.

Practical scientific research and technology demonstrations carried out through the land grant universities, ARS, and the private sector have proved successful. Research activity in solar under USDA management has been effective in promoting unique solutions to farming requirements for energy management and fossil fuel displacement. Such challenges as seasonal restrictions and variable requirements for energy utilization are currently being addressed through multiple application systems and combination of renewable resources (solar thermal, wind, and biomass). One significant characteristic of the technology is its adaptability to lesser developed countries through low-cost easily understood energy conversion techniques. The dependence on energy for high quality/high yield food production places great importance on the successful implementation of this research activity.

Having transferred program management responsibility to USDA in FY 1983 for the continuation of the solar thermal projects, DOE looks to the continued USDA excellence in the furtherance of this activity. The establishment of an agricultural energy center is a significant step in recognizing the importance of this activity. The transfer of the technical information to the user community awaits as the next challenge. The Extension Service has made significant progress in implementing this task through the innumerable projects now under way with Federal and private funding. This conference provides an excellent forum for the exchange of ideas and you are wished every success in your endeavors.

RESEARCH MANAGED BY THE SOUTHERN AGRICULTURAL ENERGY CENTER

by

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"If you were asked what is the most serious problem facing mankind now, what would your answer be? Nuclear holocaust? Ecological catastrophe? The population explosion?

"I believe that the most pressing problem is to maintain the world's energy supply. What has come to be known as the 'energy crisis' represents a threat to progress and to standards of living in rich and poor countries alike which is inevitable and imminent. Our fuels, the ones we use now, will run out and they will run out soon." (1)

The ideas quoted above are not new, they have been expressed frequently when short-term energy deficits occur. When these deficits are relieved, however temporary, the price of fuel stabilizes or even decreases slightly and the future shortages of energy are dismissed from the mind.

Since food is one of the basic essentials for life, it is interesting to see the relationship between commercial (as opposed to human and animal) energy and agricultural production and productivity. Some relationships are shown in Table I.

TABLE I. Energy Use and Cereal Output (3)

	Energy/ Area	Energy/ Worker	Output/ Area	Output/ Worker	Agric. Energy
	10^9 J/ha (10^6 Btu/ac)	10^9 J (10^6 Btu)	kg/ha (lb/ac.)	kg (lb)	% Total
North America	20.2 (7.8)	555.8 (526.8)	3457 (3080)	67882 (148662)	2.8
Western Europe	27.9 (10.7)	82.4 (78.1)	3163 (2804)	5772 (12641)	4.9
Developing Countries	2.2 (0.8)	2.2 (2.1)	1255 (1112)	877 (1921)	4.8
Centrally Planned Countries	5.9 (2.3)	6.8 (6.4)	1744 (1546)	1518 (3324)	3.2
World	7.9 (3.0)	9.9 (9.4)	1821 (1615)	1671 (3659)	3.5

North America uses a smaller percentage of its total energy consumption for agriculture than any other geographic area in the world. The energy used per agricultural worker, however, is about 56 times the world average. By effectively utilizing this energy, each North American agricultural worker is able to produce about 40 times as much cereal grain as the world average and 77 times as much as the worker in the developing countries. The productivity per unit of land area is also highly energy dependent. The energy input per unit of land area in North America is about 2.5 times as much as the world average. Correspondingly, the productivity is about twice as much in North America.

From this, it may be seen that without a dependable supply of energy, the food production capability, especially in North America would be severely reduced. Even a temporary unavailability of energy for production agriculture, if it came during either the planting or harvest season, could result in a severe reduction in North American food production.

With recognition of the importance of energy to agriculture, Congress authorized the Secretary of Agriculture to make energy an integral part of agricultural policy and programs in the Food and Agriculture Act of 1977. Specific authorization was made for regional energy research and development centers, model farms and demonstration projects, and competitive grants dealing with solar energy with respect to farm buildings, farm homes, and farm machinery. Solar energy is defined in the Act to mean energy from all forms of renewable resources including solar heat, wind, and biomass. The Act also authorized research on the production of alcohols and hydrocarbons from agricultural and forestry products and residues. (2)

The President's FY 1980 Budget requested funds to establish and operate two such research centers with the goal: "To discover, develop and demonstrate technology which will permit agriculture to be energy self-sufficient on a net basis by 1990 under conditions that sustain productivity." (2) The 1981 Farm Bill under Title XIV, states "(B) Development of new Food, Fiber, and Energy Sources - Programs to identify and develop new crop and animal sources of food, fiber, and energy must be undertaken to meet future needs. (C) Agricultural Energy Use and Production - Much of the current agricultural energy technology is relatively energy intensive. It is critical that alternative technologies be developed to increase agricultural energy efficiency and to reduce dependence on petroleum-based products. Furthermore, agriculture provides the Unites States with alternative potential sources of energy that must be assessed and developed." (4)

Thus the two USDA Agricultural Energy Centers (Southern Agricultural Energy Center, Tifton, GA and Northern Agricultural Energy Center, Peoria, IL) were authorized by the 1977 Farm Bill and were again specifically charged to conduct research to reduce dependence on petroleum-based products in the 1981 Farm Bill.

The Southern Agricultural Energy Center is responsible for research, funded partially or wholly, by USDA or USDOE (pass-through funds), to collect, store, and utilize solar and wind energy and to produce, harvest, store process, and utilize biomass energy in the forms of crop residue, animal waste products or crops produced specifically for energy.

Achieving the goal established in 1980 would ensure the energy to maintain a stable and abundant supply of food. This should help the consumers to eat well for a reasonable percentage of their income. Additionally, the potential for an agricultural production capability, not subject to potential energy disruption, should be of great strategic value as we seek world peace.

In the short time since these Centers have been established, significant progress has been made toward achieving the stated goal. This Workshop will present the findings of this research, extension demonstration projects, and related research by the co-sponsors and others interested in renewable energy for agriculture.

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Research at the Northern Agricultural Energy Center[1]

by

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The Energy Centers established in 1979 have the goal to discover, develop, and demonstrate technologies that will permit agriculture to be energy self-sufficient by 1990 under conditions of sustained production of food, feed, and fiber. Furthermore, it was envisioned that technologies developed for farm-generated energy will carry into other sectors of the American economy.

The mission of the Northern Agricultural Energy Center is to (a) identify and develop energy crop production, mechanization, and conversion systems, (b) develop innovative fermentation technologies, (c) develop new efficient substrate preparation technologies, (d) maximize value of stillage residues, (e) identify and develop plant hydrocarbon resources, and (f) develop technology for utilizing vegetable oils as diesel fuels. From this mission, it follows that our main interest should focus on readily portable liquid fuels (1). A natural extension of the mission is development of petroleum-sparing chemicals and materials from agricultural sources.

Several plant species are being studied as potential energy-producing crops. Some are under consideration as sugar-producing crops. Still others are receiving attention as crops that produce carbohydrates which can be converted to fermentable sugars. Species under study are sugar beets, sugar cane, sweet sorghum, sweet stalk corn, and sweet potatoes. Other species are being evaluated as potential sources of hydrocarbon or oil extractable from the whole plant in contrast to seed lipids.

The unused portion of the above crops, as well as that from crops such as cereal straws, cotton and sunflower stalks, and the conventional corn, contains large quantities of cellulose and hemicellulose that can be converted to fermentable sugars. Although technically feasible, no efficient or cost-effective process exists for the hydrolysis of cellulose.

1/ To be presented at the Solar & Biomass Energy Workshop, Atlanta, Georgia, April 26-28, 1983.

The processing of these underutilized crop residues and subsequent use of the substrate are being investigated on many fronts (2,3). Chemical, thermal, mechanical, and microbial conversions continue to be investigated, and fruitful searches have identified suitable organisms to ferment the substrates. Most significant examples are Pachysolen tannophilus to convert xylose to alcohol (4-6) and Candida wickerhamii to convert cellodextrins to alcohol (7).

Alcohol fermentation of unrefined substrates leaves a residue containing minerals, protein, and other substances of potential value and requires treatment steps to eliminate pollution. Whole-grain fermentation leaves about 30% of the original mass as a feed product. Research attention has been directed toward preserving wet stillage residue and maximizing the value of dried residue as feed for ruminants and monogastric animals (8-10). Current research emphasizes assessment of distillers' grains as a component of blended foods (11).

Since 1974, we have been screening the plant kingdom to identify and evaluate species as sources of high-energy, easily extractable components suitable for fuel, chemicals, and petroleum-sparing chemical feedstock (12). Nearly 500 species have been evaluated and about 70 are identified as sufficiently promising to merit further attention (13). More than 20 species consist of at least 5% oil, and nearly a dozen yield greater than 2% isoprene polymers.

Vegetable oils from seeds--such as soybean, sunflower, peanut, rape, and coconut--are being evaluated in many parts of the world as fuel for compression ignition engines (14-15). Short-term tests were encouraging; however, long-term tests revealed problems generally attributable to inefficient combustion. This observation is especially true for direct injection engines. At least partially responsible for the poor combustion of neat vegetable oils are their high viscosity and nonvolatility. Techniques to modify these properties are currently under investigation. Approaches include blending with diesel fuel (16-17), derivatization (e.g. esters), and hydridization through formation of microemulsions (18-19).

Although much knowledge still must be gained before technologies based on these renewable resources can be established, the potential for technical feasibility is very encouraging. The future of these alternatives, of course, will be determined through need and economics. And, although no renewable energy crop is likely to resolve our nation's energy problems, such crops can certainly play a part in the solution.

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TVA'S BIOMASS FUELS PROGRAM

by

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ABSTRACT

In 1980 the Tennessee Valley Authority (TVA) formally organized a Biomass Fuels Program to provide information through research and development efforts that will encourage effective use of Valley biomass (principally hardwood) by industry. Hardwoods available for energy use and underutilized marginal lands offer opportunities to significantly relieve the Valley's dependence on petroleum while using renewable resources to provide economic development without serious environmental consequences.

Preliminary estimates indicate that 30 million tons of wood could be harvested for energy annually and still have an increasing forest inventory in the Valley. This quantity of wood could replace one-third of the oil and natural gas used in process and space heating applications by commerce and industry in the Valley plus produce sufficient liquid fuel, if an economical and efficient process is developed, to displace about one-fifth of the current gasoline consumption of the region. Conversion of hardwoods to ethanol by acid-hydrolysis is a primary objective of the program. Improvements from previous wood hydrolysis work by TVA and the Forest Products Laboratory of the U.S. Department of Agriculture are reportedly in commercial use in the USSR where vastly different economic conditions exist. Study is now underway on significant further improvements which should increase the yield substantially, decrease cost of production, and improve process efficiency. Direct combustion of wood in furnace/boilers to replace oil and natural gas is currently feasible in many situations, and some technical assistance has been offered to encourage commercialization. Efforts are underway to refine wood resource information, improve management practices, and reduce harvesting costs. Use of wood for energy has potential to improve the quality and productivity of forests over time.

The Valley has 1 to 2 million acres of underutilized/marginal lands; some have potential to produce energy crops and increase farm income. Productivity of nonwoody biomass crops is being studied for Valley conditions. A small-scale fuel alcohol unit, partially supported by the Department of Energy (DOE), is being used to evaluate conversion of alternative agricultural crops and crop residues to ethanol.

Numerous coordinative and cooperative endeavors are underway. TVA is providing technical assistance to the Agency for International Development to establish and implement a bioenergy program for less developed countries

and to DOE to monitor loan guarantees for ethanol plants. Coordination activities are underway with many other Federal, State, university, and private entities.

ON-FARM DEMONSTRATION PROGRAM USING SOLAR ENERGY FOR HEATING OF LIVESTOCK SHELTERS AND DRYING OF CROPS

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For several years, the U.S. Department of Energy has provided funds to the U.S. Department of Agriculture, Science and Education, Agricultural Research to investigate the use of solar energy in the heating of livestock shelters, drying of crops, and the heating of greenhouses. In 1978, it was decided that enough positive results had been obtained from this research so that it could be put into practice on farms. The Extension Service, as the educational arm of the Department of Agriculture, was called upon to assist in developing an on-farm demonstration program in cooperation with the State Cooperative Extension Services and farmers.

The Department of Energy provided $1.2 million for a livestock shelter solar heating demonstration program and $1.05 million for a solar crop drying demonstration program.

PROCEDURE

The Extension Service entered into two contracts with the Department of Energy for the funding and conduction of pilot solar projects with the following objectives:

SOLAR HEATING OF LIVESTOCK STRUCTURES - OBJECTIVES

Demonstrate the technical and economic feasibility of using solar energy technology for heating of livestock structures.

Test solar energy technology under operating farm conditions.

In corporate energy conservation techniques.

Minimize solar heating problems.

Identify incentives and opportunities for widespread farm application of solar energy technology.

SOLAR DRYING OF CROPS AND GRAIN - OBJECTIVES

Demonstrate the technical and economic feasibility of using solar energy technology for drying crops and grains.

Test solar energy technology under operating farm conditions.

Incorporate energy conservation techniques.

Minimize solar drying problems.

Identify incentives and opportunities for widespread farm application of solar energy technology.

After the contracts and objectives had been agreed upon, the Cooperative Extension Services were invited to submit proposals for conducting these demonstrations at the farm level.

In March of 1979, Cooperative Agreements were signed with 9 States to conduct the demonstrations on privately-owned livestock farms. There was a stipulation that only poultry, swine or dairy facilities would be acceptable since these types had been researched and all required considerable heat energy input.

The proposal was to cover a 3-year period with a proposed budget of approximately $100,000 the first year and $10,000 for each of the next 2 years. In most cases, the University and farmer contributions matched or exceeded the budget requested from Extension Service.

A similar procedure was followed in awarding the solar crop drying cooperative agreements. In both programs, a minimum of 10 demonstrations per State was specified.

Also, considering that the economics of solar heating are not clearly established, the University was permitted to cost-share up to approximately 50% of the cost of solar equipment installed.

Another restruction on the program was that the engineering design for a system had to be approved by a panel of solar experts before construction was begun. This was to assure that design features and material selected conformed to the best technology available. Radical, untried systems and materials were rejected from this demonstration program and referred to research for study.

After the design had been approved and construction completed, the system was instrumented by the Extension Agricultural Engineer and monitored for a period of at least 3 months. When the system was functioning and some assessment had been made concerning the performance, it becomes the farmer's responsibility to continue to operate it as a demonstration for at least 3 years. A public information program is built around the system and its performance. This is to encourage those who observe it to install similar systems.

A great variety of solar systems are included in the program. All collector systems are non-concentrating, either air or liquid and may be roof, wall, free-standing or portable. Multi-use has been another objective to reduce the real cost of owning the system.

Collectors range in size from 622 sq. meter (6,700 sq. ft.) to 6.7 sq. meter (72 sq. ft.). Collector costs range from $753 per sq. meter ($70 per sq. ft.) for a commercial system to $3.77 per sq. meter ($0.35 per sq. ft.) for a simple home-built unit.

The Solar Heating of On-Farm Livestock Shelters initially started with 91 demonstration sites in 9 States. The States are Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, Vermont, and Virginia. At present, there are 84 livestock shelter demonstrations in the 9 States. There have been withdrawals of farmers from the program due to economic and other problems. The Extension Engineers in the various States have been able to find additional cooperators to fill most of the voids.

At present, all livestock demonstrations are operational. Some will be completing the third heating season now.

In November of 1980, 9 States were selected to participate in the On-Farm Demonstration of Solar Crop and Grain Drying Program. Each State was to establish 8 to 10 solar demonstrations for a total of approximately 90.

The 75 farmer cooperators now in the program have systems in operation for drying 12 different crops, space heating 42 buildings, and supplying hot water to 2 residences.

All of the facilities (both livestock structures and crop drying facilities) are now being used as examples in a Solar Heating Extension Education Program. Extension Specialists are writing Fact Sheets, Leaflets, and other publications based on these demonstration sites. In addition, tours, field days, meetings, and other activities are being planned and conducted to familiarize the community with the capabilities of solar heating.

The history of Cooperative Extension has proven that Result Demonstrations are extremely powerful teaching devices. Through this modest program of demonstrating the use of solar heat to replace fossil fuel in livestock structures and crop drying, we believe that American farmers can reduce their production cost and move toward energy independence.

FUTURE I: A UTILITY INTERACTIVE PHOTOVOLTAIC RESEARCH HOUSE

by

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ABSTRACT

This paper describes the design, operation, and experimental results of a utility interactive photovoltaic research house. Several advanced energy technologies are utilized in the house in addition to the photovoltaic system. A unique feature of the house is a computer system that is used for load management, security, and personal use. The prime function of the computer is to provide load control to optimize the house's electrical energy requirement with the energy generated by the photovoltaic array. Approximately 90 channels of data are recorded by the data system. Preliminary results indicate a highly reliable photovoltaic system operating at predicted performance levels.

INTRODUCTION

Georgia Power Company recently constructed a solar photovoltaic research house. The house, which is called "FUTURE I", is located in Atlanta, Georgia. The United States Department of Energy has sponsored a similar type house in the Boston, Mass., area[1]. However, Future I is one of only a very limited number of lived-in residential photovoltaic research projects, and the first in the Southeast U.S. The house contains several different types of energy utilization technologies, and is designed to study and research these technologies both independently and as an integral energy system for the house. The different applications of energy technologies include photovoltaics, passive solar techniques, energy conservation features, chilled water storage, and eutectic salt thermal storage.

PHOTOVOLTAIC SYSTEM

Description of System

The photovoltaic system at Future I consists of 64 flat plate modules set at 34 degrees to the horizontal. This is the latitude of the Atlanta area and should provide the optimum amount of energy on an annual basis. The photovoltaic array is an integral roof mount design. Besides providing the weather tight seal for the roof of the house, this type design allows more ventilation for the cooling of the modules. Since the output of PV cells decreases approximately 1/2% for each degree rise Centigrade, this is a very important consideration in a hot climate. Also, there is some concern that higher temperatures may degrade PV modules.

Table I lists the characteristics of the photovoltaic system at Future I. Under standard conditions (28 degrees at 100 watts/meter), the PV array will produce 4.1 kilowatts of electric power. This is enough to provide most of the power for the house's major appliances. Since the system is utility interactive there is no electrical energy or battery storage. Georgia Power supplies back-up energy on cloudy days and at night. Excess energy from the house will flow back to the distribution line where Georgia Power will buy back this energy.

Table 1
Photovoltaic Power System Characteristics

Array

Power Rating - 4.1 KWp
Voltage - 200 VDC, 21 Amps (Nominal)
Energy - 5000 Annual Estimated
Configuration - 64 Modules
14 rows of 4 modules
Manufacturer - Solec International

Inverter

Power Rating - 4 KW dc input
Input Voltage - 170-230
Output Voltage - 230 VAC
Efficiency - 91%
Manufacturer - DECC (Div. of Helionetics)

Experimental Results

Preliminary results indicate that the photovoltaic system is operating at predicted design levels. After some initial start-up problems were corrected, the system has had no down-time from equipment or system failure since June 1982. The system has been tested for performance output. Table II gives the rated and measured DC power outputs as recorded for an interval of time on August 26, 1982. This table shows the array operating at approximately 2.6 to 4.3% above the expected rate output.

Table II
Rated and Measured PV Array Performance

Solar Insolation	Rated Pw	Measured Pw	% Diff.
867	3259	3344	2.6
798	2999	3115	3.8
762	2864	2974	3.8
722	2714	2832	4.3

Georgia Power has performed or has planned a number of utility interface experiments for the house. This is part of a United States Department of Energy program called the Southeastern Residential Experiment Station. Emphasis is focused on power quality specifications and impact of dispersed photovoltaic systems on electric utility operations. The technical issues being investigated include (1) Fault Protection, (2) Harmonics, (3) Voltage Regulation and Power Factor, (4) Islanding, and (5) Utility Operations. Utility operations includes potential problems such as reverse power flows, transformer overload, system stability, automatic generator control and other related-type operating problems.

The effects and propagation of harmonics are also being investigated. The major problem here may be that although individual power conditioning units have low harmonics, the current harmonics may become additive[2], thus requiring a restriction on the number of PCU's on a given circuit. Some other countries have already established standards.

Voltage regulation and power factor are other issues being studied along with utility operating problems. These are planned for additional study in 1984, 1985 and 1986.

COMPUTER INFORMATION AND CONTROL SYSTEM

A unique feature of Future I is its computer system which is used for load control, security, information services, and personal use. The computer is tied by telephone line to a computer information service which provides the homeowner a variety of services. This includes, for example, news reports, weather, airline schedules, electronic mail, etc. Planned additions include automatic meter-reading and billing for utility electric service, home banking and catalog shopping, ticketing and related-type services.

CONCLUSIONS

Test results show that the PV system is operating at design output levels. After initial equipment check-out, there has been no down time or failure indicating a highly reliable PV system. As of February 1, 1983, more than 2700 KWH of electrical energy have been produced by the PV system.

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SOLAR

SOLAR PEANUT DRYING

by

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ABSTRACT

With the rise in price and occasional unavailability of our normal supply of fossil fuels over the past ten years, it has become necessary to look at alternative sources of energy. Peanuts as a food crop require timely drying after harvest to preserve their quality. This report summarizes research in developing the critera needed to design a solar facility for drying peanuts. Experiments using both a solar heated air system with rock storage and a solar heated water system were considered. Using a computer simulation model verified by experimental tests, system sizes for both systems were developed.

Introduction

Peanuts are a food crop which must be dried within specific limits if quality is to be maintained. Under current production practices in the Southeast, the plant with the pods attached is removed from the soil at maturity and inverted in a windrow with the pods exposed to the sun. After about three days, when the peanuts have dried from 40-50% moisture at digging down to 20-25% moisture, the peanuts are combined and the pods are removed from the vine and placed in wagon dryers. The wagons have a perforated-metal floor which serves as a plenum for distibuting the air. Drying of the peanuts continues using forced, heated air until the moisture reaches 10%. At this point, the peanuts are normally sold at market.

Research has shown that the temperature of the drying air must not exceed 35°C for any extended time. Prolonged subjection to higher temperatures will result in off-flavors and will increase the number of split kernels. Either of these factors will lower the price paid for the peanuts. Research has also shown that peanuts must be dried promptly so that molds and associated mycotoxins do not develop. Mycotoxin contamination will cause rejection of the lot for food purposes, making them available only for the lower priced oil-stock market.

Drying the peanuts requires energy for heating the drying air. Under normal conditions, drying requires about 38L of liquified petroleum gas (LPG) per ton. At 17¢/L this amounts to about $6.50/T or $29/wagon.

Nationwide, the fuel bill approximates $10 million. Half of this bill could be saved through use of solar energy.

The objective of this research has been to investigate the feasibility of using solar energy for peanut drying and develop the necessary criteria for designing solar peanut drying systems.

Experimental Facilities

In 1977, a solar crop drying facility was constructed by the USDA-ARS at the Georgia Coastal Plain Experiment Station at Tifton. The roof of the building slopes at 15° toward the South with 140 m^2 for solar heating air and 66 and 82 m^2 for heating water. Energy from the solar heated air is stored in a 118 T. rockbed while energy from the solar heated water systems is stored in two 5300 L concrete tanks. Each of the three systems can be used to preheat the air for a conventional peanut drying system. Peanuts, using the wagon dryers (4.72 Mg capacity), are supplied by a farmer cooperator. In experimental tests, dryers using the air/rock system and one of the water systems have been compared with a conventional dryer using LPG fuel (2).

Simulation Program

A computer simulation program has been developed to describe the solar peanut drying system (1). The solar components of the program are from TRNSYS developed at the Solar Energy Lab at the University of Wisconsin. Additonal subprograms have been developed to describe the peanut dryer and the control system. Results of the experimental tests have been used to verify the accuracy of the simulation model.

Design Analysis

The simulation program was used to determine the system performance over a range of parameters for the system. Collector area, storage volume and initial storage temperature were varied and the percent of the energy contributed by solar and the 72-h recovery temperature were determined for each condition. Ideally the temperature for a given storage volume should recover to its initial level in preparation for the next drying cycle. It was found that when drying started at 6 P.M. the first day (as would normally be encountered in practice), drying had to continue until the morning of the third day. At the end of drying, the storage temperature was normally close to ambient so that another day of radiation was required to recover the temperature.

Regression equations were then developed describing percent solar and recovery temperature in terms of the primary variables. From these equations, a series of collector area-storage volume relationships were determined that would provide 50% solar energy for a given initial storage temperature. Likewise, using the temperature equation, another series of collector-storage relationships were determined. Thus, for a given initial storage temperature and percent solar, an unique collector-storage size can be determined (3).

After relationships for the primary variables were determined, effects of other parameters were considered including the transmittance-absorptance product, collector efficiency factor, heat loss coefficient, slope, collector flow rate and storage loss coefficient. Regression equations were developed to modify system performance based on these parameters.

Water System

A similar analysis was used to determine performance of a solar heated water system for peanut drying. All of the above factors were considered in addition to heat exchanger parameters, including exchange capacity and flow rates through the exchanger (4).

DESIGN RESULTS

For a peanut drying system using average season weather data and assuming practical values for the system parameters, the design equations showed that for an air/rock system a collector area of 156 m^2 and storage volume of 56 m^3 would provide 50% of the energy from solar for drying one wagon of peanuts from 20 to 10% moisture on a three-day cycle. For a water system, the collector would be 129 m^2 with a tank volume of 22 m^3 to provide the same performance.

FUTURE RESEARCH

The two major inhibitions to acceptance of solar energy systems by the farmer are economics and the lack of a reliable energy source when the sun fails to shine. Since the fixed costs of collector and storage remain the same regardless of the amount of time that the system is used, it would be necessary to develop a system that could provide heat energy for a number of uses throughout the year. In the Southeast, peanuts are harvested in September and October. Corn and small grains, which may be dried in the same wagon dryers, are harvested both before and after peanuts. Tobacco, which must be cured, is harvested in July and early August. Other uses, such as heating a greenhouse for producing seedlings in the Spring and/or heating a shop or livestock structure in the Winter, may extend the useful period for the solar system.

The experimental system described above used LPG gas as a backup system. LPG or natural gas is convenient if it is readily available at a reasonable price. Biomass products available on the farm might also be integrated into a solar energy system. Use of these resources, however, will require additional research so that all energy sources available can be utilized effectively.

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DESIGN CHANGES SUGGESTED BY CONSTRUCTION AND EVALUATION OF A MULTI-USE SOLAR DRYER FOR HAY

BY

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ABSTRACT

A multi-use modular dryer using solar heated air has been built at the Middle Tennessee Agricultural Experiment Station at Spring Hill, TN. Its primary use is for rapid drying of large round bales of high moisture hay. Drying grain and providing a heated machinery shop (the hay drying floor area) during winter months are other uses. The dryer facility, which has the capacity to dry 32 large round bales of hay, was first used in late September, 1982. Initial moisture content of the 13-15 #/ft^3 bales ranged from 34-51%. The hay was dried with a fan static pressure of 4.5 in. water in 4-5 days of mostly inclement weather. Analysis of the system indicates that beneficial design changes are possible.

DESCRIPTION OF DRYER FACILITY

Dryer Building - The dryer building is 37.5 x 64.5 ft. with 2550 ft^2 net suspended plate collector surface in sixteen 4-ft. wide ducts covering the south wall and roof of the building. Design air flow rate through the collector ducts is 15 cfm/ft^2 collector surface. Eight lateral floor ducts, each equipped with a 3 HP vane-axial fan in a common fan room provide capability for drying 32 large round bales simultaneously. Each fan delivers 4800 cfm at 3 in. water static pressure. For grain drying, the fans are repositioned to direct air through openings leading to 5000 bu. grain bins (4 fans per bin). When the hay dryer floor is used as a shop area, four auxiliary fans supply a total of 2680 cfm of solar heated air through four of the lateral ducts. A complete description of the building in its present state is given by Bledsoe *et al.* (1981), except for the air transfer duct and manifold between the collector/storage unit and the dryer fan room. The collector/storage unit is connected to the dryer building by two 18-ft lengths of 4-ft i.d., corrugated-steel culvert (Fig. 1-A). The valve box, transitions and manifold were constructed of angle iron frames covered with sheet steel. All air-delivery components were insulated with one-inch thick polyurethane sprayed on outside surfaces and weatherproofed.

The air-entry door control mechanism at the south side of the dryer building also was redesigned for greater rigidity and precision control. A 10-ft. wide, one-ft. thick layer of white limestone rock was placed in a one-ft. deep excavation lined with a six-mil black polyethylene sheet barrier at the south of the building. The purpose was to prevent plant growth and dust accumulation at the air entrance to the collector. The white limestone also reflected additional radiation to the vertical, south-wall collector.

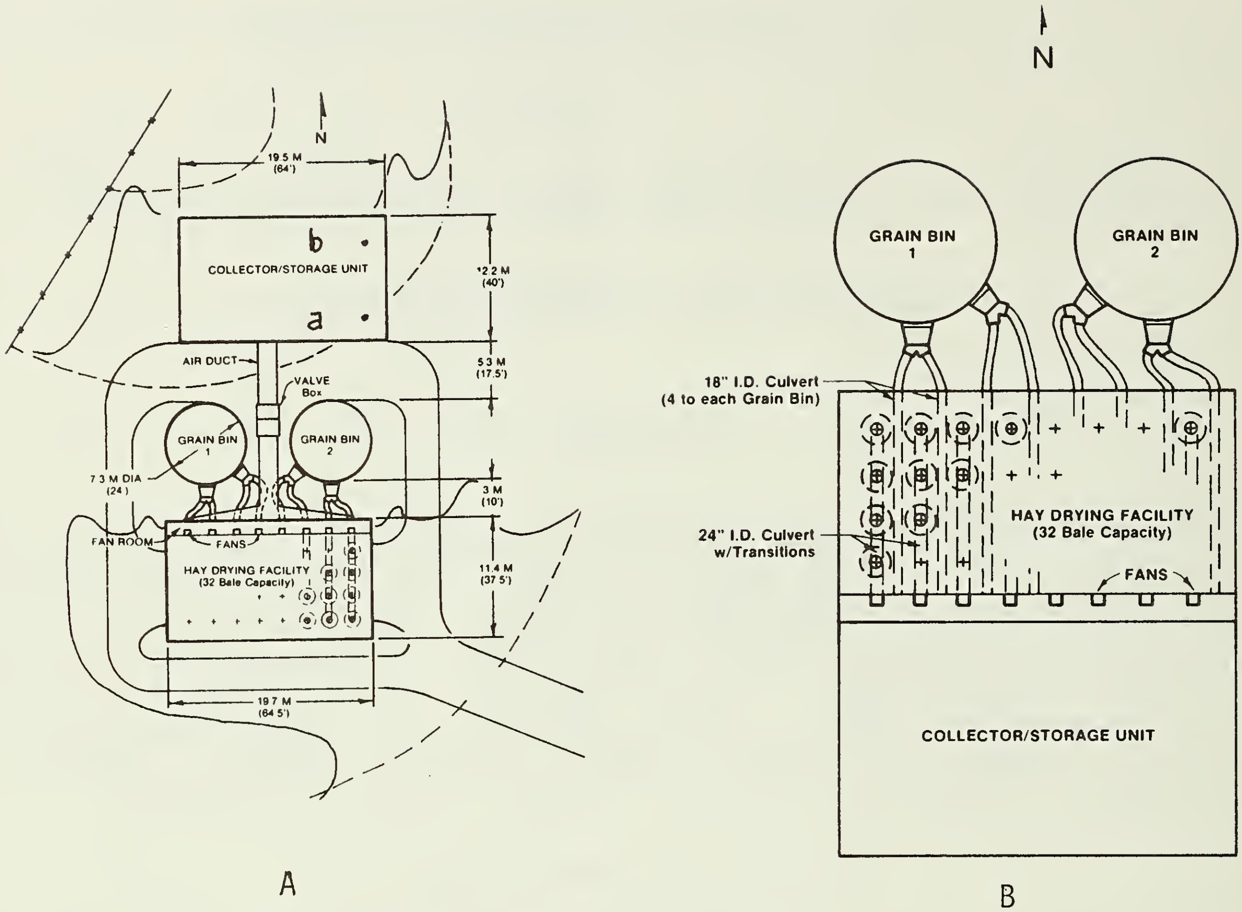

Fig. 1. Site plan of the drying facility: (A) As constructed; (B) Revised arrangement proposed to reduce construction cost.

Collector/Storage Unit - Plan size of this unit is 40 ft. x 64 ft. It has a net solar collecting area of 2119 ft^2 and a rock volume of 6357 ft^3 (2119 ft^2 x 3 ft. depth). For the heat storage mode of operation, design air flow rate is 10,000 cfm at 0.5 in. water pressure drop. The fan, positioned at the north center part of the structure, draws air from the bottom of the rock bed and exhausts it to the blackened top surface of the rocks. As the air travels down through the rocks it moves the heat down into the rockbed. The plenum space below the rock bed was constructed of bond-beam blocks placed on the concrete slab with the webs pointing upward. These blocks support a 0.25-inch thick tempered pegboard having 0.25-inch diameter holes spaced one inch apart. This pegboard was used to ensure a pressure drop through the rock bed of at least 0.5 in. of water for uniform air flow throughout the rock bed, (McGraw et al., 1983). Similar units are described by Kreider and Kreith (1982) and Howell et al. (1982). The rocks used were #24 drainfield type washed limestone (2-3 in. dia.).

For nighttime operation, 38,400 cfm of air is pulled by the dryer fans operating against hay static pressure of 3 in. water. If this flow through the rock bed is maintained at all times during the night, the rock bed will be depleted of heat during the latter part of the night. Therefore, outside air is mixed with air from the rock bed to maintain relative humidity of the air entering the hay bales at a value of no higher than 60%. A proportional damper and an adjustable humidistat are employed for this function.

DRYING TESTS

Dryer Facility Performance

The facility was completed in 1982 in time for one hay drying test in late September. The drying experiment involved high-moisture (34 to 51% w.b.) lespedeza-fescue hay and extended over a 5-day period of mostly inclement weather (only 2 fair days - not consecutive-out of 5). Air static pressure drop through the building collector was only 0.1 in. water, indicating efficient air flow. However, the dense hay bales caused plenum static air pressures of 3.4 to 4.5 in. water, resulting in lower air flow rates through the bales than desired.

The baler tension was reduced to decrease bale dry-matter density. However, a wide variation in hay moisture content and smaller than desirable windrows compensated for the change in baler tension. The result was that bale dry-matter density remained fairly constant although bale wet-weight density changed. Since resistance to air flow is a function of hay dry-matter density, no significant drying advantage accrued to the lower wet-weight density bales. Moisture was added back to bales during periods of rain.

Performance of Collector/Storage Unit

Time-temperature data were taken from sensors buried at 2 in.,12 in., and 24 in. deep in the rock at two widely separated points near the east end of the rock bed. The temperatures were measured during the daytime and nighttime modes of operation on September 23, 1982. A comparison of the data revealed that during the daytime mode of operation, non-uniform airflow occurred, with less air volume moving through the rocks farthest from the circulation fan, (Point a, Fig. 1-A). During the nighttime mode of operation non-uniform airflow again occurred, with the bed area nearest the dryer facility fans having the greatest airflow (Point a, Fig. 1-A). The end results was that higher temperature rocks were somewhat bypassed at night and much of the stored heat was not used. The following night, the collector/storage fan was left on during the nighttime mode of operation. This fan aided in equalizing airflow through the rocks to give a more thorough release of the stored heat.

Air leakage in the center hay drying unit collectors mixed with process air from storage in the fan room and increased humidity above the desired level of 60% maximum. These leaks will be repaired before further tests are conducted.

POSSIBLE DESIGN CHANGES FOR IMPROVEMENT IN COST AND PERFORMANCE

Consideration of components costs, along with evaluation test results, suggest possible design changes for improvement. A utility comparison of the three duct/grate designs evaluated for directing heated air into hay bales and serving a load bearing grates during shop use showed the 2-in. grate to be the most practical. Model tests of this design revealed that the center support column originally specified is not required to support a 10,000-lb. wheel load on the grade. An additional cover is needed on the grate side to keep out debris.

The large openings (12 ft. x 23 ft.) in the east and west ends of the dryer building allow prevailing westerly winds to sweep out moisture laden air exiting from bales. However, the tracked doors built for these openings were not as easily adjusted and maintained as desired. A new, commercial bi-fold door might be more appropriate than tracked-type doors for this application.

A more compact site plan, eliminating the expensive, connecting air-duct is shown in Fig. 1-B. Revisions in the design of the main dryer building include a raised floor, metal culvert air ducts, and a smaller fan room. These changes and a revised air circulation system for the collector/-storage unit are shown in Fig. 2. Adoption of these design changes depends on satisfactory performance of the existing dryer with reduced collector surface area in the south wall of the building. Extensive dryer evaluation experiments during the year 1983 should provide data on minimum collector surface requirements.

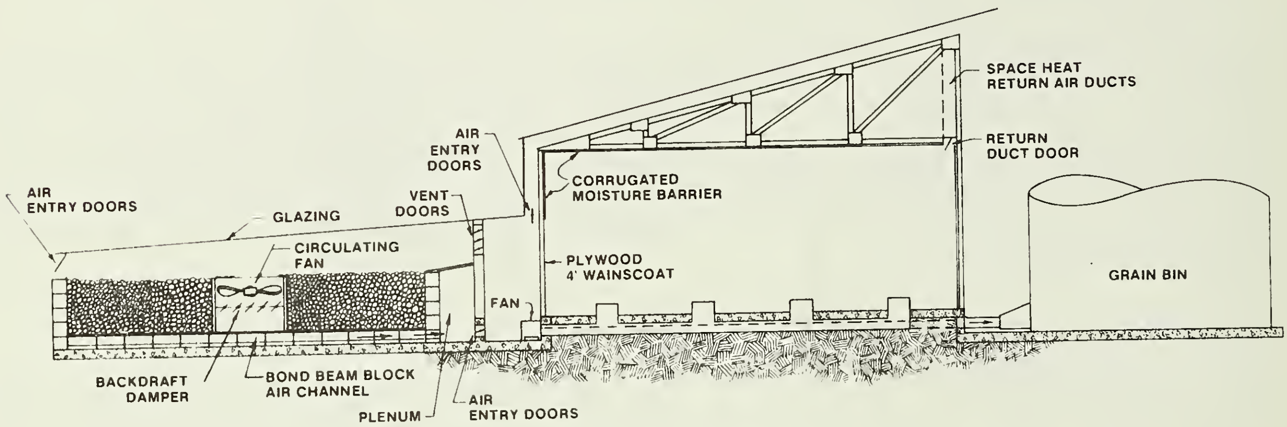

Figure 2. Cross-sectional view showing proposed revisions in multi-use solar dryer.

SUMMARY

A multi-use modular dryer using solar heated air was completed at the Middle Tennessee Agricultural Experiment Station during 1982. An evaluation test made in late September suggested operational and design changes that should reduce drying time. Analysis of construction costs and operational utility of the dryer suggested other design changes for a more usable, less costly facility. Concepts of the proposed changes are illustrated in the paper.

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SOLAR GRAIN AND CROP DRYING -- THE FLORIDA EXPERIENCE

by

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ABSTRACT

Ten hot air solar collectors were constructed and tested in Florida to demonstrate the technical and economic feasibility of using solar energy. This report is the Florida experience with solar energy utilization for drying crops and grains. The performance of the individual collectors reflects the points of success and the difficulties encountered.

Our Approach:

The solar systems were selected on a simplistic, pragmatic approach stressing:

1. Simple construction.
2. Low cost materials.
3. 20%-30% efficiencies.
4. 10^{o} - 30^{o} F temperature rise.
5. 2-4 cmf/ft^2 air flow rate.
6. Use primarily as pre-heater to reduce fossil use of conventional equipment (no heat storage).

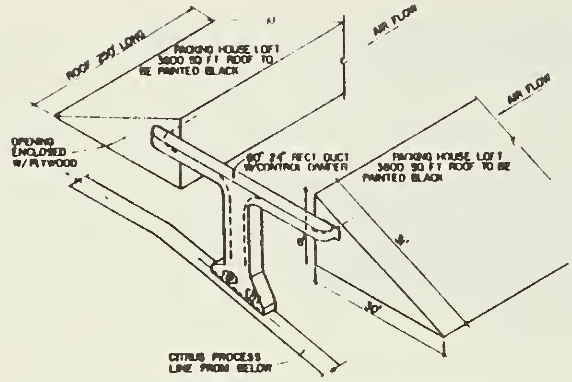
State Coverage and Crop Variety:

The project consists of solar dryers located at ten separate locations with good coverage of the State, and good crop variety (two citrus, two potato, four corn, one peanut, and one small grain/grass seed).

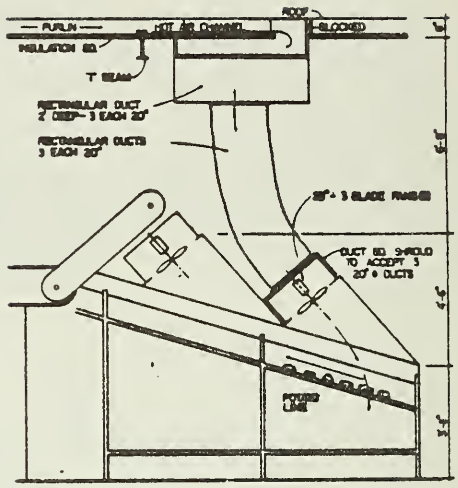
Collector Design Variety:

The project also involves good solar collection design variety:
2 - inflated plastic collectors with suspended screens
1 - roof mounted plastic collector
4 - roof retrofit bare-plate collectors
2 - roof mounted covered-plate collectors
1 - covered-plate collector incorporated in the construction of a new roof
1 - free-standing portable covered-plate collector

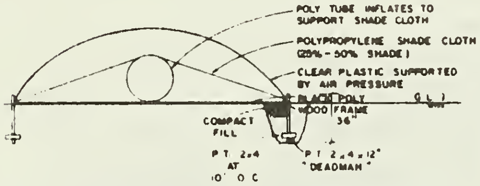
Figure 1 shows the plans for the ten solar dryers.



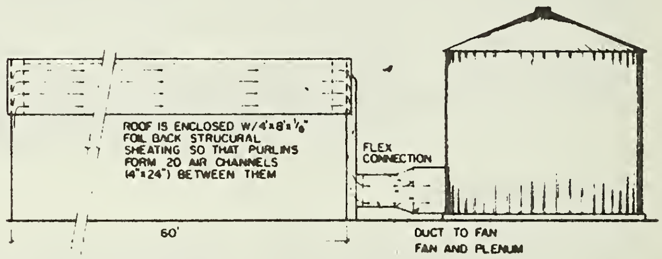
ROOF RETROFIT BARE-PLATE COLLECTOR



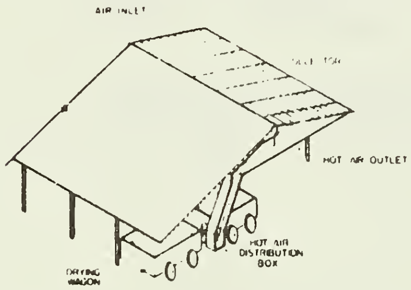
ROOF RETROFIT BARE-PLATE COLLECTOR



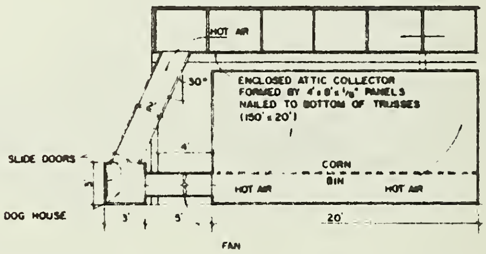
INFLATED PLASTIC COLLECTOR
WITH SUSPENDED SCREEN



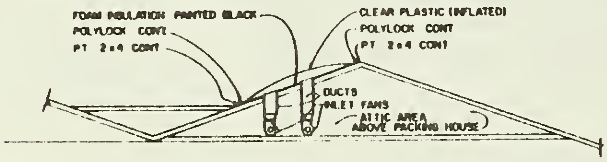
ROOF RETROFIT BARE-PLATE COLLECTOR



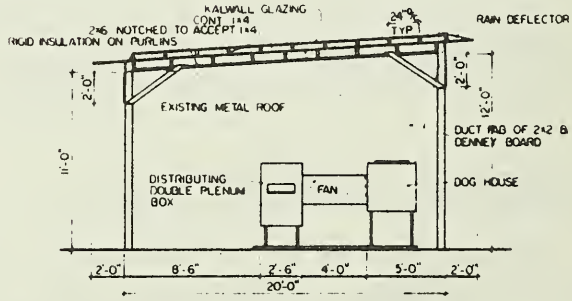
COVERED-PLATE COLLECTOR INCORPORATED
IN THE CONSTRUCTION OF A NEW ROOF



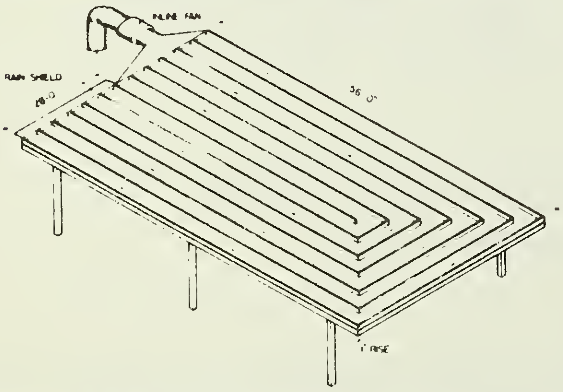
ROOF RETROFIT BARE-PLATE COLLECTOR



ROOF MOUNTED PLASTIC COLLECTOR



ROOF MOUNTED COVERED-PLATE COLLECTOR



ROOF MOUNTED COVERED-PLATE COLLECTOR

Figure 1. Plans for Solar Dryers.

Construction:

At the inception of this project, there were no full-scale solar drying systems installed in the State of Florida. After a considerable amount of effort, ten potential cooperators were identified and conceptual designs for ten projects were completed. The diversity of the collector designs resulted in several individual designs rather than an adaptation of a common design. This resulted in more time required to prepare the ten project designed, but ultimately enhanced the project by generating more information. Another factor which delayed the project design schedule was the disperse locations of individual projects. All the projects required at least a half day for visits and three required two days for a visit. This was a problem in design preparation, but it too was an enhancement of the project. Once the designs were approved management of all phases of the construction began. Our approach to project implementation and management was to purchase the solar construction materials and provide technical plans and assistance to cooperators. The cooperator was responsible for the construction of the solar collectors in accordance with the technical plans. At his option he could use local labor, available farm labor or contractors as he deemed necessary. This approach offered the advantage of greater return on the dollar invested. The approach also supported the objective of development of extension plans packets with which an average farmer could construct his own solar collector with locally available materials without having to go to more expensive contracted work. A disadvantage of our approach when compared to contracted construction work is the loss of a certain amount of control over the construction time schedules, and to a certain extent, quality control and system performance.

The approach to our management of this project required considerable administrative details. Coordinating material purchase and delivery for distant located projects at times caused construction delays. The farmers themselves had to work the solar collector construction into their management schedule and this also caused varying degrees of delay. Generally the farmers did not want to work on the construction after a particular crop season and did not want to begin construction until shortly before the next drying season. Several times other delays resulted when the construction work began to interfere with harvesting or other farm operations and the construction was again set aside. The great distances to some of the projects reduced some of the close supervision that would have been desired. The objective to minimize interruption to the normal farm operations and a desire to maintain good rapport with the cooperators resulted in very diplomatic application of pressure to speed up the completion of the construction.

The quality of the finished solar collector construction varied from demonstration to demonstration depending primarily on the construction expertise and management skills of the individual cooperator. Several were outstanding while others were not constructed as well as anticipated. However, this allowed us to evaluate opportunities to improve the designs, materials selected, etc.

Instrumentation:

Ten point thermocouple meters, mechanical pyronometers, hygrothemographs, and one data logger (CR 5, Campbell Scientific Co.) were used to monitor the performance of each project. It now appears that, for the number of projects involved, an additional data logger would almost be necessary. The mechanial pyronometers, and possibly the mechanical hygrothermographs, could have been limited to one of each and the investment used to purchase this equipment could easily have been used to purchase an additional data logger.

Performance:

The performance level of all of the demonstrations in the State of Florida should be considered basically at the conclusions of operational testing phase. Additional testing, including longer evaluation periods as well as in-season testing must be accomplished in order to fully evaluate the efficiency and economic returns on the investments in these systems. The individual performance of each demonstration are covered in the presentation.

Overall the performance of several of the collectors would be classified as very successful. Two of the cooperators are very pleased with the performance of their collectors and feel that they have already received economic returns from utilization of their system. Two of the other cooperators involve bare-plate collectors which just did not produce the amount of energy that perhaps the cooperator had anticipated. However they were within the expected design performance as far as temperature rise goes for this type of collector for which the investment was low.

Funding:

The United States Department of Agriculture with pass-through funds from United States Department of Energy has supported this project. A portion of the funding was used to cost-share up to 50% of the cooperators' cost of the solar drying system.

Summary

The construction of ten solar dryer systems was completed and each system was operationally tested by the end of December 1982. The covered plate collectors were more efficient relative to the bare plate collectors. For all the bare plate collectors the natural color of the metal roof was utilized. It is believed that painting the top of the roof black will improve the efficiency. The bare plate collectors are suited for the low temperature rise needed for drying crops such as peanuts while the covered plate collectors are suited for drying corn and surface water removal for potatoes and citrus. Efforts are being continued to further develop each project from both a data collection and extension demonstration standpoint. For more information, please contact the authors.

On-Farm Solar Crop Drying Demonstrations

by

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ABSTRACT

To insure continuing interest in solar substitution for fossil fuel use, 10 cost sharing on-farm solar assisted crop drying or curing demonstrations were established in Virginia in 1981-82. The Extension activity involved (1) the selection of farm cooperators, (2) system designs, (3) supervision of on-farm construction or fabrication, (4) obtaining cooperator agreements and subsidization of construction costs, (5) testing and monitoring of systems operations, (6) evaluation of reliability, effectiveness, and economics of systems, and (7) dissemination of information on farmer use of solar system to aid with crop drying.

The project was funded by a grant from USDA/DOE in the amount of $101,840 of which 22 percent was paid or provided in materials and services to 10 farmers for approximately 1/2 the cost of construction of the on-farm facilities. The project was successful from the standpoint of accomplishment, experience with operations, information dissemination, development of a data collection system, and potential for future application. Nine of the ten demonstrations were immediately justifiable economically. One system needs further testing and greater application. Some systems can and should be used for more crops and longer periods of time to improve economic return.

Purpose

The goal of the activity was to increase the quantity and quality of available information on the use of solar assist systems for crop drying or curing by developing on-farm demonstrations. The objective was to establish 10 additional on-farm demonstrations making use of solar assist systems which are technically and economically feasible to aid in the drying or curing of crops.

System Designs

Construction drawings were prepared for each of the solar demonstrations. These drawings included designs employing bare plate, covered plate, and suspended plate collectors. In every case an attempt was made to design the solar assisted crop drying system to be the least costly to construct, to require little or no management to operate, and to last a minimum of 15 years. All plans were drawn to facilitate construction by the farm cooperator or his workers. In a few cases, however, local building contractors actually constructed the facility. A bill of materials and an estimated cost of construction accompanied each design. Complete plans are available from the project manager.

Seven of the designs were associated with trailer crop drying systems in the major grain and peanut producing area. Four of these (3-6 trailer and 1-8 trailer) were of new construction based on designs developed by the project manager. Three existing trailer systems were retrofitted with solar collectors. One design, employing a portable collector to aid with grain and peanut drying and including a heat storage for swine house heating, can be attached to a trailer drying system without being an integrated part of it. One design in the northern part of the state is used for grain drying and shop heating as a part of an existing structure. The most costly design was prepared for a tobacco and grain farmer in southside Virginia. It involved integrated collectors in a shop attic and a trickle plate collector over a heated water storage arrangement.

Monitoring Procedure

A difficult data acquisition problem was posed by the concurrent need to collect data at 10 different farmsites. A decision was made to purchase three data acquisition systems to monitor three sites at a time. The data logger selected for automatic data collection was an A.D. Data Systems ML-20A data logger developed by Techtran*. The advantage of this 20 channel logger is that it operates unattended for 20 days with only 16 hours of battery charging. A junction box with terminal bars for each data logger was constructed to adapt the thermocouples to the data logger. The junction boxes were calibrated based on a reference temperature of 0°C and each thermocouple was accurate within ± 0.5°C.

To complete the temperature data base, six wet bulb temperature sensing units were constructed by using a small shaded pole blower to pull air through a tube and across the dry and wet thermocouples. One unit was calibrated in the laboratory where wet and dry bulb measurements were taken five times daily for two weeks. The sensing unit was within ± 0.5°C for dry bulb measurements and ± 1.0°C for wet bulb measurements. A hygrothermograph was placed at each site as a backup unit for measurement of ambient air conditions.

Three event recorders (292-4 by Gulton Industries) were used to monitor fan and burner operation. A Dwyer model 400 manometer was used to measure static pressure under varying operating conditions. Voltage and amperage were measured using a multivolt clamp-on meter and crop moisture content was determined by a Dickey-John moisture meter. Air velocity was measured using a velometer and hot wire anemometer. The farm cooperators recorded the dial reading of electric meters and fuel tanks daily, initial and final moisture contents of entering and exiting crops, and general operating procedures. Solar radiation was measured using a Belfort strip chart pyrheliograph.

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* The use of trade names in this report does not imply endorsement of the product nor criticism of other products not mentioned.

Data Analysis

The two modes of data analysis employed included an on-campus mainframe computer and a portable micro-computer. A 817 Datacassette developed by Techtran was interfaced with the on-campus IBM 370 computer to transfer field data from the magnetic tape cassette into the storage of the computer. Data reduction from strip charts involved the use of a Numonics 1224 Digitizer which was transmitted to a TI 7330 terminal where is was placed on a cassette.

On-site data analysis involved the use of a portable Apple II Plus micro-computer. The system is equipped with a screen monitor, two disk drives, and a NEC PC-8023A-C 80 character printer. Project personnel developed the software for transferring data from the memory of the Apple II onto a floppy disk and for formatting output and plotting graphs using any two data points in a data file generated by the ML-20A data loggers.

Field analysis of the data gives immediate information on the performance of the drying system. A more comprehensive analysis of the data can be obtained using a mainframe computer; however, the micro-computer gives a quick and less expensive analysis where a relatively small number of parameters are involved. The data collection system was very satisfactory except for a field problem with electric power surges (corrected by manufacturer) and manual recording of data.

Reliability, Effectiveness, and Economics of Units

Any evaluation of on-farm demonstration units needs to take into consideration several factors affecting their construction and use. Among these are the different modes of operation used by farmers and effects of weather conditions on operation. Generally, when a farmer is harvesting crops he feels he has to spend full time on saving the crop and little time recording data. To him, extra work such as weighing the crop, taking moisture samples, and reading meters may be critical in an already labor short time period. It is important that a solar crop dryer operate without attention by the farmer. Weather conditions during harvesting affect the rate at which the crop is harvested, but also affect the efficiency of the solar system. Solar crop dryers were less efficient in the latter part of the 1982 fall harvesting season when field drying was exceptionally fast.

Table 1 contains the cost, use, and other characteristics of the solar crop drying units. The units which cost the most to construct are those that include some type of heat storage. They are also the ones that are the most difficult to construct, operate, and likely to provide a slow return of investment. The demonstration units should not be directly compared since many variables are reflected in the results. In some cases, two years of data give different results than only one year. Solar dryers, when used only for peanuts, showed around 30% savings in 1981 but somewhat less in 1982. In some cases, the results in the table are associated with the drying of only one crop when the multi-use of collector was projected in the design. Payback is based on cost, energy saved at $.80 per GLP, 15 year collector life, 6% annual inflation rate, 12% interest on investment, and 4% of investment for annual taxes, insurance, and maintenance. Payback varied from 2.4 to 10.2 years without tax credits and 1.8 to 7.6 years with tax credits.

Table 1. Use, Characteristics, and Costs of Solar Crop Drying Units

Use	Collector Area (sq. ft.)	Unit Cost ($/sq. ft. of Collector)	Energy Saved by Solar (gal. LPG)	% Savings	System Cost ($)	Present Value ($) 15 yr. Investment	Payback Period (years) w/o Tax Credits
grain, peanuts	1,940	1.51	764	30	2,927.04	6,695.81	5.3
grain, peanuts	1,933	1.41	476	30	2,714.26	4,343.94	8.7
grain, peanuts	1,827	1.81	490	32.5	3,309.20	4,642.03	10.2
grain, peanuts	2,418	1.42	1,898	29	3,436.01	17,306.46	2.4
grain, peanuts, greenhouse	3,160 1/	1.22	800	38.7	3,830.41	7,010.40	6.8
grain, peanuts	2,625 1/	1.80	1,094	21.5	4,714.50	8,679.88	6.1
grain, peanuts	3,204 1/	1.44	800	32.7	4,599.19	7,578.03	8.4
grain, shop	7,926 1/	.33	760	66.6	2,615.90	6,029.89	5.7
grain, peanuts, swine	576	10.39	959	10.5	5,983.39 2/	8,403.72 4/	9.2
grain, tobacco, shop	1,272	10.23	936	10.4	13,021.57 3/	5/	

1/ Existing structure retrofitted.

2/ Includes cost of 30 ton rock storage.

3/ Includes cost of 10,000 gal. water storage.

4/ Includes projected savings from swine house heating.

5/ Need more information to determine rate of economic return.

INTEGRATED MULTIPLE-USE SOLAR SYSTEM WITH BIOMASS GASIFICATION-COMBUSTION BACKUP

by

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ABSTRACT

The following is a progress report of the activities conducted under the research grant by the above title. As the title suggests, this project has both solar and gasification research objectives.

SOLAR

The solar development objectives of this project were to determine the thermal performance of air-type collectors with flow over the absorber and under the absorber. Two collectors, constructed alike with flow channels in each collector over the absorber and under the absorber, are being tested using three methods: sun tracking, stationary tests, and a night test. The facility utilizes a computer controlled data acquisition system which evaluates the measured performance and computes a theoretical performance. Efforts are being made to determine the performance of these collectors and to develop engineering design data so that collector performance can be predicted for each of the collector types.

In order to achieve steady state and to validate the computed values the securing of data has been restricted to clear days, and in the case of night tests to clear nights. Although testing has proceeded at a slow pace under these conditions, the data obtained indicates that the stationary test can be correlated with the sun tracking test. At this stage the development of loss coefficients using a single night test instead of a large number of day tests with a heated air input has not been correlated with the sun tracking test data. During the remaining year an effort will be made to develop correlations for each of the testing methods and to determine the performance of the collectors with flow over the absorber and flow under the absorber.

GASIFICATION

The major objectives of the project during the past year as related to gasification were to:

1. Determine the amount of trapping of particulates in grain being dried by exhaust from a cob-fueled gasification system.

2. Determine the effect of the depth of the grain being dried on trapping efficiency.

The most general measure of grain contamination due to direct-fired drying with biomass gasification is the amount of particulates deposited on the grain. This parameter was determined by collecting particulates from the airstream before entering the grain and after passing through the grain. The difference in these two values, with some adjustment for grain dust, was assumed to be the amount of particulates deposited on the grain.

This trapping efficiency was determined for different depths of grain by running drying tests with 2, 4, and 6 inches of grain. A series of preliminary tests were run to gain proficiency with the system and to obtain initial values for planning a statistical test series.

The tests were run with a constant airflow of approximately 90 CFM. Thus, the velocity of air and particulates through the grain was constant for all grain depths. The drying air entering the grain was also maintained at a constant temperature of 160°F.

The results from the preliminary tests are tabulated in Table 1. The amount of particulate trapping is expressed in terms of percentage of total particulates retained. The main conclusion to be drawn is that the trapping of particulates in the grain can be as little as 20% or as much as 50% of the total particulates. The range is largely due to the varied test conditions and other initial problems in testing. These tests indicated that an increase in the initial moisture content of the grain caused less particulates to be trapped. This aspect has not been pursued in further testing.

A second set of tests were recently completed and at the present time the analyses of this data are somewhat incomplete (Table 2). However, indications are that 19% of the total particulates were retained by the grain with no appreciable difference due to grain depth. The reduced values from those shown in Table 1 could be attributed to three factors: 1) improved consistency in sampling technique, 2) an adjustment due to calibration between the inlet and outlet sampling points, and 3) an overall larger quantity of total particulates in the exhaust produced by the gasifier (probably due to a difference in the quality of cobs).

Again, it has been indicated that there is little if any difference in particulate retention among the 2 inch, 4 inch, and 6 inch depths. This would indicate that almost all trappable particulates are trapped in the bottom 2 inches (or less) of the grain. This could have important consequences for any efforts to clean up or prevent contamination.

TABLE 1: SUMMARY OF RESULTS OF PRELIMINARY TESTS - Percent of Total Exhaust Particulates Passing Through Grain

	Effect of Initial Moisture Content of Grain			
	Dry Grain	20%	25%	30%
Percent Retained	51.6	35.0	38.2	20.3
Number of Test Values	8	5	5	6

	Effect of Depth of Grain		
	2 Inches	4 Inches	6 Inches
Percent Retained	42.8	36.4	51.2
Number of Test Values	15	17	16

	Effect of Time of Drying		
	5-30 min.	30-50 min.	50-70 min.
Percent Retained	34.7	32.7	35.6
Number of Test Values	15	15	14

	Overall Results	
	Test of Moisture Content	Tests of Depth
Average Percent Retained	37.5	43.3
Number of Test Values	24	48

TABLE 2: RESULTS OF FINAL TEST SERIES (to Date)

	Percentage of Total Particulates Retained		
Test	2 Inches	4 Inches	6 Inches
1	17.2%	18.2%	21.3%
2	12.4%	9.6%	-
3	-	22.2%	-
4	39.0%	32.0%	28.78%
5	6.5%	22.5%	1.0%
6	-	-	-
AVE.	18.8%	22.9%	17.0%

OVERALL RETENTION - 19.2%

WIND POWERED INDUCTION GENERATOR

by

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ABSTRACT

The objective of this project is to develop operating procedures, sensing techniques, and microcomputer software for a wind driven three-phase induction motor operated as an induction generator. In the self-excited mode the generator is able to produce three-phase power for grain drying and space heating use with no utility connection. In the single-phase mode the generator supplies power to the single-phase utility distribution system. This paper describes the circuits required for the two modes, gives circuit component values, and presents some experimental results.

Self-Excited Mode

An induction motor becomes a generator simply by driving it above synchronous speed with a prime mover. Its low cost, good reliability, and easy availability make it a logical choice for the electrical generator on a wind turbine. When three-phase utility power is available near the turbine, operation of the induction generator is extremely simple. When a utility connection is not available or not economical, operation in a stand alone mode requires a more complicated operating procedure. This procedure can be illustrated with the basic self-excited circuit of Fig. 1.

Voltage buildup is obtained by removing the resistive loads and spinning the induction machine at a speed close to rated speed. The external capacitance and the machine inductance form a resonant circuit. Oscillation is initiated by the small voltage due to residual magnetism in the rotor. Voltage buildup continues until limited by saturation. This buildup typically requires several seconds to occur, being more rapid with a higher rotational speed or with larger values of capacitance. The value of capacitance is given by

$$C = k_c I_R / \omega V_R \qquad \mu F \qquad (1)$$

where I_R is the rated current, V_R is the rated line to line voltage, ω = 377 for a 60 Hz machine, and k_c is experimentally determined. 'Optimum' values for k_c were 0.30 for a 40 hp Baldor high efficiency induction motor and 0.42 for a 5 hp Dayton motor. Satisfactory operation was obtained for capacitance values within perhaps ± 20 percent of the 'optimum'. The 'optimum' value in this context is the experimentally determined capacitance which allows the induction generator to deliver rated generator power to a resistive load at rated synchronous speed and a voltage of perhaps 110 percent of rated. Rated generator power is defined as the rated motor shaft power divided by the rated motor efficiency.

Once the control system senses that voltage has built up, it closes the three-phase switch S_1 so the R_1 resistor bank is connected to the generator. The switches would probably be solid state relays for reliability and speed. Adding load tends to lower voltage and slow down the generator. When the wind is adequate to spin the generator at its rated speed with the first load, the resistor bank R_2, is added, and similarly for R_3. The variation of normalized shaft speed with respect to normalized input shaft power P_{in} is shown in Fig. 2. With a shaft power of about 0.08 of rated, the turbine is able to overcome losses and spin the generator at a speed where self-excitation occurs. As P_{in} increases from 0.08 to about 0.2 of rated, speed increases to near rated. When load R_2 is switched in, both speed and voltage decrease. As P_{in} increases to 0.5, speed and voltage again increase until load R_3 is switched in. It is possible to select values of R_2, R_3, and C such that speed does not change at this switching point, but only the voltage. (This reduces mechanical transients on the turbine.) The values of the resistors are given by

$$R_i = k_i V_R / I_R \qquad (2)$$

where the k_i were found experimentally for the 40 hp machine to be k_1 = 5.1, k_2 = 2.8, and k_3 = 1.4. Similar values would be expected for other induction machine sizes and manufacturers. The actual value of each wye connected resistor R_1 for the 40 hp machine rated at 230 V and 96 A is 5.1(230)/96 = 12.2 Ω.

Single-Phase Mode

During the summer months, the wind generator would not be needed for grain drying or space heating, so power would be available for sale to the utility. Most utilities are summer peaking so the utility may be a willing customer for this seasonal power. A majority of farms are served by single-phase distribution lines, so a practical system must interface a three-phase generator to a single-phase utility line. Perhaps the simplest circuit which does this is shown in Fig. 3. Phases a and b are connected to the two ends of the 120/240 V transformer secondary. Phase c is connected to phase b through a capacitor C and perhaps a resistor R. Correct phase sequence (abc rather than acb) is important to the correct operation of the circuit and should be checked with a commercial phase sequence indicator. The current flowing through the capacitor helps the generator to operate in a balanced fashion. It also reduces or eliminates the need for reactive power from the utility.

The power that the induction generator can deliver to the single-phase utility line is 2/3 of its three-phase rating since only two out of its three phases are actually producing power. The resistor R can be connected to the third phase to absorb the remaining 1/3 of its rating if there is a need for local power, such as heating domestic hot water. Adding this resistor helps to balance the generator, especially in heavy load conditions. There may be circumstances where the resistor R should be added when the power P_{in} exceeds 2/3 of the three-phase rating, even if the energy produced is dumped to the atmosphere, just to improve balance and smooth out vibrations produced by unbalanced operation. Adding R when P_{in} is less than 2/3 of rated reduces the sale of energy to the utility and, depending on the value of the energy produced in R, would normally be avoided.

The variation of the normalized line to line voltages and the normalized line currents with input power for a 40 hp Baldor induction generator with R = 8.92 Ω and C = 700 μF is shown in Fig. 4. The corresponding values of k_c and k_i for Eqns. 1 and 2 are 0.63 and 3.7, respectively. The voltage V_{bc} and the current I_c do not vary significantly with power. The currents in phases a and b first decrease and then increase as power increases. The three currents and the three voltages are nearly the same for P_{in} about 0.6 of rated, indicating the generator is nearly balanced at that power level. As P_{in} increases past this point, the generator becomes more unbalanced, with I_a reaching its rated value at P_{in} about 0.8 of rated. This power level should not be exceeded, except for short periods followed by time at lower power levels when the generator can cool. The generator is delivering the maximum possible power to the utility at this operating point. More power can be delivered to the local load by changing R but no more can be delivered to the utility.

The generator would be operating more nearly balanced at power levels above 0.6 of rated if a larger C were used. However, this would make the imbalance worse at lower power levels. Experimental results show the best efficiency with a current I_c between 0.5 and 0.7 of rated, depending on power level. For this particular generator, a capacitance of 550 μF and no resistance yielded higher efficiency for P_{in} less than 0.5 of rated, while C = 700 μF and R = 8.92 Ω yielded higher efficiency for P_{in} between 0.5 and 0.8 of rated. The larger capacitance helps meet the larger reactive power requirements of the generator at larger power levels.

The generator should be connected to the utility when the speed reaches synchronous speed, between 1800 and 1805 rpm for a four pole machine. The generator will probably not have time to build up voltage while the turbine is accelerating, so there will be two or three cycles of high magnetizing current when the connection is made. This should not pose a problem to operation since there will be little or no mechanical transient. When the wind dies down the generator should be disconnected when the speed drops below 1800 rpm, to prevent drawing power from the utility.

SUMMARY

Laboratory tests have shown that three-phase induction motors in the 5-40 hp range can be used as induction generators, either in a stand alone mode supplying power to a local load, or in a single-phase mode supplying power to a single-phase utility distribution line. Both modes require a sophisticated controller which can sense voltage and rotational speed and send control signals to solid state relays to change the load or to connect to the utility. Details of a microprocessor controller designed for this purpose will be reported later.

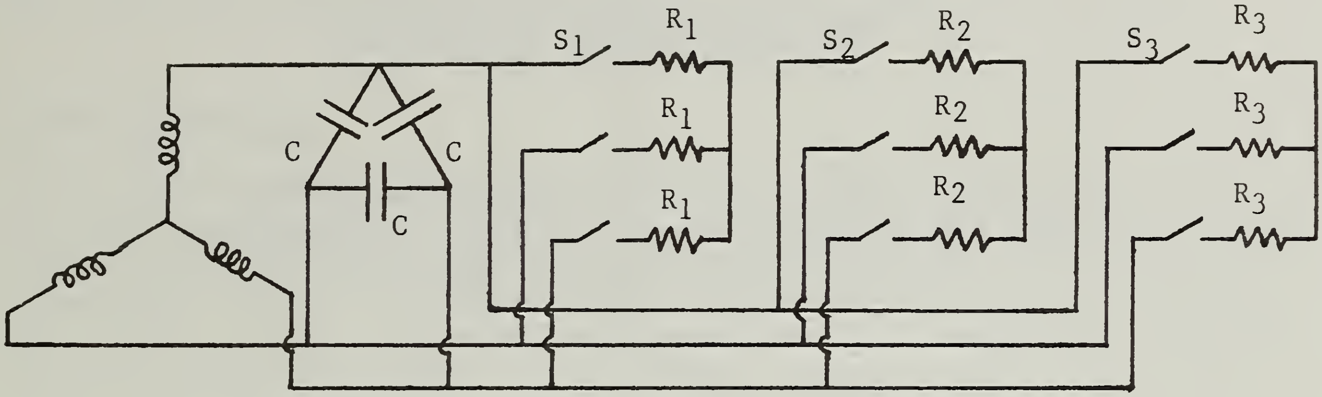

Fig. 1

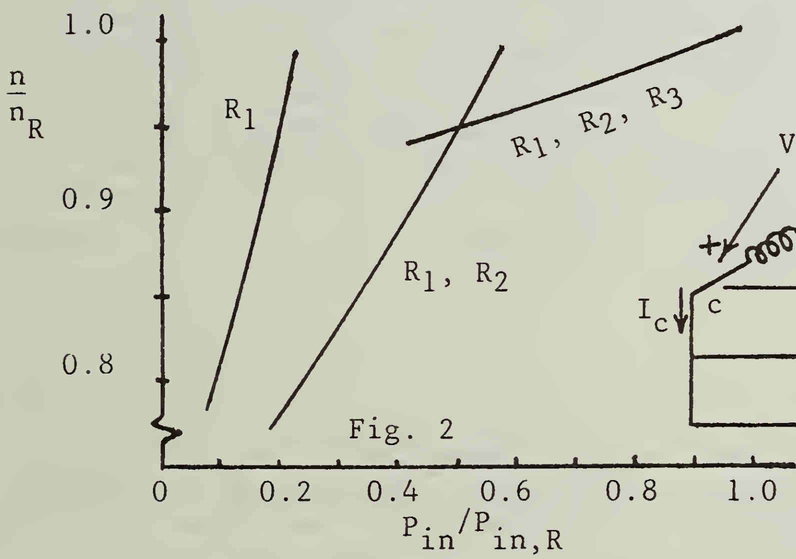

Fig. 2

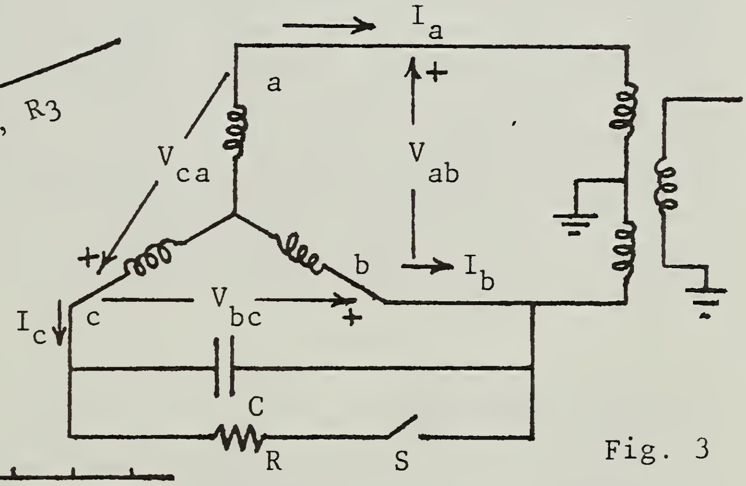

Fig. 3

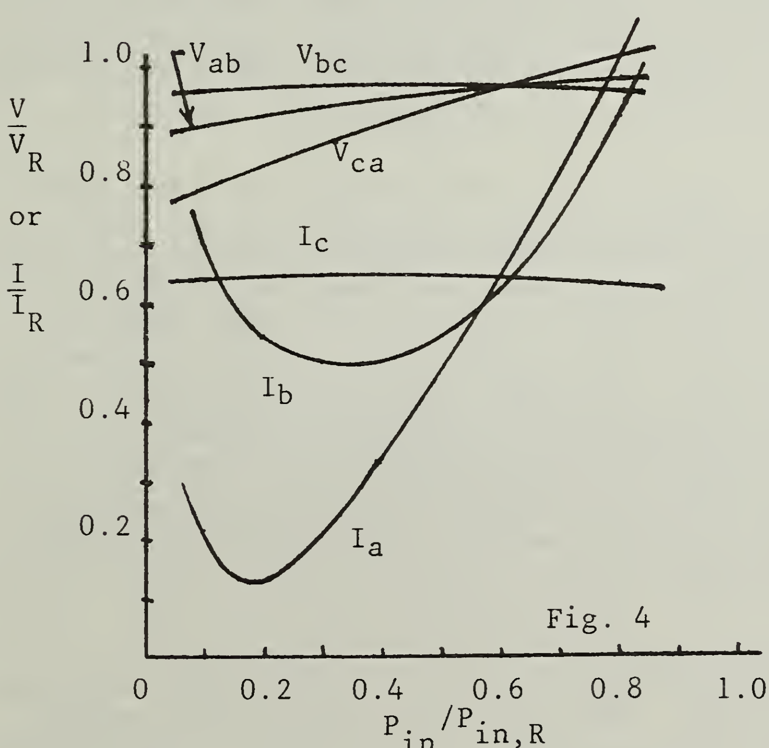

Fig. 4

SEI-TES: DESIGN AND TESTING FOR AIR AND WATER HEATING

by

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ABSTRACT

Research began in 1976 to develop a portable, low-cost, concentrating solar system for agricultural applications. Each year since, the design has been modified to improve efficiency, reliability and system economics. Tests during 1981 and 1982 documented seasonal efficiencies of 38, 24 and 25%, respectively, for grain drying, livestock building heating and water heating. A computer model was developed and validated which predicts collector and storage unit temperature profiles and efficiencies. This model allows sizing of systems to particular applications. Energy savings from the system repay initial materials costs in 5 to 7 years.

System Description

The solar energy intensifier-thermal energy storage (SEI-TES) system is a portable, concentrating solar unit designed for grain drying, livestock building heating and water heating. A 3 m high, parabolic shaped, polished aluminum reflector concentrates solar radiation onto the north side of a .8 m high collector unit (Figure 1). The collector unit, triangular in cross-section to hold rocks for thermal storage, has low iron glass on the south and north sides to receive direct and reflected solar radiation.

For grain drying and livestock heating air is pulled under the top cover of the collector unit, downward behind the low iron glass and in front of the steel absorber plate, upward behind the absorber plate and in front of the plywood back, then into the triangular cross-section (Figure 2). When grain drying, the air is pulled from the triangular cross-section directly into the wet grain using the existing bin fan. The triangular cross-section is filled with 8-10 cm rock for livestock applications. Air is pulled downward through the rock and into the building through the existing building ventilation system. The volume of rock is sized so that the ventilation air is preheated over the 24-hour period including and following a sunny day, with the peak heating effect achieved during early morning hours.

Water heating requires slight design modifications to allow for recirculating air flow, plus incorporation of an air-to-water heat exchanger and a fan within the collector unit. The air inlets are blocked and air is pulled through the collector units and the heat exchanger. Water flows from the heat exchanger to a storage tank by thermosiphon (Figure 3).

System Performance

SEI-TES seasonal efficiencies for grain drying, livestock building heating and water heating during 1981 and 1982 were 38%, 24% and 25%, respectively. Grain drying efficiencies are highest because: (1) the air flow rate through the collector is highest resulting in lower temperature rises and heat losses, and (2) the collected thermal energy is immediately used in the grain drying application without energy storage losses. Air flow through the solar system was reduced from 66 m^3/min for grain drying to a range of 2-12 m^3/min for livestock building heating and to a range of 13-19 m^3/min for water heating (Table 1) (VanZweden et al., 1982).

Objectives of the water heating tests were to document performance and to determine the effects of tank height and air flow rate through the heat exchanger on system efficiency. Increasing air flow from 13 to 15 m^3/min improved efficiency by 27%, further increasing air flow to 19 m^3/min improved efficiency an additional 7%. Increasing the elevation difference between the bottom of the water storage tank and the top of the heat exchanger from .6 m to .9 m improved efficiency from 23.3% to 24.8%.

Modeling

Models were developed to predict collector and rock storage temperature profiles and efficiencies so that design alternatives can be evaluated and so SEI-TES systems can be sized for specific applications. Both models are based on thermodynamics and heat transfer theory and use finite element techniques. The models were validated by comparing predictions with test data. Collector efficiency predictions were within 2-8% of measured values. Rock storage temperature profiles were less accurate, but were within $1^{o}C$ (VanZweden et al., 1982).

Economics

Materials for a 44.5 m^2 SEI-TES system cost \$2500 without the water heating adaptations, and the water heating adaptations add approximately \$1000 to the system cost. The reflector unit costs approximately \$1300 and the collector-storage unit costs account for approximately \$1200. Livestock building heating and grain drying in a northern climate (180 day season, average insolation of 70% clear day average) result in \$550/year energy savings when valued at \$.05 kWh (Hellickson et al., 1981). This is based on actual data and accounts for heat losses that occur because not all collected thermal energy can be utilized. Adding the water heating option can increase annual savings to \$1000 providing a need exists for approximately 1500 Kg of hot water per day.

SUMMARY

A portable and modular solar energy intensifier-thermal energy storage (SEI-TES system was developed for agricultural applications. Seasonal efficiencies of 38%, 24% and 25% were documented for grain drying, livestock building heating and water heating, respectively. A computer model was developed to evaluate design changes and to enable the system to be sized appropriately for each application. Material costs for a 45 m^2 SEI-TES system are $2500 without the water heating option and $3500 with the water heating option. Annual savings are $550 without water heating and $1000 with water heating.

References

Hellickson, M.A., L.L. Christianson and A.J. Heber. 1981. Multi-use SEI-TES system performance. ASAE Paper 81-4555. ASAE, St. Joseph, MI.

VanZweden, J., M.A. Hellickson and L.L. Christianson. 1982. SEI-TES system testing, evaluation and simulation. ASAE Paper 82-4544. ASAE, St. Joseph, MI.

Table 1. SEI-TES test results.

Parameters	Grain Drying Study	Livestock Building Heating Study	Water Heating Study
Collector area	44.5 m^2	26.0 m^2	16.2 m^2
Collector air flow rate	66 m^3/min	2-12 m^3/min	13-19 m^3/min*
Number of agricultural units	52.7 m^3/corn	12 sows & litters	490 Kg water
Average temperatures			
Collector	4.12°C	13.1°C	31.0°C
System		8.6°C	35.2°C+
Average efficiency			
Collector	37.9%	26.4%	28%*
System		24.0%	24.8%*
Average energy provided	1.33 kWh/D·m^2	.96 kWh/D·m^2	1.14 kWh/D·m^2

* Air flow was varied to determine its effect on efficiency. Highest air flow resulted in the highest efficiencies.

\+ Final minus initial average tank temperature after a clear day.

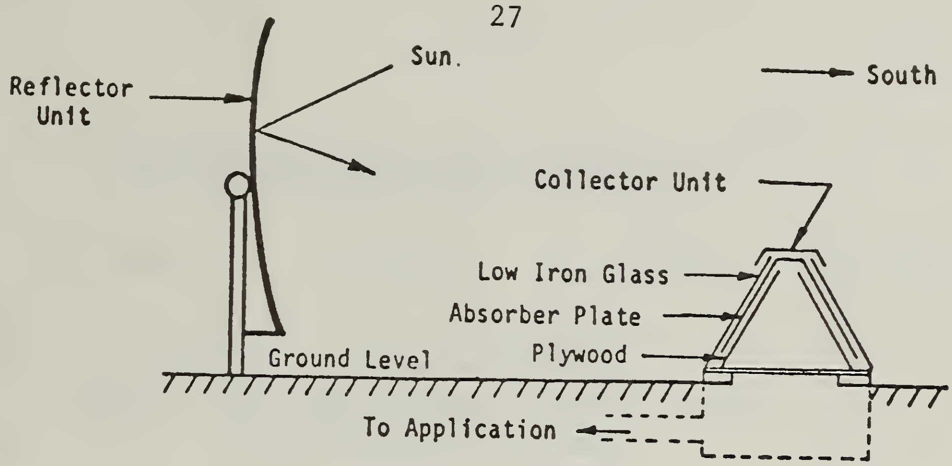

FIGURE 1. SEI-TES Schematic.

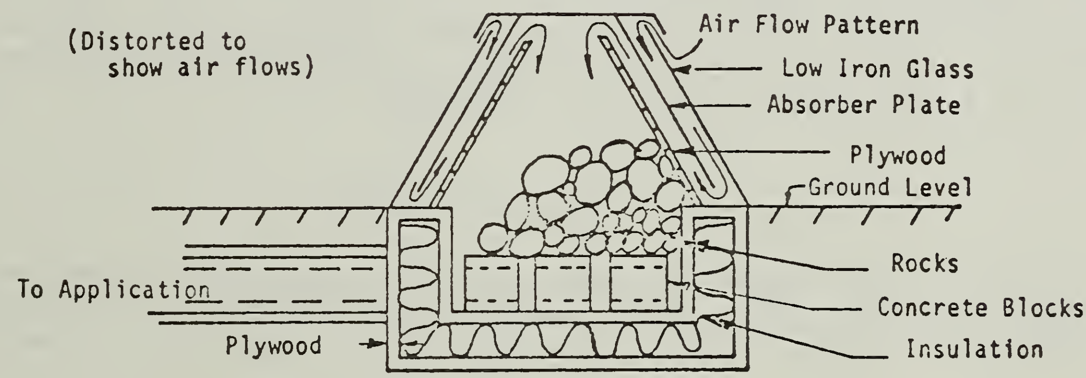

FIGURE 2. SEI-TES Air Flow Pattern in Collector Unit for Livestock Building Heating.

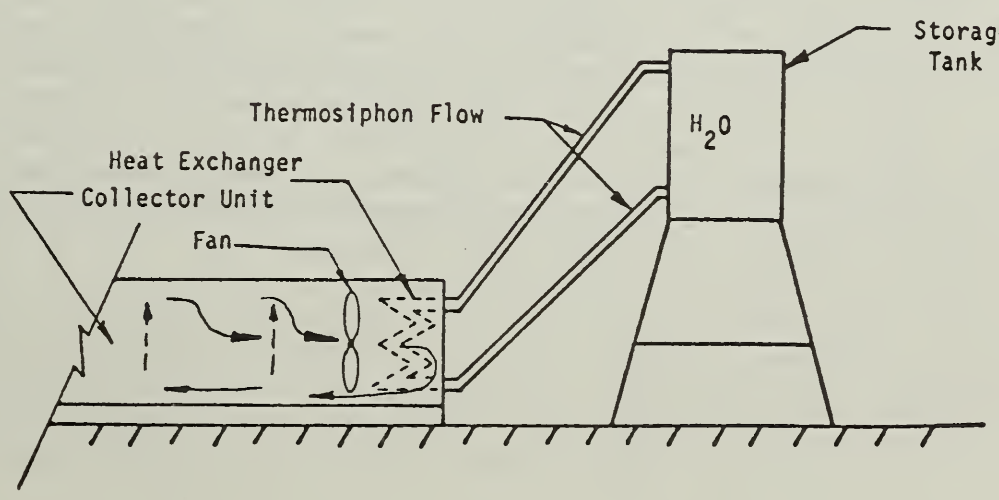

FIGURE 3. SEI-TES Water Heating Schematic.

INTEGRATION OF TWO ALTERNATIVE HEATING SYSTEMS FOR BROILER HOUSES

by

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ABSTRACT

A supplemental solar heating system for a broiler house has been operated for 40 months by the Delaware Agricultural Experiment Station. The unique design utilizes a cylindrical line-concentrating collector and a combination heat storage/exchange tank. Recently the system has been modified to evaluate the use of off-peak electricity in addition to solar energy as an alternative to LP gas brooders.

THE SOLAR SYSTEM

The Delaware Solar Brooding System uses a cylindrical, line-concentrating, pressure stabilized solar collector (CLCPSC). Proper curvature of the 29.3 m (96 ft.) long flexible reflector is maintained by a vacuum of .71 cm (.28 in.) of water. Sunlight is focused on a finned tube receiver, heating a water/ethylene glycol mixture that is pumped inside to the heat storage/exchange tank. Electronic controls regulate fluid flow rate and maintain proper focus of the collector.

Through computer simulation and extended field testing, the instantaneous efficiency of the solar collector has been improved and now averages above 40%. Table 1 summarizes collector performance during five test flocks. Under ideal conditions, the system has collected energy at a rate of 92.4 kWh/day. However, ideal conditions for solar collectors can be infrequent on the Delmarva peninsula. During a recent test flock (Dec. 13, 1982 - Jan. 31, 1983) rates averaged only 22.4 kWh/day (cloudy and overcast weather limited performance even though the collector operated at relatively high efficiency). Because the heat storage/exchange tank was felt to have significant capabilities, an alternative tank heating mode was sought.

Table 1. Summary of Solar Collector Performance

Flock	# Days Energy Collected	# Days Data Recorded	# Days System Operational	Energy Collection Rate Peak (kWh/day)	Avg.
Winter 1980	12	28	30	73.7	26.1
Spring 1981	26	29	47	58.5	20.3
Fall 1981	21	22	50	92.4	51.6
Winter 1981	20	36	50	81.8	24.5
Winter 1982	29	50	34	64.8	22.4

Note 1: These values indicate recurring problems with magnetic tape data storage unit.

Note 2: Typical flock lasts 50 days

Our experience indicates that premature failure of the reflective surface will occur as a consequence of stress concentrations that develop at each end of the collector. Under extreme weather conditions (high winds, heavy snow), small tears develop in the end regions. Although pressure sensitive tape will effectively repair the tears, the loss of the stabilizing vacuum for a long period allows the tear to propagate and destroy the entire surface. A recent failure of the type resulted in the loss of an 18 month old surface which, under normal weathering, would have lasted much longer. On the other hand, the 14 mil black polyethylene used for the non-reflective surfaces has proven very durable. Rips up to eight feet in length have been patched using contact cement and pieces of black polyethylene.

THE OFF-PEAK SYSTEM

The alternative selected, off-peak electric heaters, is being studied to determine the economic and technical feasibility of broiler house heating with off-peak electricity and a heat/storage exchange tank. The off-peak system was installed in parallel with the solar collector at House #5, Georgetown, Delaware (see Fig. 1). From 10:00 p.m. until 7:00 a.m. the working fluid is pumped past a bank of immersion heaters (18 kW of resistive elements). This heated working fluid then enters the storage tank and transfers its heat to the water.

The system has been tested in two modes: 1) as a supplement to the solar collector; and 2) as a stand alone heat source. As a supplement to solar, the off-peak system has increased the reliability of the heat storage/exchange tank as a heat source during periods of extended cloudiness. It has also raised storage tank temperatures to levels (60-75 deg. C) necessary to maintain brooding temperatures. As a stand alone heat source, the off-peak system is capable of maintaining the required tank temperatures with a transfer efficiency of about 84% i.e., 84% of the electrical energy consumed is input to the tank in the form of heat.

THE HEAT STORAGE/EXCHANGE TANK

The heat storage/exchange tank contains 6570 L of water. The effective energy storage capacity is approximately 10(6) kJ. A thermostatically controlled fan (2500 cfm) draws air through an annulus surrounding the tank. The tank surface is corrugated to enlarge the surface area and to stimulate more air turbulence. Both of these effects serve to increase the rate of heat transfer from the water to the air. The heated air is then discharged into the broiler house.

The solar/off-peak combination has been developed such that it is capable of achieving design tank temperatures (160-180 deg. F) on a regular basis. With this capability, we have been able to deal more realistically with problems associated with the transfer of heat from the storage tank to the house. Using laboratory scale models and the commercial sized unit we are investigating latent heat losses, optimal use of tank insulation and, most importantly, the build-up of dust to the outer surface of the tank.

SUMMARY

The complete dependence of the poultry industry on LP gas suggests that alternative energy sources be considered for brooding. Two such alternative systems are being studied by the DAES, solar energy and off-peak electricity. Current LP gas prices are low and relatively stable enough to make both alternative systems economically unattractive. The technical feasibility of both systems depends upon improvements in the water to air heat exchanger. An investigation of the heat exchanger is currently underway.

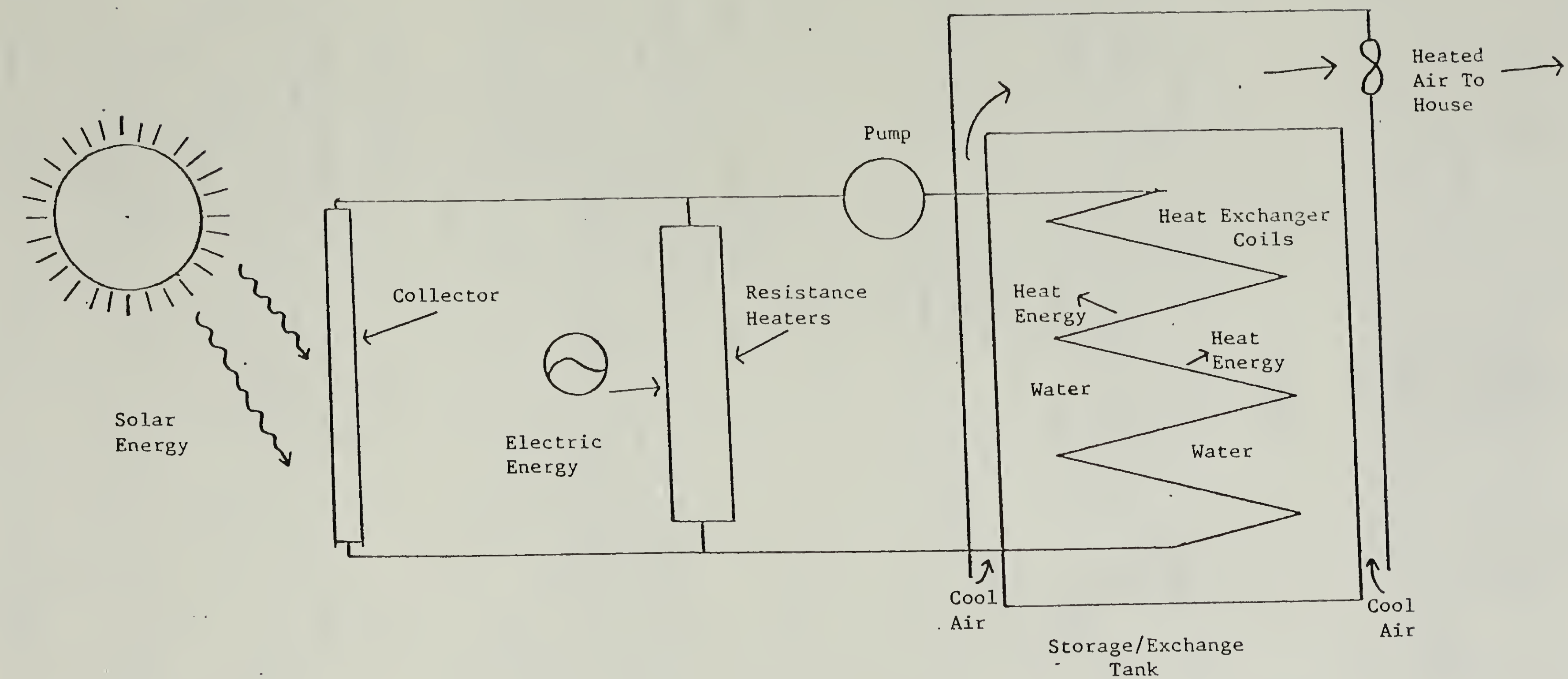

Figure 1. Energy Flow Diagram for Alternative Heating Systems.

EVALUATION OF A SOLAR BROODER HOUSE

by

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ABSTRACT

This program was to design, build, operate and evaluate a passively heated and cooled poultry brooder facility. The building has a combination water-wall and direct-gain passive heating system designed to sustain an indoor temperature of 90 +/- 5 deg. F., as required by 1 week old chicks. Evaluation to date indicates that this temperature range can be sustained by the proposed system with less than 10 % of the auxiliary heat that would be required by a comparable size non-passive brooder house. A provision for ventilation cooling is incorporated to prevent overheating and to provide cooling when necessary, particularly for older brooder chicks.

Project Description

The performance of a water-wall and direct-gain system has been extensively studied in recent years by numerous investigators. Perhaps the best documented testof building validated heating performance data has been obtained by the Los Alamos Scientific Laboratory. Those results are reported in the recent Passive Solar Design Handbook by J. D. Balcomb. Supplementing this information are the performance results reported in the Passive Solar Handbook for California by P. W. Niles et. al., which includes passive cooling as well as passive heating performance and design data. This system is unique in that it will operate at higher temperatures than are attainable in most residences.

The periodic heat flow to and from a south facing wall is caused by ambient temperature changes and insolation throughout the 24 hour period. The outer wall surface temperature variation approximates a sinusoidal wave over this time. The greater the heat storage capacity of the wall, the less the variation of inner surface temperature, i.e., the sine wave is "smoothed out." Depending on climate and season, this average temperature may be too high or too low for the design conditions inside the structure. Therefore clear insulation (glazing) can be used to enhance the solar gain of the storage wall during the winter. Inside the structure, heat must be removed from the massive south storage wall during the heating season. There is natural convective air circulation up the inside face of the storage wall. In addition, the storage wall surface will transfer heat radiantly to the occupants and other surfaces within.

This process will contribute a significant amount of heat to the interior.

In operation, the processes of insolation, convection and internal conduction take place simultaneously and vary periodically, making thermal performance (and analysis) extremely complex. This operation is highly dependent upon the specific design; however, once proper sizes of the storage wall, convective air parts and glazing spacing have been ascertained, the thermal averaging characteristics of this type of system produce the desired environment with a minimum of cost and complexity.

Environment

There are two basic operating environments that would be ideal for normal growth in a brooder house. First you could have one temperature zone where the whole room is at a constant temperature; starting off at 85 deg. F and decreasing by 5 deg. F/wk. until 70 deg. F is reached. The second would be a two-zone system with a hot zone at about 90 deg. F and the rest of the room at about 70 deg. F and 70% relative humidity.

In order to get a feel for the chicken's effect on its environment, one needs to look at: Temperature (T), Sensible heat BTU/hr (Qs), Air flow rate (Ma), Moisture rate (Mi), Humidity (Rh),and Absolute humidity (W). From Reece & Deation (Trans. ASAE vol. 13 #5 pp. 636-638; 1970) it was calculated that 300 3.5 week old birds would require 3600 BTU/hr. of sensible heat with a moisture rate of 3.6 lb. of water/hr. At 7.5 weeks the sensible heat is up to 6346 BTU/hr. and the moisture rate is up to 6.8 lb. of water/hr. It should be noted that there is a lot of scatter in the data obtained from different references.

The ventilation requirements were calculated using PG&E mean hourly temperature and absolute humidity for the month of February. The average absolute humidity W1 was equal to 0.0054 lb. water/lb. dry air and the average temperature T1 is equal to 50 deg. F. The ventilation discharge was T2 equal to 70 deg. F, the relative humidity, Rh was equal to 70%, and absolute humidity, W2 was equal to 0.011 lb. water/lb. dry air. The air flow rate can then be calculated from:

$$
\begin{aligned}
Ma &= Mi / (W2 - W1) \\
&= Mi / 0.0056
\end{aligned}
$$

This equation predicts that for chicks at 3.5 weeks old, using Mi equal to 3.6 lb. of water/hr., Ma would be equal to 643 lb. of air/hr. of 150 cfm. For chicks 7.5 weeks old, Ma would be equal to 1214 lb of air/hr or 275 cfm. As a comparison of required air flow rate from the Commercial Chicken Production Manual:

$$
\begin{aligned}
cfm &= 0.012 \text{ (bird wt.) } T2 \text{ (number of birds)} \\
&= 0.012 * 3.0 * 70 * 300 \\
&= 750 \text{ cfm}
\end{aligned}
$$

For chicks at 0 weeks old it was assumed that Qs = 0.0 BTU/hr., and the ventilation rate would be 0.1 cfm/bird or 30 cfm.

TABLE 1 Chicken Effect

age weeks	building gain Qs	cfm	ventilation loss	net
0	0	30	630	-632
3.5	3680	150	3159	521
7.5	6346	275	5792	554
		750	16800	-10454

It can be seen from Table 1 that the chicks have very little effect on the building performance except in the latter stages of their growth. For first-week chicks, an indoor average temperature of 95 deg. F is required. A 30 cfm ventilation rate is required to supply the need of 300 chicks. The 300 chicks will have a metabolic output of approximately 30 BTU/hr.

For fifth-week chicks an average inside temperature of 75 deg. F is required, with a ventilation rate of 750 cfm., and a metabolism rate of approximately 6500 BTU/hr.

Experimental Plan

A data-acquisition system has been designed and built, by the Agricultural Engineering Department, using components of an Apple II micro-computer. During the middle of November this data acquisition system was programmed and installed in the Solar Brooder House at Cal Poly. The house was being operated with maximum ventilation for the first week, and the water bed did not go above 90 deg. F. To cut down on the heat losses from the water bed, a canvas skirt was placed around the sides of the bed. This helped increase the air temperature under the bed but didn't make much difference in the night drop in temperature of the bed.

It was decided to make the top of the water bed double glazed to decrease the heat loss out of the top of the water bed. This helped but was not enough to bring the air temperature up to the desired 86 deg. F. Next, the water bed temperature was set to 124 deg. F, and the air temperature did reach 86 deg. F. Bedding material was spread, a temporary barrier of cardboard was placed in the house, and 169 two day old chicks were placed in the house.

Temperature data is recorded on two of the four water drums, i.e. the water bed, the air temperature below the water bed, the ambient air, and the air temperature next to the north wall. Also vertical solar insolation and the percent time the heater in the water bed is on are recorded. This data is read every minute and hourly averages are saved to the disk every hour. The disk in the data acquisition system can be qued and transferred to a temporary storage disk to be analyzed in the office. In the office, the data is read off of the storage disk by an APPLE II computer, analyzed and printed. The data can also be sent to a Hewlett Packard 9825 computer and plotted on a HP plotter, Figure 1.

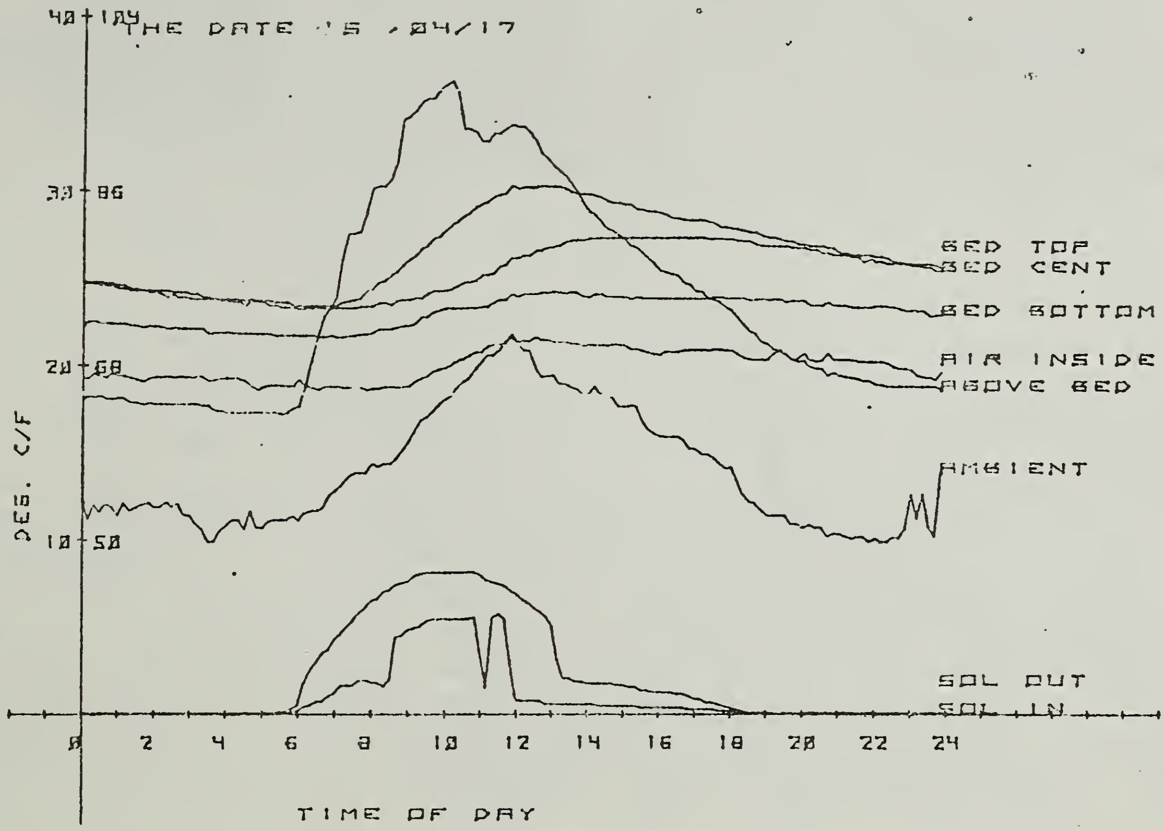

Figure 1 Temperature profiles in brooder house and bed

Cost Effectiveness

Calculations of fuel costs per chick for small brooder houses range from about \$0.05 per chick to \$0.025 per chick depending on location and operating mode. Recent records of Zacky Farms and Foster Farms showed that their heating requirement was \$0.03 per chick. The estimated operating cost of the drum wall is \$0.006 per chick for a 500-bird facility. If this cost is projected for the brooder industry, the net fuel savings could amount to \$120 million per year at current fuel prices. Since the energy from the solar system is fixed, as fuel prices continue to rise the savings will grow.

SUMMARY

The solar heated brooder house does work and provides an adequate environment for brooder chicks. There is some problems with the temperature stratification in the water bed. During sunny days the top of the bed will be 14 deg. F hotter than the bottom. This is a thermal disadvantage since the chicks occupy the space adjacent to the bottom, and it also hinders the collection efficiency. Thermal mixing can be obtained by the addition of a small amount of auxiliary heat to the bed.

RENEWABLE ENERGY FOR HIGH-DENSITY POULTRY BROODING

by

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ABSTRACT

This research project was initiated 1 October 1982 and has as its primary objective the incorporation of renewable energy and passive solar design into a high-density rotational rearing brooding facility utilizing mechanical exit of the birds at three and one-half weeks of age. The desirable and complimentary requirements of energy self-sufficiency, energy conservation, and efficient energy utilization to provide environmental control for optimum bird growth suggests greater probabilities of success when using high quality environmentally controlled facilities and one or more renewable energy sources. The resulting economic considerations dictate high coefficients of utilization of both space and time. These factors coalesce to suggest a high density solarized brooding facility utilizing methane gas from poultry waste as the primary heating fuel and stacked cages to attain high space utilization and facilitate mechanical exit of the birds to limit additional labor. Implementation of this facility within the rotational rearing concept would increase time utilization and enhance economic justification. Potential problems associated with disease, waste management, and the enhanced importance of ventilation will be addressed. Preliminary studies leading to the development of a prototype facility are underway in a high-density solar brooding facility.

INTRODUCTION

The trend in poultry is toward higher brooding densities via partial house brooding. The impetus for this trend has been the savings in energy costs realized by brooding at two to three times the original full-house bird density. Savings of fuel used for brooding of 30 to 50% due to 50 to 70% reductions in brooding areas are commonly reported (Reece, 1978). Numerous studies have placed the minimum floor space per bird on litter to be at or near 0.35 ft^2 for optimum trade offs between bird weights, feed conversion, energy savings, and litter moisture problems. Fuel energy consists of approximately 25% of the total energy utilized for broiler production with over 90% of this energy being expended during the first three weeks. Therefore, additional measures toward concentration and energy savings are probable. Two approaches seem feasible. First, energy cost savings could be realized if energy self-sufficiency was achieved by utilizing poultry waste products to generate methane gas for combustion and heating. Utilization of solar energy would also help in this regard. Secondly, partial house brooding guarantees incomplete utilization of the fixed investments in facilities while the concept of rotational rearing relieves this problem and compliments the development of a special purpose high-density brooding facility. However, this concept has been researched (Longhouse et al., 1967) but has not gained acceptance by the broiler industry due to potential disease problems arising from the maintenance of groups of birds of different ages at the same production site. Assured control of this problem would allow the rotational rearing concept to accommodate the implementation of a special purpose facilitiy to brood chickens to three and one-half weeks of age. This facility could provide for solar energy, methane combustion, high density brooding, and mechanical exit of the birds to avoid additional labor. In order to facilitate high density brooding and mechanical exit of the birds, a system of brooding in stacked cages seems probable. The use of cages for the first three and one-half weeks would also produce a litter-free waste product that is more easily converted to methane gas.

The objective of this project is to incorporate renewable energies into the brooding phase of rearing chickens to attain energy self-sufficiency and to reduce the cost of energy so used. Solar and methane gas produced from poultry waste are the two most likely candidates. It appears that the probability of success in achieving these objectives will be enhanced by coalescing several technologies to form a complete brooding system. These technologies include a) solar and methane application, b) cage brooding to three and one-half weeks to attain high space utilization and to compliment mechanical exit of the birds, c) a mechanical exit system to avoid the addition of a laborious moving operation, and d) the rotational rearing concept to attain high time utilization of the facilities. The state-of-the-art of these technologies will be discussed briefly.

STATE-OF-THE-ART

Renewable Energy

Alternative energy sources for poultry brooding requirements have been explored and solar and methane produced from poultry waste appear to be the most probable and most carefree renewable sources. The technology to produce methane gas from animal waste products is readily available except in the case of poultry waste diluted with litter. The pure waste product alone is an abundant source of methane and can be readily implemented. The primary work here would be in the application of heat from the combusted methane gas to a compatible brooding facility. Warm room brooding as might be done with cage brooding appears particularly compatible.

Solar assisted heating applied to poultry brooding has been investigated with varied results dependent upon geographic location. Reece (1980) demonstrated a 90% reduction of broiler heating costs due to a solar application. Other studies have reached marginal conclusions. Esmay (1980) concluded that the largest pay-off could be from improved feed to weight conversion ratios during the fast grow-out period. Since 90% of the broiler energy is utilized during the first three weeks, it is generally agreed that energy saving efforts should be concentrated on the brooding period. It is also generally agreed that economic justification of solar applications is enhanced by energy conservation and high brooding densities.

Cage Brooding of Broilers

A number of studies have compared cage brooding to floor with litter brooding. Thaxton et al.(1980) reported that birds brooded three weeks in cages and then transferred to the floor system exhibited lower final body weights and lower feed conversion ratios than floor reared birds. However, other studies including Andrews and Goodwin (1973) have reported caged birds to be heavier than litter reared birds although a number of other problems were more numerous with the caged birds. An important variable is the material comprising the cage floor. While the literature appears to be inconclusive, the many advantages and possibilities that the cage system affords could outweigh some problems including even slightly lower gains. The most obvious advantages of the cage brooding system is the attainment of higher volumetric densities and the increased compatibility of cages with mechanical exit systems.

Rotational Rearing

The most common program for boiler rearing in recent years has been the "all-in, all-out" system in which only one age of broilers is on the farm at the same time. With this system there is a period when no birds are on the premises and this breaks any cycle of infectious disease. The "all-in, all-out" system theoretically requires a complete cleanout and disinfection to work as intended. However, many commercial producers now reuse litter and raise several broods before cleaning out a house. This partially defeats the purpose of this system and raises questions concerning the actual necessity of utilizing the "all-in, all-out" system. It also raises questions regarding the present-day validity of the disease problem traditionally associated with the rotational rearing concept.

The rotational rearing concept provides for greater utilization of facilities and compliments the high density brooding system advantages. However, it remains relatively unaccepted due to potential disease problems thought to arise whenever two ages of birds are maintained at the same production site. This problem could be countered by growing out the birds at a remote location. Also, recent advances in isolation and disease control have made it possible to keep chicks of several ages on the same farm. There are operations following this procedure, but careful management is required.

Longhouse et al. (1967) addressed this problem and encountered problems only after deliberate infection of the flock. While no absolute conclusion was drawn, the mortality problems were less than massive even though drastic steps to control the disease were intentionally not taken. Any problems of condemnation of the birds during processing was not reported.

Mechanical Movement of Broilers

Mechanical movement of birds has been studied at the University of Georgia (Reed, 1972) with successful systems resulting. However, no system has been adopted by the broiler industry. Most early attempts dealt with floor reared birds. The problem would be somewhat simplified if the birds were caged at the time of moving and the system was designed only to exit the birds from the cages and building. This is more in line with the requirements of such a system to be used with a special purpose brooding facility with translocation occurring at three and one-half weeks of age.

SUMMARY

Energy self-sufficiency would provide a number of benefits to the broiler industry including independence from the world energy industry and reduced energy costs. Renewable energies provide the most likely path to a successful realization of self-sufficiency and solar and methane gas produced from poultry waste are the most likely candidate energy forms. A successful implementation would be enhanced by energy conservation and improved utilization of facilities in both space and time and would avoid increased labor requirements. These criteria suggest a high density cage brooding facility utilizing solar and methane for heating energy and mechanical exit of the birds. An evaluation of the state-of-the-art of these technologies suggest it is possible to coalesce them into a workable system implemented in a rotational rearing system.

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THERMO-CHEMICAL ADSORPTION REACTIONS FOR LATENT STORAGE OF HEAT

by

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ABSTRACT

The feasibility of a latent heat storage system utilizing salt-ammonia compounds is largely dependent on the salt's availability, its price, its physical behavior and the possible storable energy per unit volume. In order to simulate the use of solar, geothermal or waste energy, the temperature for the desorption reaction was kept below 180°C while heat was extracted at temperatures between 35°C and 45°C. The salt complexes formed with $ALCL_3$, LiBr, CuI, $SmCL_3$ and $ZnCL_2$ were thoroughly investigated in a large number of experiments. Considering all selection criteria, $ZnCl_2$ proved to be the most promising salt, since 1485 kJ/kg of salt or 297 kJ/dm^3 of volume of energy could be stored. This salt remained in a powdery state and even after 18 consecutive runs no performance decrease could be observed. Taking its low price of $3 per kg of salt into account about 495 kJ per dollar of salt can be stored, while the other salts investigated range between 3 to 44 kJ per dollar of salt.

Experimental Determination of Storable Energies

With a storage system utilizing the capability of a large number of salts to form a complex, ammoniated compound thermal energy can be stored for an indefinite length of time and released on demand by means of a reversible chemical reaction. Until now about 700 possible reactions have been examined from a thermodynamical point of view, yielding a very comprehensive data compilation /1/. During earlier investigations 12 compounds have been examined for heat storage purposes /2/. The results obtained range between 661 and 3420 kJ per kg of salt of storable energy. However, for practical applications not only the energy storage density but also its price, its availability and its physical behavior have to be considered. Therefore five previously uninvestigated salts have been selected to find a low cost and/or very high energy density storage material.

The endothermal reaction that leads to partial or complete dissociation of such a complex compound can be described as follows:

$$S \cdot mNH_3 + nNH_3 \underset{\text{desorption}}{\overset{\text{adsorption}}{\rightleftharpoons}} S \cdot (m + n)\, NH_3 - Q_1 \qquad (1)$$

The products of this dissociation or desorption reaction store the thermal energy which can be released by the reverse exothermic reaction between the products. The equilibrium relationship between the temperature, pressure and the heat of formation for a dissociation step can be described by Nernst's equation:

$$\log p = \frac{Q_o}{2.303 \; R \; T} + 1.75 \log T + a \, T + C \qquad (2)$$

where C = 3.3 and a = -0.0017 ÷ -0.0024 are experimentally determined constants /3/. T represents the absolute temperature, p the pressure in bar and Q_o is the dissociation energy for a particular reaction step. As an example the p-T diagram for the $ZnCL_2 \cdot NH_3$ complex is presented in Fig. 1.

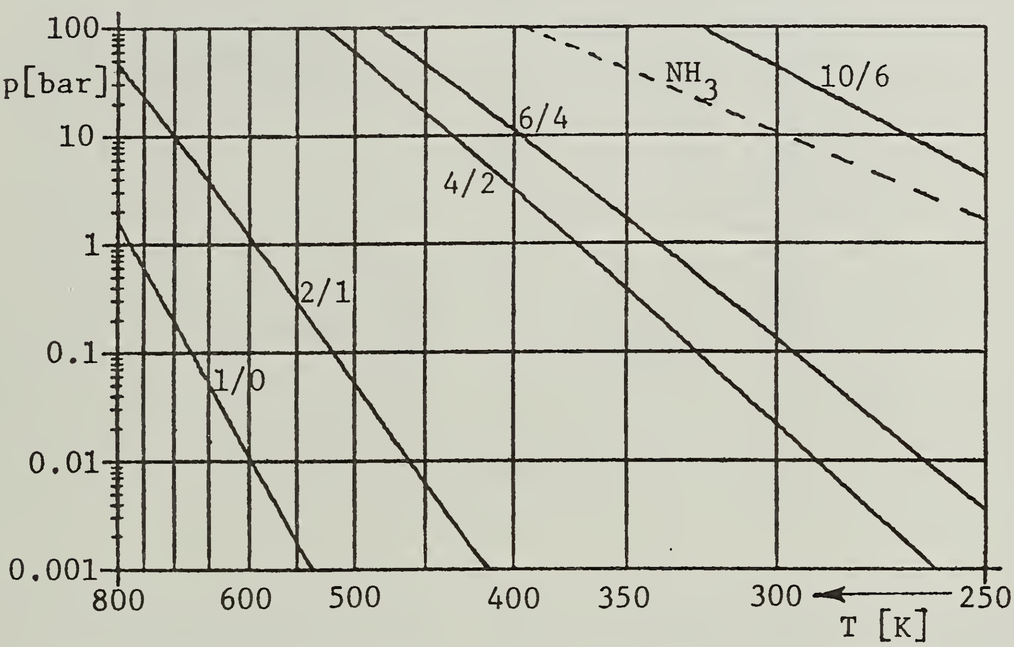

Fig. 1. p-T Diagram for the $ZnCl_2 \cdot nNH_3$ Complex

As one can immediately see from this diagram, a latent energy storage system could be operated at well above 50°C, if the ammonia vapor would enter the reaction vessel at 15°C (288 K). Assuming a condensation temperature of 27°C (300 K) the necessary regeneration temperature would be about 160°C (433 K). These temperature conditions determine a feasible cycle and based on old literature data /4, 5/ 659 kJ per mol salt can be released in the exothermic formation reaction for the two dissociation steps in the defined temperature range.

Because of its wide availability and its low price of $3 per kg of salt the $ZnCl_2 \cdot NH_3$ compound was investigated thoroughly in 18 consecutive experimental runs. In Fig. 2 the time slope for one adsorption reaction is presented. Immediately after the adsorption reaction is initiated the salt temperature rises from 45°C to about 106°C. With the heat transfer fluid's inlet temperature kept constant at 45°C, the stored energy is extracted and after about five hours the reaction stops. The momentary heat flux is represented by the $\dot{Q}$-curve and Q_{total} is the total heat extracted up to a certain time. The average total heat extracted for the set of experiments was 698 kJ per mol of salt or 1485 kJ per kg of salt. Compared to the literature data about 5.9% more heat was extracted during the endothermic reaction. This offset can be due to either transducer inaccuracies or inaccurate literature data. After the experiments were conducted

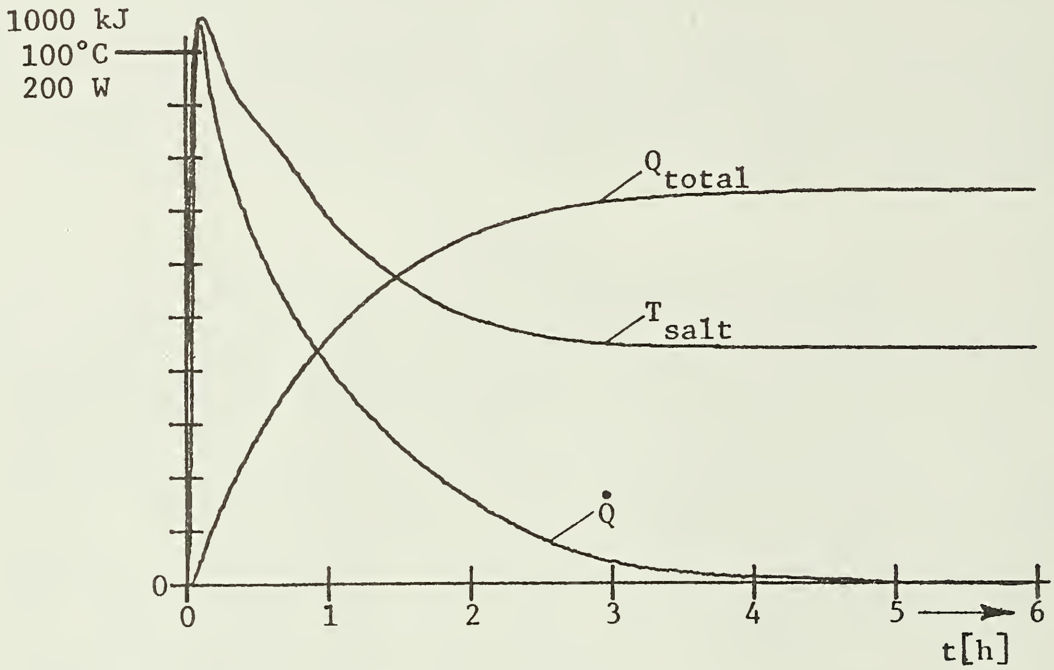

Fig. 2. Time Slope of an Adsorption Reaction

the reaction vessel was opened and the swell factor of the salt due to the ammoniation was determined to be 6.9. The salt remained in a very loose, powdery state.

In Table 1 the five salts investigated are compared. Although the $ZnCL_2$-NH_3 complex has the best energy per mass unit relationship, more energy could be stored per unit volume of salt with the $SmCL_3$-NH_3 complex, but its price of $128 per kg makes it uneconomical for practical applications. The LiBr-NH_3 and CuI-NH_3 complexes become slushy or solid after ammoniation and the extractable energies decreased from experiment 2. The values presented are averaged over only 2 to 4 runs. Although $ALCL_3$ is also quite inexpensive and remained in an excellent physical condition, it is not very practical because of its low storage capacity.

SUMMARY

Five different salt ammonia complexes have been investigated to determine their latent heat storage capacity and their long term behavior. The $ZnCL_2$-NH_3 complex compound proved to be the best system for a practical application because of its low price and its excellent thermal and physical characteristics. Compated to water at a pressure of 6 bar, cycled between 120°C and 50°C, this salt could store more than 5 times

as much energy per mass unit of heat storage media. Since the investigated system is a latent heat storage system, heat could be stored indefinitely and no expensive insulation to prevent heat losses is necessary.

Salt	$/kg	kJ/mol	kJ/kg	kJ/dm^3 Ammoniated Salt	Physical Condition	kJ/$Salt	Swell Factor
$ZnCl_2$	3	698	1485	297	Powder	495	6.9
$AlCl_3$	6	35	263	39	Powder	44	8.0
LiBr	30	68	780	483	Slush	26	0.8
CuI	59	31	165	268	Solid	3	1.2
$SmCl_3$	128	128	500	540	Coarse Powder	4	1.0

Table 1. Comparison of Investigated Salts

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BRINE DRIVEN EVAPORATORS-- OPERATING CHARACTERISTICS AND PROBLEMS

by

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ABSTRACT

The results of extensive operating tests of components of a solar-based, brine-driven evaporation system are reported. These include: evaporation rates, heat-transfer coefficients and brine-generated ΔTs as functions of brine and food Reynolds numbers and concentrations and non-condensibles levels in the brine-driven evaporators; energy collection efficiencies for sun-tracking parabolic-trough collectors used to reconcentrate the brines; and water stripping efficiencies for a stripper heatable by steam generated during brine reconcentration. Multiple-effect evaporation was successfully simulated by throttling vapor generated in a brine-driven evaporator prior to its absorption in brine, so that its pressure equalled that for vapor from the third effect of a three-effect system. Extensive corrosion occurred during the tests. This corrosion and the high capital cost of the solar energy collection system are major problems which must be resolved in order to assure economic feasibility.

Background

In brine-driven evaporators, which were invented by Schwartzberg in 1976, water vapor emanating from films of liquid food flowing down the inside walls of evaporator tubes passes into a shell surrounding these tubes where it is absorbed in films of $CaCl_2$, LiCl or mixed $CaCl_2$-LiCl brines flowing down the outsides of the tubes. Heat slightly exceeding that required for evaporation is generated by the absorption. The ΔT provided by the brine's boiling point elevation causes this heat to be transferred to the liquid food, thereby inducing sustained evaporation. The brines, which become diluted in this process, are reconcentrated by boiling off the absorbed water in a solar collector, thereby restoring their water absorbing ability. Because of the brine's high boiling temperatures, focussing-type, sun-tracking collectors are needed in order to obtain reasonable energy-collection efficiencies. The steam generated by boiling can be used to heat air which in turn can be used to strip water from the diluted brines before they go to the solar collector. Because the brines can be stored without energy loss, solar energy collection and use do not have to be synchronized.

The feasibility of brine-driven evaporation was demonstrated in small glass and stainless steel prototypes. The work reported herein deals with tests carried out in larger systems whose design features are similar to those used in commercial evaporators, solar collectors and strippers. One objective of this work is to demonstrate the feasibility of brine-driven multiple-effect evaporation in which vapor from the last effect is absorbed by brine flowing down the outside of the tubes in the first effect.

Evaporator Tests

Two evaporators were built and tested: A unit with a single 4-m long, 50.8 mm diameter tube providing 0.605 m^2 of heat-transfer area, and a unit with seven, 1-m long, 25.4 mm tubes providing 0.625 m^2 of heat-transfer area. These units were tested at tube wall irrigation rates of 0.07-0.50 kg/m-s for the food and 0.06-1.25 kg/m-s for the brine. The corresponding Reynolds number ranges were 500-4000 for the food and 240-1750 for the brine. Liquid food concentrations up to 37% sucrose were tested. The brine concentrations tested ranged from 31.2% for $CaCl_2$ to 53.1% for a 1:4 LiCl-$CaCl_2$ mixture. Roughly similar behavior was obtained in both evaporators. The corresponding boiling point elevations (B.P.E.) ranged between 11.9°C and 33.1°C, but the actual ΔTs were 71% to 88% as large as the corresponding B.P.E.'s. Reduction of water vapor pressure at the brine surface due to the presence of non-condensibles caused 10 to 14.2% of the 12 to 19% reduction in the theoretically available ΔT, and concentration polarization in the brine caused the remaining 2 to 4.8%.

Evaporation rates between 6.6 and 8.3 kg/m^2s and U values between 1400-1500 W/m^2 °C were obtained, but U decreased to 900-1200 W/m^2 °C at high liquid food concentrations. U dropped radically when the brine Reynolds number fell below 600, probably because incomplete tube wall wetting occurred at these low Reynolds numbers. U increased markedly as ΔT decreased and values as high as 4000 W/m^2 K were obtained at a ΔT of 2.5°K. At a 10°C ΔT,U's for brine driven evaporation were roughly 63% as large as for steam driven evaporation, but the corresponding ratio at a 5°C ΔT was 84%. Such behavior indicates that brine driven multiple-effect evaporation should be feasible. Increased non-condensibles levels not only decreased available ΔTs but they also caused marked reductions in U. U was not significantly affected by evaporation temperature between 55.7°C and 91.5°C.

Multiple-effect evaporation was successfully simulated by throttling the vapor generated in the seven tube evaporator. This reduced the available ΔT to 9.3°C compared to a B.P.E. of 29.0°C and provided vapor which was equivalent to that generated in the third effect of a three-effect system.

Marked corrosion occurred during the evaporation tests. This was significantly reduced by the use of sodium molybdate passivation. Low temperature operation, which apparently can be used without impaired heat transfer, would help reduce such corrosion. Multiple-effect operation, in which the corrosive environment occurs only in the first effect, would also limit the impact of corrosion. Particularly severe corrosion occurred in the vortex-type brine pump, where cavitation no doubt enhanced corrosive attack. The deterioration of this pump was so severe that it may not be possible to carry out proposed future two-effect tests unless a suitable replacement pump is obtained.

Solar Collection

Two parabolic-trough, sun-tracking collectors, one with an east-west horizontal axis and one with a north-south tilted axis were tested. The average peak (solar noon) collection efficiency for the east-west unit during water boiling tests was 47%, and efficiency declined in a predictable fashion on either side of solar noon. In the north-south tilted axis unit the efficiency remained roughly constant from 11:00 AM to 3:00 PM, the duration of the test, and it should remain nearly constant for roughly eight hours. Adjusting for improper tilt, the north-south unit efficiency was 40% for water boiling using an unshielded absorber, and 49% with a top-shielded absorber. With a top-shielded absorber the collection efficiency when concentrating 26% $CaCl_2$ was 42% and for 40% $CaCl_2$ it was 31%. Analysis indicates that poor focussing and greater exposure to the wind caused a 9% reduction in efficiency for the tilted collector, and that increased temperature only caused 7% of the 18% loss in efficiency caused by the use of concentrated brine. Taking all factors into consideration, e.g. siting density, damage susceptability, horizontal collectors appear preferable.

Stripper

The strippers functioned well and their performance could be accurately predicted by using a computer program based on standard heat and mass-transfer correlations for packed beds. Thermal efficiencies up to 69% were obtained. Low brine concentrations, high brine circulation rates and high air temperatures yielded high thermal efficiencies. Efficiencies close to the maximum attainable (as indicated by a 1.9°C difference from the adiabatic equilibration temperature) were obtained at brine concentrations as high as 35%. Attempts to achieve higher efficiencies by passing the exhaust air through the dew point in cycling recuperative beds failed because the condensed moisture did not drain from the bed.

SUMMARY

Tests performed to date indicate that the operation of solar-based brine-driven multiple-effect evaporation systems should be technically feasible but actual operation of a multiple-effect unit has not yet been demonstrated. Corrosion problems will have to be resolved and means developed for reducing the cost of the solar collectors used to reconcentrate brine in order to achieve economic feasibility.

SOLAR HEATED OR DEHUMIDIFIED AIR FOR DRYING FRESH PRODUCE

by

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ABSTRACT

A hot-air collector system, coupled with a solid desiccant energy storage, was tested in surface drying fresh citrus. The drying potential of conditioned and ambient air was characterized by the humidity ratio difference (HRD) calculated from dry and wet bulb temperatures. The average HRD level was 0.0045 kg/kg for activated alumina and 0.0052 kg/kg for silica gel, representing an increase above corresponding ambient conditions of 167 and 219% respectively. The collector/storage unit operated 53.7% of the time on direct solar heated air with the remaining 46.3% time characterized by drying through desiccant dehumidification. During a one year test period, no discernable degradation was noted in collector performance and the corrected collector efficiency averaged 48.3%. For desiccant regeneration overall system efficiency was relatively low, 4.7% for activated alumina and 7.6% for silica gel.

PROJECT BACKGROUND

One major unit operation in fresh fruit handling is surface drying the commodity after washing. For citrus, this drying operation is the most energy intensive on-site fossil fuel process in California (Mayou and Singh. 1980. ASAE Trans. 23:234-236, 241). The same is true in Florida but to a greater extent as a high humidity subtropical climate exists. An economic analysis of these fresh fruit dryers indicated 58% of overall costs for drying were accountable to direct fuel consumption (Bowman and Miller. 1982. ASAE Paper SER 82-003).

This project was directed toward the application of solid desiccants for surface drying citrus in Florida. The same process would be compatible with other fresh produce such as apples and blueberries that undergo surface drying. Additionally, the process could expand the application of low temperature drying for numerous crops in tropical or subtropical climates. Principal objectives of this research project detailed in this report were to:

1. Determine and test control techniques and solid desiccant materials for dual utilization of either solar heated-air or dehumidified air in surface drying fresh fruit.
2. Perform an overall analysis with regard to dual system energy optimization and economic feasibility.

Collector and Desiccant Storage Unit

The experimental solar unit in this study consisted of a) hot-air collectors, b) central desiccant container serving as an energy store and c) electrical control and ductwork system to facilitate either fruit drying or desiccant regeneration. The system was initially controlled by a differential thermostat (8.5°C ON, 0.8°C OFF). One probe was located in the ductwork and a second epoxied to a collector absorber plate. Secondly, the thermostat was further biased (13.0°C ON, 9.0°C OFF) by adding a 750 Ω resistor in series with the collector plate thermistor. The first mode was unsatisfactory for humid mornings as the desiccant gained moisture in the regeneration mode. In the second case, the daily operating period was significantly reduced. A third and more satisfactory control mode incorporated AND logic of a pyranometer set at an ~ 690 W/m^2 setpoint, and the differential thermostat (8.5°C ON, 0.8°C OFF). This combined control was used in latter testing with silica gel, during Spring 1982, and all testing of activated alumina for Autumn 1982.

Collector and regeneration performance was monitored at a 20 min interval via a 24-point data logger connected to ASR-33 teletypewriter. Inlet and outlet temperatures of each collector were monitored as well as desiccant mass, wind velocity, plus ambient, desiccated and heated-air dry and wet-bulb temperatures. A Fortran computer program was written to calculate collector efficiency, desiccant moisture content, ambient and conditioned air humidity ratio differences, and the temperature increase of each collector.

RESULTS AND DISCUSSION

Component Analysis

An overall loss coefficient, U_L, for the collectors was calculated from Duffie and Beckman (1980. Solar Engineering of Thermal Processes. John Wiley) and varied from 6.75 W/m^2-°K at 40°C plate temperature to 8.38 W/m^2 -°K at 100°C. Instantaneous collector efficiencies for the entire 8-module collector system were calculated for each reading. The value of U_L was determined based on plate temperature and collector efficiency corrected by a $[(mc_p A)/(mc_p/A+FoU_L)]$ factor. Resultant collector efficiencies are summarized in Table 1. These values represent the condition, $T_i-T_a = 0$, and the 2-series collector configuration. As expected, the second collectors in series had a smaller temperature rise, $T_2 = 6.6 \pm 1.3$°C, than the first collector, $T_1 = 9.8 \pm 1.7$°C. Due to an airflow imbalance, the north set of collectors exhibited a higher temperature difference, $T_n = 16.9 \pm 2.4$°C than the southern collectors, $T_s = 16.5 \pm 2.2$°C. Combining data from the complete test period and comparing via a paired t-test, a significant difference (1% level) existed both between first and second collectors in series and between north and south sets of collectors. Using heated air directly, the total system static pressure was 0.34 kPa. During desiccant drying, the pressure drop across the desiccant hopper was 0.21 kPa for activated alumina and 0.22 kPa for silica gel with a total system static pressure of 0.28 kPa. The higher pressure drop for silica gel appeared to be related to particle size. Geometric mean diameter for activated alumina solids was 3.9 ± 1.2 mm and for silica gel, 3.8 ± 1.3 mm.

Table 1. Summary of Direct Solar Energy Tests for Fruit Drying and Desiccant Regeneration

Parameter	Activated Alumina (Autumn 1982)		Silica gel[1] (Spring 1982)	
	$\bar{x}$	s.d.	$\bar{x}$	s.d.
Insolation, W/m	480.4	123.4	523.1	118.3
Collector Efficiency %	48.1	5.9	48.4	4.9
Desiccant Regeneration Efficiency %	4.7	3.6	7.6	4.7
Resultant HRD-fruit drying kg/kg	0.0045	0.0008	0.0052 (0.0057)	0.0013 (0.0008)
Ambient HRD-fruit drying kg/kg	0.0027	0.0005	0.0024 (0.0026)	0.0007 (0.0002)
Resultant HRD-Regeneration, kg/kg	0.0070	0.0011	0.0065 (0.0073)	0.0013 (0.0012)
Ambient HRD-Regeneration, kg/kg	0.0029	0.0006	0.0032 (0.0037)	0.0003 (0.0006)

[1]Numbers in parenthesis represent data for silica gel corresponding to same control mode operation as activated alumina.

Overall System Evaluation

Data for 1982 testing of silica gel and activated alumina are summarized in Table 1. The insolation level was slightly higher for silica gel as the testing continued until June 1982. No discernable decline was noted in the collector efficiency which averaged 48.3%. Desiccant regeneration efficiency was calculated from $(100 \cdot \Delta \cdot m \cdot h_{ads})/I$ (Miller. 1981. Agricultural Energy. 3:581-585. ASAE Publ. 5-81). These low regeneration efficiencies are interrelated to the fruit drying schedule and system usage in the desiccant drying mode. After conditioning to a low moisture content, further solar regneration simply results in ~ 0 efficiency. In general, efficiency correlates with the available moisture to be vaporized (Miller, 1981). Hence, higher regeneration efficiencies were attained for silica gel which had a moisture swing from 28.2 to 11.7% than activated alumina with 7.6 to 0.9% moisture variation.

A humidity ratio difference (HRD) was calculated to indicate drying potential of ambient or conditioned air. A slightly higher HRD was achieved for silica gel than activated alumina. Comparing the elevation above ambient HRD, the ratio for activated alumina was 1.67 and 2.19 for silica gel. The HRD distribution for all surface drying tests indicated that silica gel achieved a HRD $\geq$ 1.5 in each test while 23.1% of activated alumina tests fell in the 1.0 to 1.5 range. HRD levels for the regeneration mode in Table 1 represent the solar heated-air potential for desiccant regeneration.

Three control systems were used in evaluating silica gel. In the first mode with a differential thermostat only, the unit operated 98.1% of the time between a 9:00 a.m. to 4:00 p.m. EST daily schedule. For the differential thermostat plus added bias, the % time ON was reduced to 32.6%. The most satisfactory control unit with differential thermostat and pyranometer, resulted in 53.7% time ON. Note that 100 minus the above % operating times yields the % time for desiccant utilization (fruit drying) or % time collectors were nonoperational (non-fruit drying, desiccant regeneration only). Electrical parasitic power associated with air movement was measured for each fan. Average power level was 1.32 kW. For a 7 h/day operation, total energy requirement was 33,260 kJ for fan operation. Comparing parasitic energy to the solar input, collector output and overall regeneration of Table 1, a negative balance was observed for overall heat and mass transfer in desiccant regeneration. Even in directheated air drying, parasitic energy for the air moving devices was significant, 30%. It would appear that the desiccant storage could only be justified as an emergency unit when either fossil fuel or electric energy sources were not available. A control system sensing desiccant moisture content could reduce operating time in the regeneration mode when a minimum moisture level was achieved. Material costs for this system were: collector(s)-\$48.95/m^2, structural support-\$14.00/m^2, storage container-\$280.00, ductwork and controls-\$3,250.00, activated alumina-\$0.66/kg, silica gel-\$2.25/kg. Ductwork and controls include labor for sheet metal fabrication as that phase was handled on a contract basis. Desiccant costs were based on dry weight. Considering the water adsorption experienced in the test phase of this project, the comparison between activated alumina and silica gel yielded 9.85 and 13.65 \$/kg-H_2O uptake respectively. Silica gel had a lower bulk density, 0.72 g/cm^3, compared to activated alumina, 0.90 g/cm^3. Therefore, these two solid desiccants were economically competitive.

SUMMARY

A 23.0 m^2 modular solar hot-air collector system was designed and built to carry out the functions of direct heated air drying, solid desiccant regeneration and energy storage via the desiccant. Activated alumina and silica gel were the most satisfactory solid desiccants found in previous studies and both were tested for the fruit drying application. Resultant HRD levels were 167% above ambient for activated alumina and 219% for silica gel. These levels were achieved with the collector and storage unit operating 53.7% of the time on direct solar and 46.3% with desiccant dehumidification. Collector efficiencies averaged 48.3% and the collectors did not display any degradation over the one-year test. An overall low efficiency was found for desiccant regeneration. Related to available moisture for vaporization, the regeneration efficiency averaged 7.6% for silica gel and 4.7% for activated alumina. Parasitic energy for air moving devices associated with regeneration was greater than the stored energy based on moisture loss and heat from adsorption. Major costs associated with the pilot-scale unit were the collectors (\$48.95/m^2), ductwork and controls. The two desiccants were in the same cost range with activated alumina estimated at \$9.85/kg-H_2O uptake and silica gel at \$13.65/kg-H_2O.

A SOLAR-BIOGAS SYSTEM FOR FOOD DRYING

by

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ABSTRACT

This research project was initiated in September, 1980 with the objective of improving solar drying of foods with a hybrid system utilizing direct solar radiant energy, solar-heated air and biogas. Two combined mode solar dryers were built to dry tropical foods during daylight hours. Biogas with more than 50% methane generated from anaerobically fermented papaya waste heats up ambient air to about 49°C in a heat exchange system to augment solar energy for drying (Fig. 1). Total drying times of papaya, banana and pineapple slices with and without biogas were comparable, averaging 12 to 15 hrs, but solar-biogas drying could be completed in one day and resulted in better product quality. Experimental results have shown this system to be technically feasible. Work on an improved biogas collection system and a study of economic feasibility are in progress.

Problems and Objectives

Substituting solar energy for conventional energy, e.g. electricity or natural gas, in food drying poses several problems: (1) temperature control in the solar dryer; (2) intermittency of the availability of solar energy during the day; and (3) continuation of drying at night. Previous work on solar drying of tropical foods at the University of Hawaii has shown that the combined mode solar dryer using direct solar radiant energy and solar-heated air is a practical, versatile dryer (Moy, 1979; Moy et al., 1979). To overcome the problems stated above, we have demonstrated the feasibility of generating biogas from processed papaya waste and using the methane to heat ambient air to augment solar drying (Yang et al., 1983).

The overall objective is to improve solar drying of foods with a hybrid system utilizing direct solar radiant energy, solar-heated air and biogas.

Solar-Biogas Drying System (Figure 1)

During the past year:

(1) Several important parameters in the combined mode solar dryer were studied and determined;

(2) Biogas generation in terms of loading rates and methane quality was optimized;

(3) A heat exchange system was designed and constructed to provide for the utilization of methane to heat up the ambient air for drying whenever solar energy was insufficient or unavailable;

(4) Drying experiments on tropical fruits were conducted.

Experimental Results

(1) Combined Mode Solar Dryer

(a) Solar radiation collection efficiency in the Model UH-SB solar dryer was measured to vary from 47 to 68%, averaging 59%. This was based on multiple measurements of thermal energy gained by the air in the dryer over the solar energy available to the dryer.

(b) Drying efficiency in drying 0.6 cm thick taro slices with 62.3% initial moisture, 4.7 kg/m^2 loading density to 80% dryer capacity was determined to be 45% (Energy utilized over energy available).

(c) Contributions of various thermal energy to heat transfer in the solar dryer were measured: radiant heat transfer, 30%; convective heat transfer, 51%; all others, 19%. (This was done by using the direct mode and indirect mode solar drying.)

(d) Heat and mass transfer coefficients: the highest values measured were 12.1 kcal/m^2 °C hr and 8.0 kg/hr m^2 atm respectively.

(2) Biogas Generation: A biogas with a minimum of 50% methane has been produced at a rate of 0.38 liter methane per liter of digester volume per day. (Maximum digester volume was 188 liters, organic loading rate was 1.6g TVS/ℓ/d with a hydraulic retention time of 15 days.)

(3) Heat Exchange System: A simple S-shaped stainless steel heat exchanger with a total of 0.85 m^2 heat transfer area was constructed to allow ambient air to be heated by combusting methane. The heated air was admitted to the bottom of the solar dryer and the exhaust gas let out to the atmosphere. The heat exchanger was housed inside a fire-brick chamber. Biogas to the ignitor and burner was activated by a thermostat inside the dryer with a temperature setting of 49°C.

(4) Drying of various fruits to 5-10% moisture (w/w) showed:

	Papaya (6.4 mm)		Banana (6.4 mm)		Pineapple (10 mm)	
	Solar	Solar-Biogas	Solar	Solar-Biogas	Solar	Solar-Biogas
Solar drying	5-8 hr	5-8 hr	8-10 hr	8-10 hr	7-10 hr	7-10 hr
Biogas drying		3-8 hr		3-7 hr		5-9 hr
Solar drying	3-6 hr		3-8 hr		4-9 hr	

These results showed that:

(a) The total drying times between the two dryers in replicate runs for tropical fruit slices, which were placed on screen trays with a loading density of 4.7 ± 0.3 kg/m^2, were comparable, varying from 12 to 15 hrs because of fluctuation of air temperature which is a function of solar insolation. The advantage of the solar-biogas system over the solar-only system is that the latter requires 1 1/2 to 2 sunny days to complete the drying while the former completes the drying within a 24-hr period.

(b) Drying rates and air temperature measurements indicated the solar-biogas system to be better controlled. The quality of dried fruits in the hybrid system was better than those in the solar-only system.

(c) The solar-biogas system is a workable drying system and is a better system than one relying on solar energy alone in terms of utilizing the capacity of the dryer. With further improvements and refinement, the solar-biogas drying system could be quite adaptable in cottage or small-scale industry to food drying when solar energy and biomass such as processed fruit and vegetable wastes are available.

Future Plan of Work

Work is in progress to build an automatic gas collection system by using a small compressor to transfer biogas into a storage tank from which the gas will go to the burner when needed. The compressor will be controlled by two level switches on the gas receiving tanks. A study of the economic feasibility of this drying system is also in progress.

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Yang, P. Y., Moy, J. H. and Weitzenhoff, M. H. 1983. A hybrid solar-biogas system for food drying: Bigoas generation from processed papaya wastes. J. Food Sci. (in press)

SUMMARY

A solar-biogas system was constructed for food drying (Fig. 1). The combined mode solar dryer uses direct solar radiant energy and solar-heated air with a solar energy collection efficiency of 59% and a drying efficiency of 45%. Thermal energy contributions to heat transfer were: radiant, 30%; convective, 51%; and all others, 19%. Biogas generation by anaerobic fermentation of papaya waste was optimized at 0.38 liter methane/ℓ digester vol./day. Biogas quality was 50% and higher. A heat exchange system was built to use the biogas for drying at night. Total drying times of tropical fruits with and without biogas were comparable (12-15 hrs) but the fruit quality was better in the solar-biogas runs.

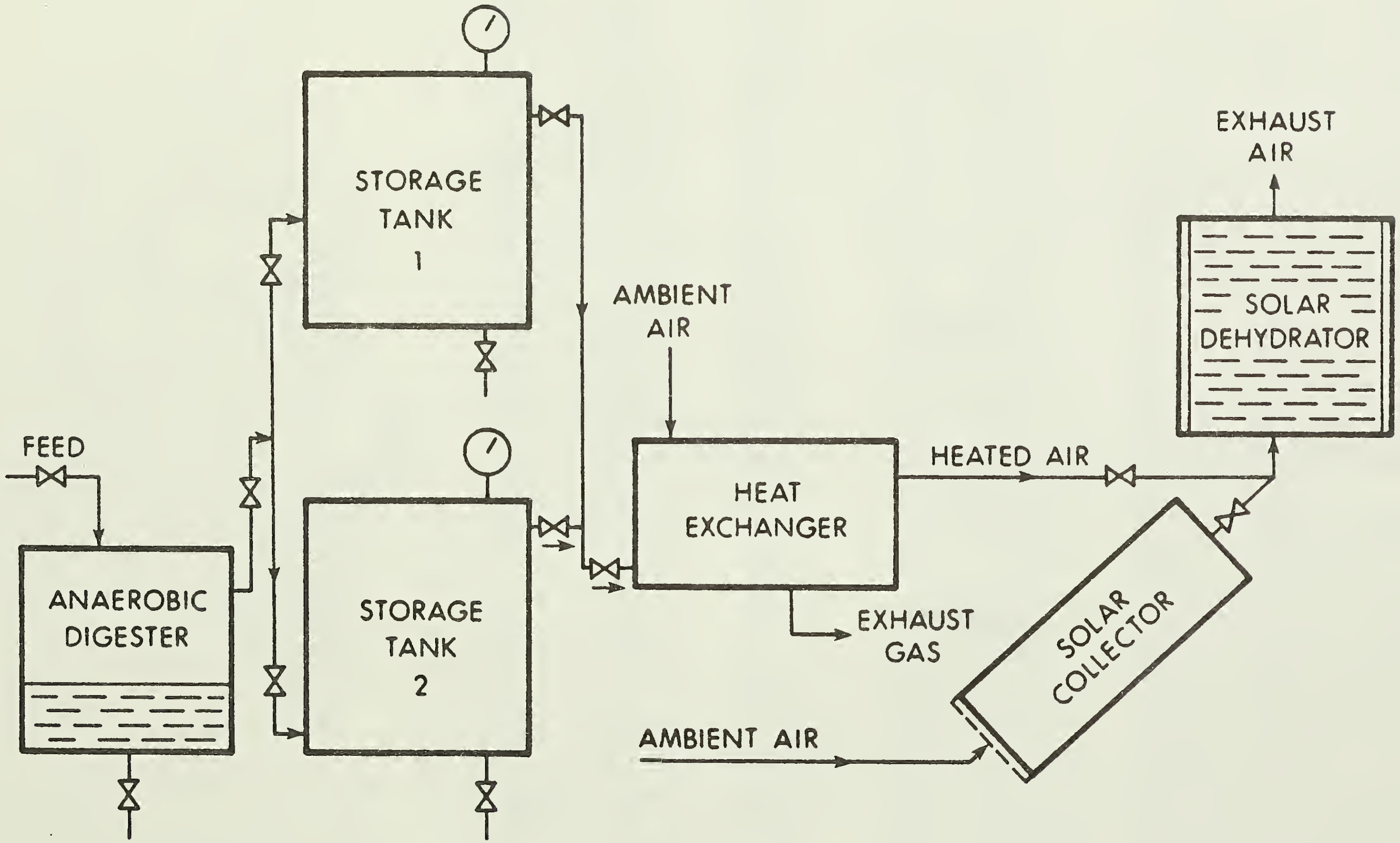

Fig. 1 - A SOLAR-BIOGAS SYSTEM FOR FOOD DRYING

DIRECT PASTEURIZATION OF FLUID FOODS UTILIZING SOLAR ENERGY

by

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ABSTRACT

The development and testing of two devices having the potential to reduce the nonrenewable energy usage in the fluid food pasteurization process are described. A solar pasteurizer, utilizing an evacuated tube solar collector, was used to pasteurize both fluid milk and single strength grape juice. A biomass furnace was developed to study the use of grape pomace for steam generation in fruit juice processing plants.

Solar Pasteurization

A pilot plant for the pasteurization of fluid foods with solar energy was constructed on top of the Agricultural Engineering building at Washington State University. The pasteurizer consisted of a 2.5 square meter evacuated tube collector, a two section APV Junior Paraflow plate type heat exchanger, an insulated stainless steel holding loop, a 1.5 kilowatt 60 liter water heater and two remote control variable speed pump heads. The components could be plumbed to configure either a direct or indirect solar pasteurizer.

Direct Solar Pasteurization

The direct solar pasteurizer is shown in Figure 1. In this system, the product was pumped through the solar collector where it was heated to the necessary level to insure proper pasteurization. Exiting the collector, the product passed through one section of the heat exchanger. The exchanger allowed the heat in the pasteurized product to preheat the incoming raw product. As the daily insolation level varied, the product flowrate was adjusted with the variable speed pump, so to maintain a constant processing temperature

The direct solar pasteurizer was used to successfully pasteurize single strength grape juice and fluid milk. The maximum processing capacity was in excess of 400 liters per day (for a clear June day in eastern Washington).

A major problem with this system was maintenance of collector sanitation. Since the product passed through the collector, it was necessary that the entire collector be sanitary. This required extensive cleaning after each day of processing. With the 2.5 square meter collector used in this study, the sanitation problem was only a daily inconvenience for the operators. However, it is felt that when using a larger collector area, collector sanitation could become an unmanageable problem.

Indirect Solar Pasteurization

In an attempt to circumvent the collector sanitation problem and increase production capability, an indirect solar pasteurization configuration was developed. This system is shown in Figure 2. It was used to pasteurize fluid milk with the High Temperature Short Time (HTST, 71.7°C for at least 15 seconds) combination.

The indirect approach heated water with both the evacuated tube collector and a 1.5 kilowatt, 60 liter water heater. As the daily insolation level varied, power to the water heater was adjusted to maintain a constant water temperature. The heat in the water was transferred to the fluid milk by pumping the water and the milk, in a counterflow fashion, through the heat exchanger. The heated milk passed from the exchanger to an insulated holding loop where it was retained for a sufficient amount of time to insure the HTST Time-Temperature combination was satisfied. Exiting the holding loop, the pasteurized product passed through a separate heat exchanger, preheating the incoming raw product.

The indirect solar pasteurizer was used to successfully pasteurize up to 2,000 liters of fluid milk per day. Quality of the milk processed with this system was evaluated for degree of pasteurization and taste. Plate counts of the solar pasteurized milk showed reduction in pathogenic organisms sufficient for pasteurization standards. Taste tests revealed there was no significant difference in organoleptic qualities of the solar processed milk as compared to commercially processed milk.

Process Control Computer

Automatic process control and data acquisition was done with a custom built microprocessor based control system. The process control computer was located in a small room below the solar pasteurizer. It was programmable in BASIC, Pascal, and assembly language. A thermocouple scanner interfaced the computer to Type T thermocouples located throughout the pasteurizer. Turbine type flowmeters were used to monitor system flowrates. For the direct pasteurization configuration, process control was obtained by automatic manipulation of product flowrate through a remote control variable speed pump. Process control for the indirect configuration was obtained with automatic modulation of the power to the water heater. A color CRT terminal served as an operator interface and for real time display of operating conditions.

Biomass

The feasibility of combusting pomace to produce steam for the juice processing industry was studied. A combustion test of grape pomace was performed to evaluate pomace combustion characteristics and verify a computer combustion simulation.

Two hundred and fifty kilograms of grape pomace were obtained from a local juice processing plant and air dried to 24 percent moisture content wet basis. The pomace was burned in the circular vortex furnace shown in Figure 3 at a feed rate of .455 kg/min. Excess air was varied from 70 to 250 percent which caused a corresponding change in furnace efficiency. Furnace efficiency ranged from 67 to 88 percent respectively. The highest flue gas temperatures (over 600°C) were observed in the 70 to 120% excess air range which agrees with reviewed literature. Flue gas was analyzed using an Orsat gas sampler and was measured at each excess air level. Carbon dioxide, oxygen, and moisture concentrations were observed.

Orsat samples were compared to the computer combustion simulation and were within two percent of each other. This verifies the accuracy of the program giving credibility to its results. Results from the computer program are being used in environmental statements concerning the installation of large scale combustors.

SUMMARY

Two different solar pasteurization systems were developed. The first utilized a direct approach where the product was pumped through the solar collector. An indirect approach was used with the second system. This method pasteurized the fluid food product with water heated by the solar collector. Fluid milk and grape juice were successfully pasteurized with both methods. No degradation of the organoleptic qualities of the solar pasteurized foods were found.

Grape pomace was obtained from a local processing plant and was burned in a circular vortex furnace. The pomace was air dried to 24% moisture content before it was burned. The pomace burned satisfactorily and produced stack gas temperatures in excess of 600°C. Combustion efficiencies ranged from 67% to 88% depending on the amount of excess air used. An analysis of stack gases revealed a correlation between particle count and percent excess air.

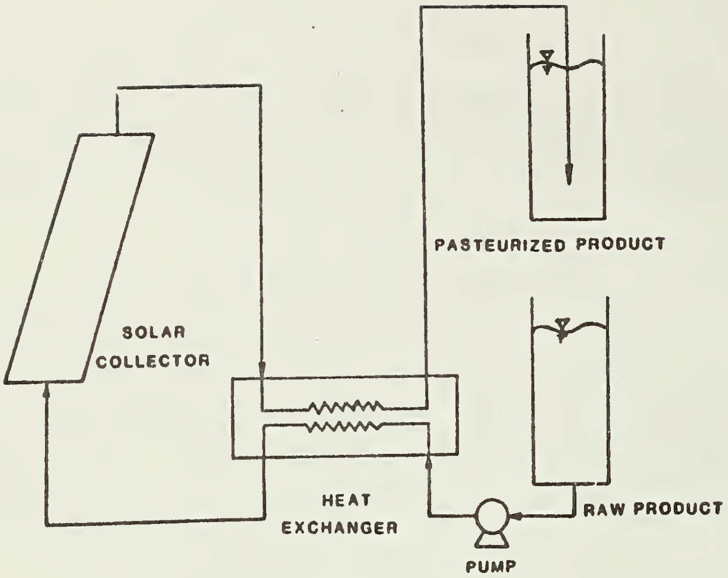

Figure 1. The direct solar pasteurizer.

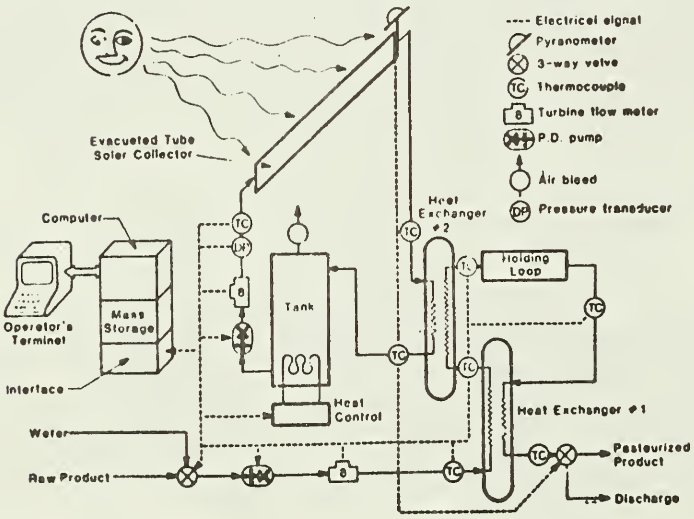

Figure 2. The instrumented indirect solar pasteurizer.

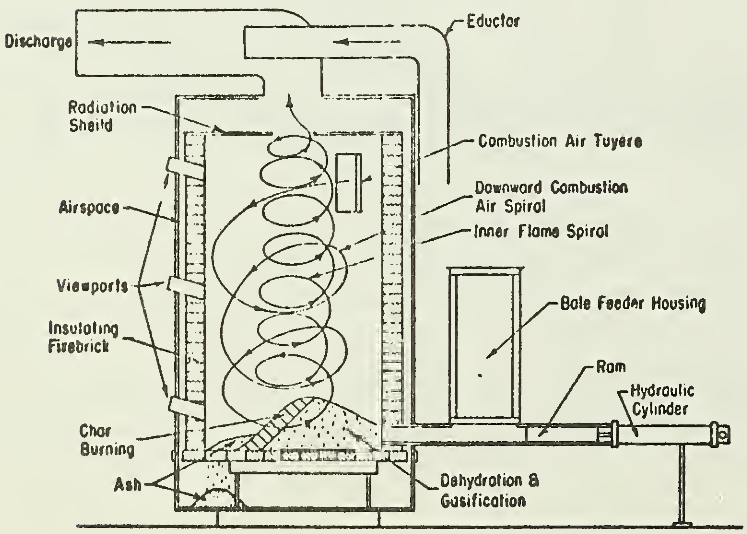

Figure 3. The concentric vortex biomass furnace.

TOMATO PRODUCTION IN AN ENERGY EFFICIENT GREENHOUSE WITH SOLAR HEATED SOIL

by

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ABSTRACT

This project was initiated in October 1980 with the goal of the development of an energy efficient greenhouse with a south front solar energy collector which, when combined with an active air fluid solar heat collector for heating the plant soil, would reduce the need for fossil fuels by about 85 percent. The experimental greenhouse selected is 7.32 m wide by 10.97 m long. It has a single-sloped roof with a 4.88 m high south front and a 2.44 m high north wall. It also has a permanently insulated north wall, a removable insulated ceiling, and openable and closeable insulating curtains (drapes) over the south, east and west walls. Three crops of tomatoes were grown in the greenhouse. In the first trial in 1981-82, a too low minimum ambient temperature was selected for supplementary heat to be added, thus tomato production was low. In the second crop in 1982 Cultivar-Tropic tomatoes were grown and production was excellent exceeding normal production by about 25 percent. Production in the fall of 1982 with Cultivar-Dombito tomatoes was low with yields about one-half as good as the 1982 production. Supplementary energy requirements were low with solar energy supplying about 45 percent of all heat required.

INTRODUCTION

Greenhouses offer a potential for increasing year-round production of food at a time when world food production is a serious concern. Unfortunately most of the current designs are inefficient in the use of energy; thus food production in greenhouses is usually expensive. For most greenhouse facilities, optimum growing temperature range is 10°C to 27°C. This requires an average annual heat input that is typically between 70.7 x 10^9 to 120.3 x 10^9 joules per hectar. Fuel costs have been estimated at 40 to 80% of all costs for greenhouse operations. It was with these facts in mind that this project was initiated to: 1) develop a passive solar collector system for a heat conserving greenhouse design, which when combined with an active solar heat energy collector system for heating the plant soil, reduces the need of the normally required supplementary fossil fuel energy; and 2) find the improvement in plant growth (crop production) rates of selected vegetable (tomatoes) produced in the heated soil.

Description of the Greenhouse

The greenhouse is 7.32 m wide and 10.97 m long. It is oriented with its long axis in an east-west direction. The roof is a one-slope type about 2.44 m high at the back which faces north and 4.88 m high on the front which faces toward the south, as shown in Figures 1, 2 and 3. The north

*The authors wish to express their appreciation to Polly Burkhart, Research Technician, the Dept. of Horticulture, for her dedicated assistance in the crop production of this research.

wall is covered with color coated steel on both the outside and inside with six inches of vermiculite insulation in the cavity. The remaining walls and roof are covered with Filon coated corrugated fiberglass on the outside and a layer of tedlar on the inside. Insulating drapes are mounted on tracts on the walls so they can be opened in the daylight periods and closed at night. A double layer of 2.35 cm Thermax rigid insulation panels covered with aluminum foil is suspended under the roof with taut airplane cables. These panels may be added or removed as desirable to let the rays of the sun in or to reduce the heat loss.

A fan jet system ventilation system in conjunction with two thermostatically controlled exhaust fans are used to mix the air in the greenhouse and to provide fresh air as requried to prevent the building from becoming too warm.

The Solar Energy Collector and Its Operation

The solar energy collector used in conjunction with the greenhouse is an air type, 3.7 m x 11 m in dimensions. It is fabricated of the same type of cover materials as the greenhouse with a blackened aluminum collector plate placed over 10 cm of Styrofoam insulation and 2.35 cm of Thermax insulation immediately beneath the aluminum.

The solar collector is connected to the soil heat storage in the greenhouse by 0.5 m by 0.7 m, insulated 1 cm thick plywood manifolds placed below grade on both the east and west ends of the solar energy collector and greenhouse. Forty-five 10 cm non-perforated plastic tiles extend in two layers from the manifold on one end of the greenhouse through the soil to the manifold at the other end. A 1/4 horsepower centrifugal blower located in the solar collector forces the solar heated air through the manifold on one end, then through the plastic air ducts to the manifold at the other end to heat the soil.

EXPERIMENTS PERFORMED AND RESULTS

Three crops of tomatoes have been grown in the experimental greenhouse to date: (1) October 15, 1981 through January 19, 1982; (2) February 24, 1982 through July 1982; and (3) October 1, 1982 through January 10, 1983. A fourth crop was started March 4, 1983. Supplementary energy requirements have been low for each planting.

Supplementary Energy Requirements

For the first crop of tomatoes a minimum temperature of 5°C was selected for the greenhouse before auxiliary heat was used. The maximum temperature slected was about 27.5°C. During the 111 days of this crop growth and production, 8,048 mega joules of energy were required to maintain the minimum conditions selected.

For the second crop of tomatoes the minimum temperature was set at 15.5°C with the maximum of about 28°C except when the outside temperature was higher. During the 126-day period, 1832.8 mega joules of energy were required to maintain the minimum conditions selected.

For the third crop of tomatoes from October 1, 1982 through January 10, 1983, the minimum temperature was again set at 15.5°C with the maximum fluctuating up to about 28°C except when the outside temperature was higher. During the 102-day period of growth and production, 9,126 mega joules of auxiliary energy were required.

Because of many indeterminate factors involved, such as the direct solar energy received by the greenhouse, the solar heated soil and the fluctuating outside and inside temperatures, it is difficult to make any specific statements about what the auxiliary energy requirement meant. The experimental greenhouse with the insulated north wall and ceiling curtains on the other walls is rated as a 27.4 mega joule/(°C) (day) building. A similar size greenhouse, without the insulated north wall and ceiling and curtains on the other walls but with a lining is a 57.1 mega joule/(°C) (day) building. A similar size greenhouse without the lining is a 110.8 mega joule/(°C) (day) house.

Table 1 gives a summary of the energy contributions of the auxiliary heater and solar heated soil for the heating season in 1982-82. The supplementary energy required during this period was 3,909 KWH. In contrast a regular greenhouse, without the lining and solar heated soil, would have requried 27,926 KWH of energy. Thus the 3,909 KWH required for this experimental greenhouse is an 86% reduction in the auxiliary energy requirement for an unlined greenhouse. Contrasted to a lined greenhouse auxiliary energy was reduced by 73%. For the comparison with the unlined greenhouse, the reduction in auxiliary energy requirements was about as expected.

Table 1. Monthly Energy Contributions from the Soil and Auxiliary Heater

Month	Auxiliary Heater Contribution	Soil Contribution (KWH)	Total Demand (KWH)	Soil Percent (KWH)
October	Nil			
Nov. 81	120	306	426	71.83
Dec. 81	563	839	1,402	59.84
Jan. 82	2,169	839	3,008	27.89
Feb. 82	1,057	1,013	2,070	48.94
Seasonal Total	3,909	2,997	6,906	43.40

Tomato Production

Tomatoes were grown on an area equal to 0.00406 hectars (0.01 acre). The harvested salable quantities are shown in Table 2. Rows were numbered from south to north. Figure 4 shows the tomatoes grown in the greenhouse.

Table 2. Kilograms of Tomato Fruit Produced in the Greenhouse.

Row 1	2	3	4	5	6	7	8	9	10	11	12
Cultivar-Tropic (February 1982 - June 1982)											
18.8	18.1	17.5	15.7	18.8	15.5	17.4	14.6	15.0	11.0	12.4	10.9
Cultivar-Dombito (October 1982 - January 1983)											
4.1	5.3	5.5	5.7	7.8	7.8	8.7	7.9	10.6	8.9	12.2	7.2

Summary of Production Equivalency in Kilograms per Hectar and Pound/Acre

Cultivar-Tropic: 45,565 KG/Hectare (40,666 lbs/acre).
Cultivar-Dombito: 22,674 KG/Hectare (20,240 lbs/acre).

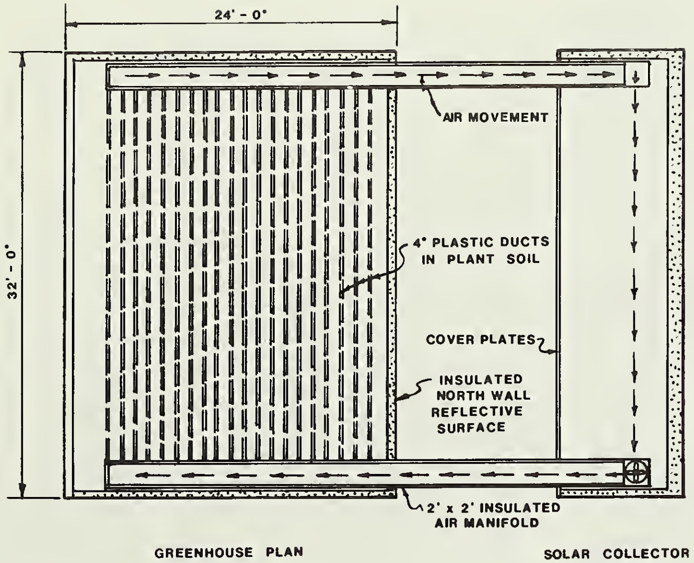

Figure 1. Plan of the Greenhouse and Solar Heating System.

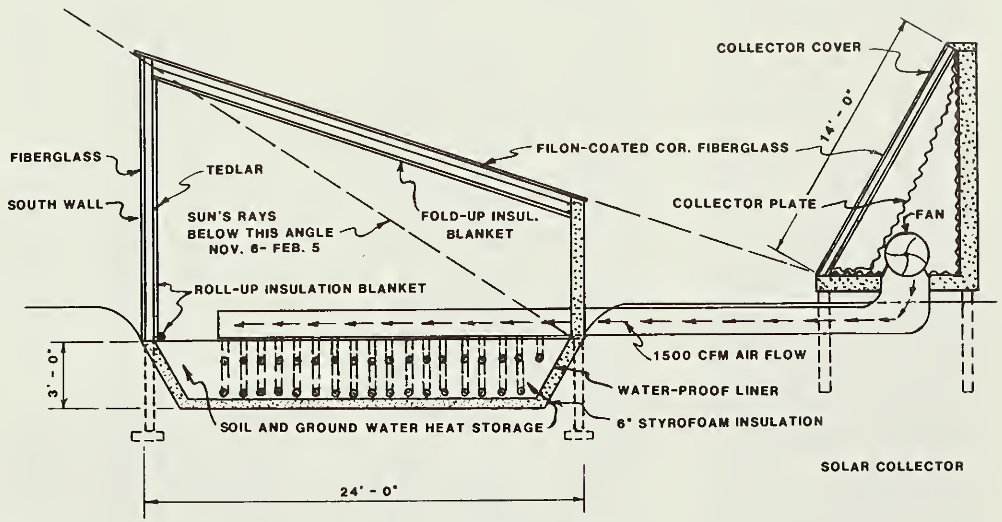

Figure 2. Cross-Section Through the Greenhouse and Solar Collector.

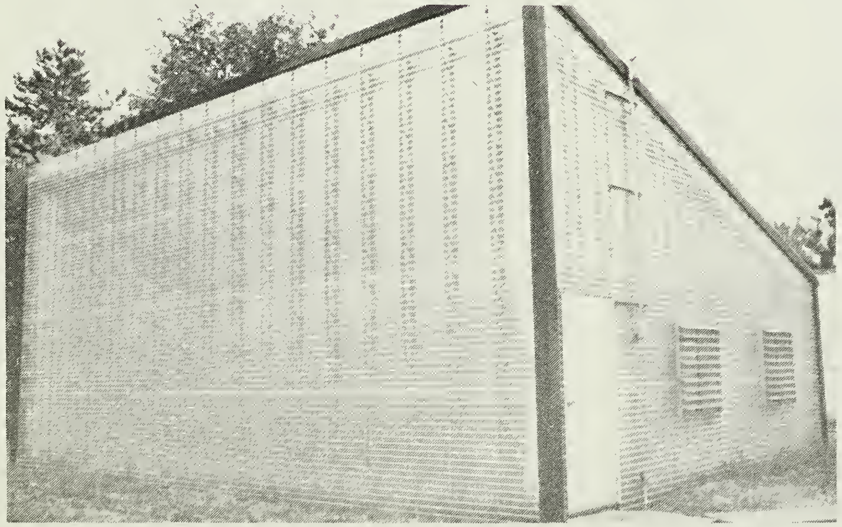

Figure 3. An Outside View of the Special Energy Conserving Greenhouse.

Figure 4. Tomato Production Has Been Good With Low Supplementary Energy Requirements.

TEST OF A FLUID-ROOF GREENHOUSE AS SOLAR COLLECTOR

by

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ABSTRACT

A small (22 m^2) test greenhouse located near College Station, TX was fitted with a roof made of 6 mm blue-green heat absorbing glass, covered by an inflated clear plastic film, with water running down the glass as a thin film, both for heating and cooling purposes. The solar energy collection efficiency of such a roof, in the cooling mode, is about 40%. The system was operated continuously from December 1982 through date, with a lettuce crop being grown in containers. Temperatures in the greenhouse were maintained between 7 and 27 °C, without heating and with little ventilation, but by storing excess solar heat in a tank during the day and by using the roof as a radiator at night or during cold days. The tank capacity was equivalent to a water layer of 60 mm and the water flow rate was 1 mm/min, or a turnover rate of 1 per hour. In spite of an unseasonally cloudy winter a good quality lettuce crop was produced in 80 days.

INTRODUCTION

The first application of the fluid-roof concept to energy conservation and environmental control in greenhouses was made by using an infrared absorbing fluid (3% copperchloride) in hollow methylmethacrylate or in hollow polycarbonate clear glazing. Theoretical analysis of the concept showed considerable promise (1). As a matter of engineering practicability, the next application was made with blue-green heat absorbing glass, over which water could be made to flow as a thin film. The flowing water was protected from the environment with a second sheet of clear glass. Results obtained at Avignon, France in a 200 m^2 greenhouse for tomato production, showed close agreement with a computer simulation model, and, also, that heating and ventilation could be eliminated altogether, if an aquifer at 14 °C was substituted for a storage tank in the circulation loop (2).

As the use of a second sheet of glass adds considerably to the mass and the cost of the roof construction, and decreases the light level inside, an alternative approach is now in the last phase of experimental testing at College Station, Texas. This approach retains the blue-green infrared absorbing glass, used in as large a single pane as feasible, with each pane provided with a thin, clear plastic film that is inflated to form a domed rectangle. This report concerns the final phase of the project: a test in a pilot-size greenhouse in which a crop is grown. Having started in the winter of 82/83, the pilot test will continue into the hot weather period of 1983.

EXPERIMENTAL

The pilot greenhouse was square, 22 m^2 in area, and provided with insulated walls, 25 cm thick with metallic reflective inner surfaces. The roof was made as a single-gabled roof with a 7^o slope toward the eaves, consisting of 4 panels facing E and 4 panels facing W. The glass sheets, about 1.1 by 2.4 m in size, were cut from 6 mm LOF monolithic float glass (blue-green, heat absorbing). A redwood frame, 15 cm high, supported and sealed each glass sheet and, also, a sheet of Tefzel film, 1 mm thick, separated from the glass by about 12 cm. At the upper vertex of the panel 8 brass nozzles were installed so as to produce a downward water spray impinging on the glass. The water, by reason of an added wetting agent, delivered at a pressure of about 0.1 bar to the nozzles, formed a uniform sheet flowing downward toward 3 drainage outlets at the lower vertex of each panel. Hence, the stream of water was manifolded to a common return tube into a 1500 L underground reservoir. From there, the water was returned by a submersible pump at a rate of about 25 L/min to the spray nozzles.

The Tefzel film was kept inflated by two small squirrel cage blowers, each serving 4 panels through an air inlet in each panel. The film was completely taut and essentially undisturbed by the strongest wind gusts. Before the entire pilot greenhouse was constructed, a test panel was made and evaluated during the summer of 1982. To this end, measurements of total and "visible" solar radiation were made above and below each panel, generally during the middle of sunny days. Also, the rise in temperature of the water, as it flowed over the glass panel, was recorded.

The pilot greenhouse was equipped with a ventilation fan, capable of producing about 25 airchanges per hour. A ventilated thermostat, set for 25 ^oC, controlled the power to the fan. Two other thermostats in the same ventilated enclosure, turned the water pump on if the air temperature exceeded 20 ^oC or was less than 15 ^oC. Aspirated psychrometers recorded the dry and wet bulb temperatures, outside and inside the greenhouse. A record was also kept of solar radiation outside and under the roof of the greenhouse, as well as of the time that the pump and ventilator were running. Finally, the difference in water temperature between the inlet and outlet manifolds to the roof was recorded, as was the water temperature in the tank. Measurements were routinely made at 4 AM and 4 PM, and, on selected days, every 2 hours.

With brief interruptions, the record was started on December 9, 1982 and continued to date, with the latest available data obtained on March 10, 1983. A lettuce crop was grown, 4 plants to a 7 L container, with 4.5 pots per m^2, or 100 in total, by planting on November 23, 1982 and harvesting on February 8, 1983. The plants were watered daily by an automated drip irrigation system, dispensing the equivalent of 3 mm per day of a Steiner nutrient solution. Excess solution drained from the containers into the gravel-covered soil forming the floor of the greenhouse.

The object in growing a lettuce crop was not to conduct a production trial, but rather to create a representative environment, specifically through transpiration and the equivalent energy flux.

RESULTS AND DISCUSSION

As the investigation is still in progress, only the salient features of the data obtained to date can be given. These are confined to the winter period at College Station for 1982/1983, which was cooler than normal, but lacking extremely cold or warm periods. A principal item of interest is the air temperature in the greenhouse, which is a close approximation of the crop temperature, under the circumstances. Figure 1 shows the daily values at 4 AM and 4 PM, and the thermostat settings. Control was obviously obtained at the upper set point with a minimum of ventilation. The lower set point value was not maintainable, but the temperature seldom dropped below 10 ^{o}C. Figure 1 also shows the cooling, heating, and ventilation action.

One observation of interest was heavy condensation on the interior face of the glass. Relative humidity was often above 95%, as the greenhouse was essentially a closed system. As we have stated earlier, a fluid-roof greenhouse requires ventilation for humidity control and carbon dioxide supply, but this amount of ventilation is minimal. On the other hand, it is obvious that the system is ideal for CO_2 enrichment which can more than compensate for the light level, which will be somewhat lower than that under a normal glass roof.

Condensation also occurred on the bottom side of the Tefzel film, resulting in a light reduction of about 5%, as compared to a dry film. The film itself performed well, showing no deterioration, algae growth, or stretching. In general, the system performed faultlessly for the entire period.

Lettuce growth was adequate, with the heads being less dense than normal. This was also observed in standard greenhouses nearby and appears related to the below-normal amount of sunshine in December.

Our experience shows that a fluid-roof greenhouse can operate through a normal winter in S. Central Texas solely by solar heating, using the greenhouse roof as the collector. For some crops and for emergencies, a standby heating system would still be required, however. Whether the system will also perform adequately in the summer, in providing daytime cooling, remains to be seen, through evidence already in hand makes the proposition plausible.

SUMMARY

A fluid-roof solar greenhouse, in which a thin film of water flowed over slanted glass panels, made from heat-absorbing glass and covered with a clear, inflated film was operated for about 100 days. Mechanically and horticulturally the system performed well, without supplemental heat and with little ventilation. Interior condensation was a problem, that would require humidity sensing and control by ventilation. The test is con-

tinued into the warm season to evaluate the cooling ability of the system.

REFERENCES

(1) Van Bavel, C.H.M., J. Damagnez and E. J. Sadler. 1981. The fluid-solar greenhouse: Energy budget analysis by simulation. Agricultural Meteorology. 23:61-76.

(2) Chiapale, J. P., C.H.M. van Bavel, and E. J. Sadler. 1983. Comparison of calculated and measured performance of a fluid-roof and a standard greenhouse. Energy in Agriculture. In press.

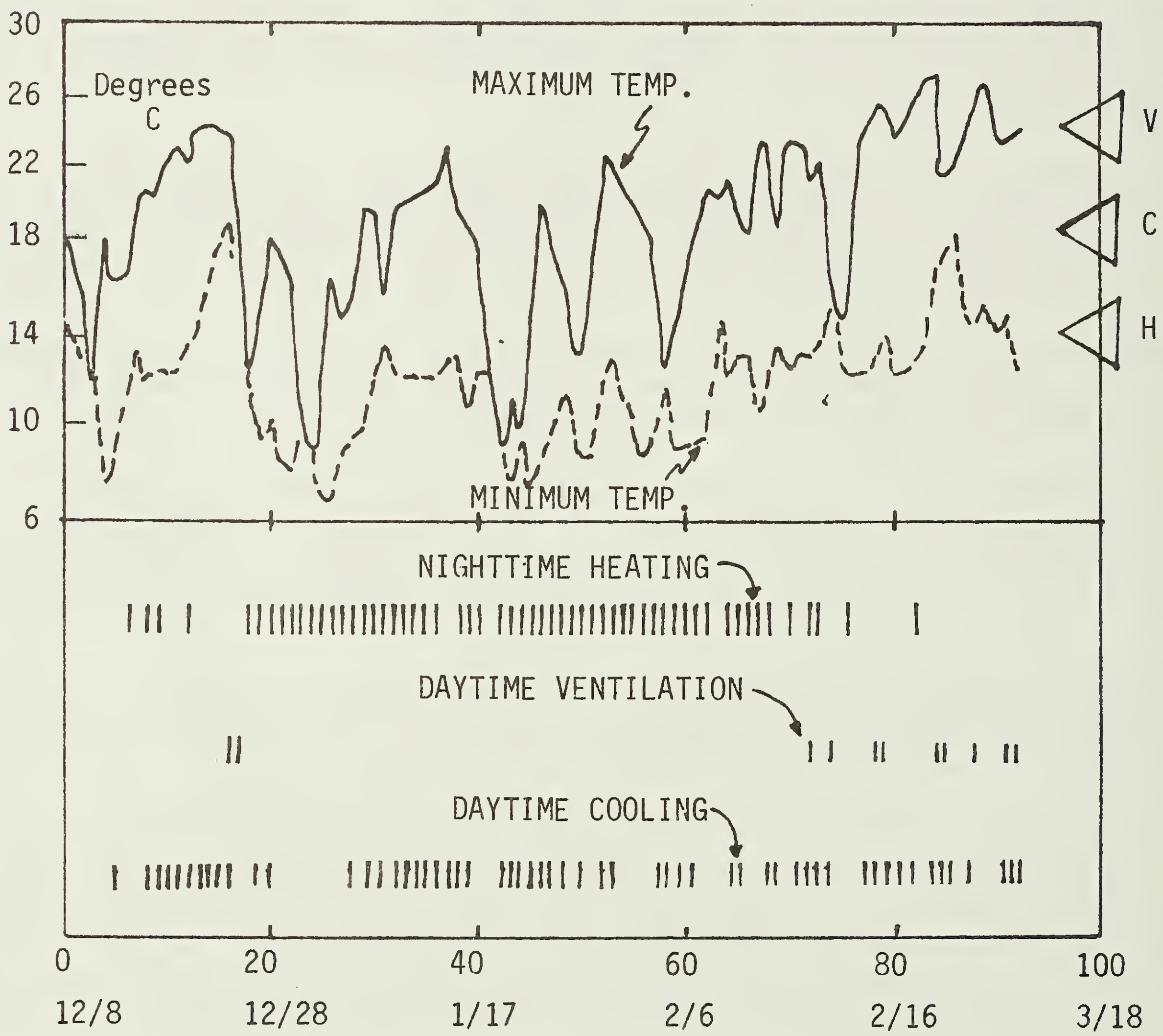

Figure 1. Maximum and minimum air tempertures in an unheated fluid-roof solar greenhouse during the period December 9, 1982 through March 10, 1983. Also shown is the occurrence of significant nighttime heating and daytime cooling by fluid circulation, and ventilation with outside air. Thermostat set points indicated as H, C, and V, respectively.

A WARM FLOOR SOLAR GREENHOUSE INSULATED AT NIGHT WITH POLYSTYRENE PELLETS

by

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ABSTRACT

A greenhouse energy conservation project combining nighttime, polystyrene pellet insulation, soil heating and solar pond energy supply was undertaken. A tomato crop was grown in the greenhouse to insure that the results applied to a properly operating system. The solar pond was used in its normal operating mode to passively collect and store summer, solar energy and then it served as a representative source of low temperature thermal energy for heating the greenhouse. Heat was distributed to a moist sand soil as warm water circulating through buried polyethylene pipe, and as much as 34 percent of the maximum, uninsulated, heat requirement of the greenhouse was supplied through the soil. Pellet handling equipment was able to fill the roof of an 18.5' x 96' greenhouse with a 4 to 6" blanket of polystyrene pellets in about 45 minutes, and empty it in about 35 minutes. Planned improvements should reduce these times considerably. The pellet blanket reduced the nighttime heat requirement by 90 percent and made it possible for the soil heating to meet the full greenhouse heat load. In addition, initial economic considerations indicate a very favorable return on investment for the pellet insulation system.

Introduction

This project combined three energy technologies that have been developed over the past ten years at O.A.R.D.C. - a solar pond, soil heating and polystyrene pellet nighttime insulation. This combination constituted a demonstration of the effectiveness of a total greenhouse energy conservation program that has the potential for dramatically changing the economic prospects of the greenhouse industry.

Solar Pond

The solar pond is a salt-stabilized body of water (60' x 28' x 10' deep) that collected and passively stored summer radiant energy as heat for use in winter. It was operated throughout the project with only minor modification. In terms of its overall function in the system it was representative of a wide range of relatively low temperature heat sources (solar and non-solar), and should not be thought of as a requirement of the system.

The solar pond has an energy storage capacity (at a peak temperature of 130°F) of 60×10^6 Btu. Based on energy requirements when nighttime insulation was used, this would have been enough energy to have completely heated both 18.5' x 96' bays of the adjacent, experimental greenhouse for most of a winter season. However, various practical and experimental considerations made frequent use of the regular, gas-fired heating units desirable, and, therefore, the solar pond was only used sparingly.

Plant Growth

Tomato plants, variety CR-6, at commercial density, were transplanted on October 12, 1982, into both bays of the greenhouse. A peat-vermiculite bag culture, with automatic feed drip irrigation, was used for plant maintenance throughout this last winter. The plants were topped in late February and will be finished producing in late April.

The tomato plants were grown in order to maintain an "honest" greenhouse energy environment and only gross horticultural effects were studied. However, it should be noted that high humidity arising from the soil heating system and/or lower light levels caused by some of the pellet insulation work did seem to adversely affect production and that, therefore, system modifications in these respects will need to be made.

Soil Heating

High density polyethylene pipes, 3/4" in diameter, were buried 8" deep in moist sand in one of the two bays of the experimental greenhouse. These pipes were spaced 8" apart and ran the length of the house in a pattern of alternating supply and return pipes connecting between supply and return headers at one end of the system. A plastic liner at 12" deep supported a 4" water table in pea gravel up to the depth of the pipes. This liner was underlaid with a 1" thickness of Thermax™ insulation on dry soil.

Data were collected from 80 thermocouples throughout the system, and from water and gas flow meters. Warm water at up to 105°F was circulated through the soil heating pipes, and a temperature drop between the supply and return headers of up to 6°F was observed. This represented a heat supply to the soil of up to 630 Btu/ft^2/day. At this supply level, 10 percent of the soil heat penetrated the insulation and was lost to the deep soil. The remaining 567 Btu/ft^2/day represented 34 percent of the 1650 Btu/ft^2/day maximum heat requirement for the uninsulated greenhouse (a figure obtained in previous studies under harsh, winter conditions).

Two major experimental design limitations made it quite difficult to interpret the data. First, the boiler that supplied the hot water was in an uninsulated section off the main greenhouse and suffered a significant, unnecessary heat loss; and second, the single plastic sheet that separated the two bays into "independent" heating units represented a considerable heat exchange area and transferred considerable quantities of heat when the air temperatures in the two bays differed significantly. Nevertheless, it was determined that, on those occasions when the air temperatures in the two bays were approximately the same, the fully insulated bay required approximately 10 percent as much heat as the uninsulated bay.

In addition, it was determined that the temperature of the soil surface and the temperature in the growth culture bags were, for the highest temperature soil heating water, both raised in the heated soil bay 20°F above the equivalent values in the other bay. For the mild winter conditions of this last year, this meant that rather higher than desirable temperatures were produced in the growth medium. Similarly, when high soil temperatures were maintained in the insulated house then nighttime air temperatures throughout this greenhouse were 15° to 20°F higher than desirable. Thus, while it was not directly demonstrated, there is considerable indication that the soil-heat-plus-insulated-roof combination has the capacity to fully heat a greenhouse even when very harsh winter conditions might occur.

The open soil surface system studied produced fairly high relative humidity in the greenhouse when the sand was kept moist to the surface. When the sand surface was allowed to become dry this problem was alleviated to some extent. However, it is anticipated that a white plastic mulch spread on the surface of the sand will, in future designs, control the humidity without greatly reducing net heat transfer while at the same time reflecting needed light back to the plants. In addition, the thermal mass of the sand/moisture system increases the thermal response time of the greenhouse, and routines for building lead times of the order of 4 hours into greenhouse management procedures will need to be developed.

Pellet Insulation

The roof of each of the greenhouse bays was modified by the addition of a pellet "gutter" bolted along the standard rain gutter on each side and by providing a double bow, plastic clamp mechanism at each end. In this way, the standard double poly roof was converted from an enclosed air pillow sealed at a single perimeter to a set of independent plastic sheets, each having its own perimeter fastening system, with a nominal, 4" separation between them at all points. This new system required some ingenuity to keep sealed but made it possible to insert and remove pellet insulation. In addition, all the external walls of the greenhouse were fitted with 2" thick sheets of polystyrene board. This provided the full insulation needed for proper data collection, but it is anticipated that future work will produce a removable insulation system for greenhouse walls.

The polystyrene pellets were stored in a 2100 ft^3, hopper type grain bin. The pellets were drawn from storage by a 5 hp, 1500 cfm, 3400 rpm, 315 AW Aerovent air wheel. They passed through this "blower" with the air stream, and were carried to the peak of the west end of the greenhouse in a 6" pipe. Along the peak of the greenhouse, between the two plastic sheets, there was stretched a tube (26" circumference) made of sail cloth and with a zipper running the length of the tube along both its north and its south sides. The zipper pulls were operated from the west end of the house by long cords. Initially, the fill of the roof was accomplished with the zippers pulled closed to the east end of the house so that the "far" end of the house was filled first. Then, as the roof progressively filled, the zippers were pulled open to the west until the whole house was filled. After some experience was gained in operating the system, the roof could typically be filled in about 50 minutes and a fill time as low as 35 minutes was achieved. It should be noted, however, that air loss from the sail cloth tube through the closed zipper teeth limited the possible pellet delivery rate when the east end was being filled and that the west half of the roof was usually filled in only 10 to 15 minutes. Thus, improved zipper design could significantly reduce the total filling time.

Pellet removal was accomplished by sucking pellets from the gutters, through the blower and back into the storage tank. The efficiency of this process depended on the air pressure balance in the roof, and, initially, removal took about 3 hours. Much of this slowness resulted from the relatively strong vacuum drawn by the blower that collapsed the cover sheets tightly together and greatly restricted the access of the pellets to the air stream. To counteract this effect, a small (1 hp) blower was used to blow air into the peak zipper tube, and when this air input was throttled back appropriately bulk removal could be accomplished in 30-40 minutes. However, the relatively flat, barrel arch design of the existing greenhouse tended to retain "pockets" of pellets and required additional "blow down" to produce a really open, clear-to-the-light structure. A higher profile, gothic arch structure should overcome this problem.

Glycerine treatment of the pellets made problems of static electricity nonexistant, and there was little difficulty in keeping moisture accumulation in the pellets below the point where it interferred with pellet flow. Some minor evidence of pellet damage (presumably caused by the blower) was observed, but the few resulting fragments behaved entirely like small pellets and did not cause any difficulties. There was some damage to the plastic film of the roof due to excessive pressure during the early runs, but this was brought completely under control as the air balance of the system became better understood. Thus, while the fill and empty times for the system are still somewhat marginal for complete utility, and while automatic operation of the system still needs to be achieved, present work is continuing to make progress in these areas, and the development of an effective, reliable and highly economic system is anticipated.

System Cost

Only the most rudimentary cost analysis has been undertaken up to this point. The pellet handling system should cost between \$1.00 and \$1.50/ft^2 and, relative to most fuels, should be able to pay for itself in fuel cost savings in approximately one year. The floor heating system can cost between \$0.50 and \$2.00/ft^2. These figures, however, need to be compared with normal soil preparation costs and/or reductions created in the heating system costs normally incurred in greenhouse construction. In addition, the possible horticultural benefits (or detriments) need to be considered in determining the net value/cost of a soil heating system.

SUMMARY

Low temperature soil heating and polystyrene pellet nighttime insulation were demonstrated successfully in a commercial type greenhouse. The present design was capable of meeting all of the heating requirements of a greenhouse tomato crop at an energy savings of approximately 90 percent. Satisfactory filling and emptying times were achieved for moving the insulating materials, but various components need improvement and automation. Even with current technology, this scheme is more energy efficient than any other competing technology, and holds great potential for improving the competitive position of the greenhouse industry.

SPACE-TIME MINIMIZATION TO CONSERVE GREENHOUSE ENERGY USE

by

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ABSTRACT

Resource use in a greenhouse is directly related to the space occupied by each plant and the time it takes to grow. To significantly minimize these two requirements, we may need to develop automated growing systems based on free-cell containers. In this study, I analyze the relation of area, volume and time in the seedling production cycle.

Introduction

The greenhouse is a structure to modify the environment of plants being grown in it. As such, it encloses in some sense a volume of space. It does this more or less for an indefinite period of continuous time. A plant starts its growth cycle from a "point source," such as a seed or some cellular material. As plants grow, they require more space if they are not to be constrained. At some point after growth is initiated, each plant needs access to sunlight or other radiation to supply energy for photosynthesis.

Let us assume, for this discussion, that plants are started from seeds. Most, if not all, real-world seed lots have the following characteristics:

1. Not all seeds germinate and emerge as seedlings.
2. Seedlings do not all emerge at the same time.
3. Seedlings are not equally vigorous.

Let us further assume that we are dealing with tomato or pepper plants. The reader should not find it too difficult to extrapolate the analysis to other varieties.

The actual use of resources in raising seedlings is related to space in two ways:

1. The application of fertilizers, water, etc. and the use of solar radiation are related to the area the plants occupy.

2. The heating/cooling requirements and the gaseous medium in which the plants are immersed are related to the volume the plants occupy.

The use of resources in raising seedlings is also related to time. For example, sub-optimum temperatures normally lengthen the time required to produce acceptable seedlings.

Growing Systems

Growers have developed techniques to integrate the vagaries of seed lots with the need to minimize resource use. They may plant multiple seeds per container cell, then thin plants in excess of one per cell. They may plant seeds thickly in flats, then use these crowded seedlings to transplant into individual cells for growth to field transplant size. The practices are labor intensive and increasingly expensive.

A better approach might be to use a minimization principle, then follow its consequences through the growth process to see if fewer resources would be used to raise seedlings of equivalent or better quality to those now being raised. One such principle is:

> "Give a plant (or seed) only the space it needs to grow at a particular time. The plant must demonstrate that it needs more space before more is committed to it."

The first consequence is that a seed would only be given a volume of space about 0.5 x 0.5 x 1.0 cm^3. If a seed germinates, it is given a container cell of its own. Total volume allocated might be 2.5 x 2.5 x 12 cm^3. If a seedling emerges, it would be given space in a greenhouse. Initially the volume allocated might be 2.5^2 x 24 cm; later, when the seedling is larger, the volume might be increased to 2.5 x 5.0 x 34 cm^3.

Analysis

These assumptions, as well as some about growing time and survival in three different growing systems, are summarized in Table 1. Table 2 shows the space-time requirements that result from the assumptions. Table 3 compares space-time requirements of the growing systems.

The assumptions are reasonable and modification to conform to specific experimental data should not invalidate the following major conclusions:

1. An 85% reduction in resources spent on a volume basis could be realized if most of the room above and below seedlings could be eliminated from greenhouses (Table 3).

2. A 15% reduction in resources spent on an area basis could be realized if seedlings were grown in a staged system (Table 3). In addition, the seedlings from the staged system would spend

the important last ten days of their greenhouse growth in twice the area available in the other growing systems.

The first benefit (85% reduction) implies no humans walking around in the greenhouse area. The second benefit (15% reduction) implies an economical way to handle seedlings on an individual basis. Both of these conditions could be met by automating seedling production around a free-cell container system (Brewer and Batal).

SUMMARY

Significant savings are possible in greenhouse production of seedlings if we can change the stereotypic thinking about what a greenhouse should look like and about how seedlings relate to the container systems in which they are grown.

Reference

Brewer, H. L. and K. M. Batal. 1982. A free-cell system of raising seedlings to conserve greenhouse energy use. Paper No. 82-4051 presented at the 1982 Summer Meeting of the ASAE.

Table 1. Assumptions concerning space and time requirements of seedlings in various growing methods.

Growing Method	Area per Unit* (cmxcm)	Volume per Unit (areaxcm)	Total Units	Growth Time (days)
Staged:				
Germination	0.5x0.5	0.25x1	152**†	3
Emergence	2.5x2.5	6.25x12	137	3
Initial growth	2.5x2.5	6.25x24	123	10
Final growth	2.5x5.0	12.50x34	111	10
Combined Stages	2.5x2.5	6.25x34	152†	26
Present Grower Practice	2.5x2.5	6.25x213+	152†	30

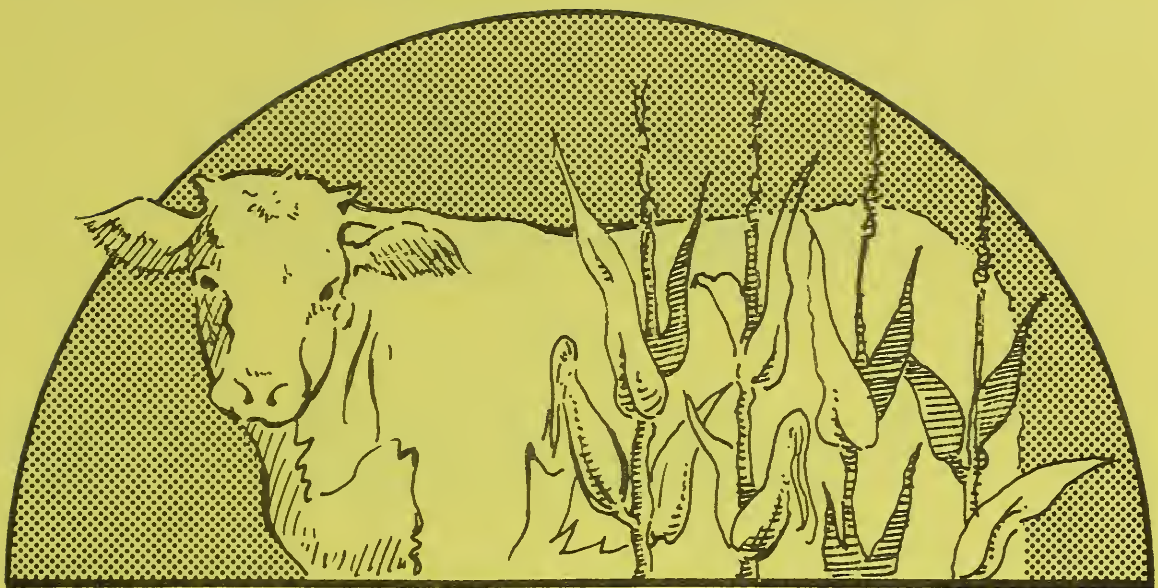
* Unit = seed or seedling.
**Assume 90% of units are successful in moving to next stage.
+ Floor to ceiling height assumed to be 7 ft.
† Number of seeds started to produce 100 good seedlings for the field.

Table 2. Consequences of assumptions in Table 1 for staged production of seedlings.

Growing Method	Area-time (cm^2-days)	Percent of Total (%)	Volume-time (cm^3-days)	Percent of Total (%)
Staged:				
Germination	114	0.5	114	0.0
Emergence	2,569	10.6	30,825	4.5
Initial Growth	7,688	31.7	184,500	26.8
Final Growth	13,875	57.2	471,750	68.7
Total	24,246	100.0	687,189	100.0

Table 3. Comparison of space-time requirements of three growing methods.

Growing Method	Total Area-time (cm^3-days)	Comparisons (%)	Total Volume-time (cm^3-days)	Comparisons (%)
Staged	24,246	85.1	687,189	11.3
Combined Stages	24,700	86.7	837,824	13.8
Present Practices	28,500	100.0	6,069,360	100.0



BIOMASS

AN INTEGRATED ON-FARM ENERGY SYSTEM

by

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ABSTRACT

An integrated farm energy system has operated this past year at Columbia, MO. The system produced daily a net of 354 kw-hrs of electricity and 20 gallons of ethanol. The effluent solids from the digester were used in beef, swine, and poultry rations.

Energy Production

This presentation is an introduction and overview of the integrated farm energy system located at Columbia, MO. The system converts manure from a livestock production unit into thermal and electrical energy and liquid fuel (Fig. 1). For the system to operate at capacity of 20 kW of electricity, 1500 pounds of volatile solids (VS) need to be added to the digester per day. This amount of volatile solids is produced by 400 sow farrow-to-finish pork system, 400-750 pound beef cattle, or 40,000 layers. The digester converts the 1500 pounds VS into 11,200 ft^3 of biogas with an energy content of 6.5 x 10^6 Btu's. The internal combustion engine and electrical generator daily convert the 11,200 ft^3 of biogas into 3.0 x 10^6 Btu's of thermal energy and 480 kW-hrs of electrical energy. The digester requires 0.9 x 10^6 Btu/day for temperature maintenance on a winter day with outside temperatures averaging 0^oC. Also, the digester requires 36 kw-hrs of electrical energy for gas compression, agitation of digester contents and slurry pumps required to operate digester. Production of 20 gallons of ethanol in the liquid fuel plant requires 1.25 x 10^6 Btu's of thermal energy and 90 kW-hrs of electrical energy. Thus for one day, the system produces a net of 354 kW-hrs of electricity and 20 gallons of ethanol.

Ration Formulation

Approximately 900 pounds of solids leave the digester each day in the effluent. These solids can supply 2% of the solids in the ration for laying hens and 8% of the solids in a beef ration. Thus, sufficient rations can be formulated to feed 180,000 laying hens. Whereas, approximately 40,000 hens are required to supply the digester with sufficient solids for energy production. For beef - a ration can be formulated from the effluent of the digester to feed approximately 640 cattle. This is 240 more cattle than required to maintain the energy production of the system.

For swine, 5% of the ration can be supplied by effluent total solids or 18,000 pounds of ration can be formulated. This is sufficient for a 400-sow farrow-to-finish operation.

SUMMARY

The integrated farm energy system operated successfully this past year. On a daily basis, 1500 pounds of volatile solids can be converted into 400 kW-hrs of electricity and 3.0×10^6 Btu's of thermal energy. Utilizing 1.3×10^6 Btu's of thermal energy and 90 kW-hrs of electricity, 20 gallons of ethanol was produced. The effluent from the digester has been successfully formulated in swine, beef and poultry rations.

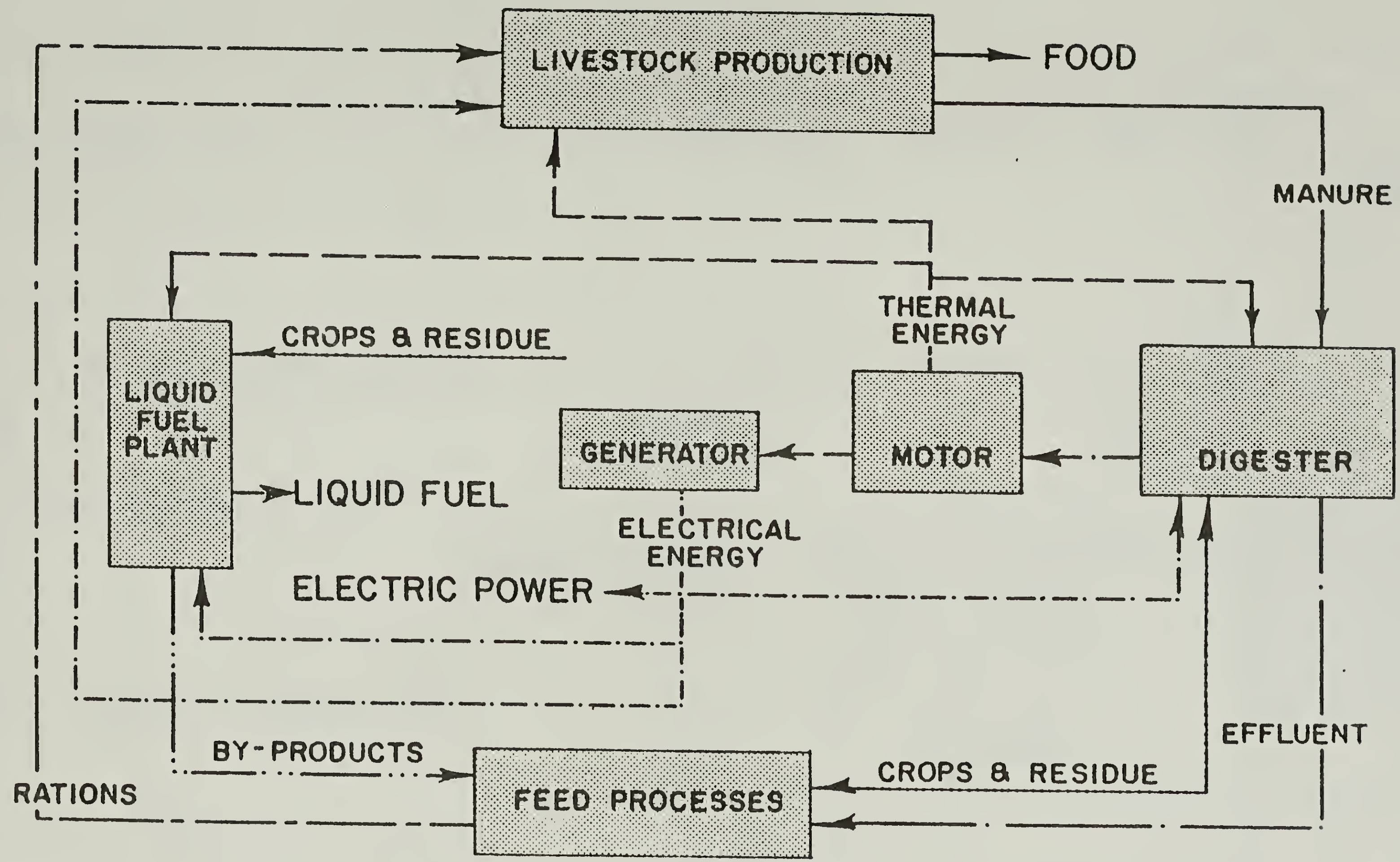

FIGURE 1. SCHEMATIC REPRESENTATION OF INTEGRATED FARM ENERGY SYSTEM LOCATED AT COLUMBIA, MO.

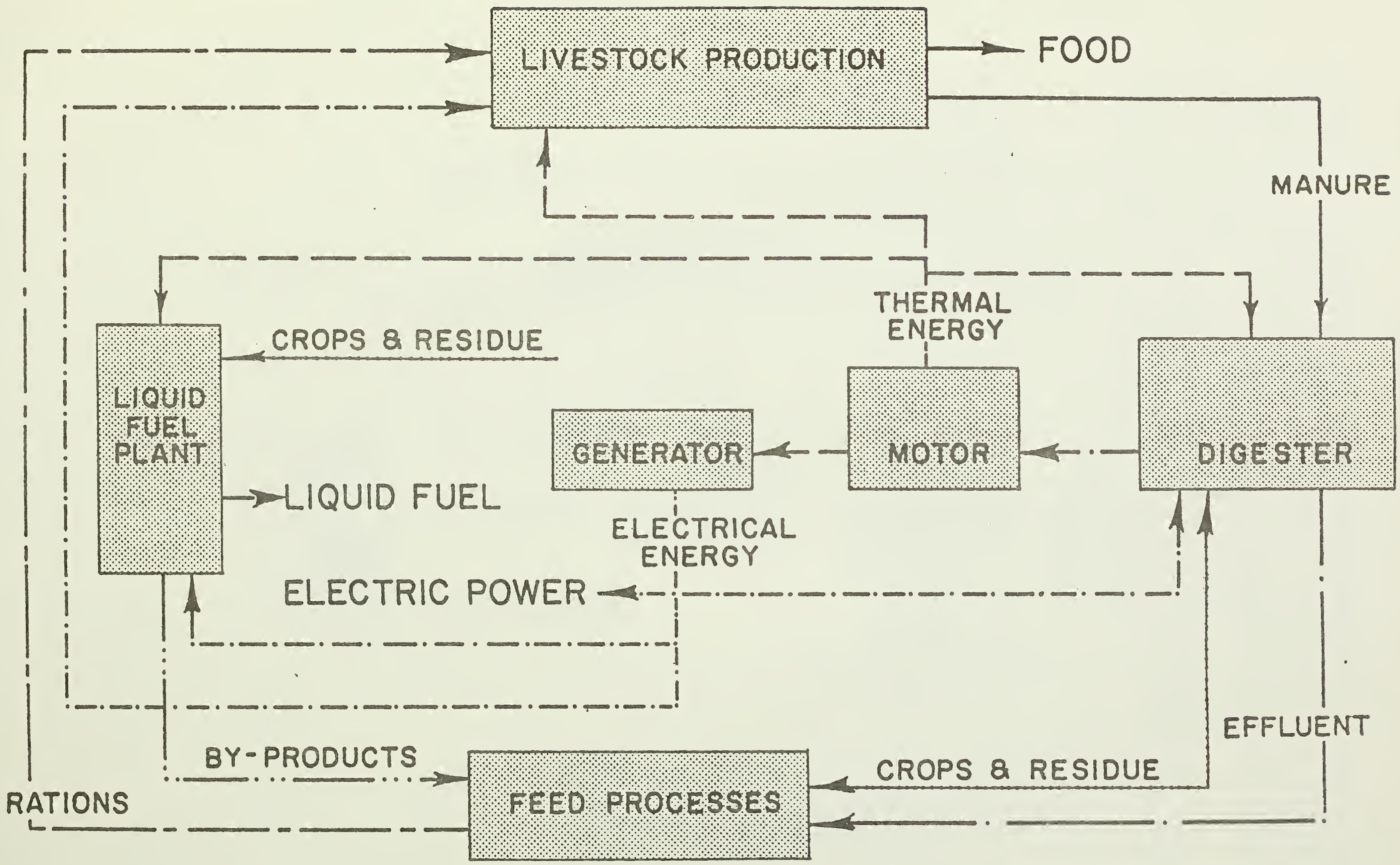

FIGURE 1. SCHEMATIC REPRESENTATION OF INTEGRATED FARM ENERGY SYSTEM LOCATED AT COLUMBIA, MO.

CHANGES IN A SWINE MANURE ANAEROBIC DIGESTER WITH TIME AFTER LOADING

by

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ABSTRACT

A computer controlled, anaerobic digester loaded with swine manure was used to determine changes with time after loading. During the initial part of the day, the pH dropped, as acetate increased. The acetate system was saturated. Hydrogen was also found in the biogas. The highest rates of biogas production were immediately after loading. The increased activity was due to degradation of colloidal particles found in manure. The data support the hypothesis that the most critical period is that following loading.

INTRODUCTION

Anaerobic digestion can be depicted in simplist form as occurring in two stages: 1) degradation of complex molecules to volatile acids and 2) conversion of volatile acids to methane. Methanogenesis from short chain acids is normally considered the rate-limiting step in the digestion of dissolved organics. The hydrolysis of insoluble polymers is rate limiting for the overall process of digestion. Anaerobic digestion of swine manure to methane is, for the most part, stable. However, we have experienced periods of reduced biogas which has been associated with both stages. The accumulated information indicated that the important period was right after loading and that the significant data was missed. This paper defines the changes that occur in a swine manure anaerobic digester with time after loading.

DIGESTER

A semi-automated, anaerobic digester was designed for manual daily loading, constant monitoring of gas production, and automatic collection of liquid and gas samples for later analysis. A computer monitored, controlled sampling, collected data, displayed instructions and status, and signaled termination of events or emergencies. The digester was started with the contents of an operating, stable swine manure digester and was operated at a loading rate of 4.1 g volatile solids / liter digester volume, a retention time of 15 days and at 37 C. A total of 2.27 liters of biogas per liter of digester was produced.

LONG TERM CHANGES

After the first month, daily gas production and effluent concentrations of most parameters were stable. A compound, tentatively identified as phenylacetate, increased due to the stress during start up. In the past the compound has correlated better with reduced methane than any other parameter. After the first month, acetate concentration was found to increase for up to one week after mild disturbances (sampling or changes in the physical system). Ammonia concentration increased for nine retention times. Both the acetate and ammonia values were within sampling variation previously considered normal. A several degree increase in temperature resulted in a large increase in acetate concentration (1500 mg / liter).

DAILY CHANGES IN VFA AND BIOGAS PRODUCTION

Acetate, propionate, and butyrate were higher immediately after loading because of the acids in the manure. The concentration of these compounds continued to increase because of metabolic activity of the microbes. The pH and bicarbonate alkalinity dropped slightly as the volatile acids increased.

The highest rates (1.4 liter / hr) of biogas production were found immediately after loading and lasted for approximately one hour. After twenty four hours, the rate was approximately one half that of the initial. Compostional changes of carbon dioxide and methane were small. Previously, we had been unable to detect significant correlations with hydrogen, although hydrogen is an important intermediate leading to methane. The conditions had to be severe before changes were found. Hydrogen increased significantly after loading.

SATURATION OF THE ACETATE SYSTEM

Addition of acetate to the digester indicated that during the initial part of the day the acetate system was saturated. After a temperature shock, the proportion of the time in which the digester operated under saturated conditions increased significantly; the concentration of hydrogen was also much higher through the day.

DAILY CHANGES IN VOLATILE SOLIDS

Total and volatile solids, hemicellulose, cellulose, crude protein and lipids varied little through the day; solids destruction was balanced by loss of volume due to that destruction and by evaporation of water. Cellulose and lipids were degraded faster in the initial part of the day than later. There was little change in soluble total or volatile solids through the day. Soluble hexoses, pentoses, alpha-amino nitrogen and glucose did fluctuate with time after loading. However, a sharp initial decrease indicating addition of a large amount of solubles or an increase indicating saturated conditions was not found.

DEGRADATION OF PARTICLES

Fractions of manure and digester effluent were examined by scanning electron microscopy. The potental methane in each fraction is being determined. During passage through the swine, corn germ, floury endosperm and most of the horny endosperm were digested. The hull, with occassional clusters of horny endosperm cells attached, the tip cap area of the kernel, and the cuticular surface of the epidermis remained. Corn particles in the digester effluent were almost entirely pericarp or hull, although tip cap particles were seen. Corn hull was being degraded on the exposed edges and the non-cuticular surface. After passage through the swine, the only soybean tissues remaining were the cuticular layer, palisade cells, and vestiges of hourglass cells. After anaerobic digestion, there were very few soybean particles. These particles were heavily colonized by bacteria along the exposed edges of the palisade cells.

More than 50% of swine manure is colloidal. By SEM, this material is nondescript particles plus bacteria and small fragments of plant material. The colloidal fraction has a higher initial rate of degradation but less long term potential than the other fractions. This fraction is most responsible for the rise in volatile acids.

About 1/3 to 1/2 of the particles on 0.350 mm and 0.210 mm sieves were clusters of *Methanosarcina*, a methanogen. The surface of these clusters were colonized by other bacterial cells. These particles were not present in the manure.

SUMMARY

A semi-automted digester that permits sampling over twenty-four hours was developed and used to determine changes with time after loading. For most of the day, the rate limiting step in a stable swine manure digester is the degradation of particles (primarily corn and soybean hulls) in the manure. However, because of a large colloidal fraction, the rate limiting step initially shifts to metabolism of volatile acids. Increases in acetate pools are associated with saturation of metabolic pathways. Small disturbances of the system resulted in increased levels of acetate. After a temperature shock, the proportion of the time in which the digester operated under saturated conditions increased significantly. The data support the hypothesis that the most critical period is shortly after loading.

BIOGAS-ETHANOL INTERFACING WITH AN ENGINE/GENERATOR SET

by

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ABSTRACT

Individual components and the overall system that used biogas to fuel a four cylinder SI engine coupled to an induction generator with thermal connection to an energy storage tank were tested. The use of the stored thermal energy in the production of ethanol was evaluated.

Testing Procedures and Results

Testing and evaluation of the system that interfaces the biogas and ethanol production facilities was divided into the following components:

1. Engine. Optimal engine operating parameters for biogas fuel were determined. Engine performance was quantified for the fuel operating range of the engine within the restrictions placed upon the engine by the characteristics of the entire system. Parallel tests were conducted using commercial propane gas as a fuel to provide a comparison.

2. Generator. Generator performance was determined and dynamic interactions between the generator and the load were studied.

3. Heat Recovery. The heat recovery control system was adjusted to provide maximum performance without endangering the equipment or the operator. Total thermal output and recovered thermal energy were determined as a function of the engine operating parameters. Thermal recovery efficiency and potential thermal recovery can be calculated.

4. Thermal Energy Storage (TES). The internal energy change of the TES was determined as a function of energy exchange and in isolation. This information provides the quality of the energy to be made available to the alcohol plant.

Figures 1 and 2 provide the brake specific fuel consumption as a function of spark advance and equivalence ratio for manifold vacuum of 5 cm Hg, and 20 cm Hg respectively as examples. As a results of these data, recommended spark advance is given in Figure 3 as a function of equivalence ratio and manifold vacuum. Figure 4 is a performance map of the engine/generator showing operating limits (the left and right boundaries). Table 1 gives the system performance at or near optimal operating conditions. Figure 5 is a plot of temperature in the thermal energy storage tank at eight levels as a function of time during energy addition which clearly shows stratification. Flow rate changes plus change in mode of operation to satisfy system requirements account for the non-uniform gain. It is pointed out that the entire tank acquired a temperature of 99°C in 16 hours of operation. Figure 6 is a plot of TES characteristics as a function of time for a typical distillation process for ethanol production.

SUMMARY

The internal combustion engine operated well within specific limits of equivalence ratio and spark advance. The engine thermal efficiency was the same for biogas and commercial propane. The induction generator is well suited for this type of application due to the simplicity of interconnection and control. The open loop heat recovery system proved to operate safely and satisfactorily. The thermal energy provided by the engine and the thermal storage was sufficient to supply the thermal demands of the ethanol plant, plus an excess of electrical power over the demand of the system was generated.

Table 1. System performance at or near optimal operating conditions.

Operating Conditions		System Performance						
Manif. Vacuum	Equiv. Ratio	Power Output (kW)	bsfc (g/kWh)	Thermal Output (kJ/min)		Efficiency (%)		
				engine	silencer	power	engine heat	exhaust heat
4	.693	19.73	276.4	1340	864	26.0	29.5	19.0
5	.671	17.81	276.4	1386	591	26.0	33.8	14.4
10	.723	15.45	277.6	1214	514	25.9	34.0	14.4
15	.775	13.33	290.7	1174	447	24.8	36.3	13.8
15	.811	13.96	287.7	1034	621	25.0	30.9	18.5
20	.853	11.52	322.1	1122	414	22.3	36.3	13.4
20	.974	13.96	320.0	1106	646	23.8	31.5	18.4
31	.944	7.70	397.0	946	449	18.1	37.1	17.6

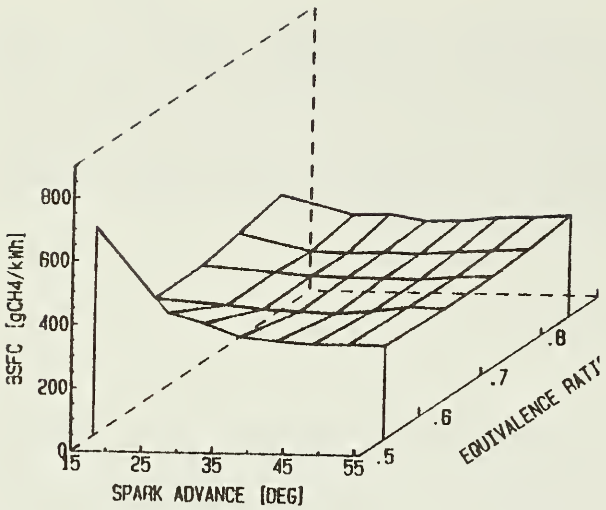


Figure 1.

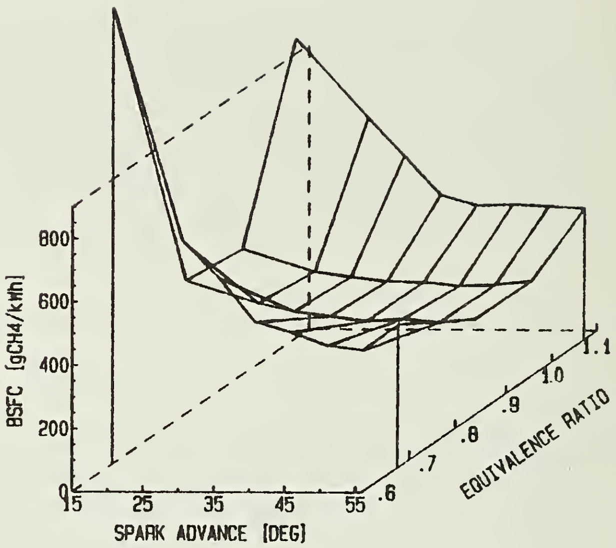
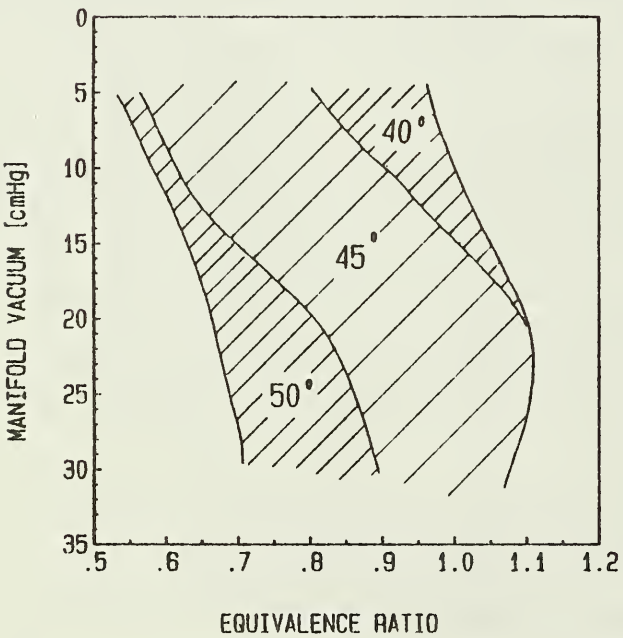


Figure 2.



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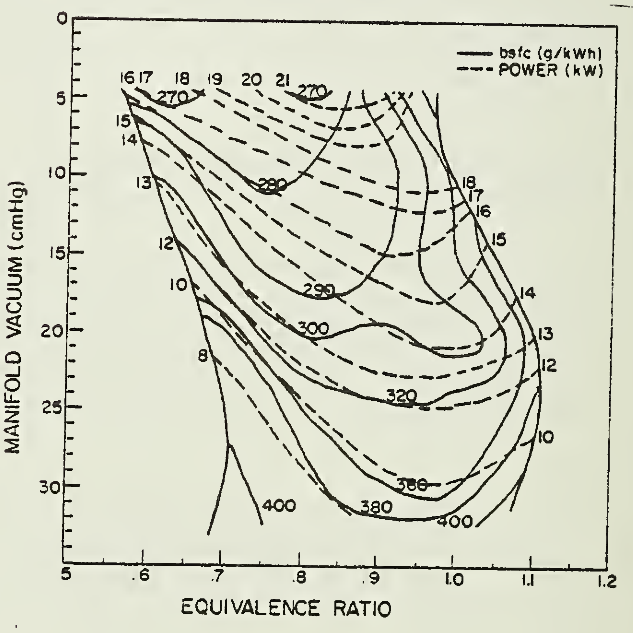

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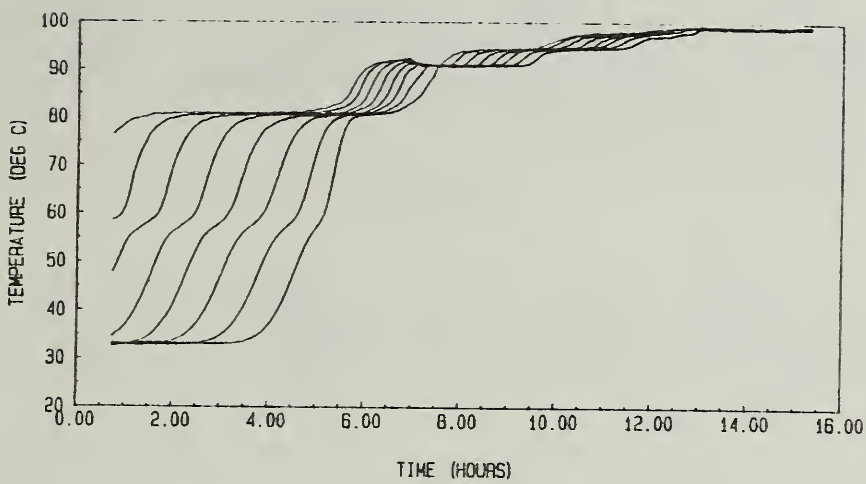

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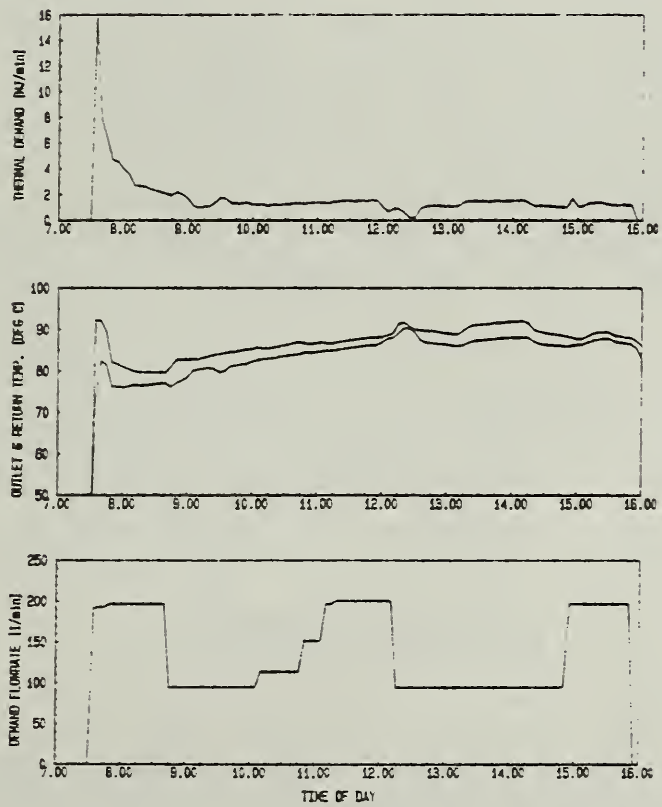

Figure 6.

ETHANOL RESEARCH ON THE MISSOURI INTEGRATED ENERGY FARM SYSTEM

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ABSTRACT

Hydrolysis of corn was compared at two temperatures of 100°C and 75°C. Starch conversion to dextrose and then ethanol were determined. Yields were 10.69% ethanol in the fermented beer for 100°C and 9.89% for 75°C. The 75°C hydrolysis required about 100 MJ less thermal energy than the 100°C hydrolysis. The effects of contamination and respiration were also assessed. Distillation energy was also compared at 75°C and 100°C. The overall net energy ratios were 1.88 and 1.67 for 100°C operation and 75° C operation respectively.

INTRODUCTION

The UMC Integrated Farm Energy System includes a Liquid Fuel Plant for processing organic fuels from biomass. It has capabilities for multiple fermentation, atmospheric and vacuum distillation and dewatering by-products for feed. Process heat can be provided as steam from a biogas fired boiler for conventional (100°C) hydrolysis. In addition 90°C water can be provided from a biogas engine generator. Thermal energy from the engine and exhaust is stored in a 4000-liter water tank. Temperature of the water in the tank is capable of reaching 90°C.

The purpose of this research was to evaluate low temperature hydrolysis and vacuum distillation using a 85-95°C water as the source of process heat. The conversion efficiencies of starch (ground corn) to glucose and glucose to ethanol and input energy for distillation were selected as the quantatative indicators of performance. In addition the effects of non-ethanolic metabolic pathways on the fermentation were investigated.

EQUIPMENT AND METHODS

The hydrolyzing tank is a dimple jacketed 1665 liter (440 gal), 304 stainless steel tank with a loose, flat cover and a dished bottom. The tank is agitated with a variable speed, 1.2 kW (1.5 HP), side mounted mixer with two 0.305 m (12 in) diameter propellers on the shaft. Steam at 68-90 kPa (10-13 psi) or hot water at 75°C is supplied to the jacket and recycled to the boiler or biogas engine. Fermentation vessels have a capacity of 1990 liter (525 gal) and have a sloped bottom, 304 stainless steel vessel with a loose, flat cover and a 0.37 kW (5 HP) slow speed mixer with a one 0.203 m (8 in) diameter propeller on the shaft.

The distillation system consists of a nominal 1893 liter (500 gal), 304 stainless steel jacketed distillation vessel, and a 5.5 m (18 ft) tall, 15.2 cm (6 in) diameter column packed with a 1.3 cm (0.5 in) ceramic Raschig rings. The vapor condenser is a shell and tube heat exchanger. The cooling water is pumped from a evaporative cooling unit. Spent condenser water is returned to the cooling unit by means of a closed loop. A vacuum pump was used to maintain partial vacuum on the distillation system for 75°C distillation.

A commercial supplier of hydrolyzing enzymes was chosen based on the results of the study on enzyme activity. Alpha amylase was used as the liquefying enzyme and a mixture of alpha amylase, amyloglucosidase and others, was used for saccharification. Yellow dent corn, hammer milled with a .826 mm (.325 in) screen was used as the substrate.

Low Temperature Hydrolysis. Using 85-90°C water from the biogas engine 1363 liters (360 gal) were heated to 75°C. Then 364 kg (800 lbs) of corn were added with 432 g of the liquefying enzyme. An additional 432 g of enzyme were added after two hours of agitation. The temperature was maintained at 75°C and agitated for an additional three hours. The substrate was then rapidly cooled in the heat exchanger to 30°C.

High Temperature Hydrolysis. Using saturated steam 1060 liters (260 gal) of water were heated to 60° C. With continuous agitation and heating 364 kg (800 lbs) of ground corn were added with 216 g of liquefying enzyme. When the substrate was at a temperature of 70-74°C an additional 216 g of enzyme were added. Heat was continued until the substrate temperature was a 100°C and maintained at that temperature for 20 minutes. Then 300 liters (80 gal) of dilution water were added to reduce the temperature to 85° C. Next an additional 432 g of enzyme wre odded and the substrate maintained at that temperature for 30 minutes. The substrate was then rapidly cooled in a concentric tube heat exchanger to 30°C as it was being transferred.

Fermentation. In the fermentation tank 432 g of active dry yeast and 216 g of saccharifying enzyme were added to the substrate. The temperature was controlled at 30°C for 60 to 84 hours.

Atmospheric Distillation. Saturated steam was supplied to the distillation tank jacket at 68-90 kPa. Vapors at the top of the column were condensed and product was collected in receiving tanks. Steam input to the distillation tank was regulated to maintain a proper pressure differential across the distillation column for vapor movement. column.

Vacuum Distillation. Heated water from the thermal storage tank was supplied to the distillation jacket to provide thermal energy. Vacuum was applied to the distillation system when temperature of the beer reached 55-60°C. Refrigerated cooling water pumped through the condenser condensed vapor into collected ethanol product. Distillation at 16-25 mm Hg was continued for a desired time to collect the ethanol.

RESULTS AND CONCLUSIONS

The efficiency of hydrolysis and fermentation was determined by analyzing starch and glucose concentrations in the substrate. In addition substrate uptake can also be used as a qualitative indicator of the organism growth under different conditions and it can signal the end of fermentation. The ground corn used in this study was 80 percent starch on a dry matter basis. This equates to 248 kg (547 lbs) of starch per batch. The conversion efficiency during hydrolysis of starch to glucose is shown in Table 1. Complete hydrolysis, with the addition of a water molecule, yields 276 kg (608 lbs) of glucose. Each kg-mole (180 kg) of glucose fermented will yield 2 kg-moles (92 kg) of ethanol.

TABLE 1. HYDROLYSIS AND FERMENTATION PROCESS PERFORMANCE

	High Temp. (100°C)	Low Temp. (75°C)
Number of Replications	4	3
Total Starch-kg (lbs)	248 (547)	248 (547)
Glucose-kg (lbs)		
Potential	276 (608)	276 (608)
Actual	256 (565)	245 (540)
Efficiency of Hydrolysis	93%	89%
Average Ethanol Yield		
Potential-liters (gal)	178 (47)	178 (47)
Actual-liters (gal)	146 (38.5)	135 (35.6)
Efficiency of Fermentation	88%	88%
Overall Conversion Efficiency	82%	76%

Lactic acid and acetic acid were chosen as indicators of biological activity other than ethanolic fermentation, namely respiration and contamination. These acids generally arise from a pathway subsequent to the EMP pathway. A quantatative assessment of substrate diverted from ethanol can be made because each kg-mole of these acids represent one kg-mole of ethanol displaced (Table 2). This represents in part the losses contributing to the reduced efficiencies of fermentation.

TABLE 2. EFFECT OF NON-ETHANOLIC METABOLIC ACTIVITY

	Acetic Acid (mg/L)	Lactic Acid (mg/L)	EtOH Displaced in Final Yield (Liters/Batch)
High	800	4250	19
Low	500	6600	23

The energy consumed during low temperature hydrolysis was 475 MJ per batch compared to 575 MJ per batch for high temperature hydrolysis. With the low temperature alternative 100 MJ of energy per batch was saved. The 0.8 percent decrease in alcohol yield represents a decrease in total energy output of 27 MJ. Therefore, although the alcohol yield was decreased, low temperature hydrolysis resulted in net savings of 73 MJ per batch.

Table 3 gives energy efficiencies for conventional 100°C production and experimental 75°C production of ethanol, respectively. Energy efficiencies listed are the ratios of energy output to energy consumed at the hydrolization and distillation tanks. If a total efficiency of the plant is considered using biogas consumed as input energy, efficiencies for conventional 100°C production are reduced 30 percent while 75°C production efficiencies are reduced 50 percent. Efficiency values using biogas consumed are lower for 75°C production as compared to 100°C production because the engine/exhaust heat recovery system loses heat when raising temperature in the thermal storage from 92°C to 97°C. Some of the experiments required the engine to operate prior to hydrolysis and distillation to raise heating water temperature to 97°C, thus consuming more biogas.

TABLE 3. NET ENERGY RATIOS

	100°C Ethanol Prod.			75°C Ethanol Prod.		
	Trial			Trial		
	1	2	3	1	2	3
Input						
Thermal (MJ)	1676	2005	1342	1293	1345	1633
Electrical (MJ)	143	162	127	344	324	182
Total (MJ)	1819	2167	1469	1637	1669	1815
Output						
Ethanol (MJ)	2859	2766	2766	2011	1659	1678
Electrical (M)				717	991	528
Net Energy Ratio						
Output/Input	1.57	1.28	1.88	1.67	1.59	1.21

CONCLUSIONS

1. Hydrolysis at 75°C produced an average 9.26% of ethanol in beer. Hydrolysis at 100°C produced an average 10.71% ethanol in beer.
2. Ethanol yields were depressed by 0.8% for low temperature hydrolysis (27 MJ/batch) but savings in hydrolysis energy compensated for this loss by an amount of energy equal to 100 MJ per batch.
3. Contamination and/or respiration may exist without causing noticeable symptoms to the plant operation, but result in a significant reduction in the efficency of fermentaion.
5. Thermal energy input for 75°C production of ethanol is approximately equal to thermal energy input for 100°C production if heat exchange is used for 100°C hydrolysis and distillation.
6. Ratio of energy output to input for 100°C production with heat exchange was 1.88 while ratio of energy output to input for 75°C production without heat exchange was 1.67. This is primarily due to the greater amount of ethanol removed during 100°C distillation.

THE USE OF METHANE DIGESTER EFFLUENT AS A SUPPLEMENTAL PROTEIN SOURCE FOR LAMBS

By

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ABSTRACT

This research was conducted to evaluate potential methods of ensiling swine methane digester effluent (MDE) with corn grain and wheat straw and to compare MDE with urea as sources of supplemental dietary protein for lambs. Results from a laboratory silo experiment in which 0,4,8 or 12% of the total dry matter was from MDE (47.8,65.1 or 76.3% on an "as fed" basis for 4,8 or 12% silages, respectively) and the remainder supplied from corn and wheat straw found that all silages underwent fermentation with an average pH of 5.8 and average lactic acid content of 5%. Maximum lactate production occurred with 8% MDE while maximum butyrate occurred with 12% MDE. For a metabolism trial, digestibilities of dry matter and N were lower for MDE fed lambs compared with urea fed lambs, however, N retentions were similar. Rumen fluid and blood parameters did not differ between MDE and urea fed lambs. In a second metabolism trial, N balance was similar among lambs fed urea, MDE or soybean meal but were numerically lower than those lambs fed distillers wet grains. When lambs were fed urea, MDE or soybean meal, daily gains were similar but were slower ($p<.05$) than gains of lambs fed distillers wet grains. These data suggest that MDE can be ensiled with wheat straw and corn and that the protein value is similar to urea in terms of N retention and growth rate when measured in lambs.

OBJECTIVES & MATERIALS

Ensiling Trial

The objectives of this experiment were to evaluate ensiling parameters for various levels of MDE (4% dry matter product) mixed with cracked corn and wheat straw. Corn was kept at a constant 50% of the mixture with MDE added to provide 0,4,8 or 12% of total dry matter. On an "as fed" basis MDE composed 47.8% of the 4% silage, 65.1% of the 8% silage and 76.3% of the 12% silage. Water was added for the 0% silage. Silages were allowed to ferment for 17 d and upon opening were analyzed for: dry matter; pH, lactic, acetic, propionic and butyric acids; crude protein; in vitro digestibility and cell walls.

Lamb Metablism Trial 1

The objectives of this experiment were to evaluate N balance and rumen fluid and plasma parameters for sheep fed MDE and urea fed either fresh daily or as a silage. Eight percent MDE was chosen as the most desirable level to feed based on the previous trial data. Following completion of the N balance study, rumen fluid and blood samples were collected at 0,4,8 and 12 h post-feeding. Rumen fluid was analyzed for acetic, butyric and propionic acid and ammonia-nitrogen. Blood plasma was analyzed for urea nitrogen.

Lamb Metabolism Trial 2 and Growth Trial

The objectives of these studies were to evaluate N balance and rate and efficiency of gain of lambs fed ensiled urea, MDE and distillers wet grains silages and soybean meal top dressed on a control silage of cracked corn (50%) and wheat straw. Diets were formulated to contain 11.5% crude protein and 64% total digestible nutrients. The growth trial lasted 56 d.

SUMMARY

Ensiling Trial

Fermentation characteristics are presented in figure 1. All silages appeared to undergo fermentation with average pH of 5.8 and average lactic acid content of 5%. Lactic acid increased from 3.7% for the control silage to 7.2% for the 8% MDE silage. However, for the 12% MDE silage, lactate decreased to 5.4% while butyrate increased to 2% which is indicative of an undesirable fermentation. The crude protein content increased from 7.4% for the control silage to 12.0% for the 12% MDE silage.

Lamb Metabolism Trial 1

Digestibility and N balance data are presented in table 1. Dry matter and N digestibilities were lower for MDE compared with urea but N balance was similar. Dry matter digestibility was slightly greater for diets fed fresh daily compared with ensiled diets but N digestibility and balance were not affected by method of feeding. There were no interactions between method of feeding and protein source. Rumen fluid and plasma variables were similar among treatments.

Lamb Metabolism Trial 2 and Growth Trial

Dry matter digestibilities were similar among urea, MDE and distillers wet grains treatments (table 2). No differences in N balance were measured among treatments. Rate and efficiency of gain were similar among urea,

MDE and soybean meal fed lambs (table 3). Lambs fed distillers wet grains silage had the fastest rate of gain and best feed efficiency.

These data suggest that MDE is similar to urea as a protein source and that ensiling is one viable method of storage.

TABLE 1. NITROGEN METABOLISM OF LAMBS FED UREA OR MDE FED FRESH DAILY OR ENSILED

Item	Treatment: Urea Fresh	Urea Ensiled	MDE Fresh	MDE Ensiled	Main Effect of protein source: Urea	MDE
No. lambs	4	4	4	4	8	8
DM intake, g/d	596	511	511	575	553.5	542.88
DM digestibility, %[a]	62.82	53.55	57.41	50.44	58.18	53.92*
N digestibility, %	61.53	54.37	48.86	46.23	57.95	47.55*
N balance, g/d	1.23	-.76	-.20·	-1.18	.24	-.69

[a]Significant difference due to method of feeding (P<.05)
*Significant difference (P<.05)

TABLE 2. NITROGEN METABOLISH OF LAMBS FED ENSILED UREA, MDE AND DISTILLERS WET GRAINS AND TOPDRESSED SOYBEAN MEAL AS PROTEIN SOURCES FED WITH STRAW AND GROUND CORN

Item	Treatment: Ensiled Urea	Ensiled MDE	Ensiled DWG	Topdressed Soybean meal	SE
DM intake, g/d	361.2[a]	458.6[b]	439.6[b]	455[b]	21.16
DM digestibility, %	58.48[a]	58.13[a]	56.92[a]	71.07[b]	1.93
N digestibility, %	60.89[b]	51.20[c]	57.95[b]	71.8[a]	1.97
N balance, g/d	-.17	-.05	.69	.43	.31

[a,b,c](P<.05)

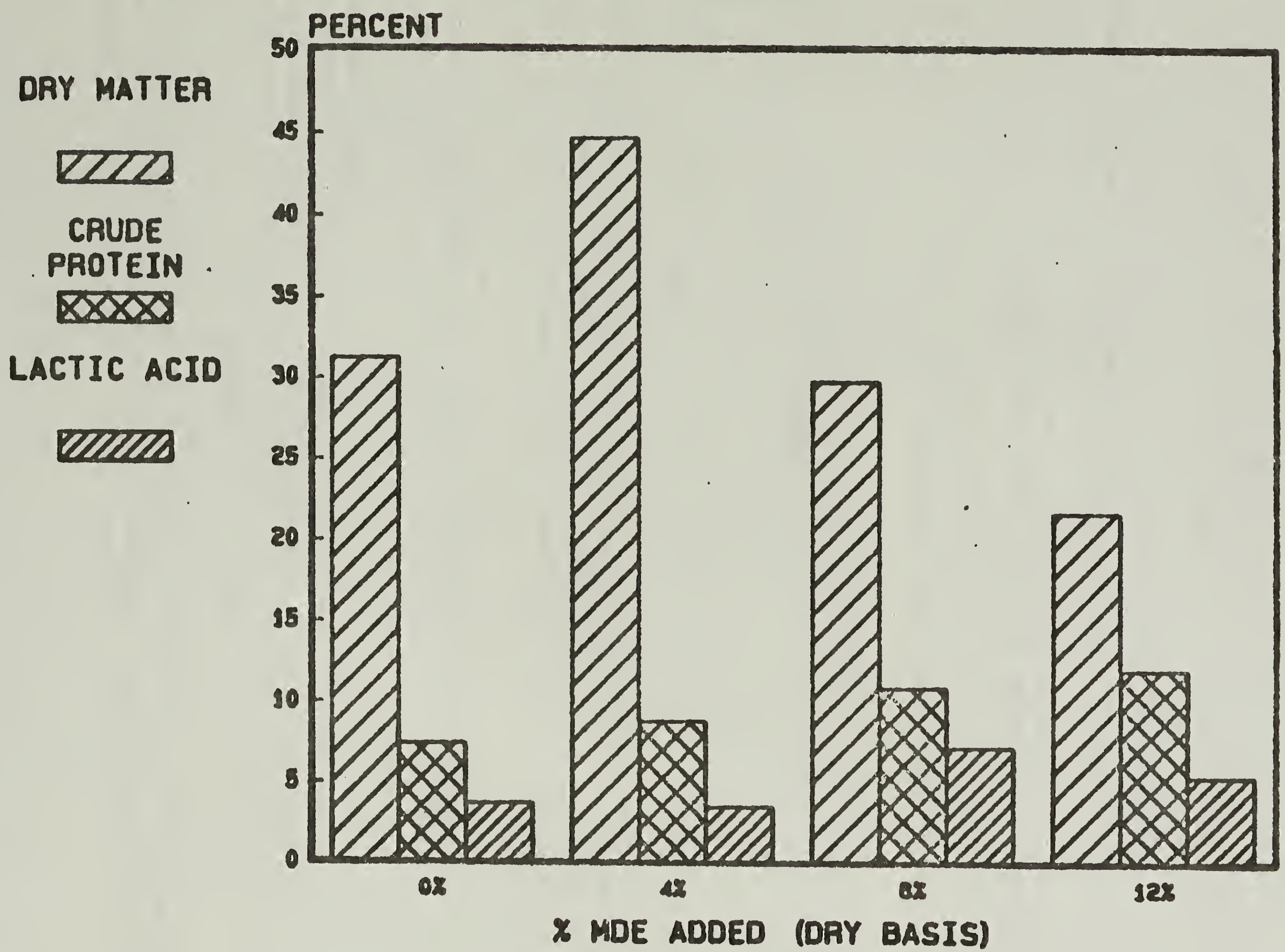
TABLE 3. LAMB GROWTH RESPONSE DUE TO ENSILED UREA, MDE AND DISTILLERS WET GRAINS AND TOPDRESSED SOYBEAN MEAL AS PROTEIN SOURCES FED WITH STRAW AND CORN

Item	Treatment: Ensiled Urea	Ensiled MDE	Ensiled DWG	Topdressed Soybean meal
No. lambs	18	18	18	18
Initial wt, kg	20.1	19.5	19.4	20.0
DM intake, g/d	694[a]	661[a]	674[a]	599[b]
Daily gain, g	76.2[b]	84.5[b]	123.3[a]	85[b]
Feed/gain	9.2[a]	7.9[ab]	5.5[c]	7.0[bc]

[a,b,c](P<.05)

Figure 1. CHARACTERISTICS OF ENSILED MDE

LABORATORY ENSILING TRIAL



METHANE DIGESTER EFFLUENT PROVIDED TO CAGED LAYING HENS VIA FEED AND WATER

by

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ABSTRACT

Methane digester effluent containing a very low level of dry matter was evaluated as a feedstuff for caged laying hens. A special watering system was developed and installed. A swine manure methane digester effluent providing approximately 2 percent of the nutrient dry matter intake was evaluated via both the feed and water.

INTRODUCTION

Increasing world population places greater pressure on food and energy supplies. Increasing consumption of feedstuffs by people decrease their availability for use by poultry. In addition certain energy production systems consume potential feedstuffs yet concurrently produce residuals that are available for disposition. The process of producing energy from a biomass is energy inefficient if it is necessary to dehydrate high moisture residues prior to use or disposal. Increased efficiency and decreased production cost can be demonstrated if the input energy is reduced. Since poultry requires approximately two times as much water as dry feed, by weight, the water in the high moisture residuals would be consumed through the feed and would not require energy for dehydration.

One such high moisture residual of an energy production system is methane digester effluent (MDE). The waste in a digester changes composition during conversion to methane. In decreasing order, carbohydrates, lipids, proteins and short-chain acids contribute to the methane produced. The amino acid composition of the influent and effluent are markedly different. The most striking differences are the increased concentration of the generally considered dietary limiting amino acids: methionine 3.9 to 5.4 and lysine 1.6 to 5.2 g/100 g amino acids.

Poultry feeding programs have been developed based upon dry free flowing ingredients. The utilization of low dry matter feedstuffs requires special consideration. Methane digester effluent from a digester containing swine waste contains 3-4% dry matter (DM). The nutrients in the DM were used in computations to formulate a diet to meet the hens requirements. An evaluation of MDE was made by providing it to cage laying hens through the watering system and mixed into the feed.

MATERIALS AND METHODS

Two banks of cages were used to house 480 30-week-old DeKalb Leghorn hens. Each bank contained 120 cages. The hens were randomly assigned two per cage. A trough feeder served five cages and an automatic Hart cup waterer was available for each cage. The watering system was modified in one bank by removing half of the automatic Hart cups and installing a 50 mm plastic pipe watering system in front of the cage just above the feed trough. The cage bank was hung at an angle to provide flow by gravity through the system. A stirrer and impeller pump were used to provide a consistent supply of 1 part of MDE to 1 part water to the hens. The MDE reservoir was weighed to determine consumption. The remaining cup waterers were attached to a calibrated storage container. Water was available on a 24 hour basis however MDE was available for 2 minutes out of 10 during the 14-16 hr lighted day. Daily water and MDE consumption were recorded.

The control diet was provided to the cages receiving water and the 2% effluent diet minus the effluent was provided to the cages receiving MDE in the plastic pipe waterer. Half of the hens in the second bank were fed the control diet and the remaining hens were fed the 2% effluent diet containing the MDE (Table 1).

Eggs were collected daily. Egg weights and feed consumption were determined weekly. Body weight and egg quality observations were made at six week intervals.

RESULTS AND DISCUSSION

The results of the 12 week study are shown in Table 2. No significant differences were observed between the control groups in both banks of cages. This permitted the data from the control groups to be combined.

The daily intake of water was slightly higher than the MDE:water mixture 222 vs 181 ml/hen respectively. When the MDE dry matter consumed through the waterer was added to the diet the total DM intake was comparable to the DM from the feed + MDE and both were significantly higher than the control diet. This indicates acceptance of MDE in the feed and through the water. Since body weight was significantly higher on the wet diet a portion of the increased consumption was used to increase body mass. Increased body weight was not observed when MDE was supplied through the water however it was comparable to the control group. The percent egg production was comparable on the 3 programs however egg weight and egg mass, was significantly greater when MDE was supplied in the feed and compared to the control. When MDE was provided in the water egg mass was not significantly different from the other treatments.

Feed conversion, g egg/g feed, was significantly better on the control when compared to the water effluent treatment however neither were significantly different from the feed-effluent treatment.

Egg shell quality (specific gravity) was significantly poorer on the feed-effluent treatment. Interior egg quality (Haugh units) was not significantly different from the control.

Table 1. METHANE DIGESTER EFFLUENT DIETS FOR CAGE LAYING HENS

	Control Diet	2% Effluent Diet
Ground corn	69.03	69.58
Soybean meal 44%	14.23	14.74
Meat and bone meal	3.54	3.26
Wheat middlings	3.82	1.27
Dehyd. alfalfa meal 17%	1.36	1.32
Ground limestone	7.41	7.23
Salt	.40	.40
Trace mineral mix	.10	.10
Vitamin mix	.05	.05
Selenium mix	.05	.05
DL methionine	.01	----
DM from effluent	----	2.00
	100.00	100.00
Calculated Analysis		
Protein, %	15	15
M.E. kcal/kg	2850	2850
Calcium, %	3.25	3.25
Phos. Avail., %	.27	.28*
Methionine, %	.27	.28
Methionine + Cystine, %	.50	.50
Lysine, %	.71	.71
Arginine, %	1.00	.99

*Assuming phosphorus as 50% available from effluent.

Table 2. CAGE LAYING HEN PERFORMANCE ON METHANE DIGESTER EFFLUENT

	Feed Cons. g/hen day[1]	Dried Effluent Cons. g/hen day	Body Weight (2 weighings) g	Production %
Control	113.5[a2]	0	1612[b]	84.3[a]
Effluent in water	119.1[b]	3.4	1619[b]	85.0[a]
Effluent in feed	121.3[b]	2.4	1687[a]	86.9[a]

	Egg Wt. g	Egg Mass g/hen day	G Egg/ G Feed	Specific Gravity	Haugh Units
Control	55.9b	47.2[b]	.421[a]	1.086[a]	83.3[ab]
Effluent in water	56.6[ab]	48.2[ab]	.407[b]	1.087[a]	84.1[a]
Effluent in feed	57.2[a]	49.7[a]	.412[ab]	1.085[b]	82.0[b]

[1]The feed consumed values included the dried effluent consumption.

[2]Means in the same column followed by the same letters are not significantly different ($P < .05$)

SUMMARY

A source of swine manure MDE was used to provide approximately 2% of the daily dry matter intake to caged laying hens. The MDE was provided either mixed into the feed or provided through a special pump and pipe system in place of the regular water supply. The basal diet was modified to utilize the nutrients supplied by MDE. The hens consumed MDE readily in the feed and in the water. Body weight maintenance and egg production on both systems was comparable to the control. Feed conversion was slightly poorer when MDE was supplied in the water however when it was blended into the feed it was not significantly different from the control.

FEEDING ANAEROBIC DIGESTER EFFLUENT TO SWINE

By

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ABSTRACT

This research was initiated to evaluate anaerobic swine methane digester effluent as a source of nutrients and drinking liquid for finishing swine. The criteria utilized were average daily feed consumption, average daily gain, and gain:feed ratio.

Experimental Approach

Four experiments were conducted utilizing 48 finishing pigs to investigate the potential utilization of swine methane digester effluent (SMDE) as a feed ingredient in the diets of finishing pigs. The average dry matter (DM) content of SMDE was 3.5%. The average composition of SMDE (DM basis) in the 4 experiments was 3.21 Mcal GE/kg, 35.0% total protein and 19.4% true protein. Essential amino acid content of SMDE, as a percentage of DM, was 1.20 Lys, .77 Met + Cys, .10 Trp, .94 Ile, .38 His, 1.24 Val, 1.06 Phe, 1.79 Leu and .85 Arg. The corn-soybean meal control diet contained either 12 or 14% crude protein and was self fed. Levels of SMDE ranged from 0 to 6.5% of the diet on a DM basis, although the SMDE was mixed into the diets on a fresh, wet basis. Pigs were adapted to the diets by increasing the amount of SMDE in the diet by .5% DM/day. Diets containing SMDE were mixed and fed wet in troughs twice daily. Followig the adaptation period the pigs remained on the diets an additional 2 to 3 weeks. The four different dietary treatments used in experiment 1 were: 0, 2.5 and 5% SMDE (DM basis) plus SMDE as a source of drinking water in a 1:1 ratio. The control diet contained 14% protein and the pigs averaged 106 kg initially. The four diets used in experiment 2 were: 0, 3.5 5.0 and 6.5% SMDE. The diets contained 14% protein and the pigs averaged 75 kg initially. The two diets used in experiments 3 and 4 contained 0 or 6.5% SMDE. The diets contained .5% lysine and the pigs initially averaged 117 and 70 kg, respectively.

Results

Performance of pigs fed 2.5, 3.5 or 5.0% SMDE was similar to that of pigs fed the control diet. Pigs fed 6.5% SMDE or the control diet consumed similar amounts of total dry matter daily, although the dialy gains and gain:feed ratio were lower for pigs fed the diets containing 6.5% SMDE.

Thus, future experiments will be conducted using 5.0% SMDE for finishing pigs.

SUMMARY

Finishing pigs readily adapted to diets containing SMDE with no detrimental effects. Diets containing 2.5 to 5.0% SMDE on a dry matter basis produced performance similar to the control diet. The 6.5% SMDE slightly reduced performance which may be associated with the high water content of this diet or greater wastage of the diet by the pigs at feeding.

RECOVERY OF METHANE PRODUCING SOLIDS FROM SETTLED FLUSHING WATER

by

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ABSTRACT

This project was initiated to determine the feasibility of using an anaerobic filter to recover unsettleable methane producing solids from flushed swine wastes. The filter worked well in treating waste, producing 0.425 liters of CH_4 per gram VS loaded. An energy balance indicated that the filter was energy deficient due to high influent heating requirements. Other methods of recovering the waste solids are being investigated.

Completed Work

Research in our laboratory indicated that 30-40 percent of the potential methane contained in flushed swine manure solids were being lost in the effluent from the settling basin used on our Integrated Energy Farm (Sievers et al., 1980) A large fraction of the lost methane appeared to be attributable to a non-settling colloidal fraction made up of proteins and lipids.

The anaerobic filter appeared to be a realistic method of capturing the methane from the colloidal solids and research was initiated to study methane production from screened swine manure (500 microns) using a limestone bed anaerobic filter (Hasheider et al., 1982).

Maximum methane production from the limestone rock filters was 0.425 liters per gram volatile solids loaded per day (0.425 L/g VS_{in}.d) at a 6d hydraulic retention time (HRT). This exceeds the 0.33 L/g VS_{in}.d observed for our pilot scale conventional digester. The higher methane production for the filter is primarily due to the quality of volatile solids entering the filter. Research in our laboratory on particle fractionation of swine manure indicated that swine manure can be divided into two basic size fractions: those with diameters less than 210 microns (particles must be centrifuged, X13,000) and those with diameters greater than 840 microns.

Particles with diameters greater than 840 microns contain the majority of cellulose (71.2%) and hemicellulose (81.3%). These chemical fractions contribute to methane production but (1) take longer to break down biologically, and (2) have CH_4/CO_2 ratios of approximately 1.0 (Water Pollution Control Federation, 1968).

In contrast, the centrifuged fraction (dia < 210 microns) consists mainly of colloidal material easily degraded by bacteria and contains the majority of the crude protein (89.5%) and lipids (91.0%) and which have CH_4/CO_2 ratios of 5.25 and 2.33 respectively (Water Pollution Control Federation, 1968). Therefore, the higher methane/VS_{in}.d observed with the filter over the conventional digester can be accounted for, in part, by the lower CO_2 yielding compounds (high CH_4%) and the absence of carbohydrate particles (cellulose and hemicellulose) which require longer retention times for breakdown.

The filter yields a high percentage methane biogas (70%) at low hydraulic retention times (HRT), which at first appears to be very economical. However, the energy gained is offset by the high energy inputs needed to heat the large volumes of influent water associated with low HRTs (assuming 35° operating temperature).

$Energy_{out}/Energy_{in}$ ratios (E_o/E_i) for a rock filter versus a conventional digester treating wastes from 1000 finishing hogs (Table 1) show that the conventional digester is three times more energy efficient (assuming equal conduction losses). The comparison is conservative because screening of manure prior to filter loading was not considered. Methane produced would be less for the filter if screening was considered and thus reduce the energy ratio more.

TABLE 1. Energy Efficiency of a Rock Filter vs. a Conventional Digester*

	Loading (g VS/L·d)	HRT (d)	CH_4 Production E_o (MJ/d)	Influent Heat, E_i (MJ/d)	Energy Ratio E_o/E_i
Rock Filter	4.0	5	5,174	1,753	2.95
Conventional Digester	4.0	20	4,037	441	9.15

*Calculations based on 1000 finishing hogs.

Consideration was given to reducing the heat requirements of the anaerobic filter by operating it at a lower temperature. A literature review on temperature's effect on anaerobic digestion suggested that below 25° biological action substantially is reduced and the methane production rate becomes too low for feasible energy recovery.

Current Work

Table 2 contains preliminary results of current efforts to determine the potential methane production of each swine manure particle fraction. The colloidal fraction (centrifuged) makes up approximately 50% of the total volatile solids (TVS) in swine manure and represents the largest single fraction of potential methane. This fraction does not settle, and from very limited data from our laboratory, is also lost to a large degree in the effluent of a digester with short HRT (<15d).

TABLE 2. Methane Potential of Various Swine Manure Fractions*

	Fraction Diameter, microns			
	1.68	0.840	0.425	Centrifuged (X 13,000)
% TVS	26	10	3	52
Methane ml/g VS_I	138	58	12	207

*digested at 35°C and 21 d HRT.

One reason for its loss from the digester is its overall rate of biological degradation, which is the slowest for all fractions tested. All other fractions ceased to produce methane after 10-12 days while the centrifuged fraction began to peak after 30 days. Digesters operated on HRT's of 15-20 days will lose a sizeable fraction of methane associated with this fraction of VS.

Our current work is aimed at developing processes which will recover this fraction and make it available for complete digestion and enhance the overall energy recovere from swine manure.

SUMMARY

The anaerobic rock filter is an excellent treatment method for dilute wastes of small particle diameter but cannot compete with conventional digesters in being able to utilize all fractions of animal manure for methane production. For the Energy Farm, the rock filter does not appear to be an efficient means of extracting methane from the settling basin effluent due to the high energy input of heating water. If flushing is to be continued, then some other process needs to be used to capture the colloidal fraction. One process might be chemical precipitation followed by centrifugation. This process might also be used to eliminate the settling basin entirely and go to a total recycle system.

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PERFORMANCE OF AN AUTOMATICALLY CONTROLLED FLUIDIZED BED CORNCOB COMBUSTOR

by

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ABSTRACT

A small, 6-inch diameter, fluidized bed combustor (FBC) with automatic control has been developed. Ability of the control system to operate the burner, using corncobs as a fuel, has been shown to be so good as to make the operation almost as simple as for a home fuel oil furnace. Results of test on burner efficiency for air-to-fuel ratios of 1.04 to 1.41 showed 56 to 62 percent of the fuel energy was collectible as totally clean high temperature air (> 1000°F) via the heat exchanger used in the system. Maximum collected heat was 72,000 Btu per hour. Burner output is fully controllable from near 0 to 72,000 Btu per hour.

Background

In the fall of 1981, design began on a small (75,000 Btu/hr), but efficient fluidized bed combustor (FBC) using corncobs as a fuel source. The developed burner utilizes a 6-inch diameter stainless steel pipe as the combustion zone and a unique fluidized bed-to-air heat exchanger system to produce a clean, high-temperature air stream for heating purposes. Because no gas is produced in the fluidized bed for combustion elsewhere, it falls in the class of a direct combustion burner system. Makanski and Schwieger (1982) discuss current designs of direct combustion FBC. In their review however, the smallest burner was rated at 4 tons of coal per hour, about 1000 times larger output than the unit reported on in this study. Figure 1 is a schematic of the burner system and indicates the other mechanical components of the system. In addition, in the fall of 1982, an automatic control system was added to complete the development phase. The unit (Figure 2) has now undergone extensive testing.

Combustion Results

Results of early 1982 tests showed that the unit burns corncobs cleanly and delivers clean heated air efficiently with minimal maintenance over long periods of time if properly operated (Keener et al, 1982). The tests confirmed that bed temperatures must not be operated above 1,400° F or ash from the burned cobs will melt and stick to the sand, causing the burner to plug. Below 1,400° F, the ash does not melt but remains solid and is carried out of the burner with the combustion air as fine particulate matter. These tests also showed that combustion of cobs must be carried out above 1,200° F. It was only above this temperature that combustible gases (such as carbon monoxide) were fully burned and maximum heat production obtained.

Following addition of the automatic controls to the system, a series of nine tests were run comparing burner efficiency for different air-to-fuel ratios. Detailed results of one such test are given in Table 1. (Note: The energy balances for the burner have subtracted out energy inputs from the fluidizing pump and the cooling fan.) This test was for an air-to-fuel ratio of 1.09 and utilized a fuel feed rate of 16.5 pounds of cobs per hour (5 percent moisture). Total usable heat out of the system was 71,700 Btu per hour, 60.7 percent of the gross heat energy of the fuel. In this test 17.7 percent of the heat was lost via the exhaust gases while 21.6 percent was "other". This "other" heat consists of unburned fuel in the form of CO, C (collectible by cyclone) and heat losses through system walls. Of these, heat losses through the system's walls are not really losses when the burner is operated within the confines of the area to be heated.

Efficiency results for all nine tests are shown in Table 2. These results showed efficiency down to 56 percent when burning with 41 percent excess air, but "other" heat losses dropped to 19.3%. For the case of 4 percent excess air, efficiency increased to 62.3 percent while "other" heat increased to 21.8 percent. Generally, as air-to-fuel ratio increased, system efficiency decreased along with "other" heat. This is expected even though high air ratios allow more complete combustion. At the same time, more heat is carried out of the system with the exhaust gases. Range of heat energy output during these tests was 50.8 to 71.7 thousand Btu/hr.

Automatic Controls

An automatic control system has been developed for the FBC. The controller developed enables starting the system with a single push button. After manual start, the controller is able to turn the burner system off and on upon (1) call by room thermostat and/or (2) sand bed temperature. During the controlled combustion test, the FBC was operated automatically both during the daytime combustion test and at night. Results of nighttime operation showed the current prototype burner would cycle on about every hour and burn 1 pound of cob to reheat the burner. Figure 3 shows result for the burner during a cycling mode (such as overnight operation) and continuous burning mode (such as when home thermostats call for heat).

System Efficiency

Estimates of electrical power used for operation of the prototype burner system is about 1.72 kW. Based on an average heat output of 60,000 Btu/hr during operation, electrical energy input would be 1/10 of the energy out of the system.

Electrical Generation

Field testing to date has centered on development of the FBC heat exchanger system and automatic control system. In addition, engineering design specifications for coupling the burner to a small hot gas turbine-generator has been underway. Results to date indicate the burner system will need to be scaled up by a factor of two to be compatible with the smallest currently available hot-gas turbo systems.

SUMMARY

Test results to date have shown the burner design to be operationally sound. Development of the automatic control system enables the burner to be used easily and safely. Pollution measurements have not been completed but preliminary results suggest the burner's exhaust to be environmentally safe when burning corncobs. Future efforts will explore ways of scaling the burner up for electrical power generation or greater heat output. The current design and size would be applicable to home heating or low temperature crop drying.

References

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Makanski, J. and Bob Schwieger. 1982. Fluidized-bed boilers. Special Report. Power 126(8):51-516. McGraw-Hill Pub. New York, NY.

Table 1. Corncob Burner Test Results, Test 42.3

		Temperature, °F		Energy	
	Flow, lb/hr	In	Out	Btu/hr	Ratio
Fuel	16.5	31.8	--	118218	1.000
Exhaust	97.9	55.6	753.6	20937	0.177
Cooling air	295.7	74.8	1024.9	71702	0.607
Other	--	--	--	25579	0.216

Fuel moisture = 5% w.b.
Excess air for combustion = 9.0%
Temperature reference for energy = 60°F.

Table 2. Effect of Air/Fuel Ratio on Burner Efficiency

Date 1983	Test	Fuel Rate lb/hr	Air/Fuel Ratio	Energy Ratios* Exhaust	Cooling	Other	Exhaust CO %
1/25	41.1	13.4	1.24	.153	.604	.243	--
	41.2	13.1	1.14	.162	.626	.212	1.2
	41.3	14.0	1.07	.153	.604	.243	1.2
	41.4	12.5	1.20	.176	.602	.221	1.1
1/26	42.1	12.6	1.30	.196	.592	.212	1.0
	42.2	15.8	1.04	.159	.623	.218	1.2
	42.3	16.5	1.09	.177	.607	.216	1.2
	42.4	12.8	1.41	.246	.560	.193	0.7
1/27	43.1	14.4	1.17	.202	.618	.181	1.0

*Ratio of energy leaving system to gross heating value of fuel.

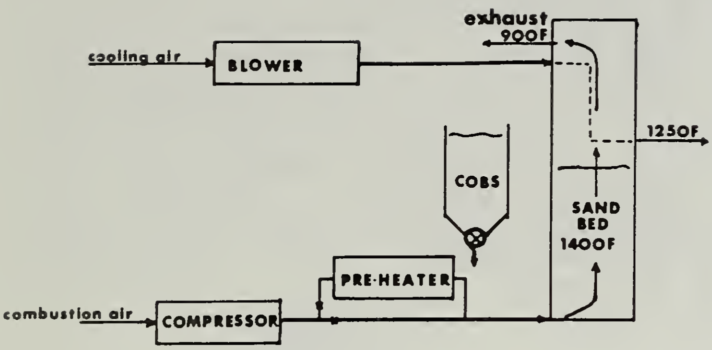

Figure 1. Schematic of fluidized bed combustion system showing flow paths of combustion air and cooling air used to remove heat from the burner.

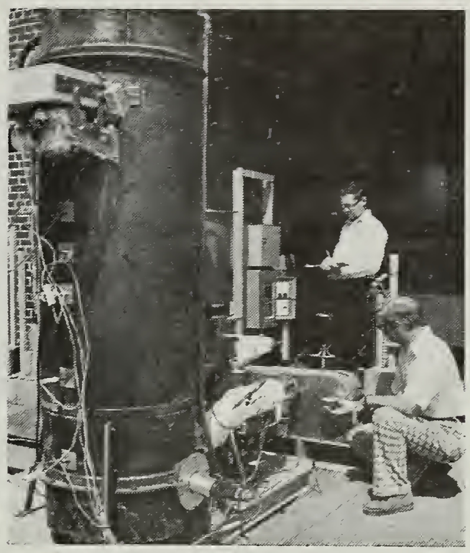

Figure 2. Prototype FBC can deliver more than 60% of the fuel energy from burning corncobs as clean, high-temperature air with no pollution.

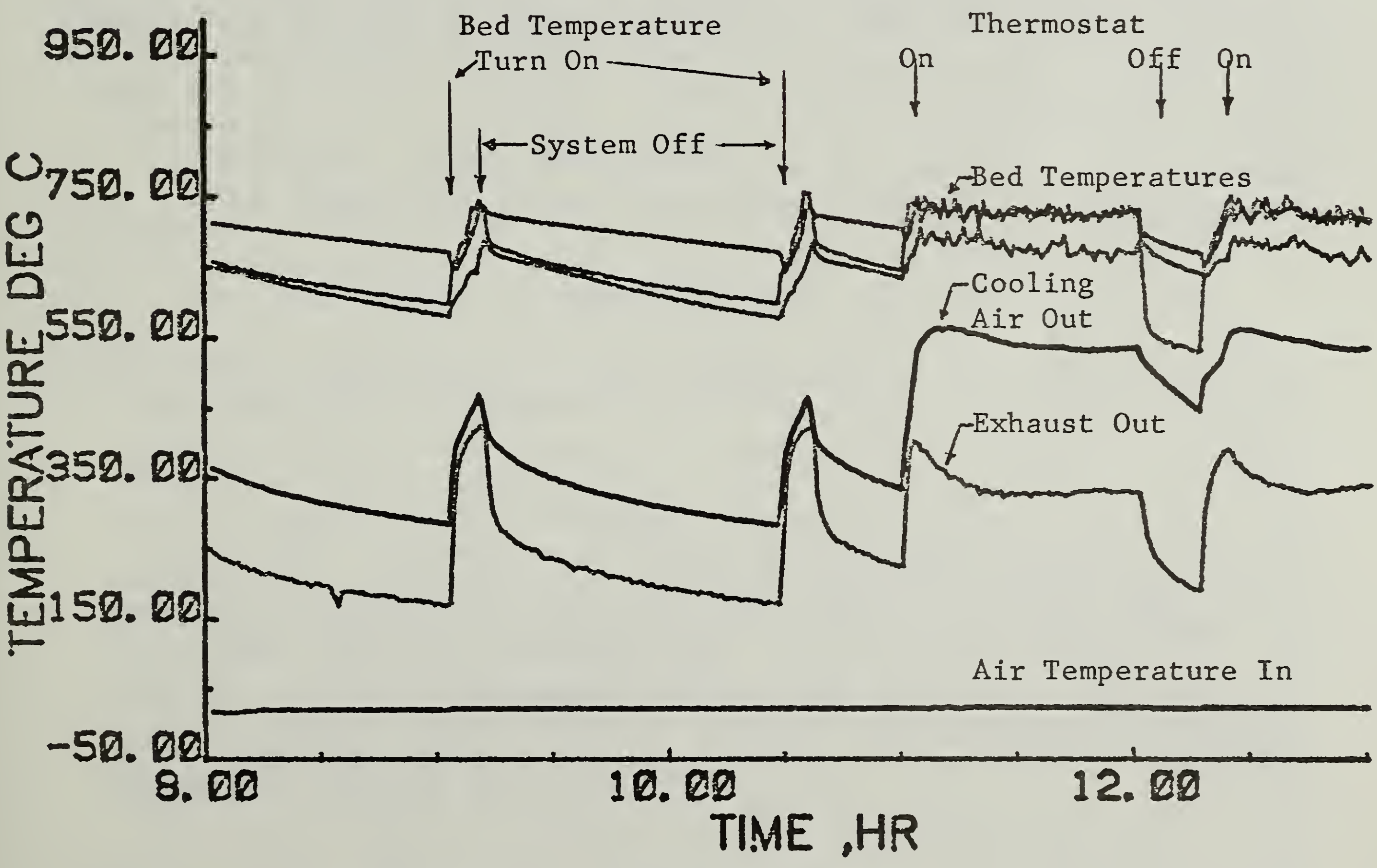

Figure 3. Temperatures of fluidized-bed corncob burner and cooling air during test of auto-restart and thermostatic control.

CATALYTIC CONVERSION OF BIOMASS - DERIVED SYNTHESIS GAS TO DIESEL FUEL IN A SLURRY REACTOR

by

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ABSTRACT

The project was initiated on September 15, 1981 with the purpose of developing a slurry phase chemical reaction system to convert synthesis gas representative of that obtainable from biomass gasification processes to diesel fuel that can be utilized directly in existing engine designs. The objectives are to maximize product yields, assess the operational reliability of the system and compare the system performance with an existing fluidized bed system. To date, design and fabrication of the system has been accomplished followed by a study of the effect of liquid type, catalyst type and conversion system inlet gas composition, temperature and pressure on product yields. Results to date indicate that product yields of about 40 gals of diesel type fuel per ton of biomass feedstock (dry, ash free) can be achieved with further improvements expected primarily via liquid media and catalyst development work.

INTRODUCTION

The primary motivation for the project was the recognition that the fuel of choice for farm applications is a No. 2 diesel fuel with the trend expected to escalate in future years. Previous work at Arizona State University (ASU) demonstrated that a quality, diesel type fuel compatible with the existing distribution system and engine designs could be produced from various biomass materials via an indirect liquefaction system consisting of fluidized bed gasification followed by fluidized bed liquefaction (1,2). However it was recognized that a slurry phase type liquefaction system offered some potential advantages over a fluidized bed. These included enhanced temperature control, operating conditions flexibility (particularly residence time), testing of unsupported catalysts etc. A possible disadvantage was increased system complexity, ie, a liquid handling system would be required. Although the liquefaction development plan was primarily tailored at the synthesis gas capabilities of the ASU gasification system, factor studies on the inlet gas composition were expected to reveal the applicability to other types of gasification systems.

PRESENT STATUS

A schematic of the completed experimental system is shown in Figure 1. A cylinder gas manifold was constructed to feed simulated pyrolysis gas to the reactor via mass flowmeters. A slurry circulation and product separation system was included as well as an off gas treating system. Instrumentation was provided to control reactor temperature, pressure and inlet feed gas compositions. Gas chromatography was used to analyze for liquid product compositions. After a series of exploratory runs were completed, a fractional factorial experiment was performed with a paraffin oil liquid and cobalt/alumina catalyst. Factors and levels were as follows:

Factor	Level
temperature	$260^{\circ}C \pm 50^{\circ}C$
pressure	195 psig $\pm$ 100 psig
carbon monoxide feed composition	30 mole % $\pm$ 10%
ethylene feed composition	15 mole % $\pm$ 10%
hydrogen feed composition	30 mole % $\pm$ 10%

Reactor residence time was held at about 40 sec. With regard to product yield, the factors in decreasing order of importance are as follows: temperature > pressure > ethylene > hydrogen > carbon monoxide. Results indicate that yields of about 40 gals per ton of biomass are possible with recycle of the reactor off gas. Analysis of the effect of the factors on product quality is currently in progress. A gas chromatogram comparison of typical experimental product with commercial No. 2 diesel fuel is given in Figure 2. As indicated, the materials are similar except at the low molecular weight end.

FUTURE PLANS

The Experimental Plan calls for iterations on catalyst and liquid media candidates with conversion system factor studies on promising combinations. Additional liquid candidates have been selected based on gas solubility and diffusivity calculations and system compatibility. Runs are in progress. Testing with real synthesis gas as well as implementation of gas recycle will be considered also.

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SUMMARY

A reaction system with the objective of converting synthesis gas from various gasifier types to No. 2 diesel fuel has been described. A quality product with a yield of about 40 gals of diesel fuel per ton of biomass (dry, ash free) can be achieved at present conditions. Improvements in the system are expected to result in diesel yields of about 60 gals/ton.

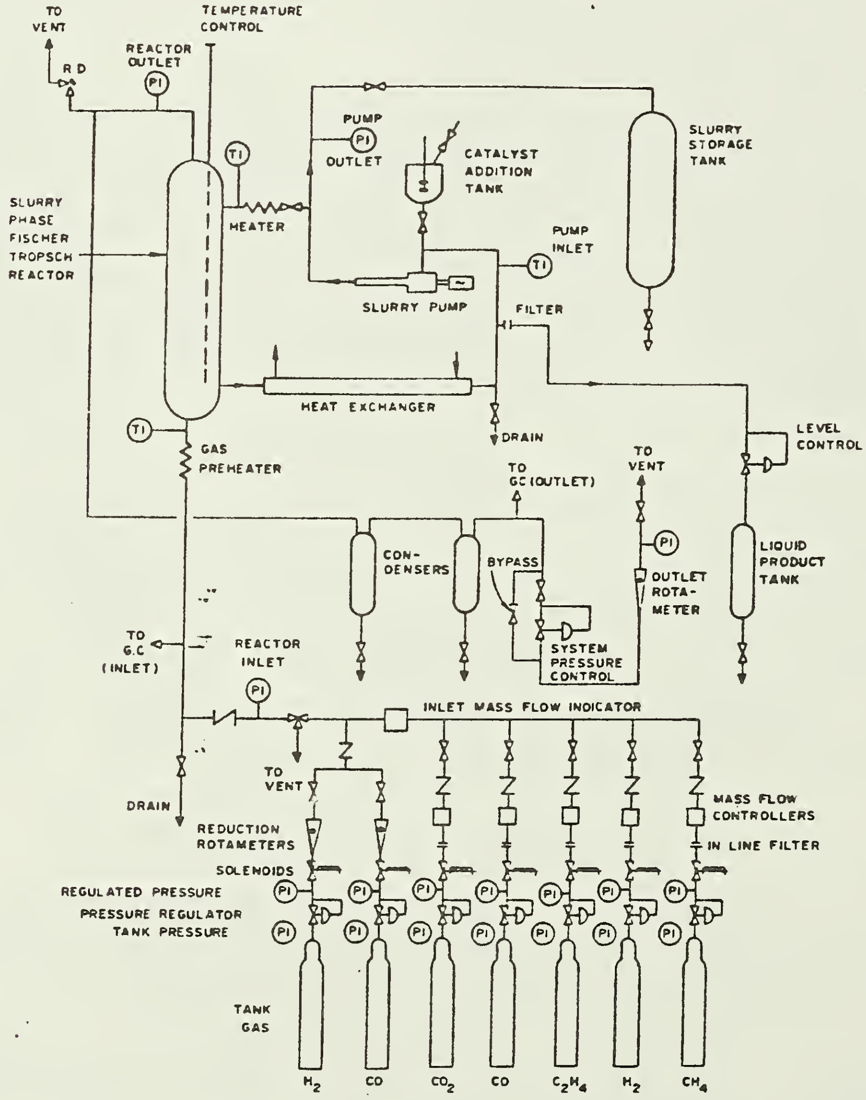

Figure 1. Slurry Phase Fischer-Tropsch Reaction System - Schematic

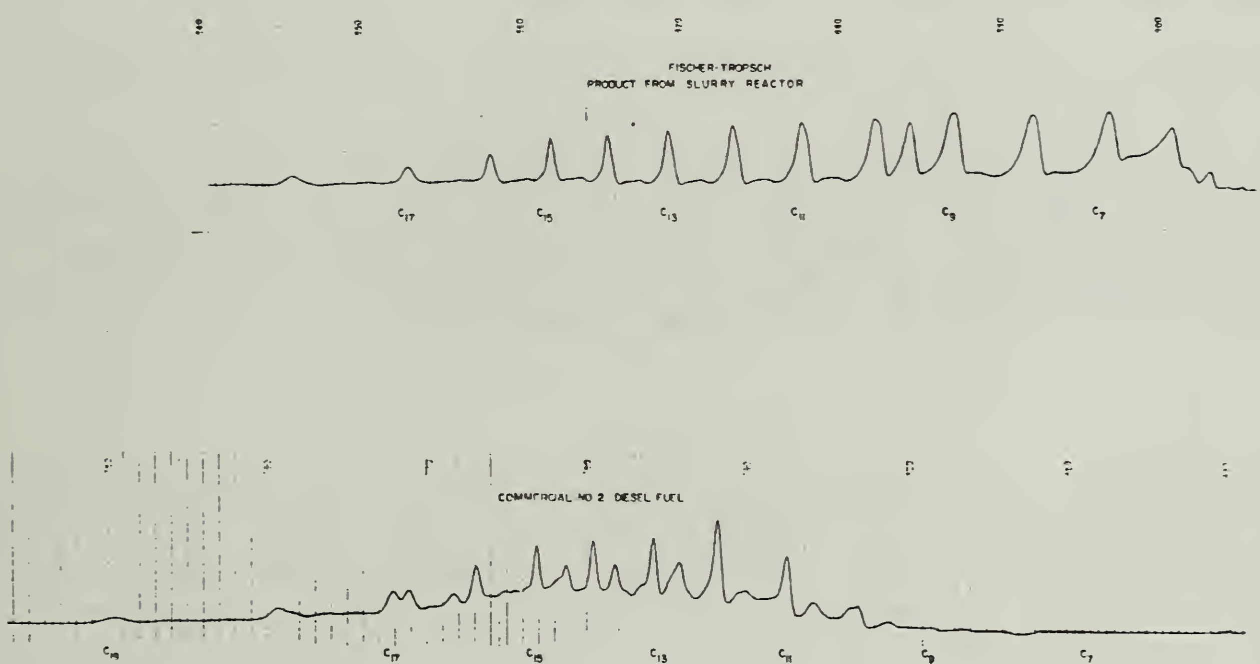

Figure 2. Experimental Product Composition vs. Commercial Diesel Fuel

FLUID-BED GASIFICATION OF CROP RESIDUES

by

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ABSTRACT

The purpose of this study was to examine the gasification behavior of corn stover, wheat straw and sorghum stover in a pilot-scale fluid-bed reactor over a temperature range of 800-1020 K. Material balances were used to extract information on the volumetric yield and higher heating value of the produced gas. The mass fraction distribution of the feed into gas, liquid and char products was also evaluated.

The volumetric gas yield and heating value were fairly close for corn stover and straw while sorghum gave a higher yield and a lower heating value than the other materials. The mass yields of gas and liquid from sorghum and straw were relatively close while corn stover showed a higher liquid yield and a lower gas yield than the other materials. Linear relationships with temperature were found for the volumetric gas yield and the mass yields of gas and liquid. Char yield was found to be independent of temperature and gas heating value varied parabolically.

INTRODUCTION

Residues from row and field crops represent a significant biomass resource base for conversion into supplemental fuels for agriculture. Gasification using low pressure fluid-bed technology is a practical conversion alternative for these materials. The purpose of this study was to determine the gasification behavior of corn stover, wheat straw and sorghum stover as a function of temperature in a fluid-bed reactor. Specifically examined were the produced gas volumetric yield and heating value and the mass fraction distribution of each feedstock into gas, liquid and char.

EXPERIMENTAL FACILITIES AND PROCEDURES

Pilot Plant Facility

A pilot scale fluid-bed gasifier operating at atmospheric pressure was used in this study. The reactor was 0.23 m I.D. with an expanded freeboard section of 0.41 m I.D. A perforated plate distributor supported the bed which consisted of an inert matrix of silica sand and a minor portion of limestone as an anti-agglomerating agent. Hot fluidizing gas was generated below the plate in the plenum section by combustion of propane under starving air conditions with the simultaneous injection of water to control flame temperature. A radiant fired jacket surrounded the bed and was used for secondary temperature control.

Feed was introduced to the bed by means of a screw feeder through a vertical feed pipe. A nitrogen purge was used to facilitate flow through the feed pipe. Feed discharged from the pipe just above the surface of the expanded bed. The off-gas and entrained char were passed through a hot cyclone for char separation and then to a venturi scrubber. The scrubber quenched the gas and removed most of the tar. The misty gas was then sent to a flare for incineration.

Supporting instrumentation consisted of rotameters, a temperature recorder, an on-line process gas chromatograph, and an elemental analyzer.

Procedure

Each experiment was initiated by preheating the reactor to the desired operating temperature. The plenum gas was then analyzed and the air, water and propane rotameter readings were noted. Nitrogen purge was commenced and the off-gas was analyzed. The feeder was then set at the desired rate and the radiant burner duty was increased to compensate for the cold feed. Continuous feeding was maintained for one hour and the off-gas was analyzed.

Over the course of gas sampling, condensates from the plenum and off-gas sample streams were collected and weighed and the volume flows associated with each stream were measured with wet test meters. The feed rate was evaluated from the difference in weight of material in the feed hopper before and after the experiment. Char production rate was determined indirectly by ash balance between the feed and char.

Feedstocks

The feed materials used in the experiments were corn stover, wheat straw and sorghum stover. Each material was hammer milled to pass a 0.64 cm (1/4 inch) screen. The straw and corn stover were field dried and the sorghum stover, which was harvested wet, was air dried in a heated building. The elemental analyses (dry basis), the as-used moisture contents and the higher heating values (estimated from the Dulong formula for dry-ash-free feed) are summarized in Table 1.

Table 1 Feedstock Analysis

Material	Elemental Analysis-Dry Basis % C	H	O	N	Ash	Moisture % Wet Basis	Heating Value (DAF) MJ/kg
Corn Stover	39.0	5.1	44.2	1.5	10.3	9.0	14.3
Wheat Straw	41.3	5.2	44.4	0.2	8.9	5.7	14.8
Sorghum Stover	38.3	5.0	44.1	1.7	10.9	7.8	13.7

Operating Conditions

Reactor temperature was the main variable in the experiments. Reactor temperature, defined as the average between the freeboard and bed temperatures, ranged from 800-1020 K. Feed rates ranged between 5 and 11 kg/hr and gas superficial velocities varied between 0.3 and 0.7 m/s.

Treatment of Data

Material balances and other derived information were obtained using the following procedures. The analyses of the dry plenum gas and reactor off-gas coupled with nitrogen balances allowed the molar, volumetric and mass rates of these streams to be determined. The liquid flow rates associated with these streams were evaluated from the condensate measurements for their respective sample streams. The directly measured feed rate coupled with an ash balance was used to determine the char rate. This information allowed the material balance closure to be evaluated for each experiment.

From the above information, the dry produced gas volumetric yield, composition and higher heating value were determined. Produced gas, defined as the difference between dry off-gas and dry plenum gas, was used as a measure of the gas produced from the feedstock. The produced gas volume flow rate was calculated as the difference between the volume flow rates of the dry off-gas and the dry plenum gas. The basis for volume calculations was 289 K and 101.6 kPa. The produced gas volumetric yield was evaluated by dividing its volume rate by the dry-ash-free mass feed rate. The produced gas composition was calculated as the difference between the molar flow rates of each component in the dry off-gas and dry plenum gas on a component by component basis followed by normalization. The higher heating value of the produced gas was determined from the produced gas composition and the heating values of the individual components.

The mass distribution of dry-ash-free feed into gas, liquid and char products was determined from the pilot plant material balance using a basis of 100 mass units of dry ash free feed. Gas yield was determined directly from the mass of produced gas, char yield (ash-free) on the basis of ash balance and liquid yield by difference.

RESULTS

The results presented in this section were based on experiments with closures greater than 85%. With the exception of the sorghum data, the lines in the figures were determined on the basis of regression analysis and analysis of variance; preliminary sorghum data were fit by eye.

Produced Gas Yield and Heating Value

A comparison of the variations of volumetric gas yield and heating value of the produced gas with temperature is shown in Figure 1 for the three feedstocks. Gas yield varies linearly with temperature while gas heating value shows a parabolic dependence. In the low temperature range, corn stover gives the lowest gas yield and sorghum stover gives the highest gas yield. For most of the temperature range, sorghum stover gives gas with a lower heating value than gases from the other two feedstocks. On the average, the yield and heating values for the gases produced from corn stover and wheat straw are fairly close over most of the temperature range. The preliminary data for sorghum stover indicate a higher gas yield and a lower gas heating value than gases produced from the other materials.

Mass Fraction Product Distribution

The mass fraction distribution of the dry-ash-free feed into gas, liquid and char is shown in Figure 2 as a function of temperature for the three feedstocks. As indicated by the figure, linear relationships with temperature exist. In the low temperature region, sorghum gives the highest gas yield while corn stover gives the lowest yield. In the high temperature region, wheat straw gives the highest yield. Char yields are invariant with temperature and increase in the order: corn stover, wheat straw, sorghum stover. Liquid yields follow the opposite trend for gas yield.

The gas and liquid mass yields for sorghum stover and wheat straw are reasonably close. For corn stover, the liquid yield is higher and the gas yield is lower than the yields for the other materials. This finding for gas yield is opposite that for gas yield on a volumetric basis, but it can be explained on the basis of gas composition variations. Limited space does not permit the gas composition data to be presented.

SUMMARY

Corn stover, wheat straw and sorghum stover were gasified in a 0.23 m I.D. fluid-bed over a temperature range of 800-1020 K. Volumetric gas yield and heating value were fairly close for straw and corn stover while sorghum gave a higher yield and a lower heating value than the other materials. Mass yield of gas was relatively close for straw and sorghum stover while it was lower for corn stover.

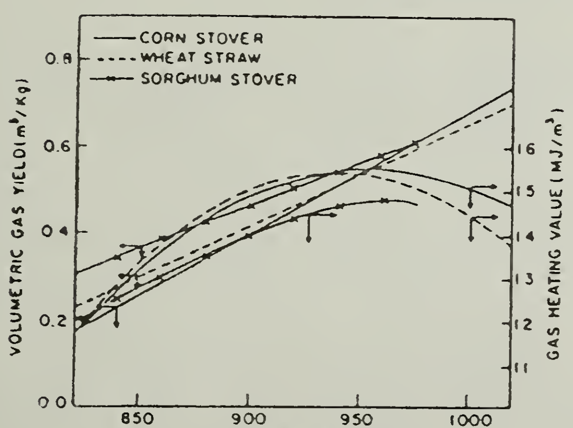

Figure I. Produced Gas Yield and Heating Value Vs Temperature.

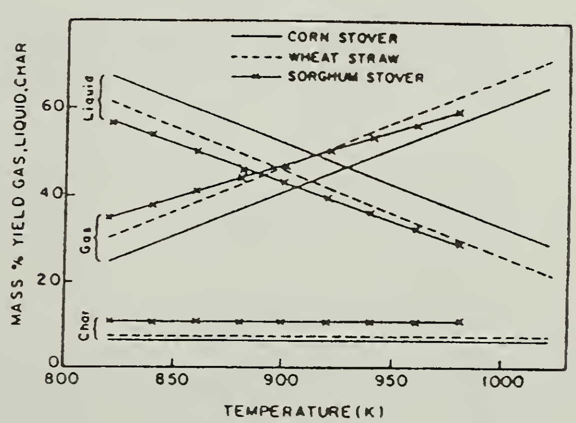

Figure 2. Mass % Yield Vs Temperature

FUELS AND CHEMICALS FROM TARS

by

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ABSTRACT

The thermochemical conversion of lignocellulosic materials, whether by pyrolysis, gasification or combustion, is a complex process which first produces char, tar and gases as primary products. In pyrolysis, reaction conditions can be selected which result in high tar yields. It is argued that the fundamental virtue of pyrolysis is as a tarification process, and that the key to commercial implementation is the identification of economically competitive technology for the production of higher-valued, upgraded, tar products. For gasification, recent progress in process technology favors systems which minimize tar production, and such systems are necessarily complex and costly. It is argued that simpler systems could be entertained if uses for tars were developed. For both pyrolysis and gasification, tar product development has lagged far behind process development. This report covers some selected approaches to tar utilization for fuels and chemicals, with particular emphasis on the derivation of internal combustion engine fuel hydrocarbons and adhesives. Advantages to the development of such products from forestry and agricultural residues are detailed.

PYROLYSIS AND GASIFICATION

All organic materials decompose upon heating. At temperature above 200°C, lignocellulosic materials (biomass) thermally degrade to produce gases, liquids (tars), and solids (chars) as primary products. Depending on reaction parameters such as heating rate, final temperature, and residence time at temperature, as well as particle size, moisture or ash content, presence or absence of air or oxygen, and so on, these primary products can undergo secondary reactions affecting yields and qualities of the final products. At sufficiently high temperatures, generally above 600°C, and in the presence of air or oxygen (conditions that are present in gasification processes), the primary tar and char products are further oxidized and broken down to yield a relatively clean, low calorific value fuel gas as essentially the only product. At lower temperatures, and under oxygen-deficient or inert atmospheres (incomplete thermochemical conversion in other words), the extent to which the primary tar and char products can undergo secondary reactions is limited. Under such conditions, tars and chars can be recovered as products, and the term pyrolysis is generally used to describe these latter processes.

Tars are desirable products in pyrolysis but undersirable products in gasification. However, the nature of gasification, as part of a thermochemical conversion process continuum, is that some tar will always be produced. Recent progress in biomass gasification processes favors complex systems which attempt to circumvent the tar issue either through longer tar retention times at elevated temperatures permitting secondary reactions to gaseous products and thus lower tar yields, or through elaborate tar recycle schemes for reentry into the reactor. Both approaches require sophisitcated hardware with attendant high costs. Simple, inexpensive gasification systems can be built which can meet gaseous fuel needs, and methods for collection of tar are being developed. However, without product value for the tar recovered, and because of its corrosivity and potentially carcinogenic nature, disposal problems prohibit their use. The basic premise here, as for any resource conversion technology, is that to solve any disposal problem, find a good used for it! For both gasification and pyrolysis, product development has lagged behind process development. The key to the commercialization of biomass pyrolysis, and to the reintroduction of simpler, inexpensive biomass gasifiers is the identification of economically competitive technology for the production of higher-valued, upgraded, tar products.

LIQUID ENGINE FUELS VIA PYROLYSIS

In any effort towards national energy independence, it would appear logical that agriculture should attempt to "grow" its energy requirements. To this end there has been, for example, considerable research activity in energy farming. Further, on-site biomass residues in and of many forestry and agricultural operations may be sufficient in energy content to satisfy on-site energy requirements of those operations. Biomass residues, however, are generally low in energy density and are in physical forms that must be altered before use can be considered. On a local level in specific operations, and on a national level in aggregate, shaft power produced via gaseous and liquid-fuelled engines is recognized as a major energy consumer in forestry and agriculture. Historically, we have generally favored gaseous fuels for stationary engines, and refined liquid fuels for vehicular engines. To produce gaseous and liquid engine fuels from biomass, several conversion options can be identified. Biomass gasification, for example, may serve stationary engine applications, and may be well suited to the scale of 2 to 200 tons biomass feed per day generally required for local energy needs. For vehicular applications, however, liquid fuel options are more complex. Several of these are given in Figure 1.

The first three options, seed oils for diesel application, sugar crops and grain to produce fermentation alcohol for gasoline application, are relatively straight-forward, have much appeal for small-scale, potentially on-farm implementation, but suggest potential conflicts in food vs. fuel issues if implemented on scales of national energy significance. The intermediary option, using residues to supply sugars for fermentation, circumvents such conflicts, but has to tackle the stubborn and, despite much research effort, yet unresolved problem of accessing sugars in lignocellulosics.

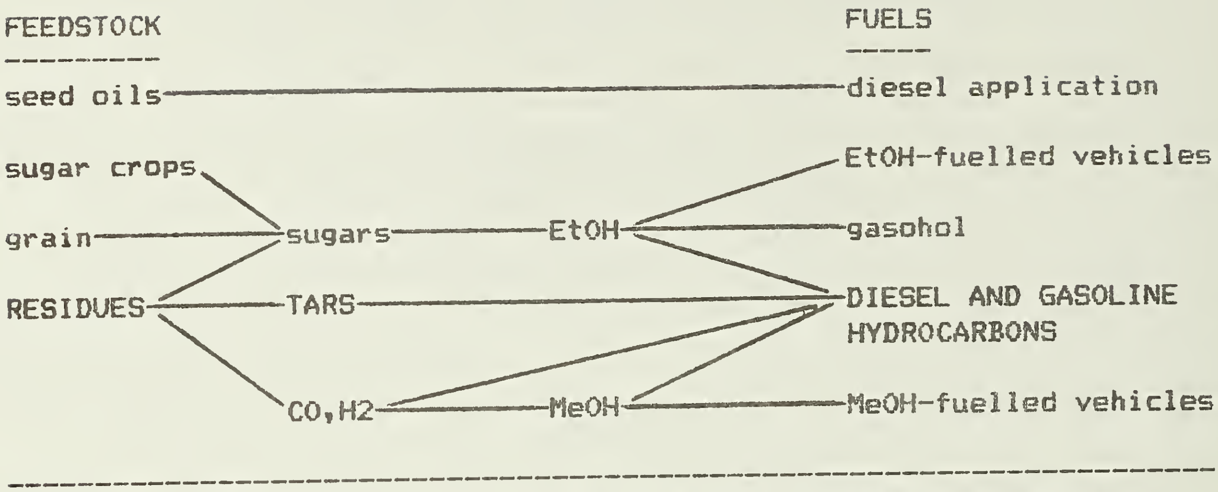

FIGURE 1. Some options for engine fuels from biomass feedstocks.

There are still other options for liquid fuels, and research in these other areas is gaining some momentum. Thermal processing can accept a wide variety of biomass residue feedstocks, even dirty residues not amenable to chemical or biochemical processing, to yield gases and tars which can be used for liquid fuel synthesis. Methanol can be synthesized from the gaseous products of biomass gasification. This methanol can be used as a fuel directly, or be converted to gasoline hydrocarbons via shape-selective zeolite catalysts. These same catalysts can be used to convert fermentation ethanol to similar hydrocarbons. Alternately, gas produced via biomass gasification can be used in Fischer-Tropsch synthesis of paraffinic fuels, or following reforming, gasoline. Lastly, biomass residues can be pyrolyzed to yield tars which can be catalytically hydroprocessed into liquid hydrocarbon mixtures from which gasoline and diesel fuels can be fractionated. The advantages to this route to engine fuels are: (1) that residues instead of primary agricultural products can be used as feedstocks; (2) that the processes used are compatible with and similar to those currently used by the petroleum processing industry; (3) that both gasoline and diesel fuels are produced; and, (4) that the products are not substitute fuels such as alcohol or seed oil but the same hydrocarbons that are currently produced and used in gasoline and diesel engines.

Progress Towards Liquid Fuel Objectives

A significant amount of preliminary work has already been completed towards objectives through two awards by the USDA Special Research Grants Program. The first USDA award was for the identification of catalysts with specificities for converting a pine waste pyrolytic tar into a mixture of paraffinic fuel hydrocarbons. The second award is for the extension of the processing developed to a wider range of biomass residues such as corn cobs, sugar cane bagasse, plywood trim, peanut shells and pecan shells. It appears that although the physical forms of such residues are different, tars produced via thermochemical processes exhibit many similaries in chemical composition, and that many differences in the composition of different tars are eradicated in catalytic hydroprocessing to yield a mixture of C6 to C30 paraffinic hydrocarbons, as well as alkyl aromatics such as toluene and ethyl benzene. This mixture of hydrocarbons can be fractionated into fuel fractions that have met some success in small gasoline and diesel engine testing.

Other Products

Fuels, however, should not be the sole products in any resource conversion process. As for petroleum, chemical values should be exploited first before relegating the bulk of any resource to fuel status. The alkyl aromatics present in the processed products are derived predominantly from the lignin component of biomass materials. Through variations in catalytic hydroprocessing, hydrotreating activities can be altered to yield reactive phenolics. These are currently being evaluated for their potentials in adhesive formulations. Why adhesives? Recent concerns about shrinking inventories of wood in diameters suitable for lumber manufacture have suggested that a potentially big market for reconstituted composition wood fiber, flake, and chip products exists, the raw material for which can be logging residue. One doesn't have to cut a 2x4 out of a tree stem; one can also make a 2x4 via extrusion of wood residue particles held together by the right adhesive. The realization of this desirable development has lagged behind the availability of an inexpensive, effective adhesive. What better use for logging residues can there be than as a raw material not only for the fiber, flake or chip destined for reconstituted products, but also for the production of the adhesive to bind these particles together? An added advantage of the use of pyrolysis in this application is that the other products, gas and char, are fuels that can be used to satisfy much of the energy requirements of the process.

There are additional uses for the chars. The hydrogen content of the chars produced in biomass pyrolysis is sufficient to satisfy the hydrogen requirements of catalytic hydroprocessing, and upon further study, may be available for such use through appropriate steam-char reactions. Activated carbon would be generated as a byproduct. Energy requirements for both pyrolysis and subsequent processing may be derived solely from the gaseous products of pyrolysis. Thus, save for catalyst requirements, all raw material and energy needs to produce fuels, phenolics and activated carbons can be supplied by a biomass feedstock.

SUMMARY

Thermochemical conversion in its various forms allows the use of non-merchanted biomass residues in the generation of useful products. These processes can be used on biomass materials to produce not only fuels, whether gaseous, tar or char in nature, can also be used as chemical feedstocks. Thermochemical conversion in the form of pyrolysis may yet provide new approaches to oxychemicals and hydrocarbons for our material and vehicular engine fuel needs.

245 BIOMASS REFINING: PROTEIN AND ETHANOL FROM ALFALFA

by

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ABSTRACT

Protein is a valuable component of biomass (plant material) that is generally neglected in current fuels and chemicals from biomass schemes. We have studied various ways in which protein might be coproduced with fuels and other chemicals from biomass, using alfalfa as the example crop. There are numerous areas in the United States where protein and ethanol production from alfalfa seems feasible. For alfalfa, the ethanol is a byproduct while protein is the primary product. Producing protein materials for feed or food also eases the conflicts between chemical and energy production from biomass and world food supplies.

BACKGROUND

Biomass conversion to fuels and chemicals (termed biomass refining) is receiving a great deal of attention. In most cases, the long-term interest is in agricultural and forestry materials. Such materials are mainly composed of cellulose, hemicelluloses, and lignin, called generically "lignocellulosics". This is a useful simplification but perhaps a misleading one. Biomass is inherently much more heterogeneous than this three-component description implies.

In addition to cellulose, hemicelluloses, and lignin, biomass can contain a multitude of other components, including, of course, protein. These other constituents may be concentrated enough to arouse interest in the same plants for other than their "lignocellulose" fraction. This is the case with the so-called hydrocarbon plants such as guayule or spurge. Most work to date has neglected the protein content of biomass. In an integrated scheme for biomass processing there are several reasons to recover this plant protein:

1. Protein may be concentrated or separated from the other components in a variety of ways.
2. Protein has a very high value compared to most other components and might provide a significant by-product credit in biomass refining if appropriate markets can be found.
3. There are conflicts between biomass production for fuel and chemical uses, and use of the same resources of land, water, and so forth, for feed and food production. Protein co-production with fuels and chemicals would reduce these conflicts.

PROTEIN RECOVERY IN ETHANOL PRODUCTION

Large-scale production of ethanol or other fermentation chemicals and fuels to replace petroleum-derived substances must ultimately rely on the crop and forest lignocellulosic materials. Most attention has focused on the cellulose, hemicelluloses, and lignin present in such materials. However, there is also considerable protein in these plant materials as Table 1 indicates.

For the species listed, an average whole plant protein content is about 9%. The average carbohydrate content (cellulose plus hemicelluloses) is around 60%. However, a kilogram of protein was worth approximately four to five times as much as an equal weight of sugar (soybean meal compared with molasses). Therefore, the protein and carbohydrate values of biomass are potentially roughly equal in value. This fact has received very little attention.

TABLE 1

PERCENT COMPOSITION OF SELECTED BIOMASS SPECIES; LEAVES AND STALKS (DRY BASIS)

Sample	Cellulose	Hemicelluloses	Lignin	Protein
Alfalfa (Leaves)	22.2	11.0	5.2	28.5
Alfalfa (Stalks)	48.5	6.5	16.6	10.5
Corn Residue (Leaves)	33.2	31.1	7.4	7.1
Corn Residue (Stalks)	43.1	10.5	9.6	3.4
Sorghum Residue (Leaves)	25.6	40.0	7.8	10.4
Sorghum Residue (Stalks)	26.1	31.1	8.0	9.3
Sudan Grass (Leaves)	35.8	29.5	10.9	6.7
Sudan Grass (Stalks)	44.1	21.3	9.1	5.1

PROTEIN RECOVERY OPTIONS IN INTEGRATED ALFALFA FERMENTATION

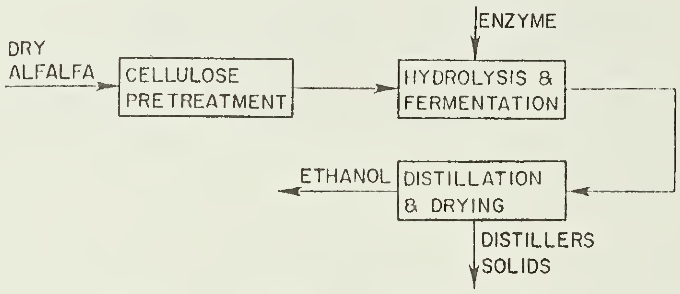
There are at least four techniques that might be used to coproduce protein with fuels and other chemicals from biomass. These include:

1. Solution extraction of proteins to produce protein concentrates.
2. Mechanical expression of protein-rich juices from leafy green plant material followed by heat coagulation to precipitate the proteins.

3. Separation of protein-rich leaves from carbohydrate-rich systems.
4. Whole plant fermentation followed by recovery of high protein distillers solids.

Due to space limitations we will only present the whole plant fermentation case here. We wish to emphasize that we are not referring to single cell protein. Well over 80% of the total protein in the fermentation residue is from the original alfalfa biomass. The remainder is from excess cell mass and adsorbed cellulase enzymes.

Figure 1 shows a block flow diagram for alfalfa conversion to protein and ethanol. The pretreatment used is the ammonia freeze-explosion process described elsewhere in this symposium. The yields of the various products are from our laboratory results. The alfalfa costs and the ethanol selling price ($2/gallon) are first quarter 1981 values.



STREAM	WT% PROTEIN DRY BASIS	STREAM WEIGHT (10^3 kg dry)	STREAM VALUE ($\$/10^3$ kg dry)	TOTAL STREAM VALUE ($)	NET STREAM VALUE ($)
ALFALFA	18	1.0	75	75	75
DISTILLERS SOLIDS	30	0.65	170	110	90
ETHANOL	—	170 liters	$0.53/liter	90	45

ESTIMATED NET REVENUES = $\$60/10^3$ kg ALFALFA

The alfalfa distillers solids (ADS) value was computer-calculated using the least-cost feed ration technique. This technique compares the nutritional content of a given feed ingredient versus the nutritional content of competing feed ingredients such as soybean meal and cottenseed meal. The price of the new feed ingredient is lowered until it achieves a significant penetration of the nutritionally balanced animal ration (> 10%). The ADS value resulting from the computer analysis was discounted by 1/3 to allow for handling and shipping costs. The operating costs for alcohol productive were taken from published estimates. The results summarized in Figure 1 indicate that protein and ethanol production from alfalfa in a commercially feasible proportion; the net revenues are about $55/U.S. ton of alfalfa processed. The driving force in the projected value of ADS. The ethanol is truly a byproduct.

About 200,000 tons of alfalfa were assumed necessary in a 25 mile radius to supply an alfalfa processing plant producing 10 million gallons of ethanol per year. Sixty three different locations in 21 states were identified which had this much alfalfa potentially available in that radius. In each case, there were 1 to 3 times as many cattle in the same area than required to consume all of the protein generated by the plant. Some representative areas and cattle data are given in Table 2. The total production potential from sites where sufficient alfalfa is available in a 25 mile radius for a 10 million gallon per year ethanol plant is over 1 billion gallons of ethanol per year.

It is worth noting that if a substantial fraction of the ADS is consumed locally, their effective value should be significantly higher than assumed in Figure 1 since a 50% charge has been assumed for handling and transportation to final users at much greater distances.

TABLE 2

SOME POTENTIAL LOCALITIES FOR
WHOLE ALFALFA PLANT FERMENTATION

State	Counties In Area	Number of 40 MM Liter Plants Possible in Area	Number of Plant Equivalents of Cattle in Area
California	Imperial	4.0	3.5
Idaho	Lincoln, Jerome, Gooding, Twin Falls	3.0	3.5
Minnesota	Stearns, Meeker, Kandiyohi	2.0	3.0
Wisconsin	Barron, Dunn, Polk St. Croix	2.8	3.5
	Total Ethanol Capacity	4.5 Billion Liters/Year	

SUMMARY

Other researchers have commented on the potential value of protein in biomass refining. While a great deal of work remains to be done in exploring the options listed here, it is nonetheless apparent that one of the most promising approaches for reducing the next cost of carbohydrates for fermentation to fuels, chemicals, and other products may lie in coproducing protein food or feed ingredients. The economic advantages of such an integrated process are obvious. Developing countries may find this approach a useful means of dealing simultaneously with two of their major problems: the need to import petroleum and the need to import food and feeds. Alfalfa seems a particularly logical and attractive choice for such an integrated process but other plants with a reasonable protein content or easily separated protein components (e.g., aspen leaves) are also viable candidates.

SWEET SORGHUM PRODUCTION, HARVESTING, AND STORAGE IN SOUTH FLORIDA

by

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ABSTRACT

Sweet sorghum was planted in February, March, and April, 1982 at Belle Glade, Florida. The sweet sorghum was planted in a pattern for harvesting using a 3-row header on a New Holland 2100[1/] forage harvester. Brix of the sweet sorghum was measured throughout the growing season using a hand refractometer. After the crop had passed maturity, it was harvested for tonnage yields. Results indicated that early planting dates for sweet sorghum are best in South Florida. Several studies on weight loss and extraction of stored billets and stalks were conducted. Storage studies using sulfur dioxide as a preservative were conducted on chopped sorghum. Storage methods using billets or stalks look promising for short term storage. Chopped sweet sorghum can be preserved using sulfur dioxide for long term storage.

Introduction

Previous plantings of sweet sorghum in April and May, 1981 in South Florida by our research unit indicated that earlier plantings of sweet sorghum are more productive. In addition, the Brix of sorghum was shown by Collier (1884) to increase as the seeds matured and then decreased. Limited storage of sweet sorghum (Eiland et al., 1982) showed that billets and stalks of sorghum seemed to retain their fermentable sugars, while chopped sorghum did not. The stalk sorghum seemed to increase in Brix with storage time which indicated stalk dehydration was occurring.

The object of this series of experiments was (a) to develop a suitable production system (b) examine Brix of the sweet sorghum across an entire production season (c) examine stalk dehydration and Brix changes during storage, and (d) find a method of storing chopped sweet sorghum over a long period at ambient temperatures.

1/ Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by USDA or an endorsement by the Department over other products not mentioned.

Materials and Methods

Sweet sorghum (Wray) was planted in 30-inch rows on February 17, 1982 with an extra 6-inch space between every third row for forage harvester wheel tracks. Planter Jr. planters were used with hole sizes of 10 to 13 used depending on seed size. Furadan was applied in a broadcast application of 2 lb/a.i. per acre to deter soil insects. On March 17, 1982, two cultivars (MN-1500 and Mer-81E) were planted in a similar fashion. On April 21, 1982, Rio was planted in a similar fashion. Preemergence herbicide, applied after planting, consisted of Ramrod at 4 lb/a.i. per acre and atrazine at 2 lb/a.i. per acre. Manganese and pesticides to control budworms were applied as needed. Stalks were sampled weekly for Brix after blooming with the first sample occurring on June 8, 1982. The stalks were sampled near the base, in the middle and about 1-foot below the seedhead. Brix was determined using a hand refractometer, and seed maturity was noted. The crop was harvested for yield data in early September for Wray, MN-1500, and Mer-81E, and they were allowed to ratoon. The ratoon crop was sampled for Brix as before and harvested for yield in January 3, 1983.

On August 24, 1982, we cut sweet sorghum by hand and with two sugarcane harvester to produce two sizes of billets (11- and 18-inch long). Three tubs (27.5 ft^3 each) of each size of the billeted sorghum. and three racks of stalk sorghum were filled. They were weighed over a 2-week period. Weight loss was determined over this storage period. On September 10, 1982, we cut sweet sorghum by hand and with two sugarcane harvesters to produce two sizes of billets. Samples were weighed and stored in a covered area. The samples were checked for weight loss over a 2-week period. Additionally, 10 pound samples were collected over a 1-month period and were milled in a fixed-clearance mill, and the percent extraction determined from the collected juice. The Brix of the juice was measured using a Brix spindle and a hand refractometer.

Additionally, a series of experiments was conducted using preservatives on chopped sweet sorghum. From the results of these experiments, sulfur dioxide seemed to offer the most promising results. Sulfur dioxide was inserted into sealed plastic buckets containing 5 pounds of chopped sweet sorghum at rates of 1000, 1500, and 2000 ppm. Brix of the sorghum was measured with storage time over a 24-day period. Chopped sorghum samples were collected and later analyzed for total sugar content.

Results

The production system utilized was reasonably successful. The Planter Jr. units contain seedplates with different hole sizes for different seeds. Occasionally a sorghum seed is too large and jams the hole. Also, soil can clog up the drop area behind the opener where the seeds fall through. A better planter or grain-drill would be preferable. No major soil insect problem was observed in the plantings. However, soil moisture was sufficient to keep lesser cornstalk borers under control. Problems with fall armyworms in the bud of the sorghum occurred and was controlled using Azodrin. Harvesting with the New Holland 2100 was satisfactory as long as the crop was reasonably erect and at our yield level. Recumbent sorghum would not be recovered satisfactorily with this unit. Yields for Wray, MN-1500, and Mer-81E were 20.4, 14.9, and 17.8 tons/acre, respectively. These yields are lower than those reported in other areas but are similar to those in South Texas (personal communication, Charlie Coble). The ratoon crop for Wray, MN-1500, and Mer-81E yielded 4.5, 4.9, and 4.7 tons/acre, respectively. Rio was not harvested for yield but was estimated at 7 tons/acre.

Brix data taken across the growing season in the plant crop showed the cultivar, Wray, maintained a 16° Brix or better for about 6 weeks beginning in early July. The cultivar, Mer-81E, maintained a 16° Brix or better for about 3 weeks beginning in mid-July. The cultivar, MN-1500, maintained a 16° Brix or better for about 3 weeks from late July to mid-August. The cultivar, Rio, maintained a 16° Brix or better for 4 weeks from late August to late September. By selecting planting dates and cultivars, it appears possible to obtain satisfactory Brix levels for a summer processing season. From our study, it appears that the Wray cultivar offers the most promise for South Florida production. The February planting appeared to grow better than the March planting. Planting earlier with Wray produced higher yields than in the previous year when it was planted on April 1 (Eiland et al., 1982)

Data in the ratoon crop showed that Brix levels peaked considerably lower than in the plant crop. However, the crop had an excellent seedhead which was not observed in the plant crop. Only Rio had one sample date where a Brix of 16° was reached. The crop did not require any input for production, but the relatively low sugar levels and yields may make it questionable for harvesting. Combining the seedheads for grain might offer a better option. Earlier harvests of the plant crop may produce better ratoon crop yields.

In the replicated test for weight loss, the chopped sorghum lost about 4 percent of the initial sorghum weight during the first 24 hours of storage. After 1 week, the weight loss was about 2 percent/day of the initial sorghum weight. After 2 weeks, 28.5 percent of the initial weight of the shorter billets (11-inch long) was lost, and 33.3 percent of the initial weight of the long billets (18-inch long) was lost. The bulk density of the long billets (9.0 lb/ft^3) was about 75 percent of that of the short billets (12.1 lb/ft^3). The lower bulk density of the longer billets probably allowed more air circulation than in the shorter billets. The stalk sorghum lost about 3 percent of its initial weight during the first 24 hours of storage. This rate of loss decreased to about 2 percent/day after 1 week of storage and to less than 1 percent/day after 2 weeks of storage. After 2 weeks, 20.6 percent of the initial weight was lost.

In the second weight loss experiment, the rate of weight loss of the billeted sorghum was similar to that observed in the first experiment. After 2 weeks, the short billets lost 25.4 percent of the initial weight and the long billets lost 33.6 percent of the initial weight. The bulk density of the short billets was 10.9 lb/ft^3 and the bulk density of the long billets was 5.3 lb/ft^3. However, the stalk sorghum lost 36.5 percent of its initial weight during 2 weeks of storage. This difference with the previous experiment probably relates to the small sample size used in this test. Brix measurements taken with the spindle method seemed to be about 1 point higher than those taken with a hand refractometer. Brix of the juice from the stalks increased from 16.4° Brix to 20.2° Brix during the 1-month storage period. Extraction of the juice averaged about 24.0 percent of the sample weight during the 1-month storage. Brix of the juice from the long billets increased from 14.4° Brix to 18.6° Brix on day 11 of the storage test and decreased to 15.5° Brix by the end of the test. Extraction of the juice averaged 16.5 percent of the sample weight during the 1-month storage. Brix of the juice from the short billets increased from 15.4° Brix to 18.4° Brix on day 6 of the storage test and decreased to 16.5° Brix by the end of the test. Extraction of the juice averaged 16.7 percent of the sample weight during the 1-month storage. The last sample date showed a significant reduction in juice extraction with 9.1 percent extraction in the short billets. This study seems to indicate that limited storage of billeted sweet sorghum would probably work if extraction can be maintained.

Trials of several preservatives to keep chopped sweet sorghum from deteriorating were conducted, and sulfur dioxide was the most promising. Levels of 500 and 1000 ppm of sulfur dioxide would maintain the juice Brix from chopped sorghum for about 2 days. Unprotected chopped sorghum lost 5.4° Brix during the same period. Levels of 2000 ppm of sulfur dioxide provided protection for several weeks with a small increase in Brix observed. Total sugar analysis confirmed Brix observations. Longer term storage will apparently require a level of sulfur dioxide of 3000 ppm.

SUMMARY

Sweet sorghum can be grown in South Florida, and a production system was devised. By choosing planting dates and cultivars, a 3-month processing season could be easily obtained. This season could be extended for up to 6 months if successful cultivars for summer planting could be found. The cultivar, Wray, seemed to be the best suited in South Florida. Weight loss of sweet sorghum during storage was monitored. Limited storage of sweet sorghum in a billeted form appears possible with longer storage of stalks possible. Sulfur dioxide appears promising as a preservative for chopped sweet sorghum.

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THE POTENTIAL LENGTH OF THE HARVEST PERIOD FOR SWEET SORGHUM

by

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ABSTRACT

Field experiments were conducted in 1981 and 1982 to evaluate the length of the yearly harvest period of sweet sorghum grown as a feedstock for fuel alcohol at Tifton, Georgia. Allowing the sorghum to mature in a single crop resulted in higher yields than attempting to ratoon (regrow without replanting.) By use of cultivars, with a range of maturities, by planting from mid April to early July and by harvesting from mid August to late December 5.7 t ha^{-1} of sugars were obtained under temperature conditions which were close to means from long-term weather records.

Introduction

The investment for construction and maintenance of processing facilities for producing fuel alcohol from fermentable sugars will be difficult to justify if they are only usable for a few weeks each year. The specific growing season for sweet sorghum [Sorghum bicolor (L.) Moench] at a location may dictate the length of time that high yields of sugars and alcohol can be obtained. Some progress with lengthening the season may come by careful selection of cultivars, by ratooning, and by selection of optimum planting and harvest dates. The objective of this study was to examine these possibilities at Tifton, Georgia.

Materials and Methods

Unirrigated field experiments were conducted on Tifton loamy sand (fine, loamy, siliceous, Plinthic Paleudult) in 1981 and 1982. The effects of maturity at harvest, the potential of ratooning (producing a second crop without replanting) and of planting date were investigated in 1981. The experimental design was a randomized complete block with five replications. Plot size was 4 rows (3.65 m) by 6.1 m. Wray seed was planted at 125 thousand seed ha^{-1}. The treatment variables are given in Table 1. Harvests were made by hand cutting $4x10^{-4}$ ha at ground level, removing the top and leaves, weighing the fresh stalks, and randomly selecting 20 stalks for chopping and fermentable sugar analysis. Factorial treatments for planting dates, harvest stage and cultivar in 1982 are noted in Table 2. The three cultivars: Wray, M81E and MN1500 were chosen from our earlier studies. The plot size, population, other practices, harvest, and analyses were as in 1981. The total harvest period extended from 18 Aug. to 21 Dec.

Results and Discussion

Sweet sorghum planted on 7 April and harvested on 5 August in 1981 had a lower concentration of sugar than when allowed a longer season, regardless of the planting date (Table 1). However, no differences were found for tonnages of stalks or sugars due to the treatments. Likewise, no differences were found between planting dates when the sweet sorghum was allowed to go to the same maturity. Planting early and harvesting early to the point of nearly scarifying yield still did not result in a ratoon crop at Tifton with Wray. It is not likely that two acceptable crops of sweet sorghum can be produced in south Georgia as has been done in warmer locations.

In 1982, stalk population and yields per ha were higher for the April and May plantings than for the June and July plantings (Table 2). The sugar concentrations were lower for the first two plantings than for the later planting. As often occurs with sugar crops, high vegetative tonnage is often antagonistic to high sugar concentration. Harvesting when the seed first reaches the soft dough stage resulted in the highest sugar yields when all planting dates and cultivars were considered (Table 2). Delaying harvest by 3 and 6 weeks resulted in 7 and 15% reductions in sugar yield. Analysis of variance indicated an interaction between planting date and harvest stage. For the first planting sugar concentration and yields were lowest for the first harvest stage; thereafter both were high for the first harvest stage (Table 3).

Wray had the highest sugar concentration in the stalks except for May planting date, but the lowest stalk and sugar yields when all harvest stages and planting dates are considered (Table 2). Its total sugar yield was 82 and 89% of those of M81E and MN1500, respectively. A significant interaction was found between planting date and cultivars (Table 4). For the April and May plantings M81E resulted in the highest sugar yields while MN1500 produced the highest yields for the June and July planting. In spite of the relatively low sugar yields for Wray, it still may be the best single choice as a cultivar for fuel ethanol production due to its resistance to lodging (which was a serious problem in the other cultivars and would make harvest mechanization very difficult) and to its high concentrations of sugars. However, highest sugar production would be obtained by using more than one cultivar. Calculations from second-order regression equations indicate that 95% of maximum sugar yields were obtained by planting from 19 April to 2 May, 19 April to 22 May and 19 April to 4 June for Wray, M81E, and MN1500, respectively. The first harvest of Wray on 18 August and the last harvest of M81E on 21 December yielded 43 and 64% of the mean experimental yield of 5.7 t ha^{-1}, respectively. These studies were conducted in temperature conditions which were (with the exception of an unusually warm December) very close to 40 year means. Therefore, the results obtained should relate well to most years in the lower Coastal Plain.

SUMMARY

Ratooning sweet sorghum in Tifton, Georgia was not successful in comparison to allowing a single crop to fully mature. Planting early-, medium-, and late-maturing cultivars from mid April to early July and harvesting over a 4-month period from 18 August to 21 December, in a year with fairly normal temperature conditions for south Georgia resulted in a mean gross sugar yield of 5.7 t ha^{-1}. Individual harvests at the very beginning and end of the period were reduced to 43 and 64% of the mean yield, respectively.

Table 1. Effect of maturity at harvest on fermentable sugar concentration in stalks and on stalk and sugar yields. Wray at Gibbs Farm, 1981

Planting date	Harvest date	Maturity at harvest	Sugar† conc.	Yields Stalks	Yields Sugar
		(days)	(%)	------t ha^{-1}	------
7 Apr.	5 Aug.	118	11.6b‡	41a	4.8a
21 Apr.	2 Sept.	131	14.2a	37a	5.3a
7 Apr.	25 Aug.	138	14.8a	36a	5.4a

† Sugar in fresh stalks.

‡ Values within a column not followed by a common letter are significantly different at p = 0.05 by Duncan's Multiple Range Test.

Table 2. Effect of the main effects of planting date, harvest date and cultivar on the stalk counts and yields at the Gibbs Farm in 1982.

Planting date	Harvest† stage	Cultivar	Stalks	Sugar conc.	Yields Stalks	Yields Sugar
			(stalk/haX10^{-3})	(%)	-----t ha^{-1}	-----
19 Apr.	all	all	93b‡	12.2c	52a	6.2a
6 May	all	all	97a	12.1c	52a	6.4a
7 June	all	all	87c	13.4a	41b	5.3b
6 July	all	all	85c	12.9b	36c	4.6c
all	1	all	92a	12.8a	48a	6.1a
all	2	all	91ab	12.8a	45b	5.7b
all	3	all	89b	12.3b	43c	5.2c
all	all	Wray	89b	13.7a	37c	5.0b
all	all	M81E	99a	12.1b	51a	6.1a
all	all	MN1500	84c	12.2b	48b	5.9a

† Harvest stage = 1 was when seed was in soft dough stage. Harvest stages 2 and 3 were approximately 3 and 6 weeks after harvest 1, respectively.

‡ Values within a column and group of three not followed by a common letter are significantly different by Duncan's Multiple Range Test, p = 0.05.

Table 3. Effect of the interaction between planting date and harvest dates on the stalk population and yields of three sweet sorghum cultivars at Gibbs Farm in 1982.

Planting date	Harvest stages[†]	Stalks	Sugar conc.	Yields Stalks	Yields Sugar
		(No/haX10^{-3})	(%)	------t ha^{-1}-----	
19 Apr.	1	92	11.6	52	6.0
	2	93	12.7	53	6.7
	3	91	12.1	50	6.0
6 May	1	97	13.0	57	7.3
	2	101	12.2	54	6.6
	3	93	11.1	46	5.2
7 June	1	87	13.5	43	5.7
	2	85	13.6	39	5.3
	3	90	13.1	40	5.2
6 July	1	92	13.2	41	5.3
	2	82	12.8	32	4.2
	3	80	12.9	34	4.4
Sign.		**	**	**	**

† Harvest stage = 1 was when seed was in soft dough stage. Harvest stages 2 and 3 were approximately 3 and 6 weeks after harvest 1, respectively.

** Interaction is significant at p = 0.01 by analysis of variance.

Table 4. Effect of the interaction of planting date and cultivar on stalk populations and yields of sweet sorghum harvested at three harvest stages at the Gibbs Farm in 1982.

Planting date	Cultivar	Stalks	Sugar conc.	Yields Stalks	Yields Sugar
		(No/haX10^{-3})	(%)	------t ha^{-1}-----	
19 April	Wray	95	13.2	45	6.0
	M81E	101	11.6	57	6.6
	MN1500	82	11.7	52	6.1
6 May	Wray	95	11.9	43	5.1
	M81E	107	12.2	61	7.4
	MN1500	91	12.2	53	6.6
7 June	Wray	81	15.0	30	4.6
	M81E	95	12.5	46	5.7
	MN1500	85	12.8	46	5.9
6 July	Wray	84	14.8	28	4.2
	M81E	93	12.0	40	4.7
	MN1500	78	12.2	40	4.9
Sign.		N.S.	**	*	**

*, **, N.S. - Interaction significant at p = 0.05, p = 0.01, and not significant at p = 0.05, respectively, by analysis of variance.

HARVESTING AND STORAGE OF SWEET SORGHUM BIOMASS

by

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ABSTRACT

A primary constraint to the use of sweet sorghum as an alcohol feedstock is the lack of suitable harvesting and storage techniques. Processing plants would need to be operated as long as possible throughout the year, requiring a lengthened harvesting season and/or storage of stalks for an extended time before processing.

Studies were initiated at Kansas State University (1) to determine sugar contents of sweet sorghum cultivars following selected harvest procedures and (2) to evaluate the potential of organic acids to enhance sugar retention of biomass during the ensiling process.

Silages made from Rio and Dale sweet sorghums in October 1981 were treated with acrylic or caproic acid (0.0 to 0.5% of fresh weight). Mean sugar recovery was increased from 26.5 to 92.5% (Rio) and from 8.0 to 50.7% (Dale) by organic acid treatment (0.5% rate).

Field study 1 compared sugar contents in plants left standing in the field beyond optimum harvest date versus that in stalks cut and stacked at that time. Depending on the cultivar, dry matter yields were reduced 15-45% and sugar yields were reduced 37-74% at the last harvest (mid December).

Field study 2 compared sugar contents of topped versus intact plants at and beyond maturity. Topped plants had slightly higher sugar contents and yielded more total sugar than did intact plants.

Silages were similarly made and treated with organic acids in November 1982 and field studies will be repeated in 1983.

Effects of Harvest Procedures on Sugar Content

For sweet sorghum to be widely utilized as an alcohol feedstock, optimum harvesting and storage techniques must be determined. High energy sorghums can likely be developed by plant breeders that have high grain yield, high stalk sugar content, and with plant height suitable to combine harvesting. Producers might first harvest the grain and later harvest the stalks with both grain (starch) and stalk sugar used as feedstocks for alcohol production. Alternatively, if sugar content could be maintained during ensiling, the biomass could be easily harvested and stored with present technology.

Two field studies were initiated in May 1982 at the Agronomy Research Center, Manhattan, KS to evaluate sugar contents following selected harvest procedures. Study 1 included the varieties Wray, Brandes, Rio, and TX623 x Rio hybrid, while study 2 contained Wray, Rio, Dale, and TX623 x Rio hybrid. Seed of all varieties was provided by Dempsey Broadhead, U.S. Sugar Crops Field Station, Meridian, MS, and the TX623 x Rio hybrid was obtained from Dr. Fred Miller, Texas A and M University, College Station, TX.

Plots contained 24 (study 1) or 16 (study 2) rows each, 76 cm apart and 6 m long. A split-plot design was used with cultivars as whole plots and harvest procedures and dates as sub-plots. Variables measured included total biomass and grain yields, % leaf, stalk, and top (study 1) or % stalk (study 2), and sugar content and yield.

Beginning with the earliest maturing cultivar, TX623 x Rio hybrid and followed by Wray, Dale, and Rio, plots were harvested beginning October 5, and at intervals through December 15, 1983. Killing frost occurred on October 22, with Brandes not yet mature at that date. In study 1, a subplot was cut and stacked at the initial harvest date, and subsequent harvests were made biweekly by sampling plants from the standing plots and from the cut and stacked material. In study 2, half of each plot was topped (heads removed to simulate grain harvest) at the first harvest date and intact and topped plants were sampled weekly for 3 weeks, then biweekly until mid-December.

In study 1, dry biomass yields were greatest near mid-October, and declined steadily to December. Harvest was possible for cut and stacked plants only at mid-December because all plants were flat on the ground at this date. Yield declines were much greater for Rio and Rio hybrid than for Wray or Brandes. Sugar contents declined markedly between early and mid-November for all cultivars, except Brandes which remained fairly constant throughout the study. Sugar yields followed the same trend as for biomass, with the Rio hybrid showing the greatest decline by mid-December (74%) and Brandes, the least (37%). Percent glucose and % fructose increased slightly with delayed harvest, but % sucrose decreased drastically, resulting in lower total sugar contents and sugar yields. With delayed harvest, the proportion of leaf and top declined (15-17%) while the % stalk increased (12%). Percent sugar was slightly greater for stacked than for standing plants for all cultivars except the Rio hybrid.

In study 2, total sugar contents and total sugar yields were slightly greater for topped than for intact plants. Wray and Dale cultivars had much greater sugar contents (32-34%) and sugar yields (4.7-5.4 Mt/ha) than did Rio or the Rio hybrid (23-18% and 3.5-2.2 Mt/ha). Although cultivars differed in their declines in sugar content and total sugar yields, the greatest declines regularly occurred between late October and mid-November. As in study 1, glucose and fructose percentages increased slightly or were unchanged with delayed harvest, but sucrose decreased markedly.

Over all dates and treatments, total sugar yields (Mt/ha) were 5.2, 4.3, 3.2, and 2.0 for Dale, Wray, Rio, and TX623 x Rio, respectively.

Effect of Organic Acids on Sugar Content During Ensiling

During October 1981, forage from Dale (monosaccharide) and Rio (disaccharide) sweet sorghum varieties was chopped with a field plot forage harvester and treated with 0.0, 0.05, 0.10, 0.15, 0.20, 0.25, or 0.50% acrylic or caproic acid (fresh weight basis). Thirteen kg of forage was treated and samples of fresh forages were frozen for sugar analyses. Treated forages were compressed in 19 liter plastic silos at 750 psi, sealed, and placed into a controlled temperature room at 18 C. Following 130 day fermentation, silos were opened and per cent dry matter and sugar recoveries were determined.

Sugar recovery was greater with higher acid application rates for both Dale and Rio sweet sorghums. Recovery was greater for Rio than for Dale at all acid application rates, with a much greater advantage at the 0.5% rate. The greatest % sugar recovery was 92% for Rio when treated with 0.5% organic acid. Dry matter recovery was greater for Rio (90-100%) than for Dale (81-92%) at all acid application rates and for the control.

SUMMARY

Field studies were conducted during 1982 at Manhattan, KS to evaluate sugar contents of sweet sorghum following selected harvesting procedures. Cultivars left standing in the field beyond optimum harvest maturity declined steadily in sugar content and total biomass yield. Percent leaf and top declined and percent stalk increased with delayed harvest. Severe lodging would have prevented any mechanical harvest after early December. Sugar content declined markedly between late October and mid-November. Percent glucose and fructose generally increased slightly with delayed harvest, but percent sucrose declined drastically. Sugar content was slightly greater for stacked plants than for standing plants. Total sugar contents and total sugar yields were slightly greater for topped than for intact plants. Total sugar yields ranged from 2.0 to 5.2 Mt/ha.

Silages were made in 1981 from Rio and Dale sweet sorghum treated with organic acids. Percent sugar recovery was greater as the amount of acid application was increased from 0.0 to 0.5% (fresh weight basis). Maximum sugar recovery achieved in this study was 92% for Rio when treated with 0.5% organic acid.

ELEMENTS FOR HARVESTING AND PROCESSING SWEET SORGHUM

BY

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ABSTRACT

The three primary elements of a system to harvest and process sweet sorghum for ethanol were defined: 1) to strip leaves from the stalks, 2) to cut the stalks into billets for improved handling, and 3) to mill the stalks efficiently with a 3-roll mill. In testing a principle for stripping leaves from sweet sorghum, a component with moving rubber fingers removed 89 percent of the leaves with a stalk loss of 1.7 percent. The component moved 5.9 km/h along a row of Wray variety sweet sorghum and used 2.2 kW·h per t of leaves removed. Results from preliminary tests of a principle using counterrotating disc-knives to cut sweet sorghum stalks into billets about 0.3 m long were successful. In milling studies with whole stalks of Wray variety sweet sorghum, juice and sugar recovery were highest from stalks with a diameter of about 20 mm. In milling studies with shredded billets, the percentage of the stalk mass removed as juice increased with feed rate and reached a maximum of about 40 percent. Throughput was doubled when shredded billets were milled, compared to the rated whole-stalk mill capacity.

INTRODUCTION

Ethanol is being produced profitably from commercial ethanol plants using corn as a feedstock. Sweet sorghum may be practical as an alternative feedstock if produced near smaller plants to reduce the need for long storage life. Managers of these alcohol plants and growers need information in order to determine the economic feasibility of using alternative feedstocks.

Information is incomplete on how leaves of sweet sorghum influence crop milling and sugar recovery. It may depend in part on the form of the crop entering the mill (such as whole or pre-processed stalks), and on the feed rate into the mill. However, there is no real evidence that leaves effect sugar recovery from milling. The sugarcane industry removes all the trash (leaves and tops) economically possible. Leaf removal increases bulk density of the harvested crop and the throughput of milling equipment by about the same amount as the leaves removed.

A study in Florida (Eiland et al., 1983) showed that losses of fermentable sugars from sweet sorghum that was harvested and then stored for one week, were 49 percent for chopped stalks and were not significant for either whole stalks or stalks cut into 0.6-m billets. The billet form of sweet sorghum is the best compromise between the whole and chopped forms for good storage life, for high bulk density, and for automated mechanical transporting and handling.

Methods and procedures are well established for milling on a large scale in the sugarcane industry and on a small scale for the sorghum syrup industry. But there is little information available for evaluating a medium sized milling operation on sweet sorghum to obtain fermentable juice for production of fuel ethanol.

Our overall objective is to provide research information useful for developing a system to harvest, handle and process sweet sorghum for an ethanol feedstock. While there are several approaches to such a system, we have chosen one containing three primary elements (Monroe, 1982). They will provide the means to:

1) Remove the leaves from the stalks for efficient handling and milling of the crop.

2) Cut the stalks into billets for efficient handling with accept able short-term storage.

3) Mill juice from the billets, either on the farm or at an ethanol plant, using a method that can be automated.

ELEMENTS

Leaf Removal

The principle we conceived and evaluated for removing leaves from sweet sorghum used rubber fingers developed for the poultry industry (Monroe et al., 1983). The fingers radiated from wheels that rotated on either side of the crop row, with the wheel axes parallel to the row. Satisfactory results could be obtained only with the wheels rotating in the direction to move the fingers up as they made contact with the crop row, because their downward movement broke many stalks and caused excessive losses. The two practical finger arrangements evaluated were with the fingers radiating in two planes on each wheel, and using either three or five fingers per plane (6 or 10 per wheel).

The percentage of leaves removed and of stalk loss for the various treatments on Wray variety sweet sorghum are shown in Table 1. Eighty-nine percent of the leaves were removed with a stalk loss of 1.7 percent in one of the better treatments with the stripper component moving 5.9 km/h along a row. Energy requirement under those operating conditions was about 2.2 kW·h per t of leaves removed, which compared favorably with published results from other research.

Cutting Stalks Into Billets

Some commercial sugarcane harvesters have counterrotating drum-type cutters that can be used to make sweet sorghum billets. A principle using pairs of counterrotating forage harvester disc knives to cut sweet sorghum into billets has potential for design simplicity, construction economy, and low operating energy requirements compared to others. A machine component to test this principle was constructed and mounted behind the leaf-removal component on the same vehicle. Preliminary results in 1982 with the disc-knife method for cutting stalks into 0.3-m billets were very promising. A minor problem in guiding all stalks properly into the knives remains to be solved. The component will be modified for further testing in 1983.

Milling

In initial milling studies, whole sweet sorghum stalks were hand fed into a farm-scale vertical 3-roll mill at the highest practical rate (Monroe et al., 1981). Juice extraction, sugar recovery, and energy efficiency were highest when using the narrowest discharge-rolls gap possible without plugging the mill. Juice extraction and sugar recovery from Wray variety were higher for stalks with a mean diameter of about 20 mm than from smaller or larger-sized stalks. This information will be important in selecting a row spacing and planting density to produce stalk sizes for maximum recovery of fermentable sugar.

Recent milling research will provide information useful for automating the feeding of billets to a mill and for mill operation to maximize rates of throughput and percent juice removal. We developed a component to shred billets to a size and form that will feed into a 3-roll mill by gravity. A small horizontal 3-roll mill was modified by spring loading the rolls to accomodate small variations in feed rate. An elevator was used to meter billets into the shredder, and the shredder discharged directly into the modified mill.

In operating the elevator, shredder and mill system, juice removal increased with increasing feed rate, until the mill plugged at high rates. The graph of juice removal versus feed rate formed a sigmoid curve. Use of the shredder ahead of the mill permitted successful mill operation at twice the rate recommended by the manufacturer, but feed rate had to be accurately controlled to avoid plugging.

Maximum juice recovery in one pass through the mill was about 40 percent of the mass of crop milled. Preliminary analyses of crop and juice indicate that maximum sugar recovery will be about 50 percent in one pass.

Sugar recovered in milling sweet sorghum can be increased by using tandem mills and other techniques developed for milling sugarcane. The added capital investment and complexity will probably be impractical on the farm. Optimum utilization of bagasse will be required for best economic production of ethanol either on or off the farm. New developments in solid phase fermentation (Bryan and Parrish, 1982) may lead to an alternative system for converting fermentable sugars from sweet sorghum into fuel ethanol.

TABLE 1. LEAF REMOVAL AND STALK LOSS IN THE STRIPPER TESTS

Treat-ment number	Fingers per wheel plane No.	Finger-wheel frequency r/min	Carrier velocity km/h	Leaves removed Percent[1/]	Stalk loss Percent[1/]
1	5	700	2.8	93.6 a	4.0 ab
2	3	700	2.8	92.6 a	6.2 a
3	5	550	2.8	89.4 ab	4.8 a
4	5	700	5.9	89.2 ab	1.7 bc
5	5	550	5.9	87.0 ab	1.7 bc
6	3	700	5.9	84.2 bc	0.9 c
7	3	550	2.8	83.3 bc	1.6 bc
8	5	400	2.8	78.4 cd	0.7 c
9	5	400	5.9	74.8 d	0 c
10	3	400	2.8	73.5 de	0.6 c
11	3	550	5.9	67.2 e	0 c
12	3	400	5.9	58.0 f	0.3 c

[1/]Means with the same letter are not significantly different at the 90 percent level of confidence.

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STORAGE AND PREPROCESSING OF SWEET SORGHUM FOR FERMENTATION

by

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ABSTRACT

The research effort is an investigation of storage and preprocessing systems for utilization of sweet stalk forage sorghum. The process involves initial grinding and ensiling of the raw material to extend the storage life and to increase the reactivity of the lignocellulosic fraction. Following ensiling, the lignocellulosic fraction is hydrolyzed with cellulolytic enzymes, and the resulting fermentable substrate is extracted and fermented to fuels and chemicals. Particular attention is given to changes of all carbohydrate and organic acid fractions during the course of the ensiling and the subsequent anaerobic fermentations.

Introduction

With increasing costs of petroleum, biomass has been investigated as a potential source of energy, chemical feedstocks and/or liquid fuels. When alternative biomass feedstocks are considered, their seasonal availability and storability create several problems for the operator of a fermentation process. Rapid deterioration of seasonal biomass allows their use for only a short portion of the year. Therefore, storage techniques for biomass must be devised and the processing plant must be able to handle and utilize stored materials so that continuous use of the invested capital in the plant can be made.

Sweet stalk forage sorghum has been selected as a model material for the proposed research. It contains substantial quantities of sugars which can be fermented directly after extraction from the raw plant material. Sorghum has limited storage stability in the raw state. Thus, if it is to be a year-round biomass feedstock, low cost and effective procedures such as ensiling need to be evaluated as a method to store the sorghum for year-round use.

Further, studies of the long-term economic viability of alcohol fuels indicate the efficient use of non-food forms of biomass may be an important consideration. This includes the cellulosic portions of the plant along with the currently used starchy and sugar parts. Varieties of sorghum look potentially attractive because of their ability to produce large quantities of biomass efficiently. The raising and harvesting of these varieties has been or is under study, but the practical procedures and processes necessary to incorporate them into fermentation processes is yet to be done.

In parallel, a substantial effort has focused on the hydrolysis of cellulosic materials into fermentable sugars. The focus of this research has not extensively considered the residual cellulosic by-products from conventional fermentation processes, but has concentrated on raw materials high in cellulose. Potentially, coupling the normal fermentation process with the new hydrolytic processes for cellulose could improve product yield for any feedstock and the economics of alcohol production.

Hydrolysis of cellulosic substances with acid or enzymes has been investigated. Enzymatic hydrolysis along with a simple fermentation process would potentially improve production yields from the biomass material. Linden et al. examined hydrolysis for forage sorghums. Results from their investigation indicated that when fresh sorghum is ensiled, the resulting disruption of the cellulosic fractions allowed 70% hydrolysis to fermentable sugars. This was contrasted to the low conversion of the cellulose when enzymatic or acid hydrolysis was attempted on the raw materials. Thus, ensiling permits a more complete hydrolysis and at a considerable savings of energy over more commonly used systems which require extensive heating before and during hydrolysis. More importantly, ensiling will increase the availability of the sorghum over a long time period increasing its utility to the fermentation process.

Materials and Methods

Sweet sorghum (Sorghum bicolor (L.) Moench var. Rio) which had been grown during the summer months at the Colorado State University Agronomy Research Center was harvested on September 30, 1982, and subjected to two different preprocessing procedures prior to size reduction in a Fitz hammer mill: (1) wilted to suitable moisture content and (2) pressed in a roll apparatus to extract cell sap. The samples were each inoculated with Lactobacillus ensilage inoculum (Silabac 1177, Lot X 2401, Pioneer Seed Company) and ensiled in plastic bottles using anaerobic procedures. The bottles were kept at 36°C in an anaerobic chamber until one of each, wilted and pressed, were removed after 4, 8, 15, 32, 65, and 155 days. The samples were subjected to multiple extractions with hot water under refluxing in order to analyze for sugars, volatile acids and ethanol by high performance liquid chromatography using a Biorad HPX-87H column.

Enzymatic conversion of structural polysaccharides in the extracted ensilage residues from the kinetic study described above was investigated using commercial cellulase enzymes. Enzymes from the Novo Corporation (Wilton CN) (2 parts Celluclast 200 L for each part Cellobiase 250 L by weight) were assayed by standard filter paper methods.

Enzyme concentration of approximately 4 IU per gram of dry substance was used in a liquid to solid suspension of 20:1. The residues were frozen, not dried, between extraction and conversion studies. Hydrolysis was allowed to proceed for 24 hours at 50°C with 150 rpm rotary shaking. Yield was calculated following analysis of centrifuged hydrolysate supernatants for reducing sugars with dinitrosalicylic acid reagent.

Pasteurization of ensiled biomass in water in a 3:1 liquid to solids ratio has been conducted at 60°C. Survival of *Lactobacillus* organisms has been monitored by dilution and plating techniques in LSB (Lactobacillus Selective Broth) medium (BBL, Baltimore, MD) following anaerobic incubation at 37°C.

Fermentations of the press juice from the sweet stalk sorghum and of extracts of the ensiled biomass have been conducted with yeast, *Saccharomyces carlsbergensis* (NRRL 41347) and the bacterium, *Clostridium acetobutylicum* (ATCC 824). Estimation of alcohol yields and substrate utilization have been based on HPLC analysis as described above.

Results

Ensiling served as a means of storing the fermentable sugars from sweet sorghum. Analysis by HPLC of the ensilage extracts from the kinetic study has shown that within the first four days following inoculation, sucrose was converted quantitatively to invert sugars (fructose plus glucose) and lactic acid. In the case of the pressed sorghum ensilage, the levels of the metabolites remained constant at approximately 100 g invert sugars, 20 g lactic acid, 2 g acetic acid, and 2.5 g ethanol per kg dry matter throughout the remaining 151 days of the kinetic study. Invert sugar levels in the wilted sorghum ensilage, which contained considerably more sugar than the pressed material, dropped from approximately 200 g/kg dry matter to 120 g/kg d.m. between 12 and 32 days of storage. Lactic acid content reached levels of approximately 30 g/kg d.m. in the wilted material four days following ensiling, but also declined to the same level maintained in the pressed sorghum ensilage throughout the study (20 g/kg d.m.); acetic acid and ethanol concentrations remained at 2 g/kg d.m. and 0.5 g/kg d.m., respectively.

Ensiling was also shown to serve as a pretreatment for cellulose conversion. The change in capability to hydrolyze the structural carbohydrate fraction with cellulolytic enzymes exhibited slower kinetics than did changes in metabolite levels described above. Using a very minimal enzyme loading of 4 international cellulase activity units (IU) per gm of dry substrate, a linear increase in the convertability of the extracted pressed sorghum ensilage samples was found to occur between 0 and 15 days. The 15, 32, 65 and 155 day samples each exhibited conversion of the ensilage which was 44% greater than that of the non-ensiled pressed sorghum sample. The pretreatment by ensiling made available under these hydrolysis conditions about 40 g of fermentable sugars per kg of original dry matter more than would have been obtained by cellulolytic hydrolysis of the fresh extracted sweet sorghum.

The microbiology of the ensiling storage and pretreatment system would appear from preliminary data to be manageable for the sweet sorghum case. Heating of a 3:1 water:ensilage (70% moisture) mixture at 60°C for a period of 15 minutes was shown to inactivate 99.9% of the *Lactobacillus* present. Hence, such a heating step prior to enzymatic hydrolysis may be sufficient to guard against infection during a 24 hour hydrolysis period at 50°C and subsequent 48 hour anaerobic fermentations at 30°C or 37°C. The respective yeast (*S. carlsbergensis*) and bacterial (*C. acetobutylicum*) fermentations have been shown to be uninhibited by any constituent of either sorghum press juice or sorghum ensilage extract and have quantitatively converted sugars from these sources to alcohol and acid products.

Summary

The concept of natural ensiling of sweet sorghum for storage of fermentable sugars and for pretreatment of lignocellulosics for enzymatic hydrolysis would appear viable. When sweet sorghum is ensiled, either with or without prior pressing, the sucrose is rapidly converted to invert sugars and lactic acid, approximately 65% of which are conserved indefinitely. This low-technology means of fermentable sugar storage would make feedstock for a fermentation facility available on a continuous basis. In addition, the acidic environment produced by the ensiling serves as a pretreatment for cellulose conversion. Compared to non-ensiled material, a 44% increased in the reducing sugar yield from enzymatic hydrolysis of constituent cellulose was observed in samples of pressed sorghum which had been ensiled for at least 15 days. In this way, enzymatic hydrolysis more than compensates the system for carbohydrate lost in the *Lactobacillus* ensiling fermentation. Preliminary results indicate that subsequent pasteurization of ensilage would render extracts thereof suitable for yeast or bacterial alcohol fermentations.

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PRESERVATION OF FERMENTABLES DURING LONG-TERM STORAGE OF SWEET SORGHUM STEMS

by

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ABSTRACT

Sweet sorghum will be a more viable fuelcrop if its stems' fermentables can be preserved simply for eventual processing. We have begun to investigate over-winter storage of whole sweet sorghum stems at ambient temperatures. 'Dale' sweet sorghum was stripped, cut, and bound into shocks of 0.5 or 1 m diameter. Bundles of each size were stored in an open shed or fully exposed to the elements. Monthly samples pulled from the bales have been analyzed for moisture and fermentables. In addition, we have monitored the temperatures within the bundles. The results obtained after three months storage show no significant decline in moisture content of the stems inside the bundles (about 73%). Fermentables have declined significantly, but essentially three-quarters of them remained in the stems three months after harvest (48% versus 35% of the dry matter). Location of bundles (inside an open shed or fully exposed) has had no effect on preservation of fermentables. Stems in the larger bundles have retained significantly more of their fermentables than stems from the smaller bundles (38% versus 33% after three months). The temperatures within the bundles tended to stay at or slightly above the daily maximum. No tendency to accumulate excessive heat was noted.

Introduction

Sweet sorghum (*Sorghum bicolor* (L.) Moench) has been bred for an ability to accumulate soluble sugars in its stems; in some cultivars, the sugar concentrations approach 50% of the stem dry matter. This high sugar content combined with the high tonnages normally produced, represent large amounts of readily-fermented ethanol feedstocks.

Sweet sorghum has a very serious limitation as a fuelcrop: the period of availability of the fresh, sugar-rich stalks is no more than two or three months per year. But the economics of small or large-scale alcohol production are such that the distillery must be used year-round. Likewise, a still that can accomodate a temporary glut of alcohol during sweet sorghum harvest could not be operated efficiently (cost-wise or energetically) at lower output levels for the rest of the year.

The possibility exists, however, for harvesting sweet sorghum stems at maturity and storing them for eventual use. In such a system, the stems themselves would act as a storage container for the fermentables. There is merit in storing sweet sorghum stems only if their fermentables do not deteriorate too rapidly. Common practice usage of sweet sorghum suggests that sugar losses by respiration and microbial action might be severe; but data to support this notion are notably lacking for most cultivars and especially for cooler climates. All published studies of whole sorghum stalk storage have investigated the effects of short-term delays in processing on sirup quality. Related studies on sugarcane have been designed to measure the losses of refining quality and sugar content but only under tropical conditions. We have begun to investigate the feasibility of storing whole sweet sorghum under ambient conditions in an area of moderately cool falls and winters. If the stems' fermentables do not decline too rapidly, sweet sorghum could become a much more attractive fuelcrop.

Materials and Methods

Fresh, mature 'Dale' sweet sorghum was stripped of its leaves, cut off at ground level, and the aligned stems were bound into shocks. Shocks, which were either 1 m or 0.5 m in diameter at the butt end, were topped to a uniform 2 m. The packing density of both sizes of the bundles was 400 kg/m^3. The bound stems were stored horizontally in an open shed or left fully exposed to the elements. Three bundles of each size (0.5 or 1 m) were placed in each storage environment.

Temperatures within each size bundle stored in each environment were continuously monitored with thermocouples. Beginning at harvest (6 Oct 82) and at monthly intervals thereafter, 5-stem samples were pulled from a radial transect of each shock. Billets were cut from these stems for determination of moisture content and fermentables. Moisture levels were determined gravimetrically following drying at 70°C. "Fermentables" were equated with the amount of total nonstructural carbohydrates detected in a colorimetric assay of the dried, ground stem tissue. Total nonstructural carbohydrates were determined following dilute acid (0.01 N H_2SO_4) hydrolysis (100°C) and digestion by a commercial mixture of enzymes ("Clarase", Miles Labs).

Results and Discussion

We now have results from the first three months of storage (October to January). The moisture and fermentables data have been analyzed statistically, and some responses are already apparent. Surprisingly, the moisture in stems within the bundles did not decline during storage regardless of bundle size or storage location. In fact, there was a slight but significant increase in moisture between October (73.0%) and December (74.7%). This was apparently due to absorption of rainwater by stems in the fully exposed bundles.

Fermentables did decline significantly during the first three months of storage (Fig. 1). At harvest, about 48% of the dry matter in the stems was simple sugars or readily hydrolyzed to monosaccharides. The mean value of fermentables for all treatments (bundle sizes and locations) was 41% after two months storage, a statistically significant drop. By January, the fermentables were about 5 percentage points lower, another statistically significant decline. Also evident in January was a difference between the two different bundle sizes. The smaller bundles were about 4 percentage points lower in presumably fermentable materials. There were no differences in fermentables associated with storage inside versus outside.

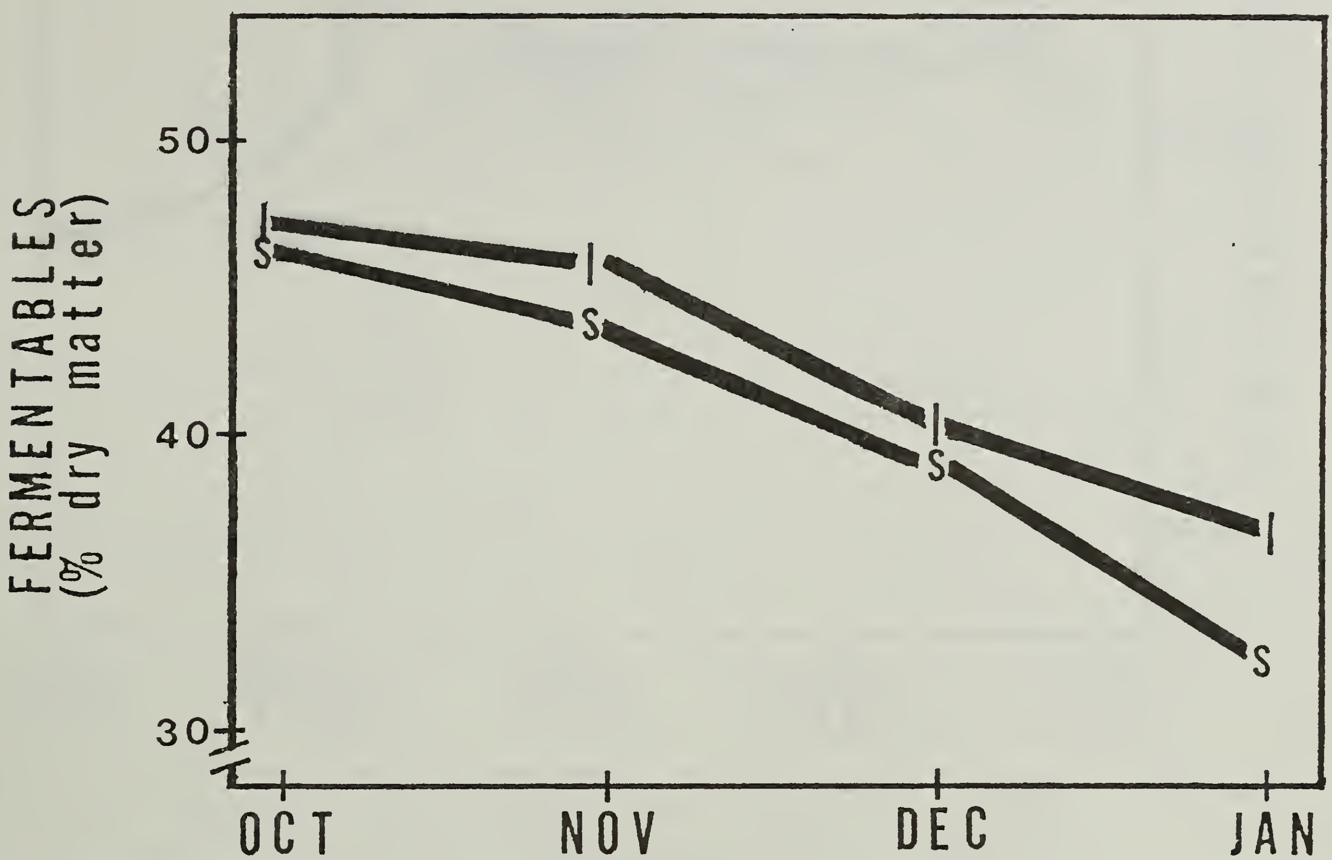

Figure 1. Decline in fermentables of sweet sorghum stems stored at ambient temperatures in Blacksburg, VA between 6 Oct 82 and 4 Jan 83. The stems were in bundles of either 1 m (l) or 0.5 m (s) diameter.

We had some concern initially that heat might accumulate in bundles of such wet tissue. Both respiration by the stems themselves and microbial activity might be expected to cause heating (and an acceleration of sugar losses). We found no evidence for such. In over 1400 hours of monitoring, the temperatures in the center of the bundles seldom exceeded the daily maximum by >3°C. The bundle temperatures tended to remain fairly stable diurnally (Fig. 2). When changes in weather patterns occurred (cold or warm fronts), temperatures within the bundles responded after a brief lag. The large bundles naturally showed this temperature buffering effect more strongly.

The results obtained thus far suggests that storage of harvested whole sweet sorghum stems for subsequent extraction of fermentables may be viable in cooler areas. The fall and winter of 1982-83 have been warmer than usual in the eastern U.S. In spite of the presumably less favorable temperatures, the measured levels of fermentables in the stored stems has declined by less than one-quarter in the large bales. This ability to hold sweet sorghum stems for extended periods poses a great potential advantage in its production as a fuelcrop in certain climatic regions.

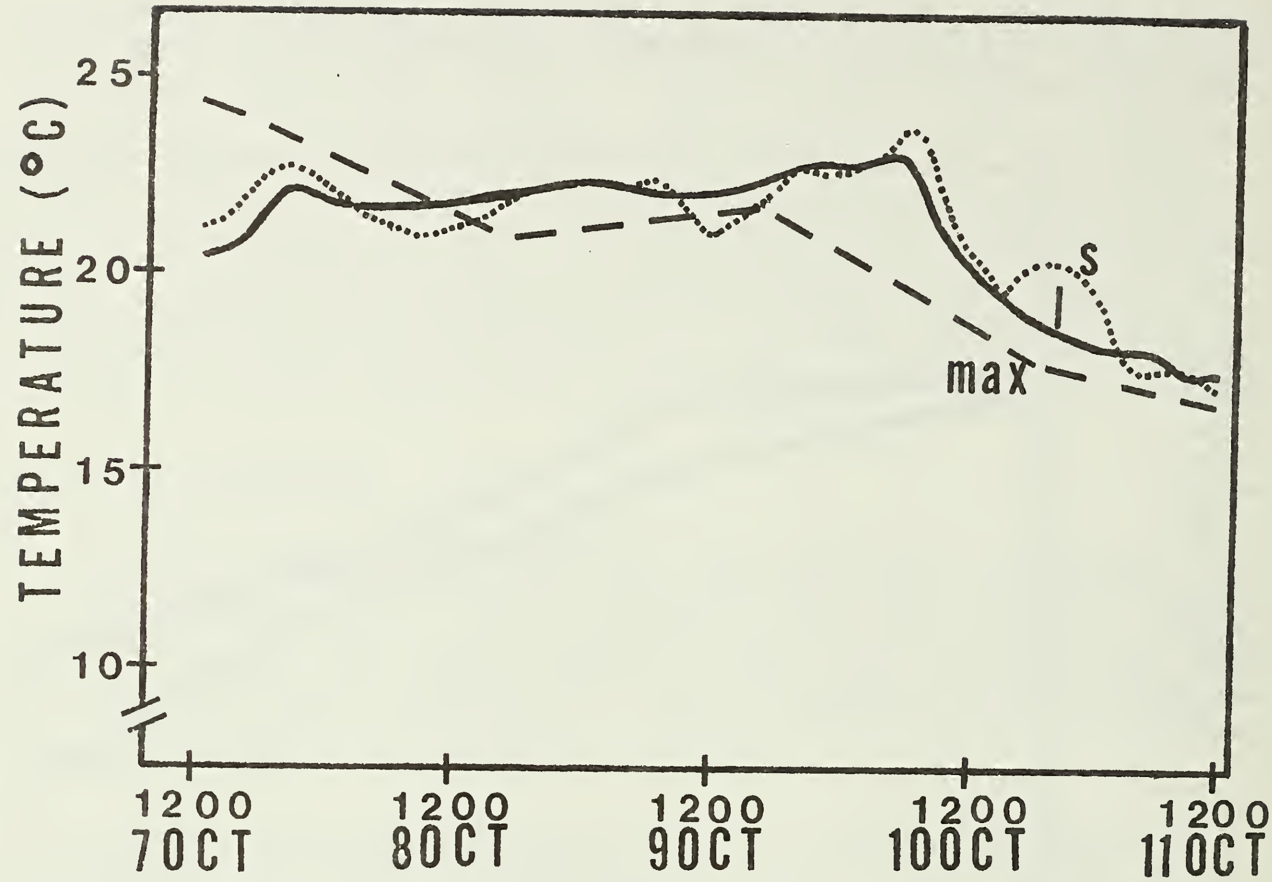

Figure 2. Diurnal fluctuations of temperatures within 1 m (l, solid line) and 0.5 m (s, dotted line) diameter bundles of sweet sorghum during the interval 7 to 11 Oct 82. The daily maximum air temperature (max, dashed line) is also shown.

SUMMARY

We have placed approximately 6 tons of whole sweet sorghum stems into aerobic, ambient temperature storage. Periodic sampling of the baled stems suggests that fermentables are declining, but perhaps not so rapidly as one might expect. Moisture levels of the stems within the bundles have not declined at all. Temperatures in the interior of the bundles have been moderate, with no indication of heat accumulation. The results obtained thus far (during a warmer than average winter) are encouraging; it might be possible to extend sweet sorghum's processing period in a fashion comparable to the "campaign" period for sugarbeets. We are continuing the current experiment through April 1983 and are planning to expand it for the 1983-84 season.

ALTERNATE EXTRACTION AND FERMENTATION PROCESSES FOR SWEET SORGHUM

by

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ABSTRACT

A practical method for small-scale production of ethanol is proposed in which the sugar in chopped sweet sorghum or in sweet sorghum bagasse is converted into ethanol by solid-phase fermentation, part of the fermented juice is removed in a screw press and the remaining ethanol is recovered by vaporization from the bagasse. Solid-phase fermentations of chopped sweet sorghum (14.2% hexose) and of bagasse (13.2% hexose) were conducted adiabatically to simulate thermal conditions in a continuous solid-phase fermentor. Temperature of chopped sorghum increased to 33.8°C (88% of theoretical temperature rise) within 45 hours and temperature of bagasse increased to 36.0°C (92% of theoretical) within 42 hours. Sugar conversions calculated from weight loss during fermentations were 92% for chopped sorghum and 98% for bagasse.

INTRODUCTION

The potential market for ethanol as an octane enhancer for gasoline is extremely large, since less expensive but toxic lead anti-knock additives are being phased out. Sales of ethanol tripled in 1982 to about 210 million gal/yr (GPY) and are projected to reach 520 million GPY of anhydrous ethanol in 1983 (Haggin and Krieger, 1982). Small distilleries (0.1 to 2.5 million GPY) numbered 47 in 1982, with a combined capacity of about 40 million GPY. The price of fermentation alcohol, made chiefly from grain in the U.S., is now competitive with synthetic ethanol and is projected to be 25¢ per gallon cheaper than synthetic by 1990.

Sweet sorghum probably could be used more profitably than corn as a feedstock for ethanol during autumn and winter. Production yields of sugar in sweet sorghum far exceed starch yields of corn. Yields for four sweet sorghum varieties seeded April 20, 1981 in Tifton, Georgia, were as follows listed in order of variety, harvest date and equivalent ethanol yield, gal/ac: M 81E, August 28, 465; Wray, September 30, 455; Mer. 71-1, October 9, 540; and MN 1500, November 9, 520. Whole stalks and billets can be stored for at least one week at 25-30°C ambient temperatures without significant deterioration (Eiland et al, 1983), and storage life can be extended through use of preservatives such as sulfur dioxide.

Because sweet sorghum consists of about 12-15% sugar and 65-75% moisture (Bryan et al, 1981), distilleries should be located close to production areas to minimize hauling costs. Small ethanol producers who can procure sweet sorghum from local farmers would have a definite advantage in reduced transporting costs, compared to large centralized distilleries. Another alternative for farmers might be to pre-process sweet sorghum by means of the processes described later and transport juice and/or ethanol solution to nearby distilleries for converting into anhydrous ethanol.

A limitation to use of sweet sorghum by small processors is low juice yield during extraction in 3-roll mills. In practical extraction tests of farm-scale mills, using eight varieties of sweet sorghum, juice yield did not exceed 40% of stalk weight and it contained less than half the total sugars originally in the stalk (Bryan et al, 1981, Monroe et al, 1981). Therefore, multiple pressing, with addition of water between pressings as practiced in the sugar industry, would be required to recover most of the sugar. Sugar cane plants commonly use 5 or more 3-roll mills in tandem with 25 to 30% addition of imbibition water (Mead and Chen, 1977).

The overall objective of this research is to develop innovative concepts for practical processes to use sweet sorghum as an alternate feedstock for ethanol production, processes that will lead to improved profits for both farmers and small ethanol producers. Immediate objectives are to develop alternate extraction and fermentation processes and to test process elements for technical feasibility.

ALTERNATE EXTRACTION AND FERMENTATION PROCESSES

Juice Extraction with a Screw Press

A horizontal screw press was tested as a potential means to increase juice yields from sweet sorghum, compared with 3-roll mills. Chopped sweet sorghum (variety Mer. 71-1, 0.6 cm length, 12.8% hexose, 28.3% dry matter) was hand fed into the hopper of a 6-inch diameter screw press that had a screen area of 0.3 m^2 (0.023 inch hole size) and an interrupted flight screw driven at 17 rpm with a 3 HP motor. Feed rate was 9.3 kg/min, and 57% was recovered as juice that contained 68% of the sugar in the chopped stalks. This was about 40% more juice and sugar than was obtained previously with a 3-roll mill. In multiple pressing with water added to bagasse between pressings, 93% of the stalk sugar was recovered in 3 pressings. However, multiple pressing required addition of 43% water, based on initial stalk weight.

Countercurrent Leaching of Bagasse

Farmers or small ethanol processors need less expensive methods to remove sugar from bagasse than the compound imbibition process practiced in the sugar industry. Fig. 1 illustrates the concept of a low-cost countercurrent leaching process in which the bagasse is carried on an endless mesh belt through a series of 4 pairs of hydraulically operated press rolls. Water is sprayed on the bagasse before the fourth pair of rolls, and the pressate, L_4, is continuously applied to the bagasse before the third pair of rolls. This process is continued to the first pair of rolls, and L_1 would then contain most of the residual sugar originally present in the entering bagasse. The efficiency of sugar recovery in this process would depend on the relative feed rates of water and bagasse, the uniformity of applying liquid to bagasse before each pair of rolls and the pressing force.

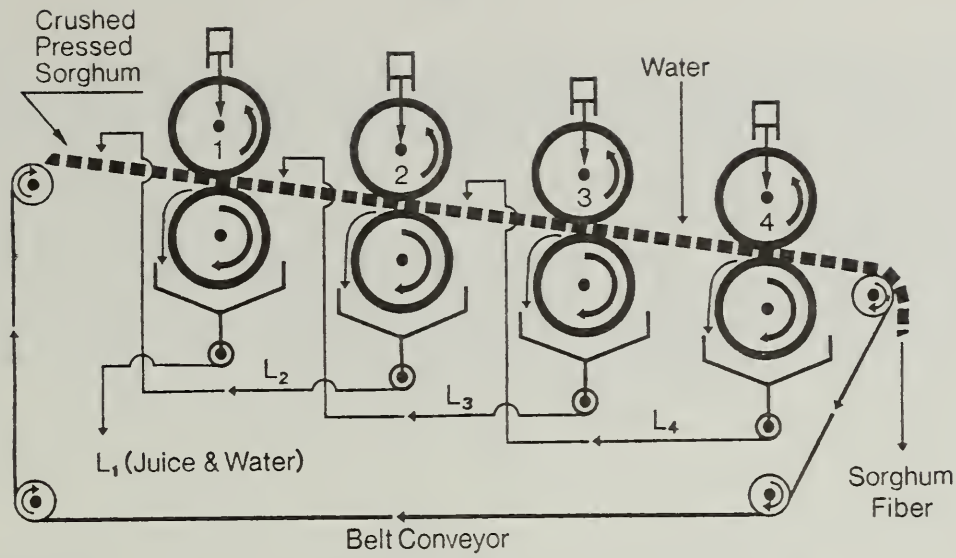

Fig. 1. Countercurrent Leaching Process for Bagasse

Separate Juice and Bagasse Fermentation

A concept is proposed (Fig. 2) for a process to produce ethanol from sweet sorghum that avoids the need for countercurrent leaching of sugar. Instead, sweet sorghum is milled and the sugar remaining in the bagasse is fermented in the solid phase. Liquid pressed from the fermented bagasse is mixed with conventionally fermented juice before distillation. Residual ethanol in the fermented and pressed bagasse is removed by evaporation or steam stripping and is recovered in the ethanol still. The amount of fiber in sweet sorghum is more than twice the amount of anhydrous ethanol that can be produced and is far more than would be needed to produce power for the process.

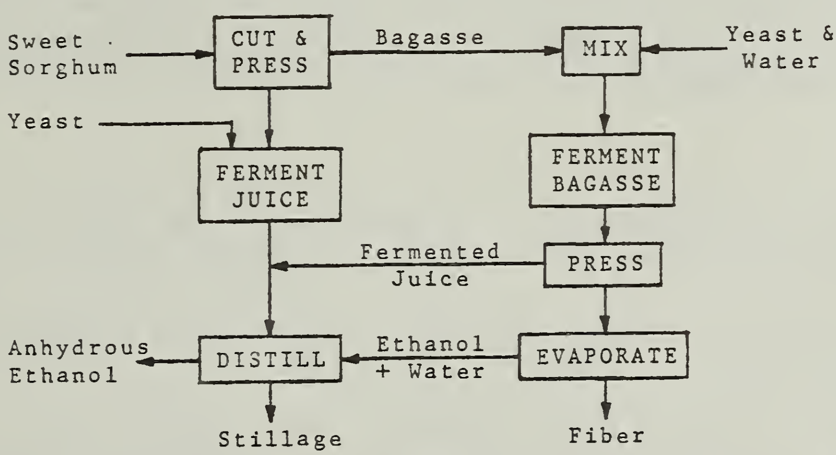

Fig. 2. Liquid and Solid-phase Fermentation Process for Sweet Sorghum

Solid-phase Fermentation

Tests of solid-phase fermentation of chopped sweet sorghum have been conducted during 3 harvest seasons, with investigation of such variables as sorghum variety, size of chopped stalks, use of sulfur dioxide to suppress competing microorganisms, amount of yeast innoculation and method of application, amount of water added and initial temperatures. The rate of fermentatation and the yield of ethanol were higher for solid-phase fermentations than for juice fermentation (Bryan and Parrish, 1982). In recent solid-phase fermentations of bagasse and chopped sweet sorghum, the rate of fermentation and the theoretical sugar conversion calculated from weight loss were higher for bagasse than for chopped sorghum (Fig. 3). The bagasse (13.2% hexose, 16.2% fiber) was prepared by pressing shredded 0.3 m billets (14.2% hexose, 12.2% fiber) of Wray variety in a 3-roll mill operated with 25% juice yield (Monroe et al, 1983). The temperature rise caused by the heat of fermentation was approximately the same as would occur in a large continuous fermentor. The theoretical maximum temperatures calculated from the heat of fermentation were 36.8°C for chopped and 37.9°C for bagasse. The heat of fermentation, 0.147 kcal/g hexose, was calculated from handbook values of the heats of combustion and solution for sucrose and ethanol.

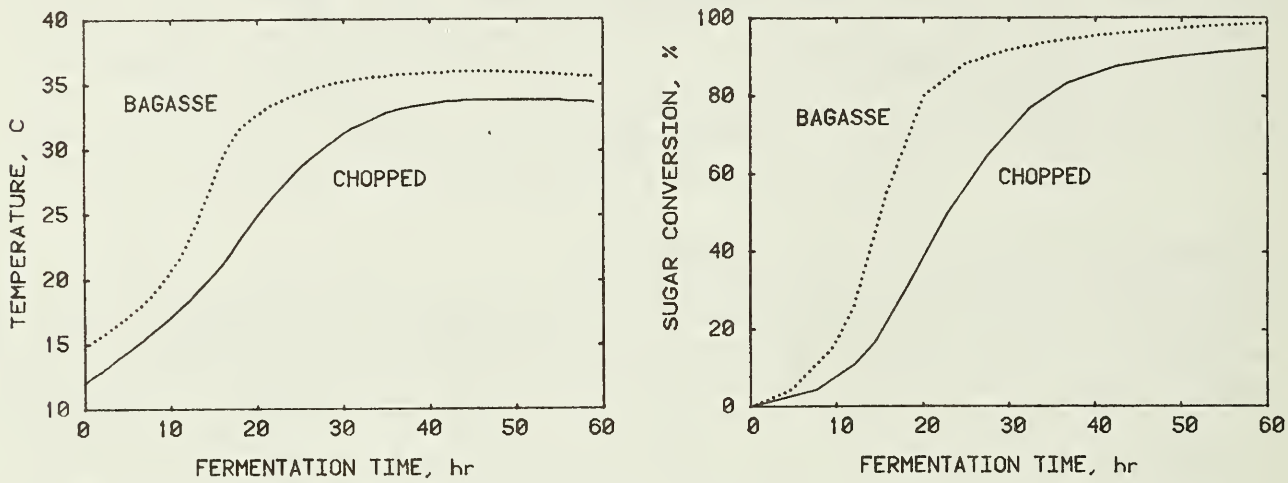

Fig. 3. Results of Solid-phase Fermentations of Sweet Sorghum

A potential limitation of solid-phase fermentation is thermal inactivation of yeast before fermentation is completed, resulting in low ethanol yields. This can be avoided in the process of Fig. 2 by removing the maximum amount of juice from the bagasse before fermentation and by adding water (or ice) to increase heat capacity and limit the peak fermentation temperature.

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Calotropis procera, A POTENTIAL FUEL AND FEED RESOURCE IN ARID AND SEMIARID REGIONS [1,2].

by

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ABSTRACT

Calotropis procera was evaluated as a potential fuel and animal feed resource. The data demonstrate that C. procera can be used as a renewable source of hydrocarbons and intermediate energy resources. The residues extracted with methanol have a presumptive value as a fibrous animal feedstuff. Hydrocarbon yield and presumptive nutritional value of extracted residues support cultivation of this plant specie in arid and semiarid regions of the World where fuel and feeds are in short supply.

INTRODUCTION

Calotropis procera (Art). R. Br. (Asclepeadaceae) is a large broadleaf evergreen which grows abundantly in arid and semiarid regions of the World without irrigation, fertilizer, pesticides or other agronomic practices. This plant is very resistant to fire and coppices profusely.

Although widely distributed, little sustained commercial use for the plant has been reported. Limited usage is due in part to toxic cardenolides contained in the plant. In small doses cardenolides tend to slow and strengthen the heart beat, but excessive doses can cause the heart to stop. Latex from C. procera was shown to cause: death in sheep fed 5 to 10 gm/kg of body weight; widespread testicular necrosis; reduced levels of protein, RNA and sialic acid in tissues. The objectives of this work were to determine the extractable hydrocarbon yields and characteristics, and nutrient and cardenolide content of unextracted and solvent extracted C. procera biomass.

MATERIALS AND METHODS

C. procera plant (aerial portion, $\leq$ 2 m in height) and individual plant components were collected in the southern coastal region of Puerto Rico. The components were oven dried (75°C), Wiley milled, and Soxhlet extracted with hexane or separately with hexane, followed by methanol. Proximate analysis and invitro dry matter digestibility of unextracted and extracted residues were performed by standard methods.

Crude protein was calculated by multiplying Nitrogen by 6.25. Total cardenolides were extracted into 95% ethanol, cleaned for quantitative analysis by lead acetone precipitation, and assayed by spectroassay and thin-layer chromatography, respectively. Thermogravimetric studies on the residues and extracts were carried out using a Perkin-Elmer thermogravimetric analyzer to determine the amount of volatile materials in the samples. Calorimetric studies were carried out to determine the heat of pyrolysis and heat of combustion.

RESULTS AND DISCUSSION

Cultivation of plant biomass as a source of hydrocarbons or chemical feedstocks has received considerable interest recently. This alternative energy production technology, however, has not attained scale-up development, due in part to a limited data base, relatively high energy inputs and production costs, and supplies of conventional fuels in developed, industrialized countries. However, in lesser developed arid and semiarid regions of the World, human resources and land are relatively abundant while conventional supplies of energy and food are short. In these areas this technology may provide a viable means of increasing agricultural and industrial production. Cultivation of biomass for liquid fuel supplies and use of processed residues as an animal feed can also reduce desertification in these regions, while increasing animal protein supplies for human consumption.

The fractionation scheme, yield and characteristics of C. procera extracts are presented in Figure 1, Table 1 and Table 2. Hexane extraction of C. procera yields a high-density fluid, rich in hydrocarbon. The ratio of carbon and hydrogen in hexane extract is similar to crude oil and the heat value is comparable to crude oil, fuel oil and gasoline. These preliminary data suggest that this extract could be used as a substitute for petroleum or petrochemical feedstock. Oxygen levels; however, were 7-9 fold greater than crude oil.

The presumptive nutritional value of C. procera residues are presented in in Table. 3. The proximate analyses of unextracted, hexane extracted or hexane and methanol extracted residues and amino acid profiles (data not presented) indicate hexane extraction reduced ether extract levels 87 to 96%, while generally increasing crude protein, ash and nitrogen free extract levels. Secondary extraction with methanol generally reduced crude protein, ether extract, ash and nitrogen-free extract levels while increasing crude fiber content. The crude protein content of unextracted and extracted whole plants was comparable to euphorbia but less than alfalfa. Although crude protein digestibility is unknown, except for stems, all residues contained sufficient total crude protein for ewes, gestating ewes, replacement lambs and yearlings, rams weighing less than 60 Kg and finishing lambs. Except for stems, all residues contained sufficient total protein for goat maintenance on semiarid rangeland, slightly hilly pastures and during early pregnancy. Similarly, levels were satisfactory for goats on arid rangeland, sparse vegetation, mountainous pastures and early pregnancy. Percent total crude protein content for all residues except stems was satisfactory for all classes of breeding cattle, growing and finishing calves and yearlings greater than 250 Kg in weight. Generally, hexane extraction and hexane and methanol extraction resulted in increased amino acid concentrations. Although amino acid availability of C. procera is unknown, the whole plant or portions other than stems, contain levels of the indispensable amino acids above the percentage requirements for all classes of swine. Amino acid levels were deficient for broilers; however, levels for egg and meat type chickens were generally sufficient in the leaf fractions for the acids isoleucine, leucine, lysine, methionine, phenylolanine, threonine, tryptophan and valine. Except for low methionine and cystine concentrations, amino acid levels in unextracted and extracted leaf residues were satisfactory for growing rabbits. All other plant components, however, were deficient in amino acid concentrations for growing rabbits. Individual cardenolides varied; only traces of cardenolides were detected in the methanol extracted residues. Methanol extraction essentially removed all plant cardenolides from the residues which would be expected to decrease the toxic effects of these residues ingested in feeds.

The data have shown C. procera to be a source of plant hydrocarbons by using a simple, relatively inexpensive solvent extraction technique. During actual production solar energy could be used to power the extraction process, thereby reducing production costs. Farm biomass production of this specie would yield a hydrocarbon extract which could be sold for cash by the individual farmer or used as a fuel, the residues could then be recycled through indigenous domestic animal species for the production of animal protein and biological fertilizers.

SUMMARY

Hexane extract from C. procera was shown to be a hydrocarbon resource potentially valuable as a fuel substitute. Hexane and methanol extracted C. procera residues were shown to have a presumptive value as a fibrous animal feedstuff.

Hydrocarbon yield and presumptive nutritional value of methanol extracted residues support cultivation of this specie in arid and semiarid regions of the World.

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Table 1. Characteristics of C. Procera extractables.

Component	Hexane Extract	Methanol extract
Carbon (%)	78.0-80.1	35.3-41.99
Hydrogen	10.9-11.4	6.5- 7.0
Oxygen	8.6-10.7	30.0-40.0
Density (gm/cm^3)	0.8-0.9	1.2-1.3
Ash (%)	0.3-0.8	9.8-14.3
Kjeldahl N	1.9	3.7
Water by distillation	<0.01	7.6
Sediment by extraction	18.0	82.1
Viscosity, 40°C	-	801.0
Flash point, °C	97.2	212.7
Free fatty acids, %	8.7	0.04
Total digitoxin (mg/gm)	0.06	19.07

Table 2. Thermogravimetric studies of C. procera extracts and residues.

Condition	Hexane extract	Methanol extract	Unextracted residue	Hexane extracted residue	Hexane and methanol extracted residue
Volitalization during pyrolysis (%)	95-98	60-68	59-67	60-66	58-69
Optimum pyrolysis temperatures (°C)	410,440	180-240,330	288,349	285,345	303,346
Heat evolution at optimum temperatures (%)	78,22	31,69	37,63	41,59	32,68

Table 3. Characteristics of C. procera residues.

Component	Unextracted	Hexane extracted	Hexane and methanol extracted
Crude protein (%)	6.7-17.7	6.7-18.2	5.3- 18.9
Ether extract	2.6- 8.7	0.3- 0.4	0.2
Ash	7.2-14.6	7.7-15.1	6.7- 15.0
Crude fiber	13.7-41.9	13.5-38.8	16.1- 46.6
Nitrogen free extract	41.7-51.0	46.6-48.3	41.2- 49.8
IVDMD	52.6-76.5	51.7-71.2	48.8- 78.7
Total digitoxin (mg/gm)	1.7- 4.0	1.4- 3.8	0.001-0.002

Figure 1. Soxhlet fractionation scheme, yield and gross energy content of C. procera.

PLANT FRACTION

4.1-4.5 Kcal/gm

Dried
Wiley milled
Hexane extraction (8 hrs.)

Hexane Extract

4.4-9.4% yield
9.9-10.1 Kcal/gm

Hexane Extracted Residue

90.6-95.6% yield
3.8-4.1 Kcal/gm

Methanol extraction (8 hrs.)

Methanol Extract

12.2-20.7% yield
4.2-4.6 Kcal/gm

Hexane and Methanol Extracted Residue

74.9-78.4% yield
3.7-4.1 Kcal/gm

WEEDS FOR OIL, POLYPHENOL, OR HYDROCARBON PRODUCTION IN THE SOUTHEAST

by

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ABSTRACT

Plant species are being screened for production of acetone and hexane extracts. The expectation is that the extracts can be processed into useful chemicals and that the ligo-cellulosic residue would be useful as biomass. Variation in populations of such extract-producing plants is being studied. Most promising species now being studied include Rhus glabra with a mean whole plant extract of 29.5 percent, Phytolacca americana with a mean of 12.2 percent and the dogfennels Eupatorium capillifolium and E. compositifolium with a mean of 11.6 percent. There appears to be little variation among the populations of Rhus that we have studied while populations of Phytolacca americana differ significantly and the Eupatorim species vary considerably with some plants producing an extract yield as high as 18 percent. Other species that have been studied produced high yields of extracts but are not considered promising because of low productivity, difficult establishment, or other problems. These include Asclepias, Solidago, Euphorbia, Ambrosia, and Artemisia species.

245 SELECTING WESTERN U.S. SPECIES FOR THE PRODUCTION OF LIQUID FUELS AND CHEMICAL FEEDSTOCKS

by

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ABSTRACT

As part of our research program on new phytochemical crops, we are examining several selection criteria which specifically apply to species for arid and semi-arid lands. The selection criteria are: yield (biomass yield x phytochemical yield); life cycle (annual, biennial, perennial); habit; range of adaptability; breedability; natural genetic variability; major products and co-products; toxicity; competitiveness; disease and pest problems; previous agronomic research available; and water use efficiency on marginal lands. These criteria are applied to several leading contender phytochemical species (gopherweed, milkweed, guayule, and jojoba) to demonstrate the utility of this approach. In general, it has been found that constraints encountered in the agronomic and biological attributes are more important than phytochemical yields per se.

It has now been shown for several species that non-polar hydrocarbons can be converted to liquid fuels by catalysts (Adams, 1982; Haag, Rodewald, and Weisz, 1980). However, at the current price of petroleum ($30/bbl, 9¢/lb), the economics for the production of fuel only is not promising (Adams, 1983). However, the use of plant chemicals (phytochemicals) as industrial feedstocks can present a very favorable scenario (Adams, 1983; Princen, 1982). This change in focus led us to examine several factors in the search for new phytochemical crops. The first factor to be considered is yield (biomass x product(s)). Although the goal of plant screening is to discover promising species for future research and development, the process also results in eliminating 99% (or more) of the species from further consideration at this time. Each of the four phytochemical crops (Table 1) are ranked as medium to high for yield. However, as previously mentioned, conversion to phytochemicals to liquid fuel is of much less interest than the utilization for renewable chemicals. The products of the four species ranged in value from 6¢-9¢/lb (gopherweed, sugars and HC) to $7/lb (jojoba oil). Life cycle has much to do with the farming costs. Annuals require seeding and generally considerable cultivation but can be rotated and weeds may be controlled in the off-season. Perennials are frequently difficult to establish but may be long-lived, saving annual seeding costs. However, the year-round growth/persistence may necessitate the use of herbicides for weed control and/or a build-up of pests in the field. In arid and semi-arid lands, perennials will likely be preferred because stand establishment is generally difficult and year-round cover is desirable to prevent soil erosion. The habit is important in determining the kind of farming equipment that can be used. A perennial forb appears to be preferable if the entire plant is to be harvested (e.g., milkweed, gopherweed). The range of adaptation is a severe limitation for guayule and jojoba. Frost areas of the southwestern U.S. are premium lands for citrus and other tropical crops where adequate water is available. In general, very little agronomic research is available for phytochemical crops. Considerable research has been done on guayule and jojoba but nothing compared to traditional crops such as corn and wheat. One potential new phytochemical crop is sunflower (whole-plant utilization, Adams and Seiler, 1983), for which a considerable amount of research has been done (at least on Helianthus annuus). The method and difficulty of crop establishment is an important factor to be considered. Direct seeding is cheaper for herbaceous crops, but transplants may be preferred for woody long-lived perennials (such as jojoba). Many of the Asteraceae present considerable difficulty in that seeds are very small and therefore the proper soil moisture conditions (a long, wet cycle) happens very infrequently in arid lands. Irrigation water may not be available, nor cost-effective to establish the crop. Milkweed and guayule both have limitations in this category. Competitiveness is difficult to assess in nature as persistence of a species may be of greater evolutionary importance than close-cover stands which crowd out competitors. However, in many of the phytochemical crops we will need aggressive species that form close-cover to crowd out undesirable competitors. This would reduce the need for cultivation and/or herbicides, making the crop less expensive to grow. Water use efficiency is of particular concern in the western U.S. where the competition between urbanization and agriculture is expected to become even more intense. Since water is generally the limiting factor for biomass growth in most of the semi-arid and arid lands, drought tolerant species and species that are very efficient in water use are of special interest. Disease and pest resistance can veto the use of some species as has been the case with gopherweed which is highly susceptible to charcoal root rot and no resistance has been found (Kingsolver, 1982). Breedability may be a significant factor, particularly if the plants only reproduce by apomixis. Having a large pool of genetic variation within a species from which breeding selections can be made and having several interfertile related species gives the breeder considerable opportunity. Some species are mono-typic,others represent isolated, relictural, endemic species that would present only a limited opportunity for breeding. Toxicity can severely limit options for biomass refining when the residue is intended for use as livestock feed or human food. Gopherweed contains the co-carcinogen, ingenol-3-hexadecanoate, which could present a serious health hazard in cultivation, harvesting and processing. In fact, each of the four taxa contain toxic compounds: gopherweed - co-carcinogen; milkweed - cardiac glycosides; guayule - allergins; jojoba - simmondsin. Harvesting methods will vary from using traditional swathing and baling to the development of new equipment for seed picking (jojoba). If processing/extraction facilities are to be used most economically, year-round processing is needed. Storage of plant material may result in the loss of volatiles, resinfication, oxidation, polymerization, and degradation. Many phytochemicals are stable if the plants are not ground and kept dry. Storage of guayule may best be accomplished in the living plant by harvesting strips of land throughout the year as needed. The extraction technology has been generally patterned after commercial solvent (oil seed) facilities. Supercritical extraction may prove to be much more economical if new facilities are constructed. Markets for most of the phytochemicals have not been surveyed. Many will have to be completely developed. Products that have no current market or have extremely small markets will likely veto the domestication of many species. Consumer acceptance can be subdivided into two categories: farmer and buyer. The farmer may be reluctant to grow "weeds" that he knows nothing about and may fear (with reason) the possible spread into traditional crops.

SUMMARY

Comparisons among four taxa currently being considered/developed for phytochemicals showed their strengths and weaknesses for 18 different criteria. This list could be greatly expanded, particularly in the markets area. It is anticipated that this or a similar framework will be useful as species are evaluated for the domestication of new phytochemical crops.

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Table 1. Selection Criteria Applied to Four Potential Phytochemical Crops.

	Gopherweed	Milkweed	Guayule	Jojoba
Yield (biomass x product	med/high	medium	med/high	medium
Products	HC, sugar	HC, specialty chemicals	rubber, resin	oil/wax
Life cycle	biennial	perennial	perennial	perennial
Habit	forb	forb	shrub	shrub-tree
Range of adaptation	frost tol. to -10°F, semi-arid	temperate, semi-arid	frost sensitive, arid, semi-arid	frost sensitive, arid
Previous agronomic research available	some	little	considerable	considerable
Crop establishment: Direct seeding	easy	variable	difficult	easy w/ irrig.
Transplants	N.A.	N.A.	preferred	preferred
Competitiveness	poor	fair	fair/var.	fair/var.
Water use efficiency	poor	fair	good/exc.	excellent
Disease and pest resistance	unacceptable	good	exc./var.	excellent
Breedability	good	poor	good	good
Genetic variation	fair	fair	good/fair	good
Toxicity	co-carcinogens allergens	toxic	allergens	toxic
Harvesting	swath/bale	swath/bale	special. swath/bale	hand/mech. pickers
Storage	rel. stable (?)	rel. stable	some oxidation	stable
Extraction tech.	oil seed & dev.	oil seed & dev.	solvent & dev.	oil seed
Markets	needs dev.	needs dev.	avail/dev.	avail/expand
Consumer acceptance: Farmer	problem	problem	fair	good
Buyer	poss. problem	poss. prob.	good	excellent

FARM PROCESSING OF OILSEEDS FOR FUEL AND FEED

BY

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ABSTRACT

Research began in 1981 on mechanical expelling of oil from the peanut and other Southern oilseeds by the acquisition of a Simon-Rosedown oil expeller. The mill has been used successfully to expell oil from sunflowers and rapeseed at input rates of 40 pounds per hour with approximately 80 percent oil removed. The maximum input rates achieved with the mill thus far are only about half of the manufacturer's suggested capacity. The texture and lower fiber content of the peanut seed make the expelling of its oil more difficult. The mill is currently being equipped with a variable speed drive such that the effect of screw speed on mill capacity and oil removal can be determined.

The economics of using vegetable oil for fuel are currently poor, but use of the meal for a high value protein feed may help. Peanuts have not found appreciable use in feed partly because the U.S. industry is directed toward the edible trade through a system of farm quotas and price supports. The value of the peanut as a feed for swine is improved by the removal of the oil and skins. High oil-content feeds cause an undesirable fat in pork and the tannins in the peanut skin make the protein less available in a ration. Removing most of the oil and skins would improve the value for feed. There is also the possibility of better utilization of low-grade peanuts in crushing for fuel. Future research will be directed toward investigation of these aspects.

PEANUT OIL AS AN EMERGENCY FARM DIESEL FUEL

by

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ABSTRACT

To evaluate peanut oil as a potential emergency farm diesel fuel, a broad systems approach has been followed. Efforts are underway to seek efficient small-scale oil production and storage technology as well as the effects of long-term use in diesel engines. The physical properties of peanut oil and blends containing peanut oil have been measured.

Oil extraction tests with an expeller and a hydraulic press were conducted. The effects of temperature, moisture, and pressure on extraction efficiency were measured. Two small engines were operated identically on the E.M.A. test cycle. Extended tests on 20:80 and 80:20 PNO:Diesel blends were documented with power, fuel efficiency, and temperature data. Engine deposits and crankcase oil condition were recorded.

Introduction

In order to prepare for possible future shortages of agricultural diesel fuel, we are examining the technical aspects of a farm fuel system based upon peanut oil. Emphasis is placed on equipment and methods which could be used in the near term. In general, simple procedures and low-cost farm or community-scale equipment has been emphasized. The fuel produced should be a direct substitute for #2 diesel fuel, requiring a minimum of changes to engine or engine operating procedure.

Vegetable oils, such as peanut oil, offer one of the most direct and least capital-intensive routes to a non-petroleum diesel fuel for agriculture. The technology for oil production is relatively simple and efficient. In the case of peanuts, crude pressed oil can be used directly in diesel engines. The current production of peanuts and other oilseeds could provide a significant fraction of the on-farm diesel need, so the raw material for this alternative fuel is already available.

Experimental Equipment for Engine Testing

The test engines were 3-cylinder water-cooled engines with 22:1 CR, 0.85ℓ displacement, and 15.KW output (20 H.P.)* These engines are believed to be good examples of modern indirect injection design. At present, a series of tests with 1-cyclinder direct injection engines is underway. 20 KW

*Mfg. by Kubota Tractor Co., Model D850

alternators were coupled to engines by belt drive. Alternator electrical output was dissipated in electric heat elements. Alternator fields were varied to control engine loading. Sensors for fuel flow, temperature (water, exhaust, fuel), rpm, and torque were monitored at 1-minute intervals. Torque was measured via strain gage/slip rings on engine crankshaft.

The data acquisition system for real-time data processing included an A/D converter and apple microcomputer. An electronic counter was fabricated and installed in the apple for processing fuel flow data.

Fuel blends for engine tests were prepared from crude peanut oil and #2 diesel. A re-circulating pump provided uniform mixing. Blends were pre-filtered to approximately 0.4μ by commercial bus filters.

Controlled, long-term tests were designed to detect power or efficiency changes over extended operation times. The rate of wear, engine deposits, and crankcase oil degradation were observed.

The E.M.A. Alternate Fuels Test Cycle was followed for up to 200 hours. Phillips Reference Fuel provided baseline values of output and efficiency before and after fuel blend tests.

A 200 hour durability test was conducted with a 20:80 peanut oil:diesel blend. When maximum power output dropped 5%, the fuel filters, injectors, etc. were examined and cleaned so that output power was restored. Testing then continued on the E.M.A. cycle. At 200 hours, the piston rings and valves were examined. Carbon and a white deposit were present at very moderate levels.

A 150 hour test was next conducted with a 80:20 peanut oil:diesel blend. Reduced power (5%) was observed at 50. hr. intervals. When injector deposits were scrapped away, maximum power output returned to normal. After 150 hours, there was a thin hard deposit of carbon in the combustion chamber area. The rings were free and cylinder walls showed no abnormal wear.

Oil Expelling Equipment and Procedure

A CeCoCo Model 52 oil expeller was instrumented for temperature and pressure at several points on the machine. The peanuts were pre-heated in a rotating oven. Moisture level in oilseeds was measured by electrical and drying oven methods.

The general procedure involved measurement of temperature, pressure and moisture content as the peanuts were processed. A statistical multi-variable analysis permitted optimization for oil extraction efficiency. This method identified optimal zones for operation of the expeller where 85% oil extraction occurred.

Approximately 60 to 70% of the oil in peanuts may be extracted in about five minutes in the simple hydraulic (carver) press. The tests show that most of the oil in peanuts can be removed using a modest hydraulic pressure of 2-3,000 psi.

SUMMARY

1. The mechanical expeller has been demonstrated to be capable of at least 85% oil extraction from runner type peanuts. The residual meal, containing approximately 15% oil, is a high energy animal feed. Approximately 60 to 70% of the oil in peanuts may be extracted in about five minutes in the simple hydraulic (carver) press.

2. Blends of crude peanut oil with #2 diesel, butanol, gasoline, or ester were prepared for physical property measurements. Five blending concentrations were examined. The data from these blends show low temperature limits for use of these fuels. The viscosity of the blends as a function of temperature and shear rate was found.

3. In the engine durability tests, a 20:80 (peanut oil:diesel) blend showed a long term (200 hrs.) performance similar to #2 diesel, with the exception of injector coking at 100 hr. intervals of operation. An 80:20 blend after 150 hours of testing on the E.M.A. cycle had no detectable abnormal wear; coking of injectors reduced power 5% at 50 hr. intervals. For emergency operation, the greatest concern appears to be fuel filter stoppage. This can be prevented by pre-filtration of peanut oil blends.

PRODUCTION AND ON-FARM PROCESSING OF VEGETABLE OIL

by

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ABSTRACT

Yield data for production of seven cropping systems are presented. Double-cropping sunflower and soybeans after wheat and winter rape seed resulted in lower yield than full season crops. The Simon-Rosedowns mini-40 press was evaluated for on-farm oil extraction of winter rape and soybeans. Research to this point indicated that the press operated smoothly with winter rape after initial problems with faulty barrel rings were resolved. Extraction efficiency of about 94% has been attained for winter rape. Major modification was required for soybean oil expression.

INTRODUCTION

Two small capacity on-farm type presses are available and being used in the U.S. by several researchers. Blake (1982) reported using the Simon-Rosedowns, mini-40 press, made in England, for extraction of oil from Conola seed. He reported problems such as blockage, excessive fine materials in the oil, and excessive oil remaining in the press. A second set of barrels was provided by the manufacturer which improved press operation. Oil output was reported to be 9-10 L/hr for 6-7% moisture seed. The feed rate was about 25 kg/hr or less for cake with less than 20% residual oil content.

Ramsey and Harris (1982) reported use of the Simon-Rosedown screw press for soybean oil extraction. About 30 bushels of soybeans were processed before the press operated smoothly. The choke setting of 24 produced meal 0.25 mm thick. With no pretreatment on soybeans, oil production was about 0.07 L/kg at a rate of 2.75 L/hr. Maximum oil output of about 0.087 L/kg was reported at a temperature of about 77°C.

The University of Idaho seed processing system utilized a Japanese screw press (CeCoCo). In processing about 180 kg of winter rape seed oil an extraction rate of about 85% was reported with a 44.5 kg/hr feeding rate. Power requirement for extracting oil was 0.08 Kw-hr/L (Peterson et al. 1982). After production of about 14,000 liters of oil the tapered end of the scroll became scored and efficiency of the press decreased. The end ring and auger were rebuilt which resulted in overall efficiency of 85 percent. About 90 kg of sunflower seed were processed with feeding rate of about 60 kg/hr. The extraction efficiency of 70% was reported using 0.13 Kw-hr/L power.

Hofman et al. (1981) used the CeCoCo press to extract sunflower oil. Oil delivery was about 13.25 L/hr with extraction rate between 70 - 75 percent. The extracted oil contained considerable seed particles which settle to the bottom of the tank after a few days. No technical problems related to operation of the press were reported.

Prinsloo and Hugo (1981) reported use of a small screw oil expeller with maximum capacity of 40 kg/hr. The oil delivery rate was 13 L/hr and 9 liters of oil was extracted per Kw-hr. The maximum extraction rate of about 88% was reported for sunflower seeds. Effects of choke setting and feed rate on percentage oil extracted from the seed were studied. It was shown that low worm shaft speed combined with a high choke setting would result in maximum oil extraction. Power consumption was increased with increased worm speed and choke setting.

EXPERIMENTS

Crop Production

Yield data for full season sunflower, soybeans, peanuts, and winter rape and double-cropping sunflower and soybeans after wheat and winter rape are presented in Table 1. Field trials were planted at two locations in Maryland. Full season soybeans yielded a maximum of 3300 kg/ha. Double-cropping soybeans after wheat and winter rape seed resulted in yields of about 2850 kg/ha and 2300 kg/ha, respectively.

Birds caused considerable damage to full season sunflower at one location. With earlier harvest of the other plots little bird damage occurred. Single crop sunflower yield was about 2700 kg/ha while double cropping sunflower after wheat decreased the yield to 2500 kg/ha. The highest peanut yield (4236 kg/ha) occurred on a well drained soil with favorable rainfall. The lower yield in the other location was likely due in part to the heavy soil. Winter cultivars of rape seed will mature early in the growing season. The earliness of rape seed should allow for higher yields from either sunflower or soybeans in a double cropping system. However, rape seed yields were less than expected. Harvest was delayed and substantial shattering occurred.

Processing

The University of Maryland processing plant consists of a Simon-Rosedowns model "Mini-40" screw press. It basically consists of worm shaft, feed end casting, barrels and choke assembly, main frame, and drive assembly. The worm shaft rotates inside twelve barrel rings which are mounted on three tie bars. Spacer washers are used between barrel rings which control flow of expelled oil. At the exit end of the press a tapered choke ring is fitted. The larger end of the taper bore faces toward the barrels. Operation of the choke is by means of the choke operating screw at the feed end of the machine. Turning the screw in moves the taper plug section of the worm shaft axially into taper bore of the choke ring, reducing the cake thickness. Turning the screw out, withdraws the shaft, thus increasing cake thickness. Choke setting is an indication of the distance the shaft is moved into the tapered bore of the choke, ranging from 0 to 30. The press is driven by a 3-hp, 230 volt, single phase electric motor with belt and chain drive which gave a wormshaft speed of about 150 rpm.

The original set of barrels was of little use for expelling oil from winter rape. Five additional sets of barrels were provided by the Simon-Rosedowns distributor in the U.S., but none performed satisfactorily. Recently a new set was received which resulted in improved operation of the press but major problems were not eliminated until a new worm shaft was provided by the distributor. After using a variety of spacer washers between the barrel rings, they were finally arranged with no spacers on the first six barrels at the feed end followed by 0.64, 0.46, 0.38, 0.25, 0.15, and 0.13 mm spacers to the choke end. This spacing resulted in high oil delivery with a minimum amount of fine materials. Several choke settings were used to determine proper setting for maximum oil extraction. Effects of choke setting on press efficiency are given in Table 2. Extraction efficiency was increased significantly (from 53.48 to 94.20) by increasing the choke setting from 24 to 26. However there were no significant changes in feed rate and power requirement. About 1250 kg of winter rape (Dwarf-Essex variety) was processed with a choke setting at 26. The feeding rate was 21 kg/hr which is lower than the nominal rated capacity of 40 kg/hr. The oil production was about 0.45 L/kg at a delivery rate of 9.6 L/hr.

Soybeans were processed with no further adjustments. The press clogged frequently and very little oil was produced. Different spacer and choke setting were tried, but none performed satisfactorily. It was decided to use one of the previous set of barrels. After several attempts, barrels with deeper grooves were chosen, with barrel spacing of 0.50 mm spacers in the first two barrels at the feed end, the next three at 0.25 mm, the next two at 0.13 mm, followed by 0.08 mm at the next three, and with no spacer for the last barrels. The soybeans feeding rate was about 50 kg/hr which was higher than that of winter rape. This was partly due to difference in barrel design which allowed easier flow of soybeans inside the press. The high feed rate combined with the high choke setting (for optimum oil delivery) resulted in overloading the electric motor. The original motor was then replaced with a 5-hp, 3 phase motor.

Three 23 kg samples of soybeans were processed at three choke settings (Table 3). The extraction efficiency increased from 18.2 to 22.74 to 27.3 percent with choke setting at 22, 24, 26, respectively. By increasing the choke setting feed rate was lowered while power requirement was increased. About 1200 kg of soybeans were processed. The oil content was about 20%. With the choke setting at 26 and no pretreatment of the soybeans extraction efficiency was about 31%. The oil production was about 0.076 L/kg at a delivery rate of 4.12 L/hr. Significant amounts of coarse particles were found in the oil tray.

CONCLUSION

This paper has addressed the production and processing of vegetable oil crops. Yields for seven cropping systems were reported. Further study is required on winter rape seed production before it can be used in a double-cropping system with sunflower and soybeans.

Significant differences were found in extraction efficiency of the press using different choke settings. An increase in choke setting increased power requirements and decreased seed feed rate. With no pretreatment of winter rape, oil production was determined to be about 0.45 L/kg at a delivery rate of 9.6 L/hr.

By using a different set of barrel rings, soybeans were processed at a rate of about 50 kg/hr. Oil output was 4.12 L/hr with an extraction efficiency of about 31%. Further research is underway to evaluate the press for on-farm oil extraction of sunflowers and peanuts.

ACKNOWLEDGEMENTS

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The authors express appreciation to Norman Martin, and Robert Dixon for their valuable assistance in setting up and operating the screw press.

Table 1. Average yields for the seven cropping systems[1] (first year).

Cropping System	Yield: Wye	Yield: Poplar Hill
	kg/ha	
Full Season		
Soybeans	2968	3363
Sunflowers	2695	na[2]
Peanuts	2289	4236
Double Crop		
Wheat/Soybeans	3767/2845	3767/2150
Wheat/Sunflowers	3767/2500	3767/2595
Rapeseed/Soybeans	604/2354	na/1428
Rapeseed/Sunflowers	604/2811	na/2762

[1] All yields other than peanuts corrected to 15 percent moisture
[2] Not harvested.

Table 2. Effect of choke setting on press efficiency (Winter Rape)

Choke Setting	Oil Extracted (%)	Extraction Eff. (%)	Feed Rate (kg/hr)	Power Requirement (W-h/kg)
24	23.0	53.48	21.5	74.11
26	40.5	94.20	20.93	76.90

Table 3. Effect of choke setting on press efficiency (Soybeans)

Choke Setting	Oil Extracted (%)	Extraction Eff. (%)	Feed Rate (kg/hr)	Power Requirement (W-h/kg)
22	4.04	18.2	74.84	11.30
24	5.05	22.74	64.14	12.42
26	6.06	27.3	46.44	14.32

BREEDING AND UTILIZATION OF WINTER RAPE AS A DIESEL FUEL REPLACEMENT [1,2]

by

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ABSTRACT

Earlier studies have demonstrated that the saturation level of vegetable oil composition affects gum formation and carbon coking preceding and during combustion; higher levels of unsaturation appear to be associated with more gum and injector coking. Oleic safflower and high erucic acid winter rape oils are two of the more saturated oils which show promise for production in the Pacific Northwest. Winter rape will produce over twice as much farm extractable oil as either safflower or sunflower. High levels of glucosinolates are the principle disadvantage of winter rape. These compounds reduce the feeding value of the meal and thus lower the total economic return. Based on these results, the current research has concentrated on:

(1) developing low glucosinolate cultivars of winter rape
(2) long term engine tests with winter rape or other saturated vegetable oils to determine the levels of these oils which could be used for emergency fuels in agricultural production.

Breeding Winter Rape

In 1980, WW827 (Sweden), Norde (Sweden) and Sipal (Sweden) were crossed with Indore (Oregon State University) to derive populations segrating in fatty acid composition (oleic (18:1) and erucic (22:1) acids) and glucosinolate concentrations. These populations were advanced in the greenhouse to derive 651 F_3 families which were screened for glucosinolate concentration. The elite 63 F_3 families were increased to the F_4 generation in the greenhouse during the winter of 1981-82. In the fall of 1982, 161 F_4 families were planted at Moscow for progeny tests of winter hardiness and seed yield. Five F_5 plants from each F_4 family were artificially vernalized and increased in the greenhouse to provide seed for further fatty acid and glucosinolate analyses. The elite F_5 lines based on field evaluations and laboratory analyses will be tested in Idaho and other selected locations in the fall of 1983 and 1984 to allow release of selected cultivars by the fall of 1985. Due to rapid seed increase that occurs in winter rape, commercial production of these cultivars could be initiated as early as 1987.

Three types of low glucosinolate cultivars will be selected. One cultivar will produce only trace amounts of erucic acid with most of the oil composed of oleic acid. This cultivar will be grown as an edible oil with the whole seed exported to Oriental markets. In excess of 50% of the oil of the second cultivar will be composed of erucic acid. The oil from this cultivar will be initially marketed as an industrial oil for use in lubricants and could also be used as a fuel oil. The third oil will be selected for a high level of mono-unsaturated fatty acids (Oleic, Eicosenoic (20:1), and Erucic); for low levels of polyunsaturated fatty acids (linoleic (18:2) and linolenic (18:3)) and for maximum oil production per ha. This oil should have both good performance as a fuel and a long storage life. Because this oil could only be used as a fuel product, the third cultivar would probably not be widely grown until fuel prices increased sufficiently to make the utilization of vegetable oil as fuel economically practical.

Engine Testing

The engine tests with vegetable oil have included (1) a long term test with two-Yanmar TC70C precombustion chamber single cylinder, water cooled 0.39 L diesel engines; (2) carbon coking tests utilizing a Lister STA-2 air cooled, direct injection,, 1.3 L, two cylinder engine on an electric dynamometer; (3) EMA screening test cycle with 3 Wisconsin, 1.0L, air cooled, direct injection engines; (4) a John Deere 4239TF, 3.9L, direct injection, turbocharged, water cooled engine connected to an electric dynamometer; (5) a Satoh Bison, 4-cylinder, precombustion chamber, 1.3L water cooled engine in a tractor used for general farm work. The specific vegetable oil tests and a brief summary of results to.date for each of the above engine configurations will be included below. In the following discussion, the engines will be referred to only by make.

Fuel Designations

The fuels currently used in the engine test programs are Winter Rape, Oleic Safflower, and Linoleic Safflower in combination with diesel fuel. To simplify the discussion the following shorthand notation will be used.

XXAA - YYBB + CCCC
XX = percent of vegetable oil AA in mixture
YY = percent of diesel fuel in mixture
AA = WR for winter rape
= SL for linoleic safflower
= SO for oleic safflower
BB = D1 for number 1 diesel
= D2 for number 2 diesel
CCCC if present indicates additive present in mixture.
CCCC = FOA2 - E.I. Dupont deNemours and Co., fuel oil additive No. 2, 0.56 ml/gal (150 ppm).
= FOA.5 - E.I. Dupont DeNemours and Co., fuel oil additive No. 15, 0.40 ml/gal (105 ppm).
= L565 - The Lubrizol Corporation, Lubrizol 563, 13.6 ml/gal (1300 ppm).

Yanmar Long Term Endurance Tests

The two Yanmar engines are on a 2500 hour endurance test utilizing 50WR-50D2 as fuel. The 2500 hours was selected as a 100,000 miles test equivalent assuming an average speed of 40 mph. Engine 11 is operated continuously on the test mixture; engine 22 is operated on the test mixture except it is switched to 100D2 for shutdown and start-up. The engines currently have achieved 1700 hours of operation. All of the winter rape oil used in the test has been obtained from the University of Idaho small scale extraction plant. The engines are performing satisfactorily to date.

	Beginning		Ending	
engine I.D. No.	11	22	11	22
hours	61	36	1650	1650
compression (psi)	436	425	450	440
power (kw)	2.7	2.3	2.4	2.5

Lister Injector Coking Tests

The Lister engine was utilized on the dynamometer in a torque cycle to obtain a measure of tendency for injector tips to coke. The torque test was used to accelerate the rate at which the carbon formed in the combustion chamber. A maximum power test was conducted at 2400 rpm on 100D2 for 10 minutes to check for possible damage from previous tests. The engine was then switched to the test fuel and a torque test initiated. The speed was reduced at full throttle in 200 rpm increments to 1400 rpm. Ten minutes of fuel consumption data was taken. The engine was then allowed to cool down by operating at 1800 rpm with no load for 5 minutes. The injector tips were photographed using a measuring microscope with 35 mm copy film forming a silhouette image. The injector tips were then cleaned with observations taken on their appearance and how easily the carbon was removed from the tip. The entire procedure required about 3 hours time. The silhouette area can be compared against a silhouette of a clean tip as a standard and the increase in tip area used as a measure of additive effectiveness. A decrease in carbon area would indicate that the additive is effective in reducing injector coking. The fuels, additives, and results of the Lister test are listed below.

Fuel and Additive	Mean Injector Tip Area (mm^2,	Std. Dev.)	Percent of Area Due To Coking of Nozzle
Clean Tip	21.79	--	0.00
100D2	22.58	0.85	3.61 a*
50WR-FOD2+L565	23.97	0.48	9.96 b
50WR-50D2	24.54	0.65	12.62 bc
50WR-50D2+FOA15	24.63	0.38	13.03 c
50WR 50D2+FOA2	24.83	0.83	13.91 c

*The increase in areas followed by the same letter of the alphabet are not significantly different using the new Duncan's Multiple Range procedure at α=0.05.

The table shows that the 50WR-50D2 alone and with the L-565 resulted in a significant drop in injector coking compared to the FOA-2 and FOA 15 additives. Prior tests have shown that the FOA-2 reduces fuel filter plugging. It is a dispersant type additive which may contribute to the additional gum entering the combustion chamber. The FOA-15 had a higher numerical score than L-565 but the coking was more easily removed from the injector tip. The coking formed by the L-565 was glazed onto the tip.

Wisconsin Engines with EMA Test Cycle

The Wisconsin engines were mounted on computer operated load units and tests conducted using the EMA recommendation for 200 hour screening tests for alternative fuels. To date three engines have completed the test cycle and three additional engines installed on the load units and are being readied for starting the next sequence. The fuel used for these tests was analyzed by Phoenix Labs, Chicago, Illinois.

The specific purpose of the first series of tests was to confirm the effect of saturation level on the amount of engine deposits and crankcase oil thickening. For this purpose, the vegetable oils selected were two cultivars of safflower, one oleic and the other Linoleic. The Oleic has a high level of saturation and the Linoleic a high level of unsaturation. A brief summary of the first three engine tests is as follows:

	50SL-50D2			50SO-50D23			100D2		
Hours	Power (kw)	BSFC (kg/kwh)	Comp (psi)	Power (kw)	BSFC (kg/kwh)	Comp (psi)	Power (kw)	BSFC (kg/kwh)	Comp (psi)
0-61	10.6	0.414	433	11.3	.367	420	13.2	.349	409
61-112	10.7	0.398	410	10.8	.433	420	14.0	.323	395
102-161	10.7	0.354	410	10.5	.383	418	13.7	.301	370
161-203	10.3	0.410	405	10.3	.471	428	13.3	.371	390

John Deere Performance Tests

The John Deere engine was used for short term performance tests with the 50WR-50D2, 50SL-50D2, 50SO-50D2 and 100D fuels. The procedure for these tests was as previously discussed. In these tests, the power output was equal for 50WR-50D2 and 100D2, 1.1% higher for 50SD-50D2 than 100D2, and 3.7% higher for 50SL-50D2 than 100D2. Fuel consumption was 7.1% higher for 50WR-50D2 than 100D2, and 4.9% higher for 50SL-50D2 than 100D2. Since the winter rape has the least energy density, the most fuel was required. Because of the lower heating value, thermal efficiencies (brake energy out/fuel energy in) for all the vegetable oil fuels were 0.5 to 0.7 percent higher than for the engine when tested with 100D2.

Satoh Bison Tractor Field Test

A 22.4 kw Satoh tractor is under test on the University farm. The tractor has 163 hours on 50WR-50D2 with no significant drop in compression or power.

VEGETABLE OIL STORAGE STABILITY

by

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ABSTRACT

Objectives of this research are to measure vegetable oil fuel deterioration as a function of storage conditions, extraction methods, and vegetable oil composition. The project is funded under the USDA Special Research Grants Program-Energy Research (Vegetable Oil as Diesel) from October, 1982 to September, 1985.

INTRODUCTION

Vegetable oils are inherently less stable than commercial diesel fuels, and the problems of fuel deterioration during storage are more severe for vegetable oils than for commercial diesel fuels. The major chemical difference between vegetable oils and commercially acceptable diesel fuels is the high degree of unsaturation of the vegetable oils. Although vegetable oils contain natural antioxidants, their high degree of unsaturation makes them susceptible to gum formation. Antioxidants can extend the induction period delaying the start of gum formation and dispersants can maintain gum in solution, but neither antioxidants nor dispersants appear to be an economically viable means of preventing fuel deterioration in storage. Gum in a fuel will escape complete combustion as do heavier ends of diesel fuels. The resulting carbon residues contributes to deposits in the combustion chamber and around nozzle tips, coking on the piston rings, and carbon residue in the lubricating oil. The injection spray pattern is disrupted, the rings sieze, and the crankcase oil viscosity increases. All these problems are common to the use of vegetable oils as a diesel fuel. Long term use of vegetable oils, especially under high engine load, is not possible unless these problems are eliminated.

Since fuel deterioration occurs mainly by oxidative polymerization leading to gum formation, the rates of oxidative polymerization will be determined for different vegetable oil compositions and environments. Results from these studies will determine the optimum conditions for vegetable oil storage. Another objective will be to apply the storage deterioration results and methodology to the analysis of diesel engine performance. Gum formation also occurs in the fuel line and in the combustion chamber resulting in carbon residue formation even when gum-free vegetable oils are used. At the high temperatures and pressures preceding combustion both oxidative and thermal polymerization occur. The solution for minimizing fuel deterioration probably lies in the control of fuel composition and storage environment. Selection of an optimum fuel composition, especially minimizing fatty acid unsaturation, will reduce both oxidative and thermal polymerization.

A reduction in the rate of gum formation in storage should also reduce the carbon residence formation during fuel combustion.

PROCEDURES

Extraction

Seven vegetable oil crops were processed. These seed crops include four varieties of safflower, two varieties of rapeseed, and sunflower. The safflower varieties include three high linoleic acid (ca 80%) varieties and a high oleic acid (ca 70%) variety. The high linoleic acid safflower variety and the high oleic acid safflower variety represents the two extremes of unsaturation among the common vegetable oils resulting from alteration of a single gene. A comparison of these two safflower varieties will demonstrate the effects of unsaturation without interference of other vegetable oil properties. The rapeseed varieties include a high erucic acid (ca 45%) and a high oleic acid (ca 60%) variety. The sunflower are approximately 75% linoleic acid. The oil seed crops were grown on University of Idaho experimental plots in Moscow and the seeds extracted on an expeller press (CeCoCo Type 52). This expeller press was operated with an oil recovery efficiency of approximately 75%. At this efficiency the phospholipid gum content of the extracted oil is negligible. The extracted oil was allowed to settle in 50 gal drums and filtered through a three stage filtering system consisting of pre-filter, 20 μm filter, and 4-5 μm filter.

Oxidative Polymerization

Rates of oxidative polymerization will be determined over the temperature range of 200-300°C. Over this temperature range the degree of polymerization doubles over 1-5 hours while at storage temperatures the rates should be lower by a factor of approximately 10^{-3} (degree of polymerization doubling time on the order of a year). Polymerization rates will be determined by measuring viscosity and degree of polymerization vs time. Degree of polymerization will be determined by high performance liquid chromatography (SEC). Monomers (triglycerides), dimers, trimers, etc. can be resolved in HPLC/SEC because of the large molecular size of triglycerides. Rates and molecular weight distributions of heated vegetable oils will be determined by HPLC/SEC.

Long Term Storage

The seven varieties of vegetable oils will be stored under conditions simulating actual storage conditions. Samples will be stored in quart jars with 3 replicates in 2 environments (aerobic and anaerobic) with storage times of 6, 12, and 18 months (7 x 3 x 2 x 3 = 126 samples). Samples will be stored at approximately 18°C. Temperature and humidity will be recorded. The samples will be analyzed for change in viscosity by capillary viscometry and degree of polymerization by HPLC/SEC.

Seeds and meal from the extraction press will also be stored under the same conditions as the oils. Oil samples will be analyzed for peroxide value (1) to measure degree of oxidation, iodine value (2) to measure degree of unsaturation, fatty acid composition by gas chromatography after conversion of oils to methy esters (3), and viscosity using a capillary viscometer. Meal will be analyzed for oil content by nuclear magnetic resonance (mmr) spectroscopy and for nitrogen content (4). Oil will be extracted from whole seeds and analyzed to compare storage deterioration of the oil in seeds to the extracted oils.

Thermal Polymerization

Vegetable oil samples will be sealed under vacuum in glass ampoules and rates of polymerization determined. Temperatures of 250-320°C will be used, and analysis will be the same as for oxidative polymerization. The HPLC/SEC results will be used to compare rates, mechanisms, and activation energies of oxidative and thermal polymerization. The relative rates of thermal and oxidative polymerization will be determined for at least seven varieties of vegetable oil with a large variation in unsaturation. Reaction mechanisms will be determined by the degree of polymerization as measured by HPLC/SEC. A thermal polymerization occuring by a Diels-Alder mechanism will give only dimer up to a high extent of reaction. A free radical oxidative polymerization should give trimer and higher oligomers at a very low extent of reaction. Activation energies will be determined by measuring polymerization rates as functions of temperature. This data will be fit by an Arrhenius expression to determine activation energies (5).

Engine performance as characterized by the rate of carbon residue accumulation will be compared to the rates of oxidative and of thermal polymerization for vegetable oils showing the most significant difference in polymerization rates. Carbon residue will be measured on the injector tip of a direct injection diesel engine by microscopy. The direct injection engine will be connected to a G.E. 150 HP electric dynamometer and run at high load to give rapid carbon coking. The engine will be run on an equal volume mixture of vegetable oil and diesel fuel. The injectors will be pulled before and after the test, mounted on a reference collar for later measurement calibration, and photographed with a measuring microscope. The collar and tip silhouettes will be analyzed by a Wang computer and digitizer to determine the area of injector tip coking. Carbon samples will also be photographed under an electron microscope to determine microstructure. Storage deterioration as well as carbon residue formation during combustion can then be related to rates of thermal and oxidative polymerization (gum formation).

PRELIMINARY RESULTS

Rates of oxidative polymerization and thermal polymerization have been measured for high linoleic safflower and sunflower and for high erucic rapeseed from 240-300°C. Thermal polymerization is negligible at 240°C compared to oxidative polymerization. At 240°C, the viscosity of safflower oil (75% lineoleic) increases by a factor of 32 over 11 hours in an air environment and shows no change in a nitrogen environment. High eruric rapeseed, a more saturated oil, shows a viscosity increase of approximately 1/4 that of safflower for oxidative polymerization. Engine tests using rape-diesel mixtures show less carbon residue than engine tests with safflower. Carbon residue was measured from photographs of the fuel injector tip after running a Lister diesel engine on a vegetable oil/diesel mixture.

Partial data from an analysis of samples stored for six months are shown in Tables I and II.

TABLE I. Fatty Acid Composition (by weight methyl esters)

	Palmitic (16:0)	Stearic (18:0)	Oleic (18:0)	Linoleic (18:2)
Linoleic Safflower	6.1	1.7	9.3	82.9
Oleic Safflower	4.8	1.4	74.1	19.7

TABLE II. Analyses of Six Month Samples

	Anaerobic Peroxide Values	Aerobic Peroxide Values
Linoleic Safflower Oil	1.38	11.32
Linoleic Safflower Seeds	0.46	0.54
Oleic Safflower Oil	0.69	2.45
Oleic Safflower Seeds	0.29	0.38

Low peroxide values for samples stored as seeds indicate that there is very little oxidative deterioration of oil in stored seeds. However, stored oils show significant levels of oxidative deterioration. Oxidation is especially significant for the linoleic safflower oil in aerobic storage. Oxidative deterioration is reduced with a more saturated oil and by anaerobic storage conditions.

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SUMMARY

Long term storage tests with varieties of safflower, sunflower, and rapeseed have been initiated to characterize fuel deterioration and to determine optimum storage conditions. Preliminary data indicate that deterioration is reduced by anaerobic storage, high levels of oil saturation, and storage as seeds rather than extracted oil.

PROPERTIES OF INDIVIDUAL FATTY ACID ESTERS AS DIESEL FUELS

by

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ABSTRACT

We have been investigating the performance of individual fatty acid esters as diesel fuels and are studying variations in ester structure on efficiencies of power production and on cetane number. Variations in ester structure include chain length of the fatty acid, degree of unsaturation and nature of the alcohol esterified. Chain lengths studied include fatty acids with 8 carbons to 18 carbons with oleic and linoleic acids representing the unsaturated acids. Alcohols included are methanol, ethanol, and butanol. Efficiencies are measured using a 3.9 Kw diesel engine and measuring the heat equivalent of the work done divided by the energy content of the fuel. Cetane indexes are calculated for the individual esters by use of equations relating the fatty acid compositions of mixtures of esters to the cetane numbers for the ester mixtures. Additionally, for several esters the cetane numbers have been determined according to ASTM D613.

Introduction

Most vegetable oils contain the same fatty acids with the distinct composition of each oil arising from variations in the proportions of the individual acids. The purpose of our study is to determine how the common fatty acid esters in pure form perform as diesel fuels. If the properties of mixtures of esters reflect the properties of the individual esters in proportion to their content in the mixture, our data eventually will allow us to predict the quality of diesel fuel produced from the fatty acid composition of the oil. Additionally, if any one fatty acid appears to possess especially good fuel properties, crops could be selected or bred to maximize the desired acid.

Procedure

Practical grades of lauric, myristic, palmitic, stearic, linoleic and linolenic acids were purchased from Eastman Kodak. Oleic acid was purchased from Fisher Scientific. Caprylic and capric acids were provided by Armak Chemical, McCook, IL. Safflower oil was obtained from a local grocer.

Esters of the fatty acids were prepared by refluxing overnight with a 4-fold excess of the alcohol containing 2% H_2SO_4 as catalyst. During preparation of butyl esters, the water produced in esterification was azeotroped off and removed. The safflower oil was first saponified, the fatty acids recovered, and then esterified as above. Esters were recovered by extraction with petroleum ether and water. The ether extracts were extensively washed, dried with anhydrous Na_2SO_4 and the petroleum ether removed by rotary evaporation at 50°C. The esters used for the fuel efficiency tests were used as is while the esters used for cetane number determination were vacuum distilled. Cetane numbers were determined by Waukesha Engine Division, Dresser Industries, Waukesha, WI. We have also estimated cetane indexes for the fatty acid esters using experimentally determined cetane numbers for ester mixtures resulting from transesterification of several vegetable oils and published fatty acid compositions for those oils. This procedure has been described in detail previously (1).

The test engine for the fuel efficiency study was a Fairbanks-Morse model 45B-81 single cylinder, direct injection diesel rated at 3.9 Kw at 1800 RPM. The engine drove an electric dynamometer at rated load and speed. Volumetric fuel consumptions were determined for each fuel and converted to specific fuel consumptions using the densities. Efficiencies for the esters were calculated by dividing the heat equivalent of the work produced by the engine by the heat of combustion of the fuel required to perform that work.

Results and Discussion

Efficiencies of the various esters as fuels ranged from 20.3% to 24.8%. When only the methyl esters of saturated acids were considered, we found efficiency to be inversely related to chain length of the fatty acid. Plotting these data indicated a linear relationship with a correlation coefficient of -0.97. Unsaturation of the fatty acid produced an increase in efficiency with the greatest effect with 18:1 with efficiency decreasing slightly with additional unsaturation. The alcohol esterified to the fatty acid also has an effect on efficiency. We tested the methyl, ethyl and butyl esters of oleic acid. We found the efficiency to decrease in order of ethyl > methyl > butyl. In fact, the ethyl oleate exhibited the highest efficiency of any of the fuels tested. We also measured fuel consumption for several triglyceride fuels. Of these, triolein produced the lowest specific fuel consumption while peanut oil had the next lowest consumption. The triolein contained 75% oleic acid while the peanut oil contained 50% oleic acid. None of the other vegetable oils contained as much as 25% oleic acid. Thus, it appears that efficiencies of triglyceride fuels reflect their oleic acid content.

Since one measure of diesel fuel quality is its cetane number, I decided to investigate the effects of fatty acid structure on cetane number. Because it is difficult to prepare sufficiently large quantities of the highly pure individual fatty acid esters for cetane number determinations, I tried an indirect approach. This procedure, which has been published (1), used the cetane numbers which had been published for several ester mixtures resulting from transesterification of vegetable oils and the fatty acid compositions of those oils to develop equations relating cetane number to fatty acid chain length and degree of unsaturation. To do this, I had to make three assumptions: 1, cetane number varied in a linear manner with chain length; 2, all double bonds introduced into a fatty acid chain affected cetane number equally; and 3, that the cetane number for an ester mixture was the sum of the cetane numbers for each component of the mixture multiplied by its proportion in the mixture. The results of these calculations are listed in Table 1, column A.

More recently I have prepared the necessary quantities of several fatty acid esters for determination of cetane numbers. These esters include the methyl and butyl esters of caprylic acid, methyl, ethyl, and butyl esters of myristic acid, and methyl esters of stearic, oleic, and linoleic acids. These esters were distilled and their fatty acid compositions determined by gas-liquid chromatography. The fatty acid compositions of the saturated esters were all in the range of 94.6% to 100%, while the methyl oleate was 76.4% and the methyl linoleate was 80.9%. The methyl stearate was prepared as a 70% solution in petroleum ether because of its high melting point. The cetane numbers determined are shown in column B of Table 1. Comparison of the calculated cetane indexes in column A with the experimentally determined cetane numbers in column B indicates generally good agreement for the longer-chained compounds while the cetane index calculated for methyl caprylate is quite high compared to the experimentally determined number. This probably indicates that the relationship between fatty acid chain length and cetane number is nonlinear. This discrepancy in cetane numbers probably arose as a result of the fact that caprylic acid is only a minor component in most oils. Also, it must be pointed out that the cetane number of 73 for methyl stearate is an estimate. The cetane number for the 70% solution of methyl stearate in petroleum ether was 66.4. If we assume a cetane number of 50 for the petroleum ether we arrive at the estimated value of 73 for methyl stearate. We must also keep in mind that most of these esters were not 100% pure. The effect will be most pronounced with the less pure unsaturated esters. The major contaminants of the methyl oleate were the more highly unsaturated esters, methyl linoleate, methyl linolenate and methyl palmitoleate, all of which would be expected to have lower cetane numbers than methyl oleate itself. Therefore, the determined cetane number of 50.4 is believed to be somewhat low for pure methyl oleate. On the other hand, all of the contaminants of the methyl linoleate would have cetane numbers higher than methyl linoleate itself. Therefore, the determined cetane number of 42.6 is probably somewhat high for methyl linoleate.

That the alcohol esterified to the fatty acid influences the cetane number is also apparent from these data. The increase in cetane number from methyl → ethyl → butyl esters of myristic acid probably represents an effect related to increasing chain length similar to that observed with methyl esters of fatty acids of increasing molecular weights. We have found that oleic acid esters exhibit high efficiency in diesel engines and that they have relatively high cetane numbers. In addition, because oleic acid has only one carbon-carbon double bond, it is not so susceptible to autooxidation and polymerization as the more highly unsaturated acids. The melting points of esters of oleic acid are not quite so low as for the more highly unsaturated esters. Ethyl esters have freezing points several degrees lower and simultaneously higher cetane number and increased combustion efficiency than the methyl esters.

Summary

We have studied the effects of structure of fatty acid esters on their performance as diesel fuels and have found a strong relationship between ester structure and efficiency as fuels. There is an inverse relationship between carbon chain length of the methyl esters of saturated fatty acids and efficiency. Methyl oleate which contains one double bond was a more efficient fuel than methyl stearate which has the same chain length but contains no unsaturation. The presence of more than one double bond appeared to decrease efficiency slightly. Ethyl ester of oleic acid was a more efficient fuel than the methyl ester while the butyl ester was less so.

Cetane numbers have been determined for a number of esters. Cetane number was found to increase with chain length for the saturated fatty acid esters, probably in a non-linear fashion.

The presence of unsaturation in the ester reduced the cetane number with two double bonds having more effect than one. Cetane number is also influenced by the alcohol which is esterified to the acid. Butyl esters of a given acid had higher cetane numbers than the corresponding ethyl ester while methyl esters had the lowest. In view of the high efficiency and relatively high cetane number observed for oleic acid, it appears that oil seeds containing high concentrations of oleic acid, especially if transesterified to produce ethyl esters, would make promising potential diesel fuel crops.

Table 1 Cetane Ratings of Fatty Acid Esters

Fatty Acid Ester	(A) Cetane Index (Ref 1)	(B) Cetane Number
Me 8:0	58.1	33.6
Bu 8:0	-	39.6
Me 14:0	66.5	66.2
Et 14:0	-	66.9
Bu 14:0	-	69.4
Me 18:0	72.1	73
Me 18:1	56.2	50.4
Me 18:2	40.3	42.6

Reference: Klopfenstein, W. E., J. Am. Oil Chem. Soc. 59, 531-533 (1982).

ENERGY BALANCE OF ON-FARM VEGETABLE OIL PRODUCTION AND EXTRACTION IN SELECTED AREAS OF IDAHO AND WASHINGTON

by

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ABSTRACT

This paper (1) presents a comprehensive method for calculating the energy required to produce ~~vegetable oil~~ fuels on the farm, and (2) determines the balance between energy inputs and outputs per hectare for vegetable oil production from sunflower, safflower and winter rape. All three oilseeds yielded a positive energy balance, based on the assumption that the meal co-product is used as a livestock feed.

Introduction

To be successful, vegetable oil fuels must contain more energy than is required to produce the product. One purpose of this publication is to present a comprehensive methodology for calculating the energy required to produce vegetable oil fuels on the farm. The second purpose is to determine the energy inputs and returns per hectare for the production and on-farm extraction of three vegetable oils.

The following analysis includes all direct and indirect energies required for production and on-farm extraction of vegetable oils. Direct energies include those which are consumed during the production and extraction of vegetable oils. The energy contained in diesel fuel, gasoline, fertilizers, chemicals, and electricity are examples of direct energy inputs. Indirect energies are those required in the manufacture and maintenance of direct inputs and durable items such as tractors and machinery. Examples of indirect energies include the energy used in producing the steel from which machinery and implements are fabricated, the energy required to refine crude oil into gasoline and diesel fuel, and the energy required to mine and process phosphate for fertilizers. Solar energy captured by plants was considered a free good and was not included.

Production Data for Oil Seeds and On-Farm Oil Extraction*

Sunflower, safflower and winter rape have potential for commercial production in the Pacific Northwest. Production information for these crops was gathered by means of personal interviews with growers. Representative production methods were determined from these data (McIntosh, 1981).

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*References and detailed information are available from the junior authors.

The three basic methods of extracting oils are mechanical or expeller extraction, direct solvent extraction, and pre-press solvent extraction. The solvent extraction systems were considered inappropriate technology for on-farm operations because of expense and size to attain needed efficiencies and because of increased and more highly skilled labor requirements.

Expeller extraction technology is simple. It is a continuous process using a screw press, consisting of a worm shaft rotating within a pressing cylinder or cage, which squeezes the oil from the seed. The seeds are usually conditioned by heating prior to extraction to increase oil yield.

A smaller expeller extraction facility (40 kg. per hour) supplies between 3 and 5 gallons of oil per hour of operation, depending upon the type and oil content of the seed being processed. A facility of this size could be assembled for less than $27,000 (Peterson, et al.; McIntosh, et al.). The University of Idaho, Department of Agricultural Engineering has been operating a 40 kilogram per hour press periodically over the past year. Data on the system's characteristics were collected during this time.

Calculation of Energy Inputs

Machinery. Estimates of the energy costs per hour for farm machinery were calculated using procedures from Doering (1980), who used steel and rubber industry data to estimate energy embodied in the steel and tires. Data obtained from farm machinery manufacturers were used to estimate the energy required to fabricate equipment from these raw materials. Doering also estimated the energy needed to supply spare parts and make repairs. These factors were then summed to obtain the total energy cost of each machine.

A specific set of machinery was selected for the production of each crop, based on the interview data. Weights in kilograms were determined for each machine and an energy value in megajoules per hour calculated. These energy values were then divided by typical machine life and multiplied by the hours used on each crop to determine energy costs in megajoules per hectare-year.

Fertilizers, Seed, Fuel, Insecticides, Herbicides. Coefficients from Lockeretz (1980) were used to convert fertilizer rates to energy costs. Heichel (1980) evaluated four methods of determining the energy costs of propagating the seed used to produce agricultural crops. The most feasible method for this study relied upon the economic costs of seed or propagation materials to estimate the energy costs. This method is based on the energy attributable to a dollar unit of gross national product.

The fuel requirements for crop production were estimated from data in the Agricultural Engineers Yearbook. (ASAE, 1980, pp. 239-250). The energy required to transport crops from farm storage to market locations was not included, since haul methods and distances were unknown. However, since the focus here is on-farm production and use, this information is not relevant.

The amounts and types of herbicides and insecticides used in the production of oilseed crops were determined from the interviews. Energy costs were calculated from this information using a list of coefficients provided by Pimentel (1980a).

Transportation, Labor, Aircraft, Irrigation. Pimentel (1980b) estimated that each kilogram of farm supplies is transported an average distance of 640 kilometers. Based on this, 1.08 megajoules per kilogram was used to calculate the energy required to transport fuel, fertilizers and seed to the farm. For labor, Goering and Daugherty (1981) assumed that a farm worker consumes 2.28 megajoules of energy per hour. The energy costs associated with agricultural spray aircraft were estimated by Johnson and Chancellor (1980). This, and data from Fountain (1982) were used to estimate the energy costs of aerial application of farm chemicals.

The energy for pumping and that embodied in wheel line and center pivot sprinkler systems was estimated from production data using information from Batty and Keller (1980). Irrigation and pumping efficiencies of 65 and 78 percent respectively, were assumed.

Oil Recovery. The energy attributable to the oilseed press was calculated in the same manner as machinery. The press used in this project was a "CeCoCo New Type 52" oil expeller. The electrical energy to operate the press system was determined by the Department of Agricultural Engineering at the University of Idaho (Peterson, 1982). An energy cost for labor was calculated based on five minutes of labor per hour of press operation.

Calculation of Energy Outputs

Average seed yields obtained by growers and the percentage oil by weight contained in the seed, determined from University of Idaho data, were used in calculating the energy yields of oilseed production, using coefficients from Driscoll (1980). A high protein meal useable as livestock feed is obtained as a co-product of vegetable oil extraction. Expeller extracted oilseed meals were evaluated for their energy content (Katz, 1982).

Apportioning Energy Inputs Between the Oil and Meal. A key assumption in calculating the energy balance is that the meal co-product is used as a livestock feed. The input energies were apportioned between the oil and meal based on the relative amounts of each obtained from the expeller and on the energy content of the co-products. Extraction efficiencies of 70 percent for sunflower, 71 percent for safflower, and 85 percent for winter rape were assumed, based on University of Idaho data.

RESULTS

A positive energy return was obtained from all three oilseeds, based on the assumption that the meal is used as a livestock feed (Table 1). The returns ranged from 1.8 for irrigated sunflowers to 4.2 for winter rape. If the energy value of the meal is assumed to be equal to zero, the positive energy balances are reduced considerably, ranging from .91 for safflower to 2.2 for winter rape. The use of sunflower and safflower meal as a livestock feed is well-established, but the meal from the varieties of winter rape used in this study cannot be fed in the quantities normally used for high protein supplement. This is because of a high glucosinolate component. Certain varieties, primarily grown in Canada, produce meal which can be fed (Thomas, et al.).

Table 1. Estimated Energy Inputs and Outputs in Megajoules per Hectare for On-Farm Extracted Vegetable Oils in the Pacific Northwest.

Item	Sunflower Power Co. ID	Sunflower Adams Co. WA	Sunflower North ID	Sunflower South ID	Safflower North ID	Safflower South ID	Winter Rape North ID
Seed	1648	1422	1373	1373	2043	2043	277
Fertilizer	7345	8295	4148	2602	4363	2981	5044
Herbicides	352	352	352	352	352	352	
Pesticides		819	204				204
Machinery	722	751	543	623	600	611	638
Diesel	3734	3558	2951	3057	2541	2940	2644
Gasoline	3278	4033	1987	2137	2295	1769	2118
Aircraft		25	13				25
Gasoline[1]		536	268				536
Defoliant		251					
Irrigation pumping	12219[2]	16293[3]					
Irrigation equipment	1115[2]	1077[3]					
Labor	22	20	13	13	11	12	11
Transportation	752	596	336	329	437	356	429
Total Input	31187	38028	12188	10486	12642	11064	11946
Oil Recovery	2518	2642	1259	1049	1173	957	1753
Total	33705	40652	13447	11535	13815	12021	13699
Yield (Oil)	32781	34149	16391	13659	13346	10918	29567
% Charged to Oil	45.36	45.35	45.35	45.35	41.99	41.99	51.29
Output/Input	2.14	1.85	2.69	2.61	2.30	2.16	4.21

[1] Gasoline for aircraft only

[2] Wheel line irrigation

[3] Center pivot irrigation

METHOD FOR CONVERSION OF CELLULOSIC FIBERS INTO FERMENTABLE FEEDSTOCKS[1]

by

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ABSTRACT

The manuscript details a novel approach for converting fibers into glucose, xylose and lignin. Laboratory-sized equipment has been designed and is presently under construction as a cooperative effort between NASA (Cape Kennedy) and the University of Florida.

The conversion process consists of three major components: Thorough mixing of SO_3 with fibrous solids, abrading of the reacted material to enhance a change of crystalline cellulose into the amorphous form, and hydrolyzing of the abraded material with saturated steam at moderate pressure.

Parameters for temperature, catalyst concentration and reaction time are to be determined for continuous processing, for optimizing production rates of glucose and xylose after addition of sulphur trioxide. Batch experimentation in the laboratory has provided a maximum of 85 percent conversion for bagasse fibers into glucose and xylose when using SO_3 as catalyst.

INTRODUCTION

A major problem for an economic conversion process of cellulose into glucose is the tight interdispersal and bonding of lignin with the cellulosic fractions on the fiber matrix. A simple process using fairly low temperatures and pressures, and requiring a moderate capital outlay, will be described in general terms herein[2]. Different phases of the processing method have been tested using batch-type methods in the laboratory, and results obtained indicate the feasibility of the method.

The alpha cellulosic fraction of fibrous materials is often present in the crystalline form that is difficult to hydrolyze when using a strong

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[1] US Patent Office Application Ser #295,814 and 374,949, respectively, assigned to the University of Florida, Gainesville, FL 32611.

[2] Research performed under grant #DE-FG4480R410169, Department of Energy.

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mineral acid as catalyst. Lignin is not dissolved by this catalyst, but crystalline cellulose will dissolve in a strong acid like H_2SO_4 at concentrations of 70% or higher. When so dissolved, the alpha cellulose is converted from the crystalline into the amorphous form. This latter form is easier to hydrolyze than crystalline cellulose when using a diluted strong acid as catalyst. Kinetics modeling reported similar rates for formation and destruction of glucose and xylose when simultaneously hydrolyzing alpha cellulose and hemi-cellulose with a dilute strong mineral acid at predetermined temperature (pressure) and time duration (1).

As a consequence of the above problems, the method for conversion of cellulose into mono-sugars should include the following successive processing phases:

- An intimate distribution of the catalytic acid throughout the fiber mass.
- The dissolution of alpha cellulose in concentrated acid to change this material from the crystalline into the amorphous form.
- Hydrolyzing the fibrous material now containing mostly amorphous alpha cellulose, hemi celluloses and lignins into hexoses, pentoses, and residual lignins.

During the actual hydrolyzing stage, the use of moderate temperatures (pressures) are preferred to minimize the formation of furfural, a substance toxic to fermentation by yeast.

METHODOLOGY

Thorough mixing of the solid fiber particles that have a low moisture content with a strong mineral acid serving as a catalyst is a difficult task. Therefore, SO_3 as a gaseous catalyst was employed for this purpose. When leading a stream of SO_3 through a column packed with fiber particles, the catalyst will react first with the moisture present in the fiber at the layer of impact. Additional admission of SO_3 at that moment will result in carbonizing the fiber material at the point of contact, and the SO_3 will not continue its path to the next layer of fiber to react with the moisture in fiber at that location. Sulphur trioxide is a very strong oxidizing agent, quickly causing localized carbonizing when present in a concentrated form. Therefore, the gas should be diluted with an inert gas. First CO_2 was used for this purpose, and later ambient air.

When liquid or gaseous SO_3 is admitted to a continuous airstream, then the SO_3 will react instantly with the moisture present in the ambient air, forming a very fine mist of highly concentrated sulfuric acid. When a stream of fiber particles is also introduced into this stream, then the mist particles will adhere to the fiber particles, coating the latter with a thin layer of concentrated sulfuric acid. Due to the large surface area of the introduced fiber, the introduced air mass and SO_3 will randomly produce an even coating on all fiber particles, thereby leading to an intimate mixing of the catalyst and fiber. Ambient air, injected SO_3 and injected fiber all flow in the same direction through a long piping system to exit at a cyclone where the treated fiber is separated from the spent airstream.

During the next processing step the fiber now coated with concentrated H_2SO_4 is admitted to an extruding screwpress. The screw is discontinuous to accomodate pins in the barrel which extend until barely touching the screw. Fiber particles are moved forward in the extruding press, and are abraded under pressure at the point of contact between the pins and the screw shaft. The combined pressure and abrading action promotes the penetration of the adhering film of H_2SO_4 into the fiber particle, and so dissolve alpha cellulose. Thus, the changed crystalline form, now converted into the amorphous form can be hydrolyzed together with hemi cellulose.

Hydrolysis takes place under 50 psi gauge pressure. Saturated steam of maximum 300° F is admitted to maintain an acid concentration of about 3% in the hydrolyzing solution for a period of 30 minutes. Glucose formation is maximized by this acid concentration and temperature during this time period, while glucose destruction increasingly takes place only beyond the stated parameters. The glucose and xylose thus formed are separated from the residual solids, mostly lignin, by the use of a "Dorr" cyclone.

After adjustment of pH with calcium, the resulting glucose may be fermented by yeast, leaving the xylose as residual after distillation. The xylose may be further concentrated for sale as a substitute for blackstrap molasses, while the residual lignin is used as fuel to energize the entire processing system.

RESULTS

With batch processing, conversion rates of 80% or higher for available alpha cellulose were obtained when using 10% acid (w/w) equivalent, and 65% when using 5% acid (w/w) equivalent on dry weight fiber. The acid equivalent is weight of concentrated H_2SO_4 as derived from admitted SO_3 when reacted with available moisture. Tests have shown that the degree of abrasion is important for the final yield of glucose obtained after hydrolysis. Extruded material should have a plasticized appearance of dark coloration; this optimum consistency is obtained while maintaining 60-80° C temperature during extrusion, and when the material already treated with SO_3 is adequately abraded.

FUTURE EXPERIMENTATION

Presently, a small laboratory-sized pilot plant is under construction, a joint undertaking among NASA, Cape Kennedy and the University of Florida, Gainesville. The small equipment will have a daily capacity to treat 50 pounds of fiber (dry basis) per day, and is meant to test the aforementioned parameters of time, pressure, and temperature for continuous processing. Detailed results for processing with individual components of this equipment will be reported in the future. A schematic diagram for processing with the laboratory-sized equipment is shown in Figure 1.

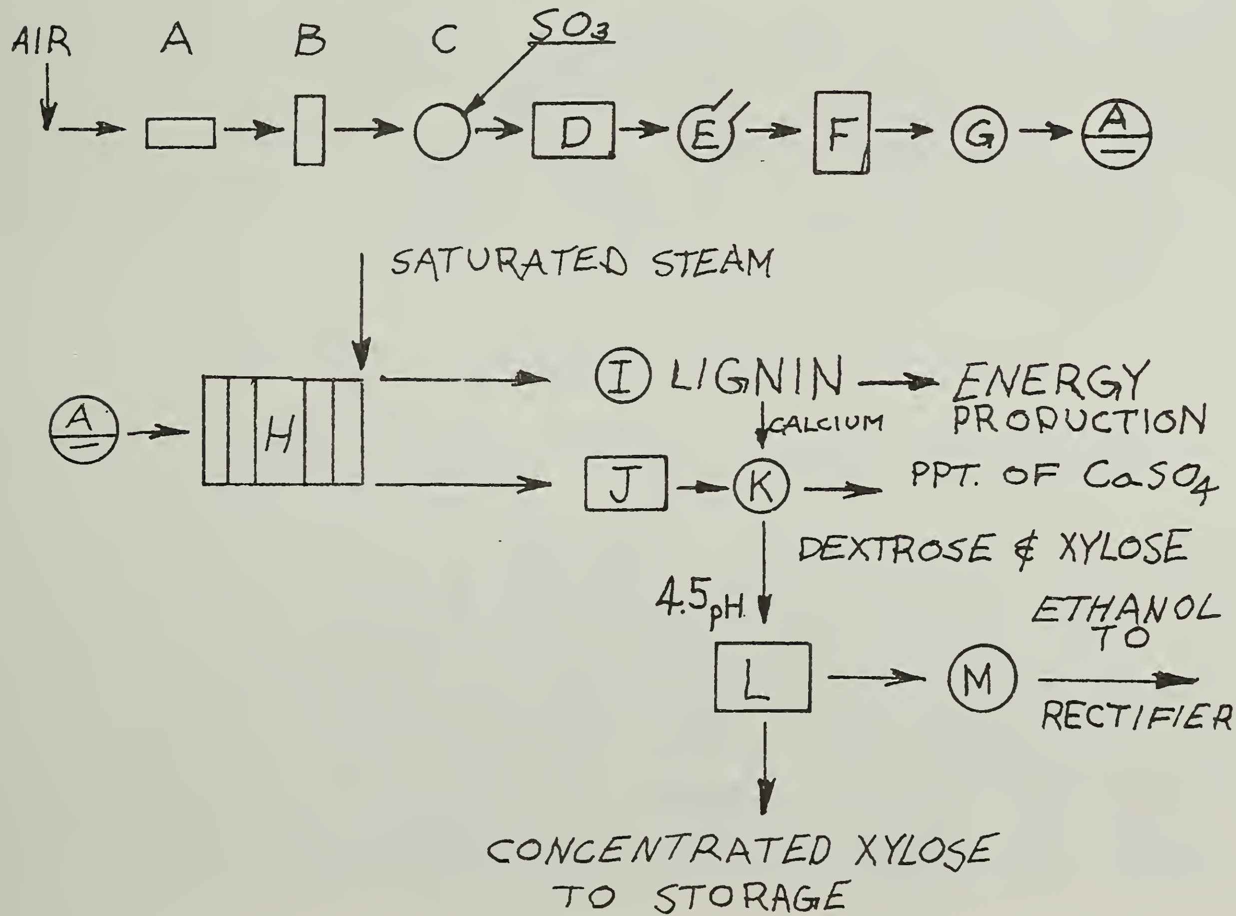
LITERATURE CITED

Seaman, J. F. 1945. Kinetics of Wood Saccharification-Hydrolysis of Cellulose and Decomposition of Sugars in Dilute Acid at High Temperature. Ind. and Eng. Chem. 37(1):43-52.

LEGEND FOR SCHEMATIC FLOW DIAGRAM

A. Air inlet regulator and heater
B. Fiber admission rotary valve
C. Metering valve for SO_3 intake
D. Reaction tubes for SO_3 and fiber particles
E. Centrifugal air mover and cyclone classifier
F. Abrading system
G. Hammer mill
H. Hydrolyzing unit: Input of saturated steam and treated fiber; output of lignin and liquid containing dextrose and xylose
I. Lignin and residual fiber stream for energy production
J. Combined dextrose and xylose stream
K. pH correction with calcium to about 4.0
L. Fermentation of combined dextrose and xylose stream
M. Concentration of combined stream of ethanol and xylose after fermentation by yeast

FIGURE 1.



A FREEZE-EXPLOSION TECHNIQUE FOR INCREASING CELLULOSE HYDROLYSIS

by

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ABSTRACT

A novel pretreatment has been developed to increase the rate and extent of cellulose hydrolysis. This technique is called the freeze-explosion method and relies on treatment of the cellulosic material with volatile liquids under pressure followed by pressure release to evaporate the liquid and reduce the temperature. Volatile liquids which also chemically swell and decrystallize cellulose are particularly effective.

INTRODUCTION

The production of fuels and chemicals by fermentation of renewable resources has received increasing attention. The most viable carbohydrate substrates for fermentation to produce fuels and chemicals will be from lignocellulosic crop and forest materials. These lignocellulosic materials also have potential as animal feedstuffs. A key problem in their utilization for either feedstuffs or fuel/chemical production is the poor yields of glucose from cellulose by acids or enzymes. Typical glucose yields are 50-60% by acid hydrolysis of cellulose and less by enzymatic hydrolysis. If cellulose hydrolysis can be increased economically, production of fuels and chemicals from renewable lignocellulosics will be more feasible and a much larger resource for animal feeding will result.

BACKGROUND: CELLULOSE PRETREATMENT TECHNIQUES

Many techniques have been used to increase the hydrolysis of cellulose. These techniques are generally chemical or physical in nature. The physical treatments include ball-milling to very small mesh sizes, two-roll milling, and attrition milling. These physical treatments do produce a more reactive cellulose. However, the large power requirements for grinding/milling methods make them quite costly. Chemical treatments with strong acids or bases or with other cellulose swelling/dissolving agents also effectively increase cellulose hydrolysis. These chemical agents are often corrosive and costly. Furthermore, they are usually toxic so that complete removal from the treated cellulosic material is necessary. A further problem with these chemical treatments is that chemical recovery requires a wash stream which must then be purified. All these factors combine to increase the expense and difficulty of such methods.

A treatment which involves both physical and chemical aspects is the steam explosion process. Cellulosic materials (usually wood chips) are saturated with water under pressure at elevated temperature, usually 400-500^{o}F. When the pressure is released, the water evaporates rapidly and the wood fibers separate, increasing the surface area for hydrolysis. The moisture and high temperature liberate plant acids which further improve the digestibility (hydrolysis) of the cellulose. Therefore, the process has both physical and chemical aspects. This process requires considerable steam. A further disadvantage is that some of the sugars are inevitably degraded by the high temperatures involved, even at small reaction times.

In attempting to develop improved cellulose pretreatment techniques, the idea of a reduced temperature explosion process suggested itself. The lignocellulosic material would be contacted with a volatile liquid at temperatures less than those which degrade sugars. After a given contact time, the pressure would be released and the volatile liquid would evaporate. The evaporated liquid could then be recovered, if desired. The temperature decrease associated with evaporation of the liquid would tend to embrittle the fiber and enhance fiber disruption. If this volatile liquid were also to swell and decrystallize cellulose, the overall effect on cellulose hydrolysis should be enhanced. A volatile liquid already known to swell cellulose is liquid anhydrous ammonia. We call this method the ammonia freeze-explosion (AFEX) technique.

EXPERIMENTAL EQUIPMENT AND METHODS

Experiments were carried out in a specially adapted one-gallon Autoclave Engineers pressure vessel. Approximately 400 grams of solids were charged to the vessel. The lid was replaced, bolted, and sealed. Anhydrous ammonia (99.5% pure) was obtained locally in a 150-pound tank. Ammonia was transferred to a breathing bottle. The bottle was then weighed. The anhydrous ammonia in the bottle was added to the autoclave through a valve and tubing arrangement and the magnetically-driven stirrer activated. The bottle was reweighed and the amount of ammonia added was determined. Pressure in the vessel was monitored. After the desired contacting time had passed, a ball valve was opened on a tube network which was connected through the vessel lid to the vessel interior. This tubing exited through the wall of the building and discharged. The autoclave lid was then taken off and the solids removed. The material stood overnight to evaporate residual ammonia.

Enzymatic hydrolysis was used to measure the response of the material to treatment parameters. The enzyme solution was prepared by mixing 1.5 gm of cellobiase solution with 3.0 gm of SP 122 Novo cellulase and diluting the resulting mixture to 100 mls with 0.1 M citrate buffer, pH 4.7. Two mls of this solution were diluted with one ml of citrate buffer and added to 100 milligrams of the cellulosic material. These enzyme levels are approximately 86 International Units (IU) of cellulase activity per gm of dry fiber (40,000 IU/lb dry fiber). Following enzymatic hydrolysis, the sugar solutions were analyzed using the dinitro-salicylic acid (DNSA) technique and confirmed by high pressure liquid chromatography (HPLC).

The primary lignocellulosic material used in this study was a low-quality (high cellulose) alfalfa hay ground to pass a 2 mm screen. Our reasons for choosing alfalfa as a biomass energy source are described in another paper in this symposium. On a dry basis, the alfalfa used contained about 40% cellulose and 9% hemicelluloses. Table 1 shows the sugar produced after a 24-hour enzymatic hydrolysis of alfalfa treated under a variety of conditions.

Table 1. Effect of treatment conditions on alfalfa cellulose hydrolysis by enzymes.

Time of Treatment, hours	Pressure, kg/cm^2	Ammonia: Alfalfa Weight Ratio, kg/kg	Sugar Yield mg glucose/ gm dry fiber	(% of theoretical conversion)
0.0		no treatment	210	(47)
0.5	12.7	1.1	404	(91)
0.5	10.2	1.7	328	(74)
0.1	11.6	2.0	400	(90)
1.0	10.2	3.3	338	(76)

It appears that a treatment rate of about 1 kg ammonia per kg of dry fiber, a pressure of about 12 kg/cm^2 (180 psia) and a treatment time of 0.1 hour or less are sufficient to promote greater than 90% hydrolysis of the available cellulose in this alfalfa sample.

While the ultimate extent of cellulose hydrolysis is important, the initial rate of hydrolysis and the amount of enzyme required are also crucial. Duplicate samples of ammonia-treated material were therefore prepared at the "optimum" conditions established previously. The resulting samples were hydrolyzed at the usual enzyme level of 86 IU/gm fiber and at 17 IU/gm fiber. Sugar production at 3 hours represented the initial rate of reaction and the amount produced after 24 hours the ultimate extent of cellulose hydrolysis. The results of these experiments are presented in Table 2.

Table 2. Initial rate and ultimate extent of cellulose hydrolysis at two enzyme levels

Replicate #	Enzyme Level IU/gm dry fiber	3-hour Hydrolysis mg glucose/gm dry fiber	(% of theoretical conversion)	24-hour Hydrolysis mg glucose/gm dry fiber	(% of theoretical conversion)
1	86	353	(80)	387	(87)
1	17	386	(87)	421	(95)
2	86	331	(75)	400	(90)
2	17	342	(77)	406	(91)
untreated	86	103	(23)	247	(56)
untreated	17	82	(18)	172	(39)

These high rates of cellulose hydrolysis at relatively low enzyme levels are very significant.

Subsequent experiments have shown that the AFEX treatment is effective up to about 30% sample moisture. If slow pressure release is used with ammonia as the volatile liquid, the cellulose hydrolysis is about 70-75%. If a non-cellulose swelling agent such as carbon dioxide is used with rapid pressure release, the cellulose hydrolysis is also 70%. Apparently there is a synergistic effect between the rapid pressure release and the decrystallizing effect of liquid ammonia that allows cellulose conversions in excess of 90% with the AFEX technique.

It appears that the rapid pressure release causes the ammonia to "boil" violently and thereby disrupts and expands the fiber. It is similar to the steam explosion process except that our temperatures and pressures are much lower. There is also a dramatic decrease in bulk density of AFEX-treated alfalfa, 0.18 gm/cm^3 versus 0.29 gm/cm^3 for untreated alfalfa. Scanning electron microscope photographs of treated alfalfa support this viewpoint. The ammonia-exploded alfalfa seems to split longitudinally on its fiber axis and is characterized by a large number of exposed fibers which have a thread-like appearance. The large increase in surface area is also indicated by a 50% increase in the water-holding capacity of alfalfa after the ammonia treatment.

In shake flask experiments, the yields of ethanol from several different batches of treated alfalfa were consistently about 250 liters (anhydrous) /metric ton of dry alfalfa (60 gallons/ton). Untreated alfalfa yielded about 150 liters/metric ton (35 gallons/ton). These results for treated alfalfa are close to theoretical ethanol yields so fermentation inhibitors do not seem to be produced.

SUMMARY

The AFEX technique may have considerable potential as a cellulose pretreatment. It obviously increases the rate and extent of cellulose hydrolysis. Also, recovery of the ammonia should be simple and relatively inexpensive. We estimate operating costs of the AFEX process at $5-10/ton material processed. In addition, the treated material is left dry and maintains its improved reactivity for many weeks. The treatment also has a pronounced antimicrobial effect which should partially sterilize the feed. Finally, no high temperatures are required, thereby eliminating the loss of sugars due to dehydration reactions which occur in the steam explosion process and other elevated temperature processes.

PRODUCTION OF LIQUID FUEL FROM HEMICELLULOSE HYDROLYZATE

by

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ABSTRACT

This research effort was initiated on September 15, 1981, to develop an energy-saving process for making hydrocarbon liquid fuels from hemicellulose hydrolyzate derived from biomass. The process employs an acid catalyzed dehydration reaction coupled with solvent extraction to convert xylose into furfural for the subsequent conversion to conventional liquid fuels, such as gasoline or heating oil, by hydrogenation. The scheduled research is concentrated in two areas:

1. The dehydration of xylose to furfural with simultaneous extraction.
2. The hydrogenation of furfural.

Introduction

Hemicellulose is known to be convertible to many combustible liquids such as furfural, furfural alcohol, and tetrahydrofurfural alcohol. There are already established industrial processes for these liquid chemicals. However, the commercial production of furfural involves a heterogeneous process where the hydrolysis of hemicellulose and the dehydration of pentose is carried out in the same vessel, and steam stripping is employed to recover the furfural. In such a process, furfural yield is low and energy consumption is high. In order to achieve higher furfural yields while reducing the energy required to separate furfural from the aqueous solution, we have proposed a process employing a homogeneous dehydration of an acid xylose solution (i.e., the so-called hemicellulose hydrolyzate) with simultaneous extraction of furfural by an organic solvent to separate the furfural. Finally, an exhaustive hydrogenation can be employed to convert the furfural into hydrocarbon liquid fuels. From this, we believe that a quality fuel at reasonable cost can be produced.

Selection of Solvent

Several solvents for the extraction of furfural during the dehydration reaction were considered. A suitable solvent must meet the criterions of acid stability, high distribution coefficient, and ease of separation from the reaction medium, among other desirable features. A total of 14 solvents have been screened resulting in the selection of toluene and trichlorobenzene for further study. The distribution coefficients measured over the temperature range of 130-170°C are 3.6 and 3.1, respectively.

Production of Furfural in the Presence of Solvent

Batch experiments were carried out for the production of furfural in aqueous acidic xylose solution with simultaneous extraction of the furfural by selected organic solvents. Xylose concentrations from 0.4-0.8 GM/L, temperature range from 150-170°C and solvent ratio of 2.3-9.0 were studied. Without an organic solvent, the maximum furfural yield of 35 mole percent occurred in 60 minutes (H_2SO_4 = 0.4 N, 150°C). When the organic solvents were utilized, the accumulation of furfural in the solvent phase gave maximum yields in excess of 55 mole percent. The volumetric ratio of the solvent and aqueous phases was 2.33. All other experimental conditions were identical to the experiment without solvent. Therefore, the substantial improvement in yield can be attributed to the presence of a solvent. Comparable yields for both toluene and trichlorobenzene were expected because the distribution coefficient is similar for both solvents. The effect of the initial xylose concentration was studied over the range of 0.8-0.4 G-mole/L (corresponding to 120-60 G/L). The yield increased from 55% to 66% as the initial xylose concentration was decreased. But the higher concentration is likely to be more economical in a realistic process.

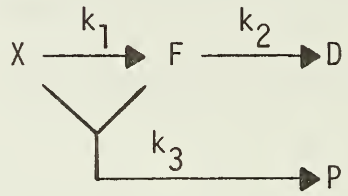
The effect of solvent ratio to the maximum yield for furfural was also studied. As expected, the yield increased substantially (from 55% to 63%) as the ratio was raised from 2.3 to 4.0. However, the yield was not improved beyond the ratio of 4. The limitation in the mass transfer rate of the current experimental system could be one controlling factor. The lack of driving force due to the very low furfural concentration in the aqueous phase could be another. Under the present conditions studied, an 80% improvement in furfural yield was achieved for the dehydration-solvent extraction scheme over the simple dehydration scheme.

The effect of temperature on yield was also studied and was found negligible over the range of our experiment (150-170°C). The consistency of the distribution coefficient in this temperature range might be responsible for the insensitive temperature response.

Aiming at further improvement in the furfural yield, a preliminary evaluation of three reaction-extraction schemes for a CSTR system had been made. It is conceivable that the continuous flow reactor may remove the product from the reaction system and therefore provides higher yields than the batch reactor. Among these three extraction schemes analyzed (counter-current, co-current and cross-current), the former gave the highest yield and best efficiency. Apparatus for single stage CSTR has been completed and experiments are in progress.

Kinetic Study of the Homogeneous Dehydration of Xylose

Based on our recent observation of a direct feed-back reaction of furfural on xylose, Dunlop's reaction model has been modified to the following working model:



where X is xylose, F is furfural, D is decomposition product, and P is polymerization product. The rate constants measured by the initial rate methods are:

$$k_1 = 2.86 \times 10^{12} [H_2SO_4] \exp(-26{,}800/RT) \qquad m^{-1}$$

$$k_2 = 1.01 \times 10^{9} [H_2SO_4] \exp(-21{,}500/RT) \qquad m^{-1}$$

$$k_3 = 1.13 \times 10^{36} [H_2SO_4] \exp(-70{,}900/RT) \qquad m^{-1}M^{-1}$$

Accordingly, k_1/k_2 increases with increasing temperature, but k_1/k_3 decreases with rising temperature. This might partly explain the insensitive temperature effect we observed previously. The fitness of this model will further be tested with CSTR experiments.

Hydrogenation of Furfural

The assembly of an explosion-protected, continuous sampling high-pressure hydrogenation apparatus for the hydrogenation of furfural has been completed. Test runs of the apparatus are started.

SUMMARY

Batch type homogeneous dehydration and extraction of xylose solution for furfural production has been performed. An 80% improvement in furfural yield has been observed. Experiments with CSTR are in progress. The extraction coupled reaction system looks promising because the presence of a solvent protects much of the furfural from being degraded by side reactions.

SWEET POTATO CULTIVARS FOR ETHANOL PRODUCTION

by

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ABSTRACT

Research was initiated on sweet potato biomass production in January, 1980, with preliminary selections made from 1979 seedlings of our other breeding projects. Through studies of selections with various flesh colors, dry matter (DM) percentages, and field yields, selection criteria for improved ethanol production have been established. Dry matter yield trials have resulted in identification of several promising selections.

Of all crops considered for energy production from biomass, the sweet potato is probably one of the most promising. It has a long growing season limited only by cold temperatures. Because it does not mature like so many other crops (such as corn) it can continue to make use of solar energy until it is harvested. It is drought tolerant and will grow on deep sands where few other crops could thrive and produce. It was thus a natural candidate for consideration as research in energy production became funded in '79 and '80. In initial comparisons with other crops it suffered badly because of a lack of adequate yield data. Many authors used crop yield statistics to estimate potentials for ethanol production of various crops. The 12.3 mt/ha (5.5 T/A) found in the crop statistics reflected only marketable yields which have little relationship to total sweet potato yields. Therefore, one of our first tasks was to generate more meaningful yield data. We have conducted field trials of many cultivars under many cultural conditions and studied correlations of various root components and dry matter yields. Roots from the field trials have been subjected to laboratory studies of the soluble and insoluble components of dry matter. In all of these studies we are characterizing the genetic diversity available for selection of new cultivars for ethanol production. At the same time we are developing selection criteria and techniques to improve the efficiency of breeding better biomass types.

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2 Clemson University, Edisto Experiment Station, Blackville, SC, Research supported by Cooperative Agreement No. 58-7B30-0-158.

We report here some of our initial progress in development of cultivars specifically for high dry matter yields. With present cultivars grown for table use we could get field yields three to four times the marketable yields reported in statistical summaries. This can be accomplished by extending the growing season beyond the time required for maximum US #1 root yields and reporting total weight without regard to market quality. Over the past 3 years 'Jewel' has yielded 5.4 to 10.2 mt/ha of DM in these trials (Table 1). We often got 30% higher yields in other trials not reported here, and therefore consider the 10.2 mt/ha DM as a conservative estimate of yield potential for 'Jewel'.

By relaxation of the many selection criteria necessary for a standard sweet potato cultivar it is rather easy to find types such as TG-2 (Table 1) with about 33% higher DM yield than 'Jewel'. Past experience indicates however that as field yields increase one is likely to experience reductions in DM which then leads to increased bulk volume and weight and consequent reductions in handling efficiency. It is even possible to find dark orange flesh table types with higher DM yields per hectare, such as W-152, but these are not likely to be any more efficient in terms of DM per unit weight handled. One of our early selections for high DM yield, W-190, continues to be one of the best we have identified to date and illustrates the kind of economy possible. With about 25% less field yield than 'Jewel' it has about 25% higher DM yield. We have other selections (W-201, 81 BM-105) with higher DM yields per hectare than W-190 which are only about 20% less efficient to handle and, perhaps, should be considered in future trials.

The DM composition of the various cultivars has differed considerably as one would expect (Table 2). The insoluble residue of W-190 was higher than we would prefer, but the sugar + starch yield per hectare was still one of the highest of all lines tested. Clearly the composition of the DM must be considered in establishing selection criteria for new biomass cultivars. With 'Jewel' one would have to harvest, haul, store and process about 6.6 mt/mt of sugar + starch. With W-190 one would have to handle only 3.2 mt/mt sugar + starch.

Only preliminary trials have been conducted on actual ethanol production from the various lines and we may find other factors that must be added to the selection criteria as we get into that phase of the work. We have some indications of variations in heavy metals (Fe, Cu, Mn, Zn) which possibly could lead to differences in fermentation efficiencies.

Previous alcohol estimates based on yields of 12.3 mt/ha (5.5T/A) were 1612 liters/ha (190 gal/A). We now know one could expect 3 to 4 times that yield or 4836-6448 liters/ha (570-760 gal/A) with 'Jewel' and about 25 to 50% more with a cultivar like W-190 which would equal 6045-9672 liters/ha (712-1140 gal/A). We believe with additional research to improve DM yields and conversion efficiencies that the potential upper limits are higher than these estimates.

Table 1. Field yields, dry matter percentage and dry matter yields[x] of selected sweet potatoes.

Cultivar	Field yield (mt/ha)			DM%			DM yield(mt/ha)			Fresh wt./Dry wt.
	1980	1981	1982	1980	1981	1982	1980	1981	1982	1982
Jewel	45.2	21.9	37.2	22.5	24.6	23.6	10.2	5.4	8.8	4.24 (100)[z]
W-152	--	31.2	45.7	--	22.7	22.8	--	7.1	10.4	4.38 (97)
TG-2	60.7	30.5	47.1	18.0	23.7	21.6	10.9	7.2	10.2	4.68 (91)
W-190	34.4	16.4	26.5	37.5	43.1	37.9	12.9	7.1	10.0	2.64 (161)
W-201	--	52.0[y]	38.6	--	30.3[y]	27.9	--	15.8[y]	10.8	3.59 (118)
81 BM-105	--	--	38.9	--	30.3	31.7	--	--	12.3	3.15 (135)

[x]These are conservative DM yield estimates. We get about 30% higher yields in some trials and probably could do better in solid stands of one cultivar managed for maximum yield.

[y]Preliminary data from a different trial in which 'Jewel' produced 8.6 mt/ha DM.

[z]A measure of relative handling efficiency when compared to Jewel.

SUMMARY

Selection techniques and criteria for identifying promising sweet potatoes for ethanol production have been developed. One line (W-190) has about 40% DM and averaged 10 mt/ha over three years. It represents future cultivars much more efficient than those presently grown. We estimate ethanol yields as high as 6045-9672 liters /ha (712-1140 gal/A) are possible with selections presently available. Continued research on production and conversion efficiencies we believe could lead to even higher yields.

Table 2. Soluble and insoluble DM components of selected sweet potatoes (1981).

Cultivar	Soluble		Insoluble residue %	Sugar+ Starch (mt/ha)[x]
	Starch %	Sugar %		
Jewel	11.9	3.2	9.5	3.3 --
TG-2	11.8	4.1	7.8	4.9 (48.5)[y]
W-190	27.1	3.8	12.2	5.1 (54.5)[y]
W-201	17.2	4.5	8.6	5.6 (69.7)[y]

[x]Conservative yield estimates - we often get about double our 1981 yields.

[y]Percentage increase relative to 'Jewel'.

FARM ALCOHOL/METHANE PRODUCTION MODEL

by

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ABSTRACT

Farm produced alcohol and methane can provide effective alternate fuel sources for agricultural production and can be integrated with traditional farm activities. Such an integrated system could include use of grain crops for alcohol feedstocks, feeding of wet stillage byproducts to farm livestock, using of animal wastes in methane digesters, producing thermal and/or electrical energy from the methane, and sharing products, equipment, and labor with other farm activities. To allow an objective and quantitative analysis of installing such fuel-producing facilities on farms, a model was developed to determine energy balances and present an interactive portrayal of the integrated farm system.

Background

Production of alcohol using corn as the feedstock will result in a large volume of distillery waste (stillage). Byproduct stillage can be fed to livestock since fermenting the corn mash removes only the carbohydrates, leaving a product that is high in proteins and digestible nutrients.

Biogas, consisting primarily of methane, can produce anaerobic digestion of livestock wastes. Biogas can be burned to produce thermal energy or burned in a generator where electricity and waste heat are produced.

A model has been developed that determines the effects of incorporating an alcohol plant and/or an anaerobic digester into the activities of a farm. The purpose of this model is to (1) size an alcohol plant or digester for a given farm, (2) determine alcohol and methane yields for each facility, (3) determine livestock rations with and without stillage feeding, and (4) provide yearly energy consumption and production figures for determining the overall effect of installation. From this information, a selection can be made of the facilities most beneficial to the farm being analyzed.

Description of the Model

The alcohol plant model has been developed explicitly for dairy animals because stillage is an ideal feed material. Stillage is about 92% water and contains a relatively high concentration of protein on a dry-weight basis; dairy cows have both high moisture (50 gallons/day) and protein requirements. Alcohol plant sizing is determined by the number of dairy animals on the farm and a preset maximum stillage consumption (27 gallons per cow per day). Transporting stillage to other farms is not cost-effective because of the increased prices of tank trucks, fuel, and labor.

The optimum combination of stillage, grain, and hay was based on recommended dairy rations. A mature milk-producing cow (about 1350 pounds) is designated 27 gallons of stillage, 5 pounds of corn, and 12 pounds of hay. The ration is adjusted as the amount of stillage is decreased, providing a final ration with no stillage of 18 pounds of corn, 2 pounds of soybean meal, and 20 pounds of hay. The ration is balanced in the program using the combination of crops available on the farm. Inputs include number of cows, heifers, and calves; acres of corn (double-cropped with wheat), sorghum (double-cropped with wheat), soybeans, hay (three choices given are lespedeza/timothy, alfalfa, and clover/timothy), and pasture; and average yields of each crop. The program output presents a yearly total of crop consumption, crop surplus available for sale, and feed purchasing requirements.

Based on the size of the alcohol plant, the model calculates the number of bushels of corn required annually, BTUs required in cooking and distilling the mash, BTUs of electricity consumed, and gallons of water used in cooking and cooling. Cooling water was assumed to be obtained from a lagoon that is sized (diameter and depth) according to daily water demand. Calculations are based on the equation:

$$1 \text{ bu corn} + 25 \text{ gal water} \longrightarrow 0.8 \text{ gal } CO_2 + 2.5 \text{ gal EtOH} + 27 \text{ gal stillage}$$

Energy figures are based on data collected from the TVA/DOE Farm Alcohol Experimental Facility. Yearly labor requirements are calculated in hours and vary with size of plant.

Yearly totals for feed and stillage consumption, energy requirements, and gallons of ethanol produced are printed in the output adjacent to the totals for the farm without the alcohol plant. Maximum alcohol plant sizing may not be advantageous in all circumstances. Therefore, after printing the output, the model returns to the beginning and recalculates rations and energy requirements for each consecutively smaller sized plant.

Methane production from manure is not limited to dairy wastes. Total volume of manure volatile solids available for anaerobic digestion is determined based on number and type of livestock. Animal choices include dairy cattle, beef cattle, swine, and poultry. Optimum digester tank retention time is set by the operator and varies with animal type. Tank volume is calculated using the total volatile solids, retention time, and dilution water requirements. Four alternative tank shapes are provided: tanks with a cyclindrical, rectangular, or trapezoidal cross-section, all having length equal to four times the width or diameter, and a vertical cylindrical tank with height equal to diameter.

Methane production depends on digester temperature, retention time, ultimate methane yield per pound of volatile solids, and total digester volume. Monthly surface heat loss and heat required to maintain digester temperature are determined from the monthly ambient temperatures for the area.

Monthly volume of methane produced can be converted to thermal heat units. When methane is used to operate a boiler, some waste heat is lost due to boiler inefficiency. When methane is used to run a generator, this waste heat becomes available with the concurrent electrical production. Generator efficiency is calculated from volume of methane produced and volume fraction of methane in the biogas.

Output for the model lists four tank shapes and dimensions required for the volatile solids volume. A table of monthly figures include tank surface heat loss and heat required to maintain digester temperature, and volume of methane, thermal heat, boiler heat, electricity, and generator heat production totals.

Another option available is to screen the stillage, feed the solids, and place the "thin stillage" in an anaerobic digester. Thin stillage, containing 25% of the original dry matter, has a higher methane yield than manure. The model determines the effect of this option on biogas production, and lists yields adjacent to biogas yields from manure digestion.

Solids collected from screening are fed wet to livestock. Since one-fourth of the dry matter has been diverted to the digester, this part must be replaced by corn and hay in the livestock diet.

Program output lists results of the biogas-from-manure digester followed by the biogas-from-stillage digester. The alcohol plant results with and without the still and incorporating the screening of the stillage are listed next. Finally, energy totals (consumption and production) are presented from each facility and combined to yield total energy input and output and supplemental energies required.

SUMMARY

A model has been developed to integrate an alcohol production plant and/or an anaerobic digester into the processes of an existing farm. Given the farm description, the model determines maximum alcohol plant sizing based on the amount of stillage consumed by livestock, and calculates energy requirements and alcohol production for the selected plant. After determining total pounds of volatile solids collectible from the livestock, the model determines the methane production and resulting thermal or electrical production. The output allows a comparison of energy exchange between systems for an overall evaluation of integrated farming.

USE OF CORN STILLAGE IN DIETS FOR GROWING-FINISHING SWINE

by

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ABSTRACT

Eleven cafeteria type feed preference trials, two switch-back feed intake trials, and a preliminary growth trial were conducted to evaluate the effects of the use of several additives in diets for swine that contained corn stillage. The addition of sodium bicarbonate increased preference and caused an increase in feed intake when stillage was mixed 3:1 with dry ingredients. During the growth trial, the addition of sodium bicarbonate did not improve performance. During a second series of cafeteria trials, the combination of sodium bicarbonate + glutamic acid greatly increased both preference ($P<.05$) and intake ($P<.01$) of stillage, when dry ingredients and stillage were fed separately.

INTRODUCTION

Research into the use of the liquid by-products of ethanol manufacturing, in swine diets, although not particularly extensive, is not new. A striking characteristic of this research is the number of trials in which it was necessary to limit the availability of water in order to assure adequate intake of the liquid distillery by-products (for example, Feedstuffs, 1981). The low palatability indicated may be as much of a problem as nutrient content, as nutrient supplementation would be to no avail if the material is not eaten. The following trials were conducted in an attempt to improve the palatability of corn stillage for swine.

MATERIALS AND METHODS

Whole stillage obtained from a commerical distillery was settled for 24 hr, the thin supernatant was removed, and the residue was stored with constant agitation while CO_2 was sparged into the material (Bryan et al., 1981). This settled corn stillage averaged 8 to 9% dry matter initially.

In the first series of eight trials, four individually penned pigs were given access to four diets placed in four-hole feeders in random order. On the third day of the 5-day trials the order of the diets was switched, and intake data for the last four days was collected. Stillage diets were 3:1, stillage:dry diet, as fed. Diets were: dry, stillage or stillage containing the following additives at the levels indicated (amount/kg): $NaHCO_3$ (4 & 11 g), artificial flavor-sweetner (.75, 1.0 & 1.5 g), artificial flavoring (.75 & 1.0 g), propionic acid (.5 & .75 g), $Ca(ClO)_2$ (.5 & 2.5 ml saturated), dried molasses (25 g), anise extract (.055 ml), dried whey (10 g) and/or KCl (2.5 g). Fresh stillage was also compared to stillage stored for approximately one month. In a switch-back trial, control stillage intake was compared to $NaHCO_3$ stillage intake in four pigs with access to only one diet on a given day. In a preliminary trial eight pigs per diet were fed a dry control diet, propionic acid containing stillage and dry ingredients, or propionic acid and flavoring stillage and dry ingredients containing $NaHCO_3$. All diets were balanced for protein, lysine, vitamins and minerals. The stillages were fed in automated feeders which mixed wet and dry ingredients as the diets were consumed.

A second series of cafeteria trials was conducted in a manner similar to the first series, except that the pigs were fed a standard amount (1.36 or .91 kg) of dry ingredients separate from liquid stillage in the four-hole feeders. All stillages contained propionic acid (77 g/kg). Treatments were control, glycylglycine (83.7 mg/kg), glutamic acid (163 mg/kg), lysine (410 mg/kg), acetamide (64 mg/kg), Na citrate (420 mg/kg), and/or $NaHCO_3$ (12 g/kg). A switch-back intake trial with four pigs compared stillage with stillage containing $NaHCO_3$ + glutamic acid.

RESULTS AND DISCUSSION

Feed intakes for the first eight cafeteria trials are shown in table 1. Pigs preferred a dry diet to diets that contained stillage. Addition of propionic acid did not significantly reduce intake. Old stillage with a higher acid content (Bryan and Johnson, 1981) was preferred over fresh stillage. Sodium bicarbonate at 11 g/kg significantly increased preference. Addition of other additives along with bicarbonate did not improve intake. In the intake trial, when given no choice, pigs consumed 9.35 kg/day of control diet and 10.57 kg of diet with bicarbonate stillage ($P<.05$).

During the feeding trial average daily gains were .77, .77 and .80 kg/day for pigs fed: dry, stillage and stillage + additive diets, respectively. Dry matter intakes and feed/gain ratios were 2.11 and 2.75; 2.18 and 2.82; and 2.33 and 2.89 for dry, stillage and stillage + additive diets. It appeared that stillage dry matter was less well utilized than that from conventional ingredients. When stillage and dry ingredients were mixed, any aversion to the taste of stillage lasted for only a few days, based on our observations. This effect may have been a factor in the outcome of the feeding trial.

During the second series of cafeteria trials (table 2) glutamic acid and glutamic + bicarbonate increased preference. Intakes for the switch-back trial were 2.53 kg/day for control stillage and 10.76 kg/day for glutamic + bicarbonate stillage ($P<.01$).

TABLE 1. INTAKE (AS FED BASIS) OF STILLAGE DIETS (3:1 STILLAGE: DRY INGREDIENTS) CONTAINING SEVERAL ADDITIVES (AMOUNT/KG) DURING SEVEN CAFETERIA TRIALS WITH PIGS.

Trial	Treatment	Intake (kg/pig/day)
1	Dry diet	1.79
	Control	1.71
	Sweetner (.75 g)	1.66
	$NaHCO_3$ (4 g)	1.51
2	Control	2.67
	Propionic (.5 g)	2.52
	Sweetner (1 g)	2.43
	Flavor (1 g)	2.32
3	Fresh stillage	2.93[b]
	Stored stillage	4.28[c]
4	Control	3.37[bc]
	$NaHCO_3$ (11 g)	4.17[b]
	$NaHCO_3$ (11 g) + sweetner (1.5 g)	3.00[c]
	Sweetner (1.5 g)	1.83[d]
5	$NaHCO_3$ (11 g)	5.60[b]
	Propionic (.75 g)	1.59[c]
	$Ca(ClO)_2$ (2.5 ml sat.)	.28[d]
	$Ca(ClO)_2$ (2.5 ml) + flavor (.75 g)	.46[d]
6[a]	$NaHCO_3$ (11 g)	3.15
	$NaHCO_3$ (11 g) + dry molasses (25 g) + anise ext. (.055 ml)	2.66
	$NaHCO_3$ (11 g) + molasses (25 g)	2.47
	$NaHCO_3$ (11 g) + anise (.055 ml)	2.41
7[a]	$NaHCO_3$ (11 g)	1.81
	$NaHCO_3$ (11 g) + molasses (25 g) + anise (.055 ml)	1.54
	$NaHCO_3$ (11 g) + molasses (25 g) + anise (.055 ml) + $Ca(ClO)_2$ (.5 ml)	1.27
	$NaHCO_3$ (11 g) + $Ca(ClO)_2$ (.5 ml)	1.23
8[a]	$NaHCO_3$ (11 g)	2.98
	$NaHCO_3$ (11 g) + dried whey (10 g)	2.79
	$NaHCO_3$ (11 g) + anise (.055 ml)	2.40
	$NaHCO_3$ (11 g) + KCl (2.5 g)	2.32

[a]All diets contained .77 g propionic acid/kg stillage.

[b,c,d]Means within trial with different superscripts were different, $P<.05$.

TABLE 2. INTAKE OF STILLAGE CONTAINING PROPIONIC ACID (.77 G/KG) AND OTHER ADDITIVES (AMOUNT/KG) BY PIGS FED LIMITED AMOUNTS OF DRY FEED[a] DURING THREE CAFETERIA TRIALS.

Trial	Treatment	Intake (kg/pig/day)
10	Control	1.09
	Glutamic (163 mg)	1.42
	Lysine (410 mg)	1.16
	Glycylclycine (84 mg)	1.14
11	Control	.93[b]
	Glutamic (163 mg)	1.33[c]
	Acetamide (64 mg)	.97[b]
	Na citrate (420 mg)	.97[b]
12	Control	.22[b]
	$NaHCO_3$ (12 g) + glutamic (163 mg)	3.46[c]
	$NaHCO_3$ (12 g)	1.49[d]
	Glutamic (163 mg)	.25[b]

[a]1.36 kg of dry feed/pig/day during trial 10 and .91 kg during trials 11 and 12.
[b,c,d]Means within trials with different superscripts were different, $P<.05$.

SUMMARY

Eleven cafeteria type palatability trials, two switch-back feed intake trials, and one growth trial were conducted with growing-finishing swine. Storing stillage under a CO_2 atmosphere does not adversely affect its palatability, although total acidity increases. Neutralizing the acidity of stillage increases its acceptability by swine. When stillage is mixed with dry ingredients, pigs are forced to consume stillage, much as they are with water restriction, and aversion lasts only a relatively short time. With further testing, neutralizing the acidity of stillage and adding glutamic acid may prove to be beneficial, especially in free choice feeding situations.

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NUTRITIONAL VALUE OF STILLAGE IN DIETS OF DAIRY CATTLE

by

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ABSTRACT

Three experiments were conducted to assess the nutritive value of corn stillage (90.2 to 92.5% moisture) when incorporated as 10% of the dry matter in conventional silage based diets for dairy cows. Cows showed an immediate and pronounced preference for the stillage diet compared to non-stillage control diet when both were available. However, this preference failed to produce increased dietary dry matter intake compared to that obtained when only control diet was fed. Two following experiments showed small, but consistent advantages of the stillage diet for small increases in efficiency of conversion of dietary dry matter into milk (3.5 to 5.0%). This was associated with a small but significant ($P<.01$) advantage of increased milk production (2.3%).

INTRODUCTION

Characteristics of distillers dried grains with solubles have been clearly defined. Use of this by-product has been extensively tested in diets for lactating dairy cows and found to be a very good high protein content feedstuff. The quantity of stillage (undehydrated distillers grains and solubles) available for feeding is expected to increase because of the energy and equipment cost for drying. Much of the information about the use of stillage for lactating dairy cows is based on observations rather than well controlled research. Because unprocessed stillage usually contains 93 to 95% water, it is likely that stillage can be used successfully to supply only a relatively small amount of the dietary dry matter in conventional silage based diets. Research was initiated to evaluate responses from including stillage in such diets in amounts equivalent to 10% of the dietary dry matter intake.

MATERIALS AND METHODS

Whole stillage obtained from a commercial beverage ethanol distillery was settled for 24 hours and the thin supernatant removed. The residue was stored with constant agitation and sparging of CO_2 for preservation (Bryan et al., 1981). Dry matter contents of the resulting batches of settled stillage blended into the diets ranged from 7.5 to 9.8%.

Corn silage supplied 50, 55 and 45% of the dry matter of diets in experiments 1, 2 and 3, respectively. Stillage contributed 10% of the dry matter in each stillage diet. The remainder of dry matter in stillage and control diets came from dry concentrates of corn, cottonseed meal, citrus pulp, soybean mill feed, and minerals. In each experiment, the control and stillage diets were formulated to contain similar amounts of energy, protein, fiber and minerals adequate to meet the needs of the lactating cows. Diets were blended and fed twice daily. In each experiment the diets were fed in excess of anticipated intakes. Refused feed was weighed at the morning feeding.

In the first experiment 45 lactating Jerseys and Holsteins averaging mid-lactation, were given free choice of stillage or control diets for 6 days followed by 6 days of restriction to control diet. For the second experiment, control and stillage diets were fed for 28 days each to 11 Holsteins and 9 Jerseys that averaged past mid-lactation. The third experiment was a switchback feeding trial involving six 28-day periods and three switches. The performance of 15 pairs of Holsteins and 16 pairs of Jerseys fed stillage or control diets was measured. All pairs were not used in all periods, but 20 pairs were used each period. When cows were initially used in this experiment they had passed lactation peak milk production, but had not reached mid-lactation.

RESULTS AND DISCUSSION

In experiment 1 cows showed a pronounced preference for the stillage diet. When both diets were available, dry matter intake and milk production averaged 17.6 and 19.7 kg/cow/day, but dry matter intake from the stillage diet was 79% greater than that of control diet. However, dry matter intake and milk production were not reduced when only control diet was available (17.7 and 20.1 kg/cow/day). Moisture contents of the stillage and control diets averaged 67 and 43%.

Moisture contents of stillage and control diets used in experiment 2 averaged 69.2 and 51.7%, but the high moisture content of the stillage diet did not reduce intake. Dry matter intakes and milk production from the stillage diet averaged 14.5 and 17.4 kg/cow/day. Performance tended to be less from the control diet; dry matter intake and milk production averaged 14.0 and 16.3 kg/cow/day. Efficiency tended to be higher for the stillage diet; 1.20 kg of milk for each kg of stillage dry matter intake compared to 1.16 for the control diet.

Trends identified in experiment 2 were evident in the larger, more sensitive experiment 3. Compared to experiment 2, the moisture contents of the diets were lower. They averaged 65.9% for the stillage diet and 47.8% for the control diet used in experiment 3. Dry matter intake was slightly less for the stillage diet, 18.7 vs 19.0 kg/cow/day. However, as in experiment 2, the efficiency was higher for the stillage diet, 1.21 vs 1.15 kg milk produced per kg of dry matter intake. The least squares mean milk production was greater ($P<.01$) from the stillage diet, 22.9 vs 22.4 kg/cow/day.

Dry matter content of the stillage diets used in these experiments varied due to periodic fluctuations in the silage and stillage used to formulate them. It appeared that a stillage diet containing more than 70% moisture would produce some seepage and present problems with blending and conveying.

SUMMARY

Three experiments were conducted to assess the nutritive value of stillage (90.2 to 92.5% moisture) when incorporated as 10% of the dry matter in conventional silage based diets of dairy cows. The initial experiment showed cows had an immediate and persistent preference for the stillage diet when both stillage and non-stillage control diets were available. However, this preference failed to produce increased dietary dry matter intake compared to that obtained when only control diet was available. The two following experiments showed a small, but consistent advantage of the stillage diet for increased amount and efficiency of milk production compared to the control diet. Results indicate that on a dry matter basis, the value of nutrients in stillage is equal to such nutrients found in conventional concentrate feedstuffs. The economy of using high moisture stillage in dairy cattle diets will be dependent upon initial cost of the material delivered to the farm and the cost and maintenance of facilities for storing, preserving and feeding it.

Reference

Bryan, W.L. and J.C. Johnson, Jr. 1981. Concentrating and storing corn stillage for supplemental feeding to dairy cows. Proc. Feed and Fuel Ethanol Prod. Symp. NRAES-17 p. 43.

TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

by

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ABSTRACT

Tropical biomass is an important source of renewable fuels and feedstocks for both developed and developing tropical nations. Tropical grasses, particularly members of the genus *Saccharum* and related genera, are receiving special attention as energy crops in Puerto Rico. Decisive attributes of such species include perennial stool development and a range of physical and physiological features that enable them to "harvest" solar energy on a 24-hour, year-round basis. Often identified as former cattle feed and sugar commodities, their planting as energy crops requires major conceptual changes in field management in order to maximize yield and to optimize energy balance and cost relationships. Puerto Rico studies on tropical grasses have culminated in the "energy cane" concept. This is a concept of production management in which boiler fuels, lignocellulosic feedstocks, and molasses figure more prominently than sugar and cattle feed.

INTRODUCTION

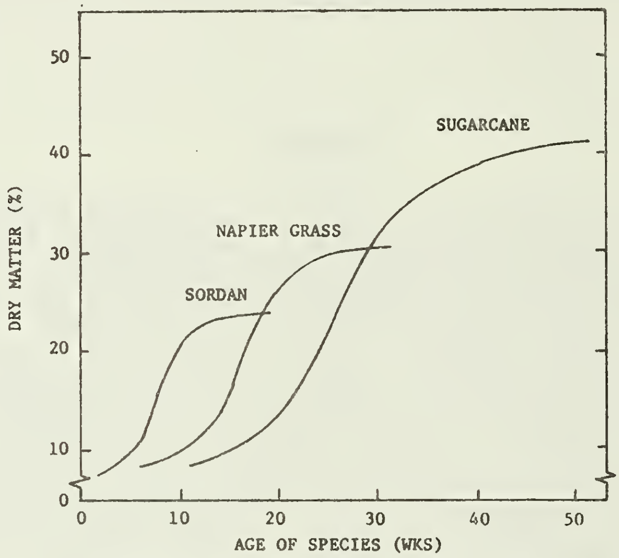
Fast-growing tropical grasses are of special importance to Puerto Rico where perennial growth attributes dovetail naturally with year-round warm temperatures and favorable soil and water resources. Sponsored first by ERDA and later by the DOE Fuels From Biomass program, studies began in 1976 on the production of tropical grasses as boiler fuel substitutes for imported oil (1). Initially a take-off from conventional sugarcane production, this work developed around four principles: (a) Integration of diverse categories to maintain year-round fuels supply; (b) maximization of tonnage to optimize cost and energy balance relationships; (c) technical requirements for moisture removal and size reduction; and (d), multiple products to sustain both fuels and fermentation industries.

TROPICAL GRASSES MANAGEMENT

Categories Integration

Although tropical grasses can be grown continuously, they are ordinarily harvested on a seasonal basis. Harvest seasons for sugarcane range from about 80 days in Louisiana to 12 months for certain tropical regions. In Puerto Rico, cane is currently harvested some four months for sugar, and there is a maximum interval of about eight months suitable for harvest operations of cane managed for energy (ie, "energy cane"). For this reason, considerable effort was directed by CEER-UPR investigators toward the identification and production-management requirements of alternative grasses adapted to shorter periods of growth and maturation. A series of "short-and intermediate-rotation" candidates have been identified as supplemental sources of lignocellulose (Figure 1). These would enable biomass conversion plants based primarily on cane bagasse to operate continuously as a 12-months operation.

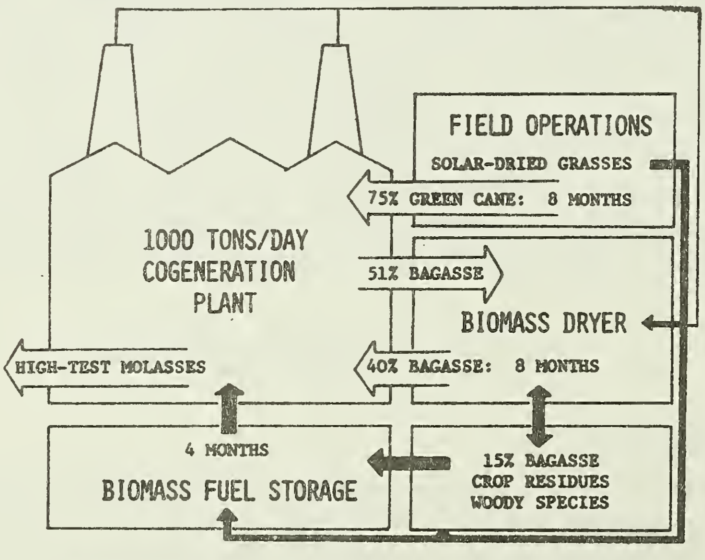
FIGURE 1



GROWTH PROFILES FOR TROPICAL GRASS CATEGORIES

As illustrated in Figure 1, the maturation profiles for the alternative grasses indicate a lower yield potential than cane, but more frequent harvest periods and hence a greater flexibility in their production, harvest, and storage operations. They have the added advantage of solar drying directly in the field, together with completely mechanized production and harvest technologies (1, 2). The integration of such species with energy cane management is illustrated schematically in Figure 2.

FIGURE 2



SCHEMATIC DIAGRAM OF YEAR-ROUND ENERGY CANE OPERATIONS

Maximizing Tonnage

Optimizing total dry matter, as opposed to sugar, protein, or other quantitative factors, requires significant changes in the field management of tropical grasses. Treated elsewhere in detail (1, 2), the example of harvest frequency well suffices to illustrate this point. A popular misconception, even among experienced agronomists, is the assumption that intensive production must require more frequent harvest operations, with all that this entails in increased fuels, chemicals, and labor costs, and an increased use of machinery with negative impacts on seedbed conditioning, soil compaction, irrigation and drainage programs, and so on.

In reality this is a totally incorrect point of view. Maximum yield from tropical grasses invariably entails a delay of harvest and extended intervals between the application of production/harvest inputs. Sugarcane is an excellent case in point. Data presented in Table 1 show a distinctly inverse relationship between increasing harvest frequency and yield. In other words, the surest way to increase the yield of a grass once established is to leave it there, to allow dry matter to accumulate, eventhough visible growth may long since have ceased. Sugarcane, in Puerto Rico, requires a full 18 months to maximize dry matter, and for most of this period there is no need for labor or machinery to enter the field at all. Hence, the maximization of dry matter requires extensive rather than intensive management.

TABLE 1

AVERAGE ANNUAL DRY MATTER YIELDS AS A FUNCTION OF ENERGY CANE HARVEST FREQUENCY 1/

HARVEST FREQUENCY	TOTAL HARVEST	TOTAL DM (TONS/ACRE)
2 Months	6	3.7
4 Months	3	9.9
6 Months	2	16.2
12 Months	1	29.0

1/ Average of 3 crop years.

Dehydration and Size Reduction

Like other biomass forms, the tropical grasses have two negative characteristics in their high water content and irregular, ill-fitting shapes that do not readily lend themselves to effective loading for transport. Hence, the high transportation costs for cane are paid mainly for the movement of water. For thick-stemmed grasses such as the sugar and energy canes these costs are compensated by the fermentable solids recovered at the mill as part of the dewatering process. Thin-stemmed grasses, such as the short- and intermediate-rotation categories noted above, can be "conditioned" and solar-dried in the field, and compacted there into round or rectangular bales. This provides for a more efficient transport and increased energy payload. Additional size reduction with a "tub" grinder further improves the transportation qualities of solar-dried tropical grasses.

Multiple Products

In addition to their high tonnage yields, grasses such as the sugar and energy canes yield a considerable range of products. Sometimes lumped together under the terms "fermentable solids" and "fiber", these include raw sugar, refined sugar, blackstrap molasses, high-test molasses, syrup, and a boiler fuel commonly known as "bagasse". When dried, clean bagasse is a suitable feedstock for numerous downstream products.

Production Costs

In 1980 the production costs for three "first generation" energy cane harvests (plant crop and two ratoon crops) were tabulated. These figures were updated in 1982 utilizing plant crop data from "second generation" energy cane (Table 2). Of special significance are the disproportionately high costs of transporting cane to the mill, together with fertilizer charges and the cost of harvest operations. Each of these inputs cost more

TABLE 2

PRODUCTION INPUTS AND COSTS FOR ENERGY CANE; 1980 AND 1982

INPUT 1/	COST ($/YEAR) 1980	1982	% CHANGE SINCE 1980
Land Rental	10,000	10,000	0
Sedbed Prep.	3,000	3,900	+ 30
Water	12,000	12,000	0
Water Application	9,600	10,752	+ 12
Seed	3,000	3,000	0
Fertilizer	36,000	44,640	+ 24
Pesticides	5,300	6,572	+ 24
Harvest 2/	20,000	24,800	+ 24
Day Labor 3/	6,048	6,754	+ 10
Cultivation	1,000	1,240	+ 24
Land Renovation	600	660	+ 10
Delivery	46,200	65,825	+ 24
Subtotal	152,746	190,144	+ 24
Management	15,270	15,270	0
Total Cost	168,023	205,356	+ 22
Cost/Acre	840	1,027	+ 22
Cost/Ton	10.12	9.33	- 7.8

1/ Assumes a planted area of 200 acres, privately owned.
2/ Includes equipment charges, depreciation, and labor.
3/ Labor not included in other costs.

in 1982 owing to inflation and the increased value of fossil energy. However, because of still larger increases in energy cane yield, the cost per ton of cane was moderately reduced.

SUMMARY

Studies in Puerto Rico with a range of both seasonal and perennial tropical grasses have culminated in the "energy cane" concept of domestic fuels and feedstocks planting. Production cost data indicate that energy cane is the most economical boiler fuel option for Puerto Rico today, amounting to less than $2.00 per million BTUs, as opposed to over $3.00 for coal and nearly $6.00 for fuel oil.

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EQUIPMENT FOR INCREASING SUGARCANE YIELDS AND RECOVERING SUGARCANE RESIDUE FOR BIOMASS IN SOUTH FLORIDA.

by

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ABSTRACT

Attempts to increase the biomass from sugarcane by selecting very close row spacings arranged for mechanical production systems was relatively unsuccessful. Sugarcane trash remaining after harvesting was dried, collected, densified, and transported using two systems. A modified forage harvester with a pickup reel, blowing chopped trash into a truck, provided material similar to sugarcane bagasse. The baled trash was twice as dense as the chopped material, but would require further preparation for the sugar mill boilers. A powered rotary rake was used to rake trash into windrows for both systems. Experiments with a hay crimper indicated that the stalk sections of the sugarcane tops could be field-dried in half the time. This would allow collection of the trash before the emerging ratoon crop is damaged by the equipment.

Experiments

Growing sugarcane in narrow-row patterns suitable for mechanical production systems did not increase total biomass. The higher populations in the narrow rows seemed to have a weak root system causing individual stalks to be pulled out by the sugarcane harvester. Sugarcane in conventional 60-inch rows had consolidated root systems which remained intact during harvesting. Yield increases up to 50 % in narrow-row production have been reported in Louisiana compared to conventional 72-inch rows of sugarcane (Matherne and Irvine, 1977).

Sugarcane was planted in 30-inch rows for an experiment in multiple harvest methods. The field was planted in February, 1980 for two harvests in the fall and spring. Cane yields were compared with a single harvest of burned cane of half the field in March. For the first crop year, double cropping provided 76.6 tons per acre, but the second crop was only leaves. The single harvest of 64.3 tons per acre provided more stalk material which contained fermentable sugar. For the second crop year, only one cutting was made of 42.3 tons per acre due to a freeze. The single harvest yielded 44.8 tons per acre. The third crop year yielded 19.3 tons per acre on first cutting and 45.1 tons per acre for the single cutting.

Multiple harvesting of sugarcane does not seem to be a viable option due to frost and freeze damage in South Florida. The early harvests seemed to reduce the ratooning ability. A forage harvester with a 3-row crop header was used for the multiple harvest cutting. The gathering system would not lift some long stalks, and they were lost. The cutting mechanism was not wide enough for some sugarcane growth. The forage harvester could not be used for the single harvest, and a sugarcane harvester was used.

Sugarcane trash (tops, leaves and suckers) can be recovered after hand cutting of seed (unburned) or mill cane (burned) in Florida. Sugarcane is cut for seed in limited acreages during August to December. Sugarcane is cut for milling during November to March. The trash should be picked up before the emerging shoots on the ratoon crop are damaged by the machinery.

Sugarcane trash was picked up in September without raking from a very immature field cut for seed. An average of 14.8 tons per acre (wet basis) was recovered with 72.4 % moisture. This translates to 4.8 tons per acre (dry basis). The 4-row windrows of trash from hand cutting were loaded with a grab loader with a pusher attachment.

Sugarcane trash from a seed field was raked into 8-row or 12-row windrow heaps with 4 or 6 passes of a PTO driven rotary rake. Approximately 5.0 tons per acre of trash (wet basis) was recovered using a forage harvester with a windrow pickup reel. The trash contained 54.9 % moisture which translates to 2.27 tons per acre (dry basis). There was a problem in raking the three 4-row windrows into one windrow, and some chokages of the forage harvester were caused by the large windrow. Combining two hand-cut windrows or 8 rows of trash was satisfactory.

Large experiments were conducted in collecting, densifying, and transporting trash from burned, hand-cut sugarcane fields. In a cooperative experiment with a sugar mill, a field of sugarcane trash was raked, picked up with the forage harvester and blown into 24-foot length trucks. The material was transported to the sugar mill and burned with the sugarcane bagasse, which is the crushed stalks after the milling process.

The rake and forage harvester operated satisfactorily and were well matched at about 25 tons per hour capacity (wet basis). The rake made 4 passes to combine 2 hand cut windrows. Some problems were encountered in raking the trash across deep furrows left by the cane wagons when the sugarcane was loaded. Approximately 4.25 tons per acre of trash (wet basis) was recovered, and it contained 60 % moisture. This yielded about 1.7 tons per acre of dry matter. Fuel consumption for raking and loading with the forage harvester was 0.49 gallons per ton (wet basis). The trucks consumed about 0.26 gallons per ton in transporting the material 3.5 miles to the mill.

The trash was chopped to the proper length for use in the sugar mill boilers, but a higher density was needed in the transport trucks. This sugar mill wanted to store the trash under a shed and needed higher bulk densities for transport and storage. Some soil was observed in the trash caused by raking the material which had been run over with wagons while loading the sugarcane. Table 1 indicates a higher ash content and sulfur content of the trash as compared to the sugarcane bagasse (Barnes, 1974). Burning of this material may cause some additional maintenance problems in the boilers and associated equipment.

Table 1: Laboratory Analysis of Fuel Value of Sugarcane Trash and Sugarcane Bagasse, Belle Glade, FL. 1981.

	TRASH DRY(%)	BAGASSE DRY(%)
Carbon	47.9	49.9
Hydrogen	5.5	5.8
Oxygen & Nitrogen	38.45	43.33
Sulfur	0.60	0.17
Ash	7.55	0.80

In an effort to increase the trash bulk density for transport, a round baler was tried. Single windrows in hand-cut fields were raked with the rotary windrower. A round baler which used steel cylinders to roll the bales was used. The bales were 4 feet wide by 5 feet in diameter. A larger model of this baler was manufactured, but was not available for this experiment.

Some chokages occurred in the area behind the pickup reel with high moisture cane tops when baling immediately after the sugarcane had been loaded. The chokages occurred before enough trash had been picked up to start the bale rolling in the bale chamber. After it began rolling, the cane tops were pulled away from the pickup reel and did not backfeed or choke. To eliminate the chokages and make the baler function properly, a roll cylinder with steel strips welded to the length of the cylinder was tried. This cylinder was more aggressive and pulled the material into the bale chamber without chokage of the reel. However, the moisture content of the cane tops was lower in this experiment.

The bales were wrapped with twine and ejected from the baler when the proper hydraulic pressure was obtained on the gate. Approximately 7.47 tons per acre (wet basis) was recovered from this field. The moisture content was 61.5 % and the bulk density (wet basis) of bales was 14.3 lb/ft^3. These bales heated up in storage with surface temperatures reaching 126°F. Methods of reducing the field drying time were needed.

A hay crimper which used rubber rolls in a chevron pattern was tried for reducing field drying time. The single windrows were raked, and the hay crimper was used to pass the cane tops through the crusher once. The stalk portions of the cane tops were crushed and seemed to remain high in the windrow. When raked without crimping, the heavy tops remained near the soil and collected moisture from the soil. The moisture content before crimping was 69.8 % and this field dried to 59.5 % 1 day after crimping, 36.9 % 2 days after crimping, and to 32.1 % 3 days after crimping. This would allow baling in 3 days after crimping instead of approximately

7 days without crimping.

The material in round bales would have to be prepared for sugar mill boilers. A cotton module builder or some device to densify and transport chopped material should be tried. The large 4-foot square baler should be tried for long and short chopped material. The cost of chopping could be reduced by selecting the best method of chopping with the maximum length allowable for the process.

SUMMARY

Growing sugarcane in narrow rows and multiple harvesting of sugarcane did not increase the biomass per acre compared to conventional cropping and harvesting practices. Raking of sugarcane trash, after hand cutting and removal of the stalks, and collection and transporting by two methods was successful. The forage harvester provides chopped material, ready for the boilers, but it is only half as dense as that baled by a round baler. On a dry basis, the forage harvester material contained 3 times the amount of sulfur and 9 times the amount of ash as in sugarcane bagasse (milled stalks). The field drying time necessary before baling cane tops was reduced from 7 days to 3 days using a hay crimper. This would allow collection of the trash without damage to emerging ratoons. Other methods of densifying and transporting chopped material by use of equipment such as a cotton module builder should be tried.

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HARVEST METHODS AND SYSTEMS FOR COTTON STALK RESIDUE

BY

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ABSTRACT

A system was developed to harvest cotton stalk residue for energy. Methods to remove the stalk from the soil, rake them into windrows, and bale them into large round bales were investigated. Field tests of their performance indicated that selected machinery for digging peanuts and for raking and baling hay could be used in the system without equipment modification.

Introduction

Disposal of cotton plant residue is a concern of the farmer since the large plant parts, particularly the roots, do not completely decay by spring planting time. Equipment to reduce the residue and accelerate decay is available but requires large investments in machinery and energy.

The cotton plant yields high residues of cellulose biomass that can produce valuable thermal energy. Yields of cotton plant residue in Georgia were 3.0 and 6.2 t of dry matter per ha for crops with stalks 0.8 and 1.5 m high, respectively. Twenty-five percent of the material was from the plant roots. Sumner et al. (1983) reported an energy value for cotton stalks of 21.3 MJ/kg and found that cotton plant residue was a better fuel than soybean and corn stover for drying grain in a biomass fired furnace. Cotton plant residue should be a suitable fuel for other residue furnaces under development. However, systems and methods must be available to collect and package the cotton residue into a useful form using minimum energy input.

The objective of this investigation was to evaluate methods and to determine a system for harvesting cotton plant residue for energy.

To reduce development time and investment cost, equipment developed to pull weeds, to dig peanuts, and to rake and bale hay were used in a system to harvest cotton stalks into large round bales. System components evaluated included three methods to remove cotton plants from the soil, two raking methods to place stalks into a windrow and two round-chamber balers to pick up and densify the residue. A single-row mechanism was evaluated for pulling cotton stalks and to determine the influence of design elements on the efficiency of plant removal from the soil.

Removal of cotton plants from the soil

A review of cotton stalk-pulling developments indicated that a mechanism that consisted of two counter rotating pneumatic tires set at an angle of 45 degrees from vertical was effective in harvesting cotton stalks from the soil (Sumner et al. 1983). Machines using this pulling method have been under development to harvest cotton plants in Africa singe the early fifties. Kemp and Matthews (1982) concluded that a recently-developed four row machine was as effective as hand laborers in loosening the plants and could harvest 420 ha in a 30 day season. Basic information on machine design as influenced by machine variables of wheel angle, wheel rotational speed and ground speed were investigated to determine their influence on plant removal efficiency. A one row counter rotating wheel unit was constructed for use in the test.

Cotton stalks were effectively pulled using two counter rotating wheels over a wide range of travel speeds and pulling wheel speeds. Stalks that were not pulled from the ground broke because they had been damaged by the picker spindle. Pulling wheels set at 15 and 30 degrees from vertical resulted in an average removal efficiency of 97.4 percent and pulled stalks completely from the soil; but when the pulling wheels were set at 45 degrees, stalks were loosened but not pulled out in all treatments. The stalk removal efficiency was high in all treatments, therefore the effect of travel speeds and pulling wheel speeds on efficiency could not be accurately determined with the variable results of this test. Additional research is needed to determine optimum machine settings of wheel angle and wheel speed that will give high stalk removal efficiencies over a wide range of harvest conditions.

A two row commercial weed puller that used counter rotating tires to pull plants was modified for use in harvesting cotton plants. Plant removal efficiency was above 95 percent when operated at 6.5 km/h. Difficulty was encountered when pulling large cotton plants in getting them to pass under the machine frame without plugging. Redesign of the support frame would alleviate the plugging problem.

A two row peanut digger with standard blades and an incline gripper chain for each row was also effective in pulling cotton plants. Ground speed of 6.5 to 8 km/h were possible with plant removal approaching 100 percent. Fuel consumption was about 10 percent higher than with the weed puller in soil with average moisture content. This peanut digger will probably be the most effective of the methods tried over a wide range of crop and soil conditions.

A modified two row peanut digger used by a local farmer for the last three years to plow up cotton stalks was evaluated. The machine plowed up plants with standard peanut digger blades, then removed from the soil with a 4-inch diameter roller and a shaker drum operating perpendicular to the rows. This method required deep plowing and moved a deep mat of soil since the pick up roller operated in the soil. The unit could only be operated at 4.5 km/h and required about 25 to 30 percent more fuel to harvest than the weed puller method. This digger was considered the less desirable of the three methods because it required more power, had a lower work rate, was a high maintenance unit, and the stalks would not pass through the machine at a uniform rate.

More testing is needed with the weed puller and the incline chain peanut digger to obtain maximum machine work rates over a wide range of cotton stalk harvest conditions. The influence of soil type and moisture content, plant moisture content, and plant size and density should be evaluated to determine their influence on harvest efficiency, fuel consumption and harvest rate. High machine capacity is expected to be necessary to allow the economic recovery of a low value residue crop.

Raking cotton stalks into a windrow

Raking cotton stalks into a windrow formed from 4 to 6 rows is needed to reduce the operational time of a baler and to reduce overall system harvest cost. Tractor-driven oblique side delivery hay rakes did not do an acceptable job when raking large high-yielding cotton stalks. Rake-tine bending and breakage were excessive with standard size spring mounted tines. A rake with fixed stripper bars allowed material to build up and be discharged into piles resulting in an uneven windrow. A rake with a rotary stripper drum allowed excessive amounts of stalks that were positioned parallel to the row to be picked up and carried over the rake bars. Stops to unplug stalks caught in the rake made raking unsatisfactory in medium to high yields. In low yielding cotton fields the rake could operate at 2.8 km/h without plugging, providing plants were uniformly distributed in the rows by the digger operation.

A ground-driven finger-wheel rake with long flexible tines could move stalks out of the furrows and could satisfactorily rake them into the windrow provided there were no large piles of stalks left by the stalk-removal operation. Cotton stalks yielding 6 t of dry matter per ha could be raked at 4.5 to 6 km/h into a uniform windrow with the finger rake. The finger-wheel rake was an effective raking method in low and high yielding cotton fields.

Baling Cotton Stalks

A New Holland 851* round baler (chain and bar compression) and a Vermeer 605H round baler (belt compression) were used to densify the cotton stalk residue. Both balers had an expandable chamber to maintain continuous pressure on the bale throughout the baling cycle. They satisfactorily

*Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or a warranty of the product by the U. S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

picked up and fed the large bushy cotton stalks into the bale chamber and there were no problems forming and compacting the material into a bale. Occasional plugging of the balers occurred when large piles of stalks in the windrow were pulled into the chamber entrance. Uniform windrows would reduce this problem.

The New Holland baler was efficient in getting most of the material into the bale and could make a 400 to 500 kg bale 1.5 m long by 1.5 m in diameter in 3 to 7 minutes depending on the volume of the material in the windrow. The Vermeer baler had a large roller in the bottom of the bale chamber that rolled the bale during formation. Some of the stalks that were parallel to the roller were forced between the belts and the roller. This caused material to drop out of the baler and onto the ground. Losses increased as the bale became larger and resulted in up to approximately 25 percent material loss. Adjustment and modification will be made on the Vermeer baler before further testing.

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ENERGY FROM SUNFLOWER

by

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ABSTRACT

Research concerning sunflower as an energy crop is presented. The seeds may be crushed to produce an oil to serve as a diesel substitute. The crop residue may be used as a solid fuel. An overview of field testing of sunflower oil, means for collecting, storing, and densifying sunflower crop residue is presented.

Sunflower is a crop which has received considerable expansion during the past decade in the North Central Region. Planted acreages during this period have increased from about 40,000 ha to 1.4 million ha at the present time. Most of the sunflower crop is an oil-type producing a seed containing 40% oil. A good yield of the crop produces 1400 kg/ha of seed.

Because of the large acreages involved with the growing of sunflower and the fact that a large proportion of the oil may be removed from the seed with a simple screw press, much local attention has been focused on the use of sunflower oil as a home-grown alternative or additive to diesel fuels. In addition, the stems and seed heads have little to no use as livestock feed or bedding; therefore subsequent efforts have evolved to determine the usefulness of the crop residue as a source of solid fuel.

The project evaluating the sunflower oil as a diesel substitute has been in operation for two cropping seasons. The objectives of the study was to determine the following:

1. If a 25 and 50 percent sunflower oil/diesel blend would create abnormal fuel handling problems in farm use.

2. If blended fuels would perform adequately in unmodified tractor engines.

3. If the blended fuels would contribute to abnormal or excessive wear or deposits.

In 1981 twelve cooperators began the study using new, unmodified farm tractors. The operators maintained logs of tractor use and fuel consumption along with a routine program of engine oil analysis. These tractors accumulated nearly 7000 running hours during the season consuming 136,000 l of fuel containing 49,000 l of sunflower oil. During the operation between April 14 and November 20, ambient temperatures ranged from -15^{o} to 38^{o}C. This did not cause any apparent fuel filtration problems or unsatisfactory engine performance. Some abnormal carbon buildup of the injectors was noted during the season, operating the tractors at near maximum load appeared to reduce this problem and improve engine performance.

In 1982 the operation was reduced to six tractors. These tractors consumed 52,790 l of fuel containing 21,040 l of sunflower oil. These tractors accumulated 2640 hours during the season. All operators noted satisfactory performance.

Disassembly of two of these tractors indicated that the engine performance would be satisfactory if placed back in service. However, there were several areas where excessive carbon and varnish exist, these areas include carbon buildup in the intake ports, on injector tips, ring grooves, above ring travel on liners, between the top ring and top of the piston, and on the base of the intake valve. A lubrication oil and fuel additive was used in one of the engines inspected. The additives did reduce deposits in some areas, but not consistently on all engine components.

In evaluating sunflower crop residue as an energy source several parameters need to be known to make use of this product as a solid fuel. These parameters include the quantity of the residue available, the amount which can be collected, the energy content of this product, and the quantity and characteristics of the ash. In addition, the amount of energy needed to collect and convert this product to a useful energy source needs to be determined. Several field trials have been performed to assess the methods appropriate for collecting the residue and determine the quantity which can be harvested.

Machines used in 1979 were a Foster Chaff Saver and a forage harvester. The Foster Chaff Saver collectes the material coming through the combine from the straw walker and sieve. Collection of residue was 1495 kg/ha, or 24.6% of available residue for normal harvesting. Cutting lower (leaving a 15 cm stubble) increased the amount to 2070 kg/ha or 34.0% of available residue. Using the residue saver decreased harvest speeds by 50% to avoid plugging the machine.

In another trial, a forage harvester was used to chop the whole crop. A stationary combine was then used for seed separation. Two lengths of chop were used, 6.4 mm and 9.5 mm. Seed recovery with the 9.5 mm cut was 94.5% of those available, 30% of these were broken or damaged. The 6.4 mm chop resulted in a lower seed recovery at 58.7% of available and greater damage to the seeds, with 37% damaged.

In 1980, a Stevens Residue Saver was tested for collection of the residue. After initial testing, it appeared that the stalks and heads had to be chopped, using the combine's straw chopper, before this chaff saver would operate properly. Using the residue saver resulted in the collection of about 1130 kg/ha, or 31% of available residue at normal harvesting levels. Speed during harvesting was 8 kmph with or without the residue saver.

The Foster Chaff Saver was also used, again chopping the residue rather than collecting it whole. This resulted in collection, efficiencies similar to the Stevens Residue Saver (32%), and at similar speeds. However, the Foster Wagon was much more difficult to unload when the stalks were chopped compared to use with whole stalks.

Using rakes and haying equipment also may be feasible. It was anticipated that the brittle stalks could be snapped off and formed into a windrow with a rake without first cutting; however, it was found that use of a mower was necessary with the harvest conditions experienced. The big round baler (Vermeer 605C) required 2 ha to produce a small bale due to the breakup of the stalks while rolling the bale. A rectangular baler can be used to make bales, but they are loose and hard to handle.

The studies of 1981 and 1982 were set up to evaluate the energy use in harvesting and the storability of the collectec crop residue. These indicate that while using the combine mounted collectors, there was no significant increase in harvest time or energy useage. Some additional time would be required for residue handling. An average of 36% of the estimated available residue was collected in these trials. Total quantities ranged from 915 to 1100 kg/ha.

Storage of the collected biomass was evaluated by testing the energy and moisture content of the residue. The 1981 tests of the residue showed moisture contents of the stored residue at 22% without significant change during the winter storage. Energy content of the biomass was 16.6 kJ/g. The piles were inadvertently removed before testing was completed.

Sample	Date	% Moisture
Uncovered	November 1982	36.0
(1125 kg)	March 1983	57.7
Covered	November 1982	36.0
(650 kg)	March 1983	37.7

Table 1. Moisture of Store Residue in 1982

	Stalks	Head	Press Meal & Hulls
Energy kJ/g	17.2	17.1	20.9
Ash	11.0%	14%	7.7%
Ash Composition:			
Water Soluble, %	60	52	41
HCI Soluble, %	34	38	51
Non Soluble, %	5	10	8

Table 2. Characteristics of Sunflower Residue

Analysis of the ash by the Grand Forks Energy Laboratory indicate the following. Silica @ 11.6%, calcium oxide @ 23.76%, potassium oxide @ 37.96%, phosphorus oxide @ 2.09%, magnesium oxide @ 8.75%. Other metal oxides 8.01%, sulfur content of the stalks was 0.14%. Tests on the ash fusibility indicate a softening temperature of 84^{o}C, and a hemispherical temperature of 870^{o}C. Flow temperature was not determined.

Densification of the sunflower residue may be necessary in order to make the product more readily transportable. Density of the material from the field is 4.2 lb/ft^3, densification may increase this to 40 lb/ft^3. A Glomera briquetting press has been available for test purposes. Sunflower residue has been briquetted to determine the effects of feed rate, moisture content, fineness of grind and temperature have on briquet quality.

Tests evaluating the effects of several variables have been completed. The independent variables were size, feedrate, moisture content, head temperature and pressure. The values for pressure refer to the pressure on a control cylinder rather than pressure on the material being briquetted. The produced briquets were subjected to several physical tests. The data was analyzed to determine a prediction equation for each dependent variable. The general form of each equation is:

$$Y = a + b*s + C*R + d*M + e*T + f*P$$

Where:
- Y = Dependent variable
- S = Particle Size
- R = Feed rate
- M = Moisture content
- T = Die temperature
- P = Die cylinder pressure

Parameters a, b, c, d, e, and f are constants or estimated values from a computer analysis using a General Linear Models (GLM) procedure and are shown in Table 3.

Dependent Variable	Interaction	Coefficients				
		Size	Rate	Moist.	Temp.	Press.
Density	1.47	-0.004	+0.001	-0.06	+0.007	*
Tumbler Resistance	99.99	+0.011	*	-0.077	*	*
Shatter Resistance	*	*	*	*	*	*
Force of Deformation	*	-2.05	+0.06	*	+1.02	*
Water Resistance	*	*	*	*	*	*
Mosture at Equilibrium	9.72	*	-0.002	+0.29	*	*

* Not significant at P-0.10.

Table 3. Coefficients and Intercepts for Optimum Conditions

In summary, sunflower oil and sunflower crop residues have been investigated regarding their suitability to replace or supplement present energy sources. Sunflower oil has been blended with diesel in field tractor testing. Sunflower crop residue has been collected. Storage characteristics of this material is being investigated.

COB HARVESTING AND BIOMASS STORAGE SYSTEMS

by

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ABSTRACT

This report covers previous research on a cob salvaging system and a new biomass storage project which started in October 1982.
The cob salvaging system, with collection and transport in a trailing wagon, collected 80% of the available cobs with 93% cobs, by dry weight, in the mixture. The system required less than 12 kW to operate.
The storage project is investigating a wet preservation method using sulfur dioxide on biomass and an externally piled dry storage system. The effect of storage temperature and SO_2 dosage level on microbial growth in corn silage is being studied. After three months storage, microbial growth was only significant on the untreated and 0.15% SO_2 samples. The external storage system is designed to use the heat of respiration to assist in drying the biomass. A 13 tonne pile of cob and husk mixture was formed and is being monitored to determine temperature changes.

COB HARVESTING

Research into the design and evaluation of a practical cob salvaging system was conducted from 1979 to 1982. The work concentrated on establishing the potential of pneumatic separation systems. Field tests of prototype equipment were followed by aerodynamic tests on cob and plant fractions and a preliminary study of cob storage. The development and evaluation of the cob salvager is covered by Smith et.al. (1982).

A cob saver attachment was mounted below the straw walkers of a JD 6600 combine harvester. A fan was used to blow air through the material as it fell off the straw walkers. The air blew most of the loose husks and stalks out of the back of the combine. Any material falling through the air blast fell into, and passed through, a straw chopper. The corncobs, cobs with attached husks, and any remaining stalk and husks, were fed by an off-loading auger into a blower, which threw them back into a trailing forage wagon. A photograph of the cob harvesting system working is shown in Figure 1. The total power required by the cob saver and trailing wagon in field use was less than 12 kW. About 80% of the available cobs were collected, with 93% cobs, by dry weight, in the mixture. The best results were obtained in corn with grain moisture below 25% and dry stalks. One forage wagon load of stalks corresponded to about 4 - 5 combine hopper loads of grain. The following relationship was developed to determine the dry bulk density of cob mixtures, with C = proportion of cobs (eg. 0.85).

$$\text{Bulk Density (kg/m}^3\text{)} = 16.0\ e^{2.35(C)^2}$$

The air suspension velocities of some stalks was found to overlap with the cob suspension velocities. In addition, some cobs in the mixture still had attached husks. These factors make complete pneumatic separation of cobs impractical.

Two 3 tonne piles of cob mixture were stored from December 1981 to August 1982 on an external concrete floor. One pile had a centrally placed duct through which a centrifugal fan blew 0.2 m^3/sec of ambient air for four hours each day, while the other pile was a control. A photograph of a section through the unventilated control pile after 9 months of storage is shown in Figure 2. Although the pile was thoroughly wetted down to the bottom of the dark layer, the interior was still at the same moisture content (30% WB) as when it was formed. A large proportion of the ventilated pile was dried down to 12% and mould growth had been reduced. The dried interior of the ventilated pile had not lost dry matter content when compared to cobs which had been stored inside since harvest. Dry matter loss in the control pile ranged from 10% in the pale colored interior, to 30% in the dark wet layer.

BIOMASS STORAGE SYSTEMS

The effect of using sulfur dioxide as a wet preservation treatment for biomass is being studied. Four storage temperatures (2°C, 12°C, 22°C, 32°C), and five SO_2 dosage levels (0.15%, 0.30%, 0.75%, 1.5%, 3.0% w/w) were applied to corn silage. After three months, samples were analysed for microbial growth. Only the lowest SO_2 dosage level and the undosed control had detectable levels of organisms. Further samples will be analysed after six months storage.

The effects of SO_2 on the formation of degradation products of corn silage are being analysed and compared to the effects of 6% H_2SO_4. After three months storage the samples will be hydrolised, leached and the sugar and degredation product concentrations determined.

The external cob storage system uses the heat of respiration to assist in drying the cobs. Thirteen tonnes of cob mixtures were harvested with the Purdue cob saver and transported to the storage site in forage wagons. A photograph of the pile being formed with an inclined elevator is shown in Figure 3. Thermocouples and mass-loss sample bags were placed inside and on the surface of the pile. A remote sensing thermostat bulb was placed inside the pile and switches on a centifugal fan when the pile interior temperature exceeds a specific value. The fan then blows ambient air through the pile via a centrally placed duct. The pile has cooled down and temperatures are being monitored during the winter and spring.

FUTURE WORK

1. SO_2 WET STORAGE - Analysis of the six month storage samples for microbial growth. Analysis of the effects of SO_2 and H_2SO_4 on degradation products of corn silage. Develop procedures to determine SO_2 sorption rates and sulfite conversion rate.

2. COB STORAGE - Determination of the physical changes within the cob pile and the effectiveness of using respiration heat to dry corncobs.

SUMMARY

A cob salvaging system was developed which used a pneumatic cob separation unit and collection and transport in a trailing forage wagon. The biomass storage project is investigating a wet preservation method using sulfur dioxide on corn silage, and an externally piled dry storage system for corncobs.

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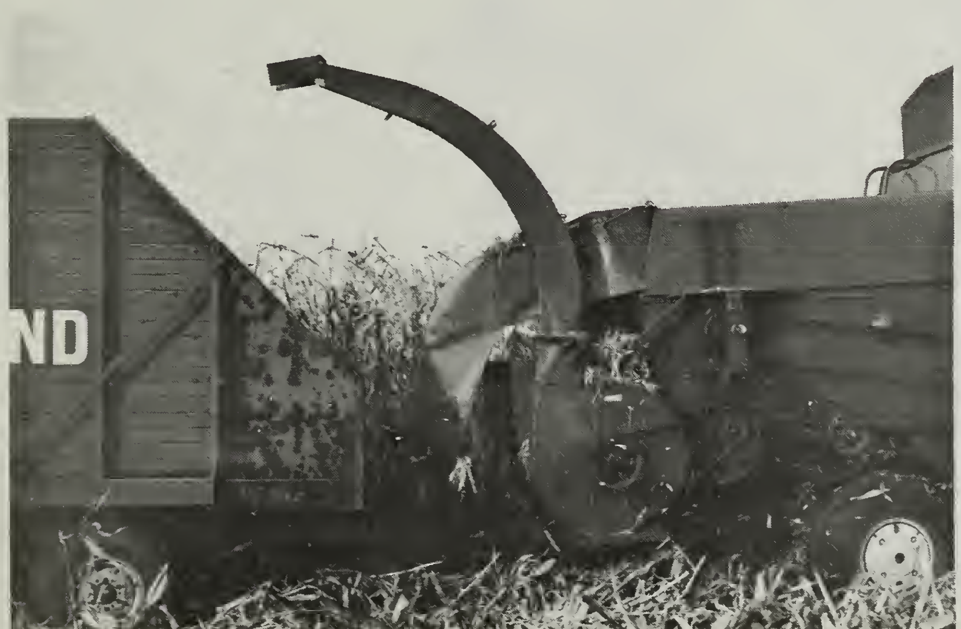

Figure 1. Purdue Cob Harvesting System

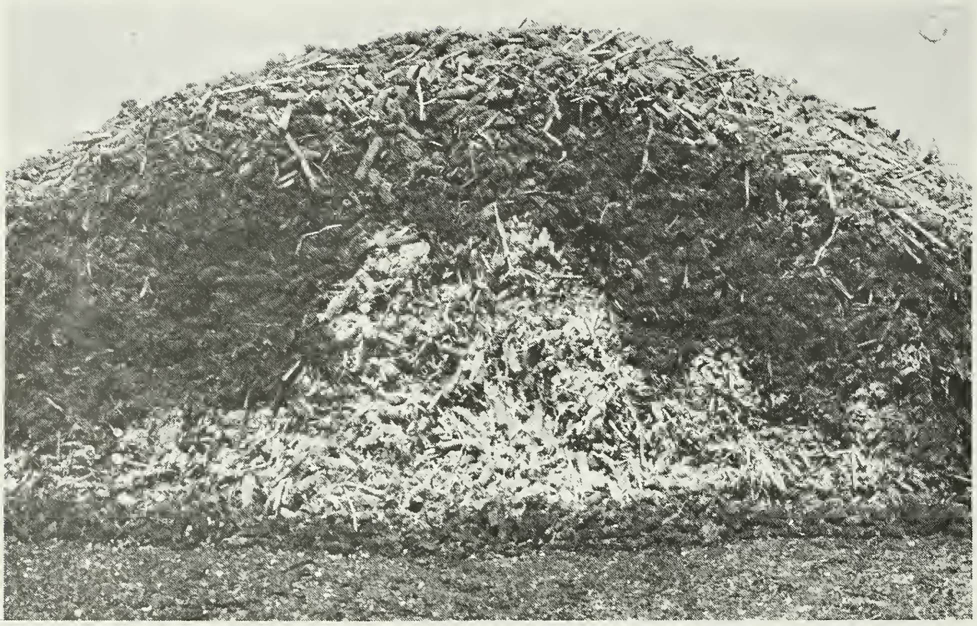

Figure 2. Section through Unventilated Storage Pile

Figure 3. Forming the External Corncob Pile

COLLECTION, PROCESSING AND COMBUSTION OF CORNCOBS TO PROVIDE HEAT FOR DRYING CORN

by

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ABSTRACT

A system to collect, transport, process, dry and burn corncobs to dry corn was evaluated. A mixture of shelled corn and cobs was harvested and transported to the drying facility where a continuous, automated system separated, dried and conveyed cobs to the combustor. Exhaust products were put directly into the drying air without adversely affecting the corn's appearance or odor.

INTRODUCTION

Successful adoption of corncobs as fuel for drying corn will require a total system for collecting, transporting, processing (size reduction), drying and gasification and/or combustion of the cobs. A potential system is under evaluation at the University of Minnesota Rosemount Experiment Station (Figure 1). A combine produces a mixture of shelled corn and corncobs. Concave clearance is reduced and sieves are opened so that broken cobs and shelled corn are collected in the grain tank. The mixture is transported to the drying facility which eliminates the need for a separate hauling system for the cobs. At the dryer two approaches are possible. One is to dry the mixture of cobs and corn in the grain dryer, then separate the mixture with the corn going to storage and the cobs to a burner to provide heat for drying. The other approach is to separate the mixture before drying with the corn going to the grain dryer and the cobs to a separate cob dryer and then to the burner to provide heat for drying. The goal is to develop a system which:

1) utilizes cobs grown in the same year as the corn as a fuel to dry the corn, and

2) is essentially automated for handling grain and cobs on a continuous basis at the drying facility.

EQUIPMENT AND SYSTEMS

A materials handling system has been designed so that both alternatives for drying the cobs discussed previously can be evaluated (Figure 2). Grain and mixtures of grain and cobs are handled with 150 mm (6 in) diameter augers. Cobs alone are transferred with a chain-flight conveyor or with a 100 mm (4 in) diameter auger.

A rotary screener is used to separate cobs and grain at the drying facility. The screen is a square mesh with 11.1 mm (0.438 in) openings. Shelled corn passes through the screen. Cobs are discharged at the end of the separator. Separated cobs are sent through a burr mill for further size reduction before being conveyed to the cob storage bin. The mill is set to provide cob pieces with a maximum dimension of approximately 25 mm (1 in) or less.

The materials handling equipment is designed to turn on and off automatically and in sequence. Level switches in the wet holding bin on top of the grain dryer control the dryer load sequence. Level switches in a surge hopper at the dryer discharge control the dryer unload sequence. The rotary screener, burr mill, and cob conveyor can be switched into and controlled by either sequence depending on whether separation of the mixture is occurring before or after drying.

The combustor is a two-stage downdraft device with a 400 to 800 kW (1.35 to 2.7 Btu/hr) heat output. The design is based on the performance of a laboratory-scale device (Morey and Thimsen, 1980). Primary air flows downward through the fuel bed which is supported on an inclined grate. Primary air is limited to control the rate of decomposition (gasification) of the fuel and, therefore, heat output. The gases produced in this stage pass into a secondary combustion zone where additional air (secondary) is added to complete combustion. The purposes of the two-stage approach are to burn cleanly and to easily control the heat output.

The exhaust gases are mixed with ambient air at the fan inlet to provide temperatures suitable for drying (95 to 115°C). A temperature controller with a sensor at the drying fan outlet automatically adjusts the damper for the primary airflow, thus controlling heat output and drying air temperature.

RESULTS FROM 1982 HARVEST SEASON

The combine worked well in producing a mixture of shelled corn and cobs that contained little husk, leaf, or stalk material. Preliminary estimates indicated that we were collecting at least 80 percent of the cobs. The grain moisture contents at harvest were from 25 to 35 percent w.b. with much of it above 30 percent.

The combustor provided exhaust gases with no apparent odor or smoke. The exhaust gases were mixed with ambient air to provide temperatures in the range of 95° to 115°C. The corn coming out of the dryer did not appear to be adversely affected by this mixture of drying air. The damper control on the primary air provided a stable drying air temperature generally ranging within $\pm$ 5°C of the mean drying air.

A number of tests were run where the mixture of grain and cobs was separated first then dried. The grain dryer worked well. We found that there was not enough drying capacity in the exhaust from the bottom section of the grain dryer to dry the wet cobs to a moisture content low enough for combustion

A propane burner in the duct carrying air from the dryer exhaust to the cob drying bin provided additional energy input to dry the cobs. Modifications are planned for next year to obtain this additional heat from the combustion air for drying the cobs, thus eliminating all propane input.

We were not able to successfully dry the mixture of shelled corn and cobs. Although the combustor burned without visible smoke, there were enough hot particles (sparks) in the exhaust to cause fires in the cobs when drying the grain-cob mixture. Fires were not a problem when drying shelled corn alone. The tendency of the cobs to segregate from the grain each time the mixture is dumped into a bin or dryer may also contribute to the problem of fires when drying the mixture. A build-up of cobs in some sections of the dryer appears to increase the fire hazard. We plan several modifications next year in an attempt to successfully dry the mixture.

Additional results are presented by Morey et al. (1982).

SUMMARY

Based on 1982 performance, the following conclusions can be drawn:

1. The conventional combine, with minor adjustments and modifications, can effectively produce a mixture of shelled corn and cobs.

2. The mixture of shelled corn and cobs can be effectively transported, handled, and separated with equipment currently used in conventional shelled corn systems.

3. Shelled corn can be dried with air which includes products of combustion from a well-controlled, two-stage combustion (gasification/combustion) process without adversely affecting the appearance or odor of the corn.

4. Corncobs can be dried separately and transferred to the combustion device in a continuous, automated system.

5. Challenges remain in drying the mixture of shelled corn and cobs using air which contains combustion products from a biomass furnace. This alternative merits further research, development, and evaluation because of the potential it offers for simplifying and thus, reducing the cost of corncob fueled systems for drying corn.

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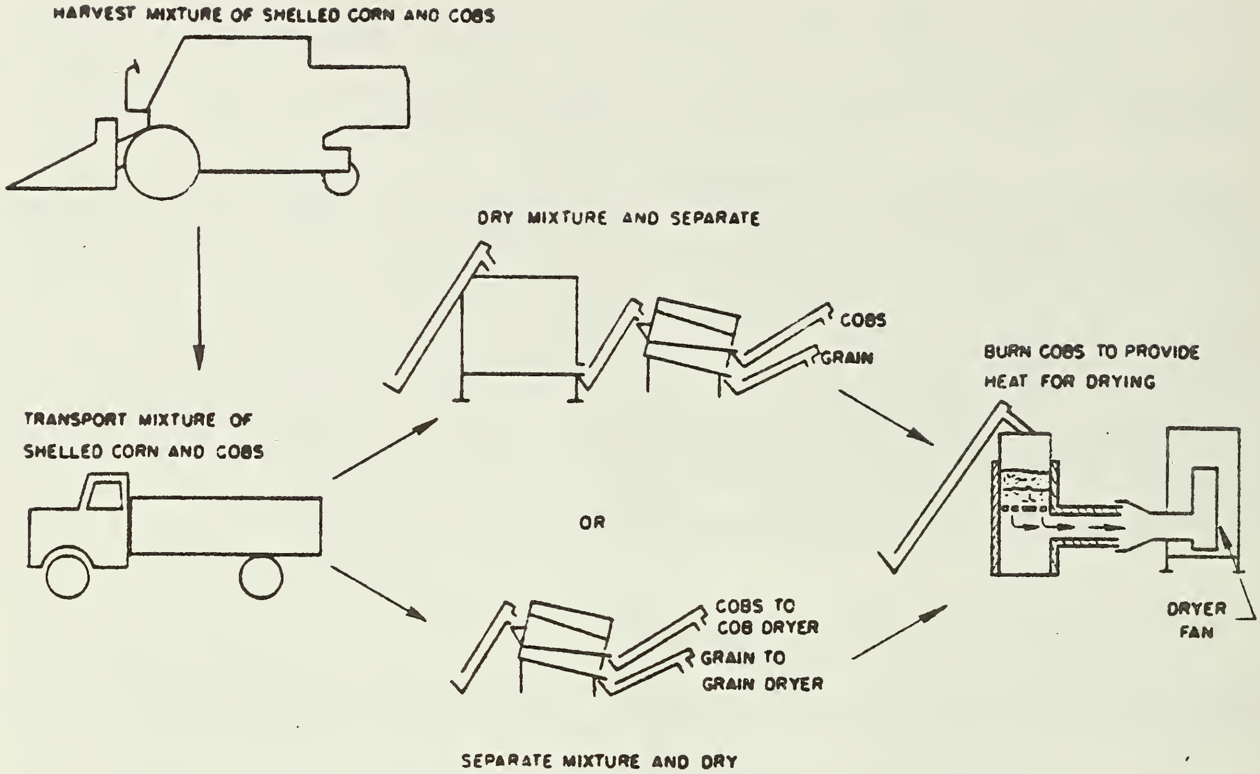

Figure 1. Schematic diagram of corncob fueled drying system.

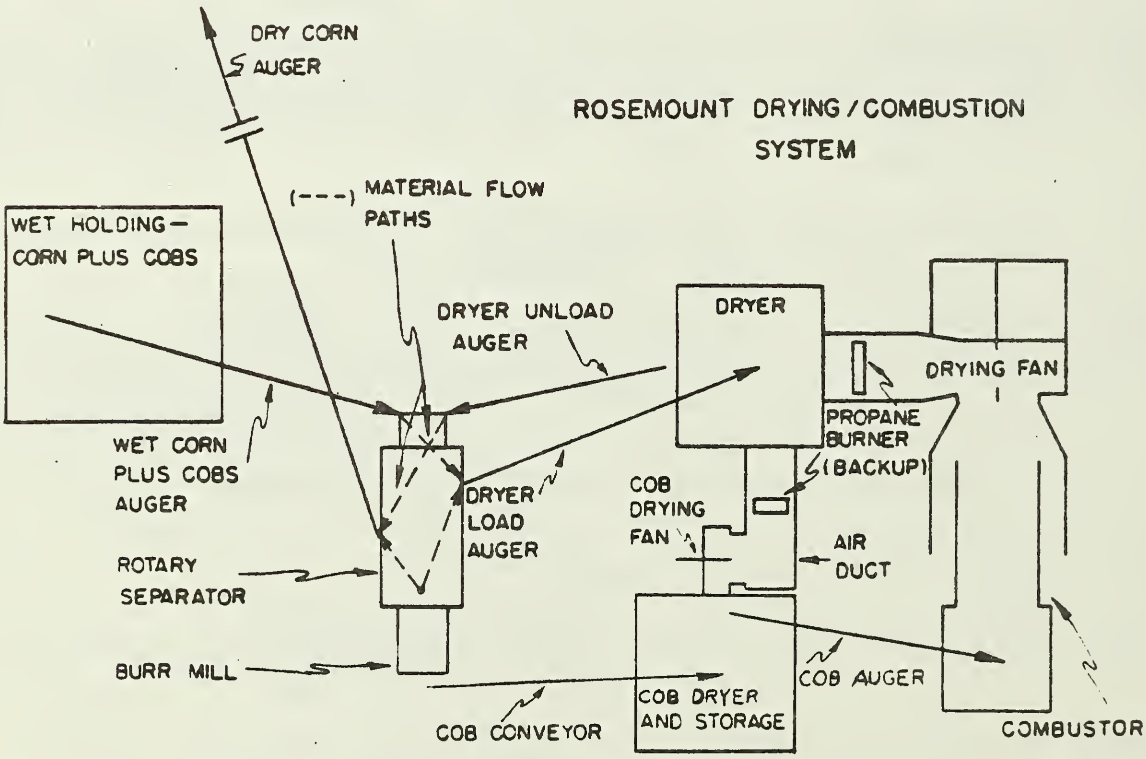

Figure 2. Layout of Rosemount drying/combustion system.

CORN CROP RESIDUE COLLECTION AND CONVERSION FOR GRAIN DRYING

by

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ABSTRACT

Corn crop residue was collected behind a combine through the fall corn harvest season. Newly harvested corn crop residue at different moisture contents was burned to determine the amount of energy available for corn drying.

Corn was planted for corn crop residue harvest and thermal conversion tests. The corn planted provided 3 varieties x 2 plantings x 3 moisture contents at harvest. The three corn varieties represented the full range of genetic variability as to cob and stalk strength and combine harvest rating.

Corn was harvested with a corn combine with a 6-row corn head throughout the fall corn harvest season. Corn crop residue was collected with a combine mounted residue saver delivering to a forage wagon pulled behind the combine. The corn moisture content at harvest ranged from 28.6 down to 21.8 percent wet basis. The corn crop residue moisture content ranged from 40 down to 23 percent. The corn crop residue was made up of corn cobs and varying portions of the corn husks, leaves and stalks. The cob portion of the corn crop residue made up from 55 to 83 percent of the collected residue weight.

Corn crop residue was burned in a full-scale furnace to measure the amount of energy available for corn drying. The residue was burned successfully without further processing or storage. The products of combustion were exhausted to the atmosphere. The feed rate to the furnace ranged from 160 to 230 kg per hour (350 to 500 lbs per hour). The furnace outlet temperatures ranged from 38 to 49 C (101 to 120 F). Furnace output of heated air usable for corn drying ranged from 855,000 to 1,330,000 kJ per hour (810,000 to 1,260,000 BTU per hour).

CHANNEL DOWNDRAFT GASIFIER MODULE EVALUATIONS

by

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ABSTRACT

This research concerns the utilization of agriculturally produced biomass as a renewable energy source involving the development of a module of a channel gasification/combustion furnace and its testing to evaluate operational characteristics and to develop furnace design criteria. Associated is the determination of the potential for contamination of the atmosphere and of crops dried by exhaust gases from furnaces.

A single channel downdraft module expandable into a commercially usable gasifier of multiple channels was designed, constructed and parametrically tested using corncobs as fuel. Primary and secondary airflows, temperatures, gasification rates, particulate emissions and other operational characteristics were monitored over the full operating range of the module. Gasification rates were evaluated at biomass moisture contents of 8.1, 23.2 and 32.0%, wet basis. Maximum capacity of the unit was about 830 MJ/h (787,000 Btu/h), with a turndown ratio of almost 3:1. Primary airflow was found to be a major factor in controlling the rate of gasification. Particulate emissions tests were conducted using a close-coupled hexagonal combustion chamber at biomass moisture contents of 10.4 and 25.0%. Isokinetic high volume sampling using EPA Method 5 techniques showed particulate emissions proportional to the second power of the gasification rate.

INTRODUCTION

The downdraft channel gasifier/combustor furnace concept was first described by Richey et al. (1981). This concept resulted from an earlier design of a crossdraft furnace (Richey et al., 1982). To further study the gasification-combustion process, a single channel downdraft module having a maximum capacity of about 830 MJ/h (787,000 Btu/h), and a close-coupled combustion chamber were designed, constructed and tested. Research herein reported was described in detail by Kutz (1982) and Kutz et al. (1982). The objectives of this endeavor were to:

1. Observe and develop relationships describing the effect of primary airflow and biomass moisture content on gasification rate and temperature using corncobs as fuel.

The first three authors are in the Department of Agricultural Engineering, the fourth is in the School of Civil Engineering.

2. Measure and evaluate the level of particulate emissions in the exhaust gas as related to gasification rate and biomass moisture content.

MODULE DESIGN

A vertical cross-section of the gasifier and combustion chamber is shown in Fig. 1. The V-shaped channel was formed by triangular air ducts of 2.7 mm stainless steel. It was 225 mm wide and 830 mm long. Primary airflow in the upper section was separated from secondary airflow. Primary air entered the gasification zone through 7.9 mm dia. holes spaced 51 mm apart. At the top of the channel the throat was one-third as wide as the entrance.

Some of the heat produced in the gasification process was used to preheat both primary and secondary air. The producer gas formed as a result of the partial combustion of the biomass flowed down through a steel grate below the ducts and entered the hexagonal combustion chamber tangentially to induce swirling. Here the producer gas mixed with secondary air and burned.

The gasifier channel was surrounded by insulating firebrick and covered by an air-tight mild steel shell. The hexagonal combustion chamber was also lined with insulating firebrick. Cooling air was diverted around the outside of the combustion chamber within the steel duct and mixed at the exit with the hot exhaust gases.

TESTING PROCEDURE

Rates of gasification and of emission of particulates were determined in two separate experiments. During gasification rate determinations the entire gasifier was suspended using an engine hoist and continuously weighed using a 4.5 kN capacity load cell. The producer gas was flared. Corncobs at 8.1, 23.2 and 32.0% moisture content, wet basis, were used. Particulate emission rates were measured using EPA Method 5 techniques in cooperation with the Air Pollution Laboratory within Environmental Engineering, School of Civil Engineering at Purdue University. The procedure is described by Barrett et al. (1983) and Kutz (1982). Corncobs at 10.4 and 25.0% m.c. were gasified and the exhaust sampled isokinetically.

RESULTS AND DISCUSSION

Moisture content of the fuel had little effect on gasification temperatures. At primary airflows of 1.75 m^3/min, temperatures did not stabilize but increased approximately 2^{o} C/min. Below this maximum primary airflow rate, temperatures remained relatively constant throughout a test, indicating that only the rates of conversion had changed, also implying that air penetration was uniform. The ratio of maximum to minimum output while maintaining stable conditions, or the turndown ratio, was almost 3:1, using 8.1% corncobs. The maximum gross heat output was 830 MJ/h (790,000 Btu/h).

Tar vapors were not a problem. The volatile components of the biomass fuel passed down through hot char where the long-chain tar molecules were cracked into smaller hydrocarbon molecules which were easily burned in the combustion chamber.

Linear regression was used to define the gasification rate, ($\dot{G}^o$, kg/min), of dry cobs as a function of primary airflow, ($\dot{Q}_p$, m^3/min at STP). Thus:

$$\dot{G}^o = 0.229 + 0.294 * \dot{Q}_p \text{ (8.1\% m.c.)}$$

$$\dot{G}^o = 0.237 + 0.190 * \dot{Q}_p \text{ (23.2\% m.c.)}$$

$$\dot{G}^o = 0.195 + 0.110 * \dot{Q}_p \text{ (32.0\% m.c.)}.$$

r^2-values were 0.900 and 0.959 for the 8.1 and 23.2% m.c. cobs, respectively. Data for the 32.% m.c. cobs was somewhat more varied, with an r^2-value of only 0.664, due to irregular movement of the cobs down into the channel. At a given corncob moisture, primary airflow was the major factor in controlling the rate of gasification.

As the gasification rate increased, the mass ratio of dry primary air used per mass unit of dry corncobs also increased for all three moisture contents. This means that although more gas was produced at the high gasification rates, the gas was diluted with primary air and was less combustible on a unit volume basis.

Preliminary results pointed to a possible dependence of particulate emissions on corncob moisture content. However, there was no real difference at the 95% level between emissions from 10.4% and 25.0% cobs. Non-linear regression analysis techniques using pooled non-transformed data were used to define particulate emission rate as a function of gasification rate. Results are shown in Fig. 2. Essentially, particulate emissions were proportional to the second power of the gasification rates.

Because no standards exist for biomass-fueled furnaces and because something was needed for comparison, the New Source Performance Standards (NSPS) for large coal-fired boilers was considered. For boiler systems greater than 74 MW (250 M Btu/h), the NSPS standard is 43 mg/MJ. Data from the module for emissions to energy-in ratios ranged from 61.3 to 243.9 mg/MJ, with an average of 133.6 mg/MJ. This does not mean that biomass conversion furnaces are dirty. Barrett et al., 1983, discuss this further.

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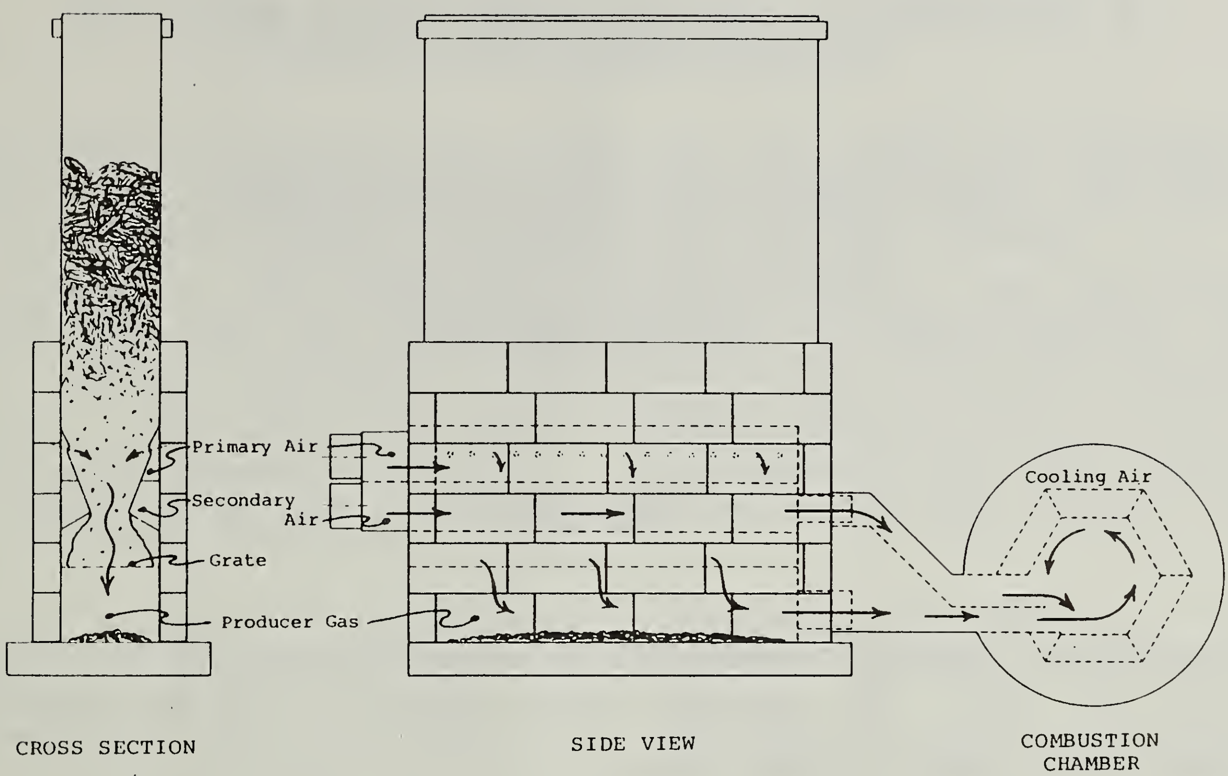

Fig. 1 Downdraft channel gasifier module.

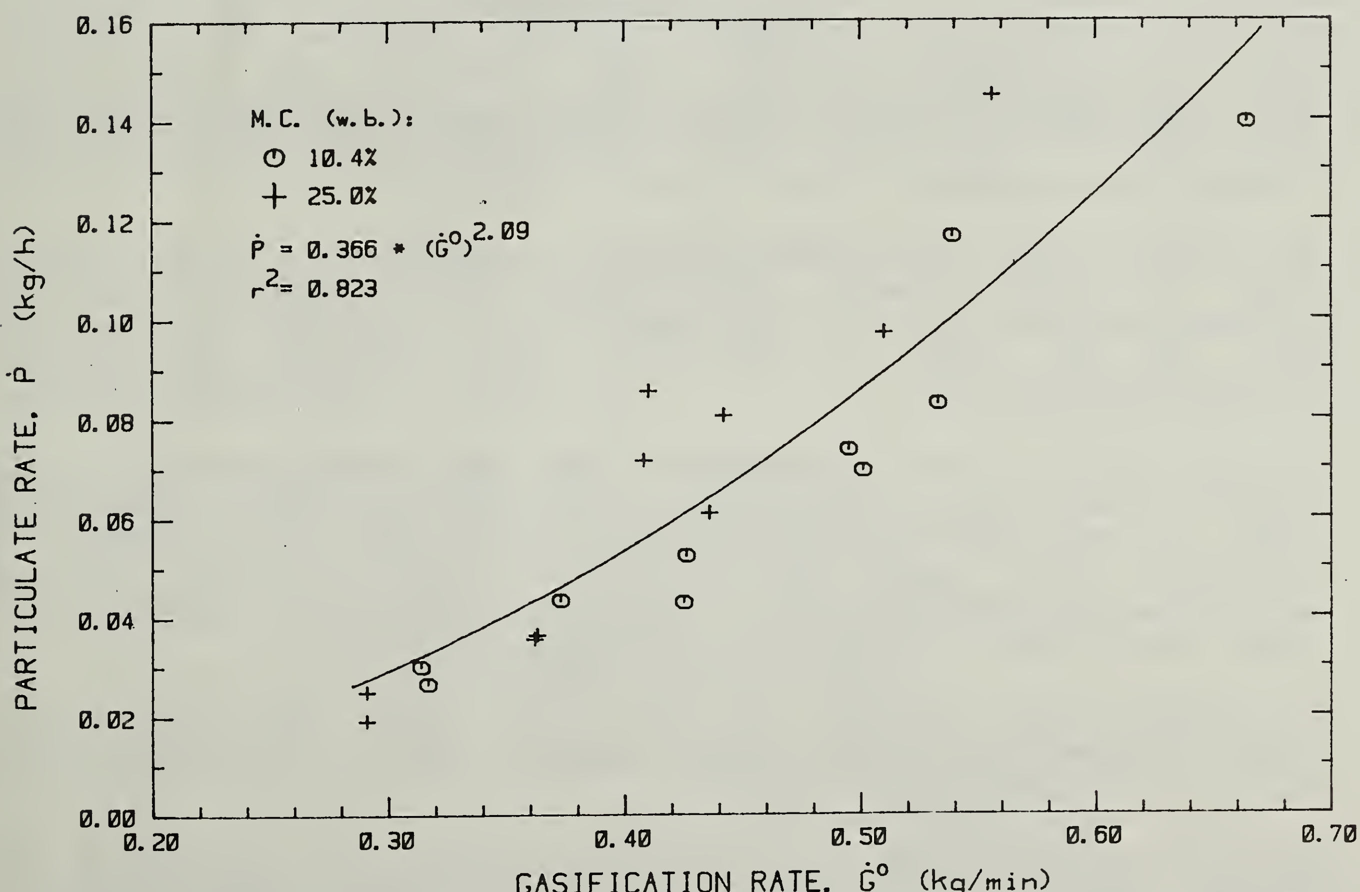

Fig. 2 Particulate emissions rate as a function of gasification rate for the pooled data at corncob moisture contents of 10.4 and 25.0% w.b.

DEVELOPMENT OF A DOWNDRAFT-CHANNEL GASIFIER-FURNACE WITH MECHANIZED FUELING FOR CROP DRYING

by

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ABSTRACT

This project on biomass utilization for on-farm heat energy was initiated early in 1980. The downdraft-channel gasifier-furnace was equipped for mechanized fueling with corn cobs. Minor modifications have been made to improve performance and durability.

MECHANIZED FUELING

The triple-channel downdraft gasifier-furnace used to dry corn in 1981 was used again in 1982 with minor firebox modification. It was, however, equipped for mechanized in place of manual fueling.

An air-lock feeder was necessary because the combustion air was pressurized. A 10-inch diameter rotary sleeve type of feeder was built and operated satisfactorily. It was, however, found necessary to limit cob flow into the feeder to avoid overfilling of the sleeve and consequent excessive cob shearing.

A 6-ft. diameter feeder tub metered the cobs into an inclined auger which elevated them to the air-lock feeder. A horizontal bar agitator two inches above the tub floor, turning at 2 rpm, metered the cobs through an adjustable hole, usually about 5 in. square, near the tub wall. The cobs were loosened as they flowed over the back of the bar, and a handful or so would drop through the hole before re-bridging occurred.

The feeder tub can possibly be used to dry moist cobs during their residence time in the tub if the bin exhaust or part of the furnace exhaust is passed up through the tub floor.

Cob level in the gasifier was monitored by a sensing arm pivoted at the chamber wall, actuated by cobs moving down their angle of repose. The arm extended out through the wall and carried a mercury switch which activated the feeding system. The mechanical sensing system worked but required rebalancing as tar built up on the inner arm.

TEST RESULTS

About 5000 bu. of corn were batch-dried with an average cob consumption rate of 128 lb/h with a net heating value of 833,300 Btu/h. The maximum rate attained was 224 lb/h, 1,274,000 Btu/h.

The primary air inlet holes became partially clogged by a soft ash build-up around the edges after 40 hours of operation and required cleaning. This was a result of thermophoresis, the attraction of a cool surface for particles in a hot gas stream. The incoming primary air cools the stainless steel air ducts as it is preheated. A temperature differential of up to 500°C exists between the primary air and the combustion gas, which contains sub-micron ash particles. The ash is attracted to the edges of the inlet holes, causing restriction of the air flow.

Recent tests with half as many inlets, thus doubling the velocity of the primary air jets up to 80 fps or more have shown no clogging after 40 hours of operation.

Heat radiation from the red-hot char in the channels caused duct warpage and slag formation when the combustion air was shut off and ceased to cool the ducts. This shut-down problem has been solved by partitioning the ducts for primary air flow in the upper portion and secondary air in the lower portion. For shut-down, only the primary air flow is stopped. Secondary air continues to flow, cooling the lower portion of the duct until the hot char has cooled. Typical operating temperatures are: primary air, 300°C; secondary air, 200°C; producer gas, 450°C; and char and ash just above the grate, 550°C.

FUTURE WORK

Continued development is needed to:

1. Improve and simplify the air-lock feeder.
2. Obtain a more reliable cob level control for the gasifier.
3. Provide for mechanized grate actuation and ash removal.
4. Improve and simplify the gas combustion chamber.
5. Design and build both larger and smaller gasifier-furnaces.
6. Modify and test the feeder tub for cob drying capability.
7. Obtain experience and data for fuels other than corncobs, including wood chips, sawdust, shredded wastepaper, shelled corn, chopped straw and stalks.

SUMMARY

An automatic corncob-feeding system has been developed. Ash clogging of the primary air inlet holes has been overcome, as well as overheating problems at shut-down.

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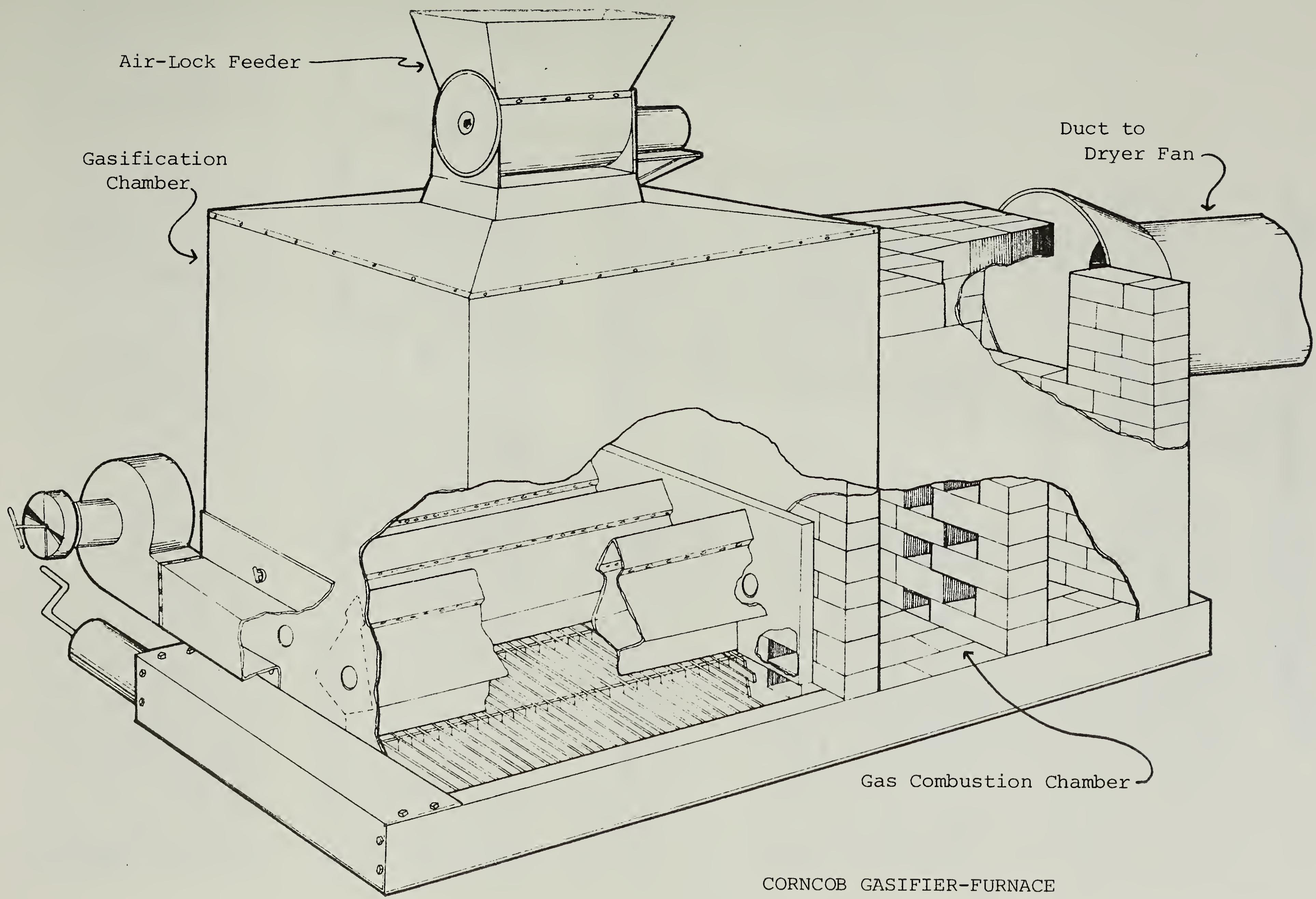

CORNCOB GASIFIER-FURNACE

BIOMASS - SOLAR COMBINATION DRYING OF CORN

by

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ABSTRACT

A combination drying system using renewable energy sources for heat was tested during both 1981 and 1982 fall drying seasons. The high temperature drying phase used heat from the gasification of corn cobs to partially dry batches of 14-16 tonnes of corn in a batch-in-bin mode. Successive partially dried batches were accumulated in layers in a storage bin in which drying was completed using forced natural air supplemented by heat from solar energy. The combination drying approach worked well and estimated energy costs were considerably lower than those for conventional high temperature drying using LP gas.

RESULTS AND DISCUSSION

The test conditions and results of the batch-in-bin high temperature drying phase for 1981 and 1982 are in Table 1. The data in the table are an average of 4 batches dried on successive days and transferred to the solar bin where drying was completed.

The heat content of the cobs used were calculated at 15,472 kJ/kg (6652 Btu/lb) in 1981 and 15,398 kJ/kg (6620 Btu/lb) in 1982. The heat input to the gasifier from the cobs burned was about one million kJ/hr. The heat supplied to the corn based on the air volume and temperature rise was 5.48×10^6 kJ and 4.95×10^6 kJ in 1981 and 1982, respectively. This represents an overall conversion efficiency from cobs to drying air heat of 73.5% in 1981 and 78.6% in 1982. Considering only the heat added to the drying air, 3112 kJ was required to remove each kg of water in 1981 and 3435 in 1982.

Low Temperature Drying

Four partially dried batches of corn were accumulated in the drying bin with a single batch added in each of four successive days. Drying was started immediately after the first batch was placed in the bin. The total airflow, and especially the airflow per tonne, was higher with part fills than when the bin was full. After the four partly dried batches were loaded in the bin, the corn was stirred with a single down-auger for 24 hours to lower air flow resistance and increase airflow.

Table 1 - Summary of High Temperature Drying
with Heat from Corn Cob Gasification
(Average of four batch-in-bin tests)

	1981 Test	1982 Test
Test period	Nov. 10-13	Oct. 12-15
Batch size - tonnes	14.5	16.5
Moisture content - %		
Initial	28.8	27.5
Final	20.7	21.6
Water removed - kg		
Total	1761	1441
Per tonne corn	121.4	87.3
Drying time - hrs.	7.2	7.1
Cooling time - hrs.	4.0	4.0
Airflow - L/s		
Total	3558	3176
Per tonne	245	192
Temperatures - ^{o}C		
Ambient	10.6	14.4
Drying air	58.9	63.9
Cobs burned - kg	481.7	409.5
Heat content kJ/kg	15472	15398
Heat input - kJ		
Total	7.45×10^6	6.31×10^6
Per hour	1.03×10^6	0.89×10^6
Per kg H_2O	4230	4376
Heat to drying air -kJ	5.48×10^6	4.95×10^6

The results of the two years of low temperature solar drying tests are summarized in Table 2. For the 1981 crop corn, the fall drying period and the spring 1982 drying period are presented separately. The corn dried to 16.8% mc in 30 days in the late fall, 1981. Ten days of additional drying in late March, 1982 reduced the moisture to a final average of 14%. A total of 4818 kg of water was removed or 83.2 kg/tonne (4.7 lb/bu).

In 1982, 66 tonnes of corn were dried from 21.6 to 13.7% mc in 17 days. A total of 6512 kg of water was removed or 98.7 kg/tonne (5.5 lbs/bu).

The total sensible heat available in the drying air is the sum of that available in the ambient air added to that from solar energy and from fan energy. Thus, the solar contribution to the total heat amounted to only 16% of the total with 70 m^2 of collector and 11% of the total with 35 m^2 of collector. Energy supplied to the 3.7 kW drying fan and to the 0.75 kW fan moving air through the two collectors amounted to 7 - 12% of the total. The remainder of the heat, 72% when both collectors were used, came from ambient air.

Table 2 - Summary of Low Temperature Drying with Solar Energy

	1981 Test		
	Fall	Spring	1982 Test
Test started	Nov. 11	Mar. 22	Oct. 13
Amount dried - tonne	57.9	57.9	66.0
Moisture content - %			
Initial	20.7	16.8	21.6
Final	16.8	14.0	13.7
Water removed - kg	2892	1926	6512
Drying time - da	30	10	17
Airflow - L/s			
Total	1850	2080	1960
Per tonne	32.0	35.9	29.7
Temperatures - ^{o}C			
Ambient	2.8	7.2	9.4
Drying air	4.9	9.4	12.9
Collector area - m^2	70	35	70
Insolation - kJ			
Total	27.0×10^6	6.46×10^6	20.29×10^6
Per m^2-da	12841	18447	17048
Percent normal	105	107	105
Energy collected - kJ			
Total	8.58×10^6	3.23×10^6	7.8×10^6
Per m^2-da	3950	9200	6520
Collection efficiency - %	31.8	50.0	38.4
Energy supplied - kJ			
Total	44.1×10^6	27.0×10^6	44.0×10^6
From ambient - %	72	82	72
From solar - %	16	11	16
From fan - %	12	7	12
Per kg water removed - kJ	15280	14040	6760

The energy used per kg of water removed is a measure of relative drying efficiency. With the poorer weather in late fall of 1981, the energy required was 15280 kJ/kg of water. This was 2.26 times the 6760 kJ/kg required in 1982. Interestingly, the difference is approximately equal to the difference in total drying time for the two tests.

Batch and Layer Drying Tests

Corn was also dried to a final marketable moisture content with heat from cobs alone. Two batches of 16t (634 bu) each were dried from an average of 24.6 to 14.9% moisture content. The drying time averaged 12.7 hours. The moisture removed per batch totaled 2265 kg or 178 kg per hour. A batch total of 681 kg (1500 lbs) of cobs were burned or about 46.6 kg/t (2.36 lbs/bu). A total of 8.57×10^6 kJ (8.12×10^6 Btu) was supplied to the drying air, based on the estimated air flow and temperature rise. Thus, 81.4% of the calculated heat content of the cobs was converted into heat in the drying air.

Finally a layer drying scheme was used in order to end up the season with the drying bin full of corn at a storable moisture content. About 16t (600 bu) was placed in the bin and dried the first day, a second similar layer was placed in the bin and dried the second and third day, with a final layer of 10.6t added the fourth day for a total of 60.2t (2368 bu). The corn was dried from 22.9 to 14.9% moisture content in 24.25 hours of drying time. Drying air temperatures ranged fdom 68 to 74°C (155 to 165°F). Moisture removed totaled 5980 kg (13,150 lb) for an average of 247 kg (542 lb) per hour. The airflow averaged 2600 L/s (5506 cfm). On the basis of the airflow and temperature rise, the heat input averaged 1.03 X 10^6 kJ (.98 X 10^6 Btu) per hour, for a total of approximately 25.1 X 10^6 kJ (23.8 X 10^6 Btu). On a per tonne basis, the heat used for drying was .417 X 10^6 kJ for layer drying compared to an average of .504 X 10^6 kJ in the batch tests reported above. However, an average of 141 kg of water was removed per tonne of corn in the batch tests and only 99 kg per tonne in the layer test. Thus, the heat required per kilogram of water removed was 3575 kJ for the batch tests and 4212 kJ for the layer test.

ANALYSIS

Energy inputs were recorded from which energy cost can be estimated. For the 1982 tests combination drying tests the energy costs for cobs, high temperature drying fan, low temperature dryer fan, collector fan and stirrer motor was estimated at $2.27 per tonne or 5.8 cents per bushel. Farm price of cobs used was $22.00 tonne; electricity cost was $0.05 per kWh. The cob cost was only $0.55 per tonne of corn dried while electricity for the low temperature fan was $1.29, over half the total. Costs for the tests in which drying was completed in the batch bin with heat generated by the gasifier amounted to $0.93/t for cobs and $0.41 for the drying fan, a total of $1.34. On the basis of energy cost alone, nothing is gained by adding a low temperature phase when using low cost cobs for fuel. However, a gasifier of 80% more capacity would be required to maintain drying capacity if the low temperature phase were eliminated. This together with the expected improved grain quality with the combination system, may warrant its use despite the energy cost relationships.

SUMMARY

Combination drying using heat from gasifying biomass for the high temperature phase and solar energy for the low temperature phase worked well despite the late harvest and wet crop encountered in 1981. For the 1982 crop, weather and harvest conditions were better than average and the system performed very satisfactory.

There appears to be adequate savings in using cobs at $22.00/tonne to justify considerable additional capital and labor to make the system work. This is encouraging to those interested in saving liquid and other petroleum fuels for motive and tractive power applications.

CONTAMINANTS FROM BIOMASS GASIFICATION

by

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ABSTRACT

The exhaust emissions from five biomass gasifiers have been quantified. The particulate emissions range from about 0.046 kg/hr (0.1 lb/hr) at an energy output of 0.21 GJ/hr (0.2 MBtu/hr) to 0.32 kg/hr (0.7 lb/hr) at an energy output of 1.41 GJ/hr (1.34 MBtu/hr). The traditional propane burner never exceeded 0.01 kg/hr (0.025 lb/hr) up to an energy output of 1.67 GJ/hr (1.59 MBtu/hr). The average emissions for the five gasifiers was found to be 145 mg/MJ (0.34 lb/MBtu). Benzo(a) Pyrene, a known carcinogen, has been identified in the exhaust particulate matter from the Purdue downdraft biomass gasifier. The aerodynamic size distribution has been found to be predominantly submicron.

INTRODUCTION

Six gasifiers were tested: 1) A direct combustion cob and stalk burner built by Sukup Mfg. Co., 2) An updraft gasifier corncob furnace built by Clayton and Lambert Mfg. Co., and 3) A series of three downdraft channel gasifier corncob furnaces being developed by Purdue University and the U.S. Dept. of Agriculture (Kutz et al., 1982). The sixth unit was a current technology propane burner of the type used throughout the United States and many parts of the world. Hereafter these units will be called: 1) Sukup, 2) Clayton Lambert, and 3) Purdue Pilot, Purdue '81 and Purdue '82, and 4) propane.

In each test, the furnaces were fired at least one hour before sampling began so that near steady-state conditions existed. Each furnace was operated following the builder's recommendations. Biomass was manually weighed to obtain fuel input rates and gas flow rates and temperatures were measured to obtain energy output rates.

After collection, the emphasis of sample treatment has been on the extraction of the polycyclic aromatic hydrocarbons from the sample. This was accomplished with a soxhlet extractor using methylene chloride as the solvent and a six hour extraction period. The extract was then subjected to vacuum filtration to remove residual particulate matter and the solvent was then exchanged to cyclohexane as the sample was concentrated to several milliliters over a steam table using a kuderna Danish apparatus.

RESULTS AND DISCUSSION

Particulate Emissions

The energy output from biomass furnaces and gasifiers is perhaps the most important single specification from the farmer's prespective. Knowing the capacity of a particular furnace or gasifier/combustor the farmer can then select the unit to meet the drying requirement. Since contamination of the drying grain by flyash is an important consideration, the mass emission rate of particulates from the various furnaces has been quantified. Figure 1 contains the particulate emissions from the six drying furnaces as tested over the energy output range from about 0.10 giga-joules/h to 1.69 giga-joules/h. It appears that a reasonable relationship exists between biomass furnace energy output and the particulate emissions. As expected, particulate emissions increase with energy output and most of the furnaces appear to group together in a family of curves with approximately the same slope.

The Purdue '82 3-channel downdraft gasifier/combustor is shown to exhibit the lowest emissions among the biomass furnaces for the corresponding energy output. Note that the Purdue '81 furnace, an earlier design version of the '82 unit, exhibited an undesirable high particulate emission rate. The higher rate of particulate emissions with energy output for the Purdue '81 unit is thought to be caused by frequent hand stoking to reduce ash buildup and corn cob bridging problems. The Purdue pilot downdraft gasifier/combustor also shows a higher rate of particulate emissions with increasing energy output than the Purdue '82 design. This is probably due to heat transfer edge effects since this unit was a single module channel design which did not need frequent stoking due to its being a second generation design following the Purdue '81 unit.

The Sukup unit is a commercially available direct combustion furnace with fuel being fed by screw auger to a combustion grate at the base of a vertical standing circular combustion chamber. Combustion air is fed tangentially in an amount from 100 to 400% of the stoichiometric requirement to affect complete combustion. The particulate emissions appear to be the highest for this unit. The lack of a secondary combustion chamber and the low turbulence levels within the unit are probably responsible for the elevated particulate emissions.

The Clayton Lambert is also a commercially available gasifier/combustor but it is an updraft design. With this design configuration, the pyrolysis gases pass upward through the descending fuel bed (corn cobs) and into the secondary combustion chamber.

An obvious conclusion from Figure 1 is that all the biomass furnaces tested had substantially higher particulate emissions than the propane burner. Since the propane burner represents current technology for high temperature grain drying, it appears the biomass furnaces need further design refinements to rival the particulate emissions from a propane burner.

It is of interest to express the particulate emissions as mass per unit of energy input to a biomass furnace as is commonly done for other combustion processes such as coal fired boilers. Table 1 contains a summary of the particulate emissions from the biomass furnaces tested with the emissions expressed as a ratio to the energy input to the furnace.

Table 1 Biomas and Propane Furnace Emissions Expressed as a Ratio to Energy Input

Furnace Types	Emissions mg/MJ	(lb/M Btu)
Sukup: direct combustion (3 test avg)	160	(0.37)
Clayton Lambert: updraft gasifier/combustor (2 test avg)	138	(0.32)
Purdue '81: downdraft gasifier/combustor (3 test avg)	172	(0.40)
Purdue Pilot: downdraft gasifier/combustor (29 test avg)	142	(0.33)
Purdue '82: downdraft gasifier/combustor (9 test avg)	112	(0.26)
Biomass furnace average	145	(0.34)
Propane Burner: (3 test avg)	4.48	(0.01)

Samples have been taken downstream of a farm scale batch-in-bin shelled corn downdraft gasifier drying operation. The 0.9 meter (3 foot) deep shelled corn bed acted as a porous bed air pollution filter with a particulate removal efficiency of approximately 50%. The atmospheric particulate emission from the biomass furnaces would, therefore, be one-half the furnace emission of Table 1 or 73 mg/MJ (0.17 lb/M Btu). Preliminary results indicate that more than twice the weight of normally occurring corn dust is deposited as flyash on the dried corn within the first 3 cm of the grain bed. The normally occurring corn dust amount corresponds to the shelled corn's "first handling".

Polycyclic Aromatic Hydrocarbons

Concern regarding carcinogenic polycyclic aromatic hydrocarbons has prompted their determination in the biomass furnace exhaust gas. Analysis of filter samples from the Purdue downdraft gasifiers using HPLC, UVS and GC/MS has confirmed the presence of the PAH compounds in Table 2 below.

Table 2 PAH Compounds in Gasificer Exhaust Gas

1) Benzo (a) Pyrene ***	8) Benzo (a) Anthracene *
2) Phenanthrene	9) Chrysene *
3) Fluoranthene	10) Coronene
4) Benzo (k) Fluoranthene	11) Triphenylene
5) Benzo (b) Fluoranthene **	12) Napthalene
6) Benzo (e) Pyrene	13) Acenaphthalene
7) Benzo (ghi) Perylene	

*Denotes the relative level of carcinogenicity. Benzo (a) Pyrene has a high level of carcinoginicity while no * indicates a lack of information to accurately label the compound as being either high or low level (Butler, 1979).

Acknowledgements

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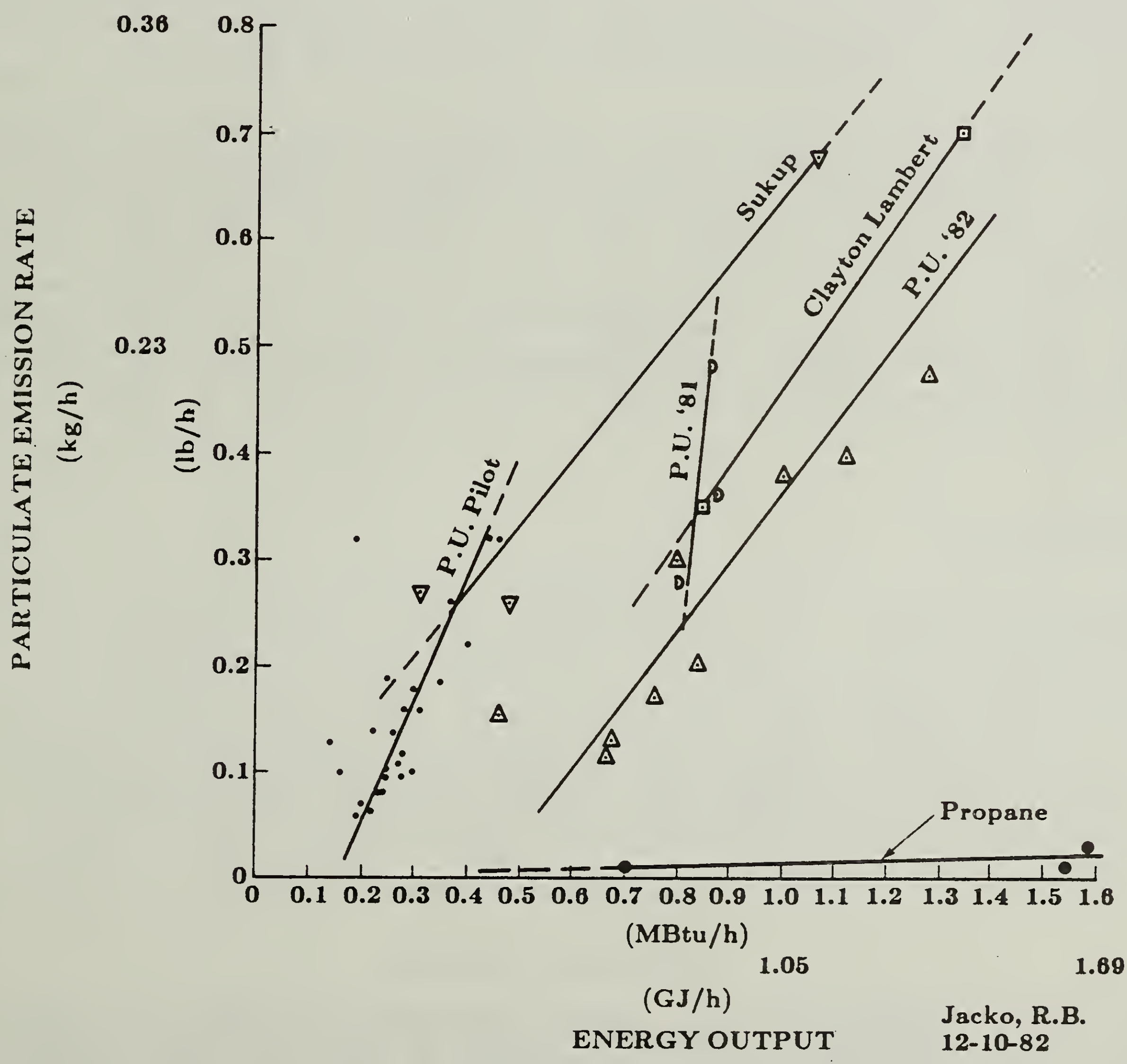

Figure 1. Biomass Furnace/Gasifier Emission Comparison.

SYSTEMS FOR DRYING FORAGES AND GRAIN WITH BIOMASS PRODUCTS

BY

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ABSTRACT

A system was developed to obtain a portion of the forage dehydration energy from corn cob gasification and the data provides a means of predicting the size gasifier required. A biomass gasifier was attached to the firebox of a dehydrator to supplement natural gas energy when dehydrating Tifton 44 bermudagrass. The range of moisture content of grass entering the dehydrator was 41 to 81% (wet basis) and the respective energy derived from corn cobs was 49.2 to 20.8% of the total energy required for dehydration. A Stormor indirect-fired biomass heat system which dries grain in 35.2 kL batches was used to evaluate biomass fuels. Corn was dried in the unit using large round bales of cotton stalks, small grain straw and Tifton 44 bermudagrass. The heat input was supplemented with propane gas. The data has not been evaluated however, observations on heat output and burn time shows cotton stalks to be the most satisfactory fuel. The biomass bales burned included those stored with and without covers. The uncovered bales, especially straw and Tifton 44 bermudagrass, often were too high in moisture to burn satisfactorily.

Introduction

The increase in cost of fossil fuels has led researchers to investigate systems for dehydrating or drying farm products using alternate fuels. This report covers two systems: one which utilized biomass residue for dehydrating forages, and one for utilizing residues for drying grain. The two systems are only similar in the utilization of biomass for fuel. In the gasification process used to dehydrate forages, the raw material is dried when it is dropped into the air stream of burnt gasses. The grain dryer utilizes the hot air from a heat exchanger in a biomass furnace to dry the grain.

BIOMASS GASIFICATION

The cost of dehydrating Coastal bermudgrass has increased 10.4 times from $5.46/t of forage in 1972 to $56.00/t in 1983 when using natural gas. Projected energy availability and cost will continue to cause increased energy costs for dehydration.

Gasification-combustion of biomass for direct heating in a dehydrator has some similar advantages to natural gas; it burns clean and the heat can be passed through the forage being dried. Fuels suitable for automatic-feed gasifiers include corn cobs, wood chips or pellets, pelleted biomass products, fruit pits and nut shells. Their moisture content should be less than 15% wet basis (wb) to maintain good burning.

The objective of our research is to develop a system to utilize biomass energy for forage dehydration with a gasifier furnace. This report covers the use of corn cobs in a gasifier to supply part of the energy to dehydrate Tifton 44 bermudagrass ranging in moisture from 40 to 80% (wb).

The dehydrator located at the USDA, Southern Agricultural Energy Center, Tifton, Georgia was modified to attach a Clayton and Lambert* Fiery furnace prototype gasifier. The duct from the gasifier was equipped with a y-valve so that the heat could be exhausted or directed into the firebox. Either natural gas or the gasifier or both could be used for dehydrator heat. The gasifier was set to burn at a constant temperature of 370°C. Tifton 44 bermudagrass was dehydrated and pelleted using corn cobs and natural gas as the source of dehydration energy.

The energy derived from the cobs burned in the gasifier was determined by multiplying the weight of the cobs burned by the heat of combustion of the cobs (19.7 MJ/kg) as determined from bomb calorimeter tests.

RESULTS

The average moisture content of the dehydrated forage was 10.6% wb. The average moisture content of the corn cobs used in the gasifier was 9.3% wb. When dehydrating bermudagrass in the range of 40.9% to 81.1% wb moisture, the energy derived from corn cobs ranged from 49.2% to 20.8% respectively of the total energy required. The average energy obtained from corn cobs was 2.86 GJ per ton of forage dry matter dehydrated. The corn cob energy was determined from the corn cob burning rate which averaged 144 kg per ton of forage (dm) dehydrated. The dehydration energy in this investigation was compared to the formula which was developed in previous research to predict energy required to dehydrate Coastal bermudagrass (Butler and Hellwig 1970). Since the data matched the curve generated by the formula $y = 1221.15\ (274e^{0.047x}+1844)$, the formula may be used to predict the total energy required for dehydrating Tifton 44 bermudagrass with natural gas and the gasifier and to determine the size gasifier which should be used. Allowance of 1.5 to 2.0 GJ/tdm energy should be made for effective dehydrator temperature control with natural gas or oil.

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*Mention of a trade or proprietary product does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

This study shows that energy from corn cobs burned in a gasifier-combustion furnace can be used to dehydrate forages. More research needs to be conducted to determine if biomass may be used as the sole heat source to dehydrate high quality forage (initial M.C. above 70% wb) which is to be used as a source of xanthophyll in feed rations. In a complete system, a gasifier may be more economical as a supplemental energy source to dehydrate forages than as a sole heat source because of slow response of the gasifier to temperature adjustment. More complete details of this study were reported by Hellwig et al. 1983. Other biomass materials will be evaluated in the gasifier to determine the influence on energy output and control.

BIOMASS BURNING TO DRY GRAIN

Direct fired burners that burn natural gas or propane fuels are the common grain drying systems used by farmers. Many farmers have round balers or stackers for harvesting forage which may be used to harvest many crop residues with little or no modification. Moisture contents, heats of combustion and burner efficiencies will determine the amount of useable energy available to dry farm products.

A Stormor indirect-fired biomass heat system was installed in Tifton to dry grain in batches of 35.2 kL. The furnace design has a heat exchanger for heating the air blown through the grain; therefore, no flame or by-products of combustion enter the grain. The firebox was sized to burn stacks or bales of crop residue. Hot air from the heat exchanger is passed through the high moisture grain in the top of the storage bin. When the drying process is complete, the grain is dumped to the bottom of the bin. The results of efficiency evaluations of three biomass fuels burned in the Stormor dryer without grain in the bin were reported by Sumner et al., in 1983. Heat available for drying grain was 49 to 69 percent of the biomass energy input to the furnaces from cotton stalks, corn stover and soybean residue.

RESULTS

The evaluation of the Stormor system was continued when corn was dried with the unit. Large round bales of cotton stalks, small grain straw and Tifton 44 bermudagrass we used in the test. The data has not been evaluated, however, observations of heat output and burn time shows large round bales of cotton stalks to be the most efficient fuel. The large round bales of straw stored for one year included bales with or without covers; and bales placed on 20 cm square wood beams with or without covers. Covered straw bales had a lower moisture content and burned rapidly and completely. When the moisture content was high on uncovered straw, complete burning required more time.

The coastal bermudagrass bales averaged 20-25% moisture and did not burn satisfactorily. Bermudagrass may be a good source of heat if bales are kept dry or they are burned in conjunction with some other biomass source. The analysis of the data may provide a method of selecting biomass material and maximum moisture content of the material for satisfactory drying. Management input effect on drying rate will also be evaluated.

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CORN DRYING USING HEAT FROM A DIRECT-FIRED CROP RESIDUE FURNACE

by

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ABSTRACT

Twenty-five field tests of corn-drying in a 4.1 t/h continuous-flow dryer direct fired from a 1.5 GJ/h concentric-vortex direct-combustion biomass furnace were carried out in 1981 and 1982. Technical feasibility is being investigated by determining dryer efficiency, furnace combustion efficiency with differing fuel types and moisture contents, the amount of corrosion of metal surfaces in the dryer, and the quality of the corn dried by this direct combustion process. Corn dried with cob fuel was found to have the lowest incidence of commercially objectionable foreign odor. Chemical and biological tests on corn samples are in progress.

Introduction

A device capable of converting crop-residue energy to useful heat for crop drying would reduce dependence on fossil fuels. A well-functioning, direct-combustion furnace could deliver greater output for a given input and cost less than a furnace equipped with a heat exchanger. The products of combustion could, however, leave harmful deposits on the grain or cause increased corrosion of metal surfaces of the furnace and drying system. Investigation of these potential problems should give information needed to decide on the direction of crop-residue energy use.

Field-Test Equipment

The 1.5 GJ/h concentric-vortex furnace was developed at Iowa State University under another Department of Energy project. A fan provides an induced vortex action within the inner concentric cylinder, the fire chamber of the direct-combustion furnace. Crop-residue is fed in the side of the furnace through a timer-controlled auger (Figure 1). The 30-cm dia. auger tube contains a 20-cm dia. auger helix to enable feeding of varying size crop-residue.

The dryer is a SUPERB model S250C continuous-flow grain dryer manufactured by Beard Industries Inc. The dryer contains a double-inlet, belt-driven, centrifugal blower with a 11.2-kW motor located outside the blower plenum. An overhead air duct was constructed to direct the furnace combustion air into both sides of the blower plenum where outside air and combustion air are blended by the double-inlet blower.

Combustion takes place in the furnace fire chamber where the flame and the volatile gases violently spin around in the upper portion of the furnace by the fan-induced vortex action. Particulate matter spins to the outer walls and drops down for nearly complete combustion. The products of combustion and heated air leave the stack at approximately 480°C and pass through the overhead air duct into both sides of the dryer air plenum. A 1-hour warmup is allowed before drying begins.

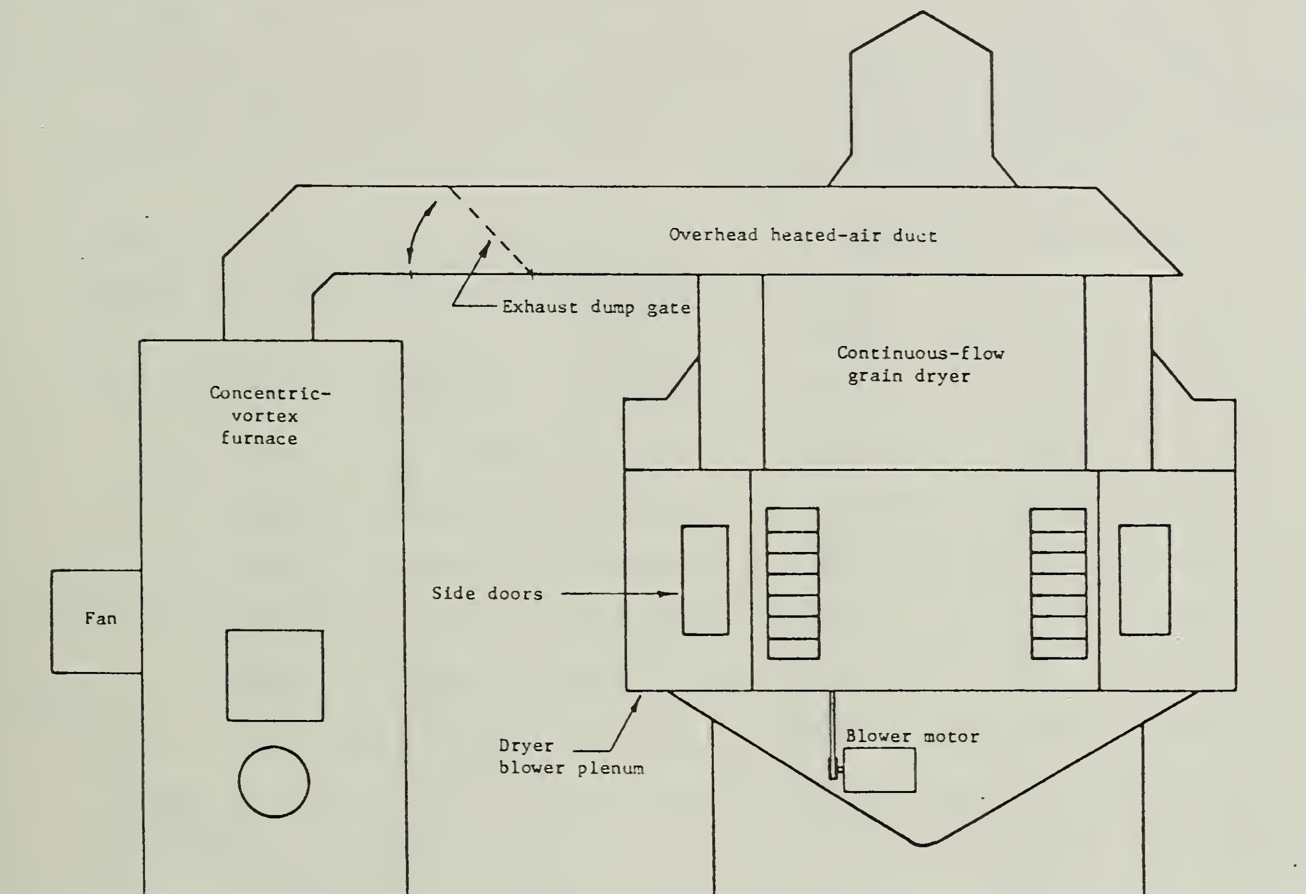

Figure 1. Schematic diagram of the concentric-vortex biomass furnace and the SUPER B model 250C continuous-flow grain dryer.

System Testing

Thirteen corn-drying tests using 5 different fuels were completed in 1981, and 12 corn-drying tests with 2 different fuels were completed in 1982. The various fuels used in testing and their origins are as follows:

Fuel type	Origin
-Whole corn cobs	- Dekalb seed corn plant
-Corn cob-husk mix	- Collected from a combine during harvest
-Corn stover	- Collected from the ground using a giant round baler
-Soybean straw	- Collected from the ground using a giant round baler
-Wood shavings	- Sawmill planer
-Tree leaves	- Collected on the ISU campus with a vaccum pickup

Corn samples were taken before and after the batch drying process. These corn samples are being chemically analyzed to determine the amount of benzo (a) pyrene, an active carcinogen, deposited on the corn.

A biological test, the Ames test, will also be performed on a sample to detect any obvious mutagenic threat to a biological system. Corn samples from all the field tests were graded by a licensed USDA grain grader.

The high-temperature airstream in the overhead duct was sampled isokinetically and filtered to determine the amount of particulate produced by the furnace. Seven of the 12 tests were sampled by this procedure in 1982.

Results

Results of the particulate sampling are shown in Table 1. The drying air temperature was inversely related to fuel moisture. Table 1 indicates that the ratio of particulate to energy out was, in general, inversely related to the drying air temperature.

Table 1. Particulate emissions

				Particulate Concentration		
Test number	Fuel type	Drying air temp °C	Rate (g/h)	Overhead duct (mg/m^3)	Drying air (mg/m^3)	Per unit energy output (mg/MJ)
482	corn cob	82	110	56.3	4.85	67.9
582	corn cob	89	4.5	2.3	0.20	2.3
1182	cob-husk	52	131	47.1	6.42	138.4
982	cob-husk	53	79.8	31.7	3.89	81.5
782	cob-husk	59	62.6	25.4	3.07	50.3
1082	cob-husk	60	43.0	16.5	2.12	38.8
882	cob-husk	61	90.8	36.3	4.44	78.5

Table 2 shows the USDA grain grade for corn dried in both 1981 and 1982. The sample grade was given because the grader smelled the corn sample with his nose and determined that there was a commercially objectionable foreign odor on the sample. Other grades lower than a 2 were given because the sample was greater than 15.5% moisture content or the test weight was lower than 54 lbs/bu. Neither of these factors are due to the type of fuel used for the drying process. Corn cobs, with the exception of one test, dried corn to a condition suitable for marketing. The exception resulted from intentional mis-management of the drying system by using wet cobs, not warming up the furnace before drying and employing 2 startups and cool downs instead of 1. The results of the mis-management was sample grade corn.

Table 3 indicates some preliminary results from the chemical testing using a gas chromatograph. Further analysis is in progress. Galvanized, perforated-metal test strips were located in the dryer at various locations to determine the degree of corrosion on metal surfaces. No significant change in weight was noted from the first year of testing. Further analysis is in progress.

Table 2. USDA Grain Grade Results

Test number	Fuel type	USDA grain grade	Basis for grain grade <2
182, 282, 382	corn cobs	3	low test weight
482, 582	corn cobs	4	low test weight
782	corn cobs	5	low test weight
381	corn cobs	2	-
681, 1381	corn cobs	3	high moisture
281	corn cobs	4	high moisture
481	corn cobs	sample	COFO[1]
882	cob-husk	3	low test weight
682, 9-1282	cob-husk	sample	COFO
781	corn stover	2	-
881	corn stover	sample	COFO
581	corn stover	lost	-
981, 1081	soybean straw	sample	COFO
1181	wood shavings	sample	COFO
181	tree leaves	sample	COFO

[1]COFO = commercially objectionable foreign odor

Table 3. Benzo (a) pyrene concentrations on corn

Test number	Fuel type	USDA grade	Corn sample size (g)	BaP Concentrations[1] (ppb) Before drying	After drying
481	cobs	sample	625, 1250	<5	<5
882	cob-husk	3	625, 1250	<5	<5
1181	cob-husk	sample	625, 625	<5	<5
1282	cob-husk	sample	625, 625	<5	<5

[1]The minimum detection level was 5 ppb with a 625g sample and 2 ppb with a 1250g sample with the anaylitical method used.

SUMMARY

A 4.1 t/h continuous-flow grain dryer and a 1.5 GJ/h concentric-vortex direct-combustion furnace were field tested for 2 years. Various crop residues were used as fuel in the furnace to provide heat for the combustion process: whole corn cobs, corn cob-husk mixture, corn stover, soybean straw, wood shavings, and tree leaves. Corn dried with cobs in the properly managed system consistently yielded a product with no commercially objectionable foreign odor. Further chemical and biological tests on corn samples are in progress.

USING CORNCOBS TO DRY GRAIN ON THE FARM

by

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ABSTRACT

This research was conducted during the 1982 drying season to determine the operating characteristics of a commercial biomass gasification-combustion unit used for drying corn with a batch-in-bin drying system. The effect of drying fuel on livestock performance was also determined. Growing swine were fed corn dried with LP gas, dry corncobs and wet cobs to evaluate feed consumption, growth rate and conversion efficiency.

Introduction

Uncertainty of fossil fuel prices and inadequate supplies during critical demand periods have stimulated interest in renewable energy sources among farmers. Burning crop residues appear to be feasible under present economic conditions. Corncobs, in particular, have been shown to be a viable, abundant and economical biomass material that can be burned to provide a high quality thermal energy for drying grain or for other heat applications on the farm (Loewer, et al., 1980; Loewer, et al., 1981; Morey, et al., 1982; Payne, et al., 1979; Richey, et al., 1981).

Corncobs or any other biomass materials should be dried to 20 to 25% to provide a clean, efficient fuel source for grain drying. Biomass gasifiers that are accidentally or intentionally fueled with wet materials produce smoke-filled exhaust air which may contaminate grain by altering its odor or taste, and may render it unacceptable as an animal feed. Information is needed on the performance of these gasifiers and the effect of drying fuel on feed intake, growth rate and feed efficiency of livestock.

This study was conducted to determine the operational characteristics of a corncob gasifier while drying corn in a batch-bin system. The effect of drying fuel on performance of growing swine was also observed.

Procedures

All corn drying tests were conducted at the University of Kentucky Research and Education Center at Princeton (Fig. 1). Whole corncobs were obtained from a local white corn seed producer and burned in Clayton and Lambert's updraft gasifier.

Yellow corn was dried by a batch-bin method using three different fuels: 1) LP gas, 2) dry cobs, and 3) wet cobs and dry cobs. Corn from these tests were fed to growing swine. The amount of corn dried in each test was determined by the feed requirements for the animals rather than by the optimum depth for in-bin drying.

The drying bin was 21-ft in diameter and was equipped with a motorized spreader, a perforated floor and a 24-inch fan with a 7.5 hp motor. Drying air temperature was observed by a dial type thermometer located in the bin plenum. The fan and heater were operated until the corn had dried to an average moisture content of 12% or less. The fan was operated to cool the grain before it was transferred into metal feed bins.

In the first test, an LP gas pressure regulator was manually adjusted to control the drying air temperature. In the remaining tests, air from the gasifier's hot air duct was mixed with ambient air by the fan on the bin to form the desired drying air temperature (Fig. 1). The amount of hot air delivered to the fan was automatically controlled by a modulating damper on the duct. Wet cobs were used in the third test to produce smoke-filled exhaust gasses from the burner. A full charge of secondary air was introduced into the burner to prevent temperatures in the combustion chamber from becoming sufficient for ignition. Smoke-filled air was forced through the corn by the drying fan for 90 minutes. Dry cobs were then fed into the gasification chamber and the burner was operated to finish drying the corn.

Another drying test was conducted to determine the amount of material required to dry a typical size batch of corn with this drying system. A 1250 bu batch was dried with dry cobs in the previously described bin.

Results

Approximately 2100 bu of corn were dried in all tests by using corncobs as a fuel. Observations during the drying tests are shown in Table 1. Cob burning rates ranged from an average of 193 lb/hr to 253 lb/hr. Approximately 1 lb of dry cobs will remove 2 lbs of water from shelled corn. A more efficient drying system could be achieved by adjusting the depth of corn in the bin. Results of the 95-day swine feed trials are shown on Table 2. Little differences were observed in average daily gain. However, the smoke damaged corn resulted in a slightly lower feed intake and an improved feed efficiency.

SUMMARY

For a cob yield of 12 lb per bushel of corn and a heat requirement of 3362 Btu per lb of water removed, the cob material produced from one bu of shelled corn could dry 3.25 bu of corn from 22% to 12% with this batch drying system. Material burning rates ranged from 193 to 253 lb/hr for the cobs during these tests.

Swine with an average initial weight of 56.4 lbs were fed corn dried with LP gas, dry corncobs and wet cobs. An average final weight of 210.7 lbs was observed with no difference in average daily gain. However, a lower feed intake was observed which resulted in a slightly improved feed efficiency for corn dried with cobs.

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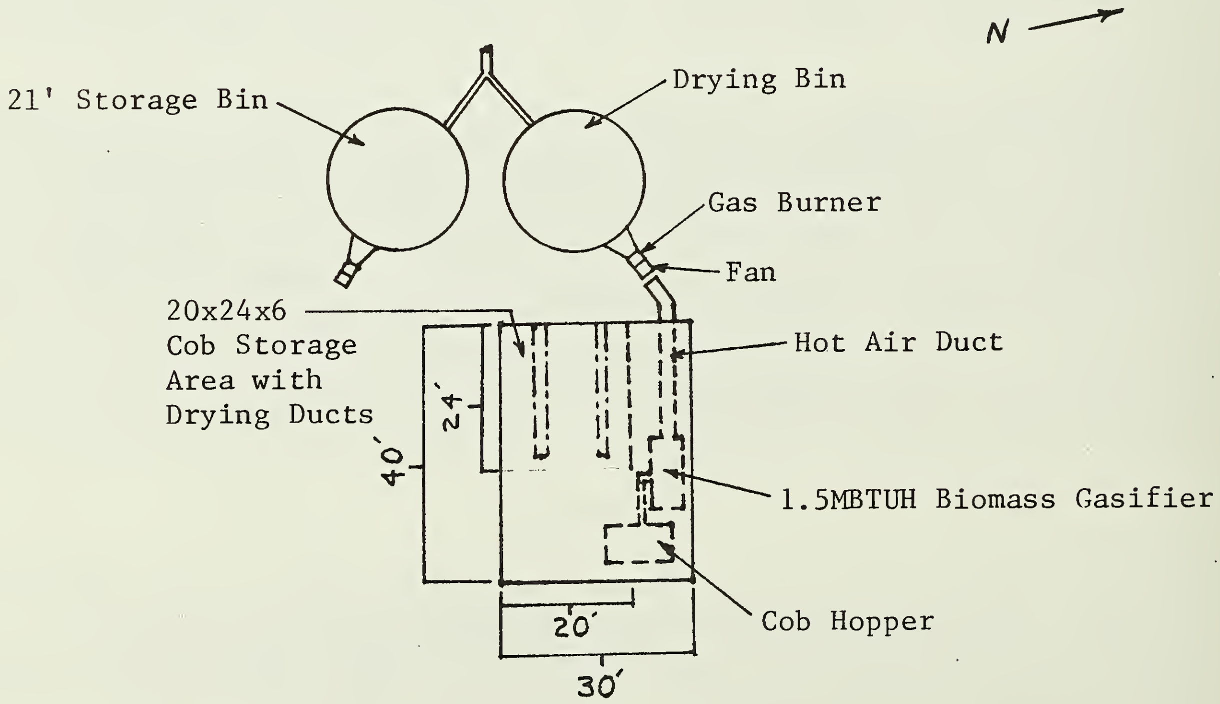

Figure 1. Biomass Burner and Cob Storage Building

Scale: 1"=32'

TABLE 1. SUMMARY OF CORN DRYING TESTS

Date:	Oct. 5	Oct. 6	Oct. 7	Oct. 9
Grain Dried, bu	278	278	278	1,250
Initial m.c., %	19.6	20.5	18.8	19.7
Final m.c., %	11.7	11.4	11.5	14.7
Water removed, (lb)	1,464	1,700	1,336	4,318
LP gas burned, (lb)	219	--	--	--
Cobs burned, (lb)	--	1,317	--	2,313
Cob m.c., %	--	13.1	--	13.1
Drying time, hrs.	5.9	5.2	5.8	12
Cooling time, hrs.	0.83	1.0	1.0	2
Temperatures, F 1/				
Dryer plenum	135	140	122	124
Ambient	82	82	80	72
Air flow rate, (cfm/bu) 2/	46	46	46	7.0
Heat content, (Btu/lb) 3/	20,000	6,277 3/	--	6,277
Drying efficiency, (Btu/lb water)	2,992	4,863	--	3,362

1/ Average of temperature readings throughout the test period.

2/ Calculated for grain depth, fan horsepower and 1.5 packing factor.

3/ Payne, et al., 1980.

TABLE 2. SUMMARY OF SWINE FEED TRIALS

	Drying Fuel		
	LP Gas	Dry Cobs	Wet Cobs
Replications	6	6	6
No. of Pigs	24	24	24
Avg. daily gain, lb.	1.84	1.88	1.84
Avg. daily feed, lb.	6.12[a]	6.09	5.92[b]
Feed/Gain	3.34[a]	3.24[b]	3.21[b]

[a,b] Data with letter superscripts are significantly different at the .05 level.

COMPUTER SIMULATION FOR BIOMASS COMPACTION

by

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ABSTRACT

In order for this nation to become energy self-sufficient, it is necessary that we not waste any of the resources that we possess. It is estimated that some 13.4 quads of biomass energy are wasted each year. Last year this nation used somewhat over 75 quads of energy. This waste could supply about 18% of our national needs, thereby cutting down our dependence on foreign oil. Tree trimmings that are left over after the prunning operation in deciduous fruits and nuts are a significant portion of that agricultural waste. The important step in the eventual utilization of agricultural waste is to be able to gather, compact, transport, and store this material so it can be used in an energy producing system.

COMPUTER MODEL

In order to effectively direct the design of the biomass compaction project, a computer simulation has been developed that will evaluate: 1) the gathering unit, 2) the compaction unit, 3) transportation, and 4) storage. Utilizing information already gathered on the compactive effort of agricultural wastes and the physical properties of the material involved, the sub-routines associated with each task in the model were developed.

Gathering

The gathering operation involves moving the tree trimmings from the ground between the rows of trees, elevating and transporting them to a compaction unit. This sub-routine used such inputs as the pounds of the brush per acre on the ground, the spacing of the trees, the area to be picked up, the speed that the machine will move down the row, the soil cone index, and the cost of fuel. The outputs from this sub-routine produced the field capacity in acres per hour, total cost, dollars per ton, and the energy required. These outputs are then used by other sub-routines. To evaluate these outputs the machine was assumed to be a commercial chain type conveyor with side friction. The horsepower was then computed as well as fuel used. The gathering unit also included equations as to the soil firmness that were used to predict the tractive power necessary to move the machine down the row.

Baling

The baling sub-routine required such inputs as the desired bale density, the baler load speed to ground speed, and the labor rate. It was assumed in this model that the baler would be hydraulicly driven with positive displacement pumps. Frictional horsepower necessary to pump the fluid through the lines and valves were calculated using the Darcey equation, as well as the power required to shear and compress the material. The time for each cycle was calculated based upon two flow rates from a dual pump system consisting of a high volume, low pressure pump to move the piston when the loads are small and a low volume, high pressure pump which will take over when the loads are too great for the low pressure pump. The baler sub-routine calculates the load time, the load volume based upon the ground speed of the gather unit, the pressure required for the operation, and the average horsepower per cycle. This then is converted into total horsepower required, dollars per ton, and total dollars involved.

Transportation

The transportation model was developed around information gathered from bulk haulers in the San Luis Obispo area. Inputs to this sub-routine consist of the distance hauled, the cost of fuel, miles per gallon for the vehicle, the bulk density of the material being hauled, and the type of material. This sub-routine, analyzing the density and the type of material, will decide whether a flat-bed truck and trailer can be used, or whether a closed vehicle will be required. It then will decide whether the load is limited by weight or by volume, and will load the truck accordingly. The sub-routine will then calculate the fuel used, the time of the haul, the total cost involved, evaluate lay time depending upon unloading requirements, the cost per ton, and the total number of trips required for the job.

Storage

The storage sub-routine is modeled to simulate the moisture loss from the wood trimmings versus time of storage. This was required since the moisture content of the material may affect the energy consumed in the compaction and the transporting of this material. Also the moisture content of the material at the time of burning will affect the energy generated. This model is based upon normalized equilbrium moisture content that can be varied according to the ambient temperature and relative humidity. From the literature review, a drying rate curve was established for moderately sized wood pieces and modified by an area to volume ratio. The normalized drying curve went from 60% moisture to approximately 9% moisture in 90 days of ambient drying. The storage sub-routine required such inputs as relative humidity, average ambient temperature, initial moisture content, size of the material, and days of rainfall. The output would then be the finished moisture content and the total time in the drying process.

Main Program

The main program then simply calls each one of these sub-routines in turn to put together the entire system. Table 1 is a example of the inputs required for a typical program run. In the simulations ran to date, the main program called the sub-routines in this order: 1) gathering, 2) baling, 3) transportation, and 4) storage. Table 2 is an example of the output for a typical run. Figure 1 is a summary of the output from the simulation program and is dollars per ton versus speed of pickup in miles per hour evaluating the material in one row, every other row, or every third row. The cutoff point indicated in this graph is where the pressure becomes greater than the maximum pressure allowable for this system. It appears that the best operation would be the material placed in every other row and a ground speed of about one mile per hour. Figure 2 depicts the horsepower versus speed required of the pickup and baler unit as a function of the rows in which the brush is placed. Here again the brush in every other row and a speed of approximately one mile per hour is a good compromise.

TABLE 1 Input data

COST/GAL FOR FUEL	1.2
DISTANCE BETWEEN ROWS FT	24
TRIMMING LB PER ACRE	2000
TOTAL ACRES TO PICKUP	40
TRIMMING IN WHICH ROW	1
PICK UP SPEED IN ROW MPH	2
SOIL CONE INDEX 15-50	20
MACHINE COST NEW	40000
BALE DENSITY LB./FT°3	20
BALE LOAD TO GROUND SPEED	1.5
LABOR PAY RATE	5
DISTANCE OF HAUL	50
MPG HIGH-8 MED-6 LOW-4	6
BALE=1 CHIPS=2	1
REL. HUMIDITY %	40
AVG. TEMPERATURE C.	20
INITIAL MOISTURE CONTENT	60
DAYS OF RAINFALL	10
INPUT FINAL M=1,TIME =2	1
DESIRED MOISTURE CONTENT %	18

TABLE 2 Output data

NUMBER OF TRIPS	= 2
ENERGY INPUT IN GALLONS	= 33.3
TIME OF ROUND TRIP, HR.	= 3
ENERGY COST TRAN.	=$40
TOTAL COST TRAN.	=$191.33
COST PER TON TRAN.	=$3.51/TON
DRYING TIME	= 37.53
HORSEPOWER GATHER	= 7.52 DAYS
COST PER TON GATHER	=$.20/TON
FEED RATE	= 4.2TON/HR
DENSITY FROM BALER	= 20LB./FT°3
HORSEPOWER TO BALE	= 34.08 HP
COST PER TON, BALE	=$8.14/TON
TOTAL COST	=$525.02
TOTAL COST PER TON	=$13.12
TOTAL TIME	= 39 DAYS

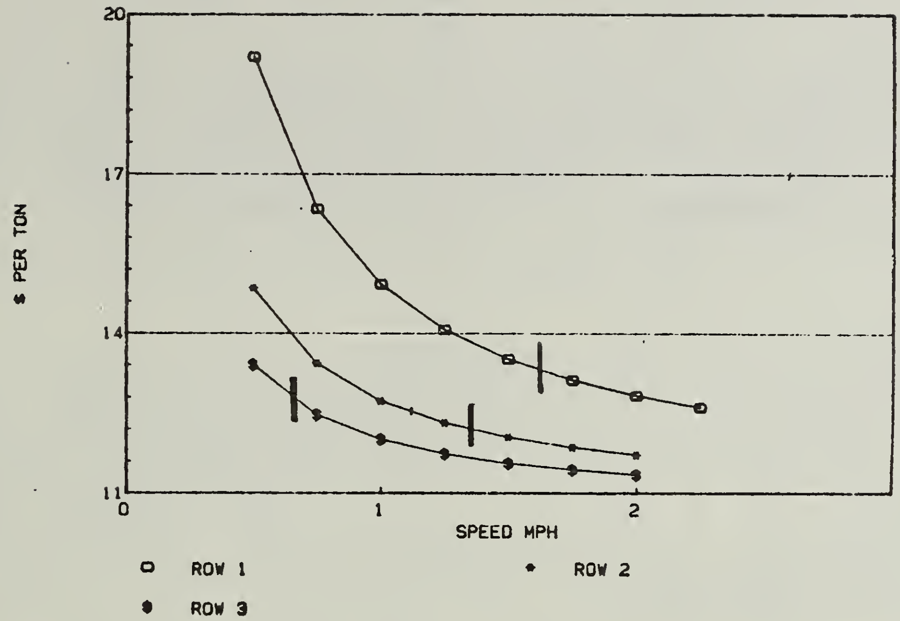

Figure 1 Delivered cost per ton for various speeds and pickup rows.

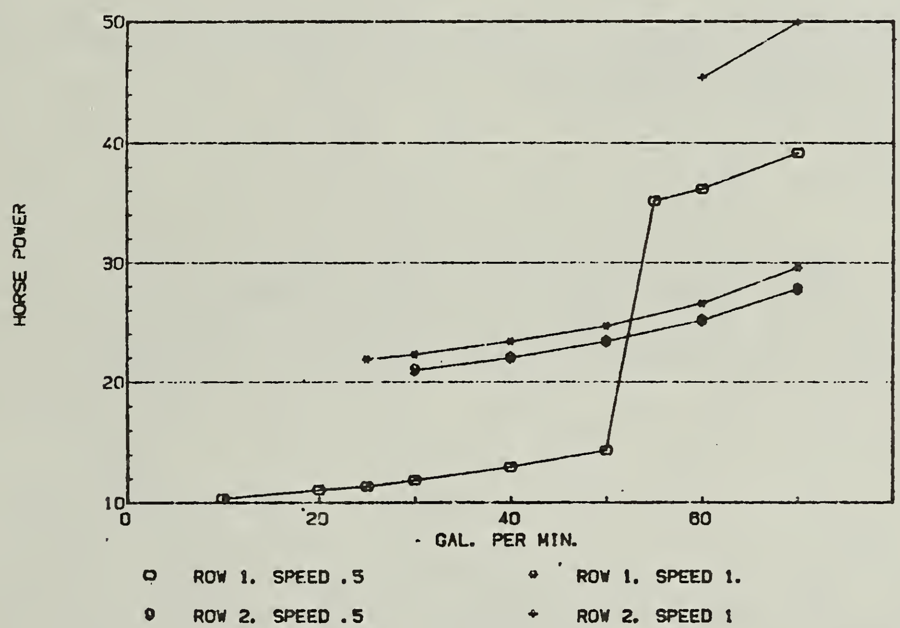

Figure 2 Baler horsepower for various pump sizes, rows and speed.

SUMMARY

The computer simulation model for biomass compaction is up and running. There are still a few refinements left to complete, such as the cost of the brush baler is fixed. It was expected to see an optimal pump size for the compaction system, but due to the fixed price of the machine no optimum appeared. Based on the simulations runs todate the design will continue using a 50 gpm main pump.

FUEL PREPARATION AND CONTINUOUS FEEDING SYSTEMS FOR DOWNDRAFT GASIFIERS

by

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ABSTRACT

Wood fuel is being processed for use in downdraft gasifiers with pulpwood chippers. The form of this fuel is not ideal because it tends to bridge in fuel hoppers and in gasifiers. It has been found that wood sheared nearly perpendicular to the grain tends to form secondary shear planes parallel to the grain and this method of reducing wood to small prismatic pieces is being researched.

Continuous refueling systems for downdraft gasifiers are under development including a ram injector type feeder and a rotary gaslock type with a fuel regulating mechanism. The ram injector has made possible prolonged gasifier operation without interruptions for refueling and the rotary gaslock appears promising.

Fuel Chipping

Wood fuel has been processed for gasifier fuel by sawing into cubes, and by chipping. The former was the common method of preparing fuel for downdraft gasifiers during World War II (1). Chipping was accomplished by various means and this resulted in smaller processing losses according to the literature from that period. Presently, small mobile pulp-wood chippers are available and these are being used for preparation of fuel for wood furnaces, as well as gasifiers. At the University of Florida, we have been chipping wood with a Morbark "Eeger Beever" pulp-wood chipper, which cuts the wood into a 0.61 inch theoretical length pieces at a 45° angle of cut. This machine performs quite satisfactorily with long straight logs, but crooked wood such as oak and citrus present problems with feeding the logs into the machine. The crooked wood catches in the feed rolls and these freqently have to be reversed to eliminate jamming. This significantly reduces the productivity of the machine. The capacity of this 60 horse-power chipper is claimed by the manufacturer to be 25 tons per day, but this can only be achieved with long straight logs. The chips from this machine often contain large pieces of wood from the ends of logs and from crooked sections that break while they are being chipped. These pieces have to be removed from the processed fuel otherwise they cause problems with feeding fuel into gasifiers and with bridging once the material is in the reactor.

It has been felt that the ideal chipped wood for paper pulp manufacturing is not the same as desirable fuel for a gasifier, because the long, thin diagonally cut chips, most suitable for paper pulp have too great a tendency to bridge and compact in a gasifier. It is felt that prismatic fuel particles would feed and react better in a gasifier than the flat chips, so experiments have been carried on to make gasifier fuel by shearing wood perpendicular to the grain with a powered shear. A simple apparatus was arranged with a hydraulic ram to push logs against a knife to cut slices perpendicular to the grain. Secondary shear plains formed parallel to the grain of the wood by the wedging action of the knife. Separation of the wood along these shear plains, significantly increased the drying rate of the wood, and facilitate the break-up of the wood slides when these were further processed in a hammer mill.

The stress required to slice green citrus wood were nearly 475 pounds per square inch when slides of approximately 1 inch thick are made. With dry citrus wood higher stresses were required . The bevel of the cutting blade was 30° and this gave satisfactorily formation of the secondary shear planes in the wood.

The maximum size of logs that have been processed are 6.5 inches in diameter. Some of these wood slices have been processed through a small hammer mill having a screen with 2 inch diameter holes. The resulting fuel is small prismatic pieces of approximately 1/4 inch minimum dimension across the grain and this appears to be desirable gasifier fuel.

Arrangements are being made to obtain a fly-wheel-type chipper which can be modified to feed the logs with the grain perpendicular to the cutters and process fuel for gasifiers. It is expected that more power will be required to chip the wood than when it is introduced into the cutter at approximately 45° from the plane of the fly-wheel, but is is expected that a more desirable gasifier fuel will be prepared.

Plans are also being formulated to develop a low power hydraulic fuel slicer, that can be used for processing small logs and limbs for gasifier fuel. This machine will probably have a clamp or vice to hold the wood safely while it is sliced.

Fuel Feeding Systems

An injector-type feeder for a biomass energized crop drier has been developed and successfully used to operate this equipment on a continuous basis (2). The downdraft gasifier on this crop drier was purposely designed with a small fuel storage volume to accommodate the continuous feeding equipment being developed. A screw-feeder was considered, but was discounted because of the insufficient seal provided by the helicoid and tube. Problems were also anticipated with pinching of fuel between the helicoid and the edge of the tube opening. The injector feeder has a square section ram which transfers fuel from a feed hopper to a gasifier fuel chamber. A stationary knife on the edge of the fuel hopper slices off any fuel that extends above the ram and provides a clean slug of fuel on each stroke. A compression rubber seal on the forward end of the ram provides a gas-tight seal and prevents gas leakage from the gasifier and air leakage into the gasifier when the ram is closed. Rapid cycling of the ram prevents the introduction of much air into the gasifier and leakage of gas out. The ram is 3-1/2 inches by 3-1/2 inches, and has a 6 inch stroke. It is hydraulically actuated by a small electrically powered hydraulic power unit. An anvil on the face of the ram prevents shearing of the rubber seal by the stationary knife. A hydraulic bridge breaker working in conjunction with the injection feeder assures a full charge of fuel each time the ram is actuated. This bridge breaker is a hydraulic ram inclined 45° to the injector ram and is actuated with the common hydraulic system. It is sequenced to extend and push fuel into the opening in front of the injector ram when the latter is fully retracted. The bridge breaker retracts before the injector starts to push fuel into the gasifier, to avoid interference between the two mechanisms.

Considerable problems with bridging of fuel in the feed hopper and in the gasifier fuel chamber were experienced before the fuel was sized by screening through a one inch square mesh. Since the large chips have been removed a minimum of problems have resulted with the operation of the feeding system and the gasifier. The unit has operated for as long as seven hours uninterrupted except for one short stop for ash removal from the gasifier.

Preliminary tests have been carried on with a rotary type airlock feeder of the type used for pneumatic material handling systems. It appears that this equipment will provide a satisfactory gaslock for a large irrigation pump gasifier. This equipment has neoprene seals on the rotor edges that are reported by the manufacturer to be capable of withstanding 16 inches WG pressure or vacuum. In order to reduce wear and jamming of the rotor with large wood chips the fuel will be sized to remove long slivers and a feed regulator device arranged to meter the flow into the unit. An inclined conveyor may be adequate for regulating the stream but plans are also being formulated to provide a bucket wheel device synchronized with the rotor that will uniformly fill each cavity in the rotor.

Fuel Level Indicators

Commercially available dry material level indicators have been satisfactorily adapted for use on downdraft gasifiers. The units used have paddle wheel type rotors that stall when in contact with the fuel and indicate the fuel level. A single unit has been used on the gasifier equipped with the ram type fuel injector and the feeder is stroked when fuel is called for. Two indicators have been installed on the gasifier using the rotary feeder to indicate low and high fuel levels. The only modifications made to these indicators were to install longer paddle wheel shafts and mounting sleaves to insulate the electrical components from the heat. It is anticipated that signals from these indicators can be used to automate refueling systems for gasifiers.

SUMMARY

Problems with using chipped wood from a pulpwood processor for gasifier fuel have prompted studies on the form and methods of preparation of

suitable fuel. Slices of logs sheared perpendicular to the grain can be easily broken into prismatic pieces which appear to be a desirable form of fuel. These can be easily dried and are less likely to bridge in fuel handling equipment and gasifier hoppers. Tests of a modified fly wheel chipper as well as a small hydraulically driven wood slicer are planned for processing of wood into this form.

A ram type fuel injector has been developed for refueling a small downdraft gasifier and this has made possible day long uninterrupted operation of a wood energized crop drier. This fuel feeder utilizes a square section, hydraulically driven plunger to push slugs of fuel from a hopper into a gasifier. A rubber seal on the plunger prevents gas leakage and a stationary knife on the ram housing assures a clean slug of wood chips on each stroke. A hydraulic bridge breaker in the feeder hopper assures a full charge of fuel on each stroke. Preliminary tests show that a rotary airlock will also be suitable for feeding chips into a downdraft gasifier while in operation.

Modified bin level indicators have been successfully used to indicate the fuel level in gasifiers and these make possible the complete automation of gasifier refueling.

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PROCESSING AND UTILIZATION OF WOOD CHIP FUEL

by

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ABSTRACT

Use of logging residues and cultivated brush crops for fuel could produce significant additional income for woodlot owners and farmers in New England. Development of space heating systems fueled by particulate wood fuels derived from these sources has been underway at the University of Maine since 1973, with recent efforts concentrated on improving the chip burners and on handling and processing of the chips.

Combustion Equipment

Twenty five wood chip burners based on University of Maine Agricultural Engineering Department designs ranging in size from 25,000 - 750,000 BTU/hour are now operating in Maine. The first units put out for field test were equipped with oil burners as igniters and used various forms of temperature sensors to control operations. More recent burners have used electric igniters. Two flame sensing control circuits were devised to be used with the electric ignition. Both worked well. The type now being used on a number of burners has an intermittent ignition oil burner primary control in which the flame detector switches off the ignition when flame is sensed. The only real problem with the electric ignition/flame sensor combination has been with the life of the igniter elements. Heat gun elements were first used, but had a very short life due to the high temperatures resulting from restricted air flow over the resistance coils.

A stop-gap measure to keep furnaces operating while the electric ignition system was being improved was obviously necessary, so four units firing hot water boilers were fitted with cycle timers to provide short bursts of fuel feed sufficient to maintain a stand-by fire, even if no heat was called for by the system control. Around 6-8 minutes of fuel feed per hour was found to be sufficient for standby. In mild weather conditions and minimum domestic hot water use even this 10:1 turn down ratio would often heat the boiler beyond the high limit setting. An aquastat was added to the units to switch on a heating loop circulator and dump some heat when this condition occurred.

The standby operating mode is extremely reliable. The fire tends to be mainly of red coals; with flame only present when fuel is actually being fed. There is no visible smoke during standby other than a slight haze for a few seconds at the beginning of each fuel burst. However carbon monoxide emissions are about 0.3% during the red coal conditions, compared with only .05% during normal firing periods. The increase is apparently caused by firebox temperatures falling below the 1100°F ignition temperature of carbon monoxide.

There have been several variations on the original two chamber firebox:
(a) Fireboxes over 500,000 BTU/hr now have three chambers.
(b) A horizontal afterburner section was used inside the boiler firebox on a chip burner retrofit to a 140,000 BTU/hr stick fired, central heating boiler. This layout gave the length of contained flame path necessary to prevent flame quenching on the heat exchanger sides and significantly lowered the minimum draft required for operation.
(c) Further modifications have been made to enable the heat exchanger to be mounted directly over the firebox. This layout appears to eliminate the need for a draft inducer, as all flue passages can be vertical; however, fuel must be fed onto the grate from the side of the firebox. The arrangement was originally used on a 25,000 BTU/hour burner designed to work as a side arm on an electric domestic hot water heater. A simplified control system was used on this unit. There was no automatic ignition, fuel feed was turned on in place of the lower element in the water heater -- the wood chip burner simply substituted for the lower element. A standby fire was maintained by the interval timer. The grate size was only 4" x 3" and fuel feed rate was 4 lb of chips per hour (dry basis). The standby mode fed only 0.75 lb of fuel per hour. The mass of water in the heater tank provided a thermal flywheel and the relief valve on the water heater provided a heat dump. The 52 gallon tank proved too small for the unit. An 80 gallon tank would probably eliminate relief valve opening. The same firebox has been used to fire a hot air heat exchanger.

A 50,000 BTU/hr firebox with the vertical flame path and side fuel feed uses a 5" x 5" grate. It was incorporated in a package unit with a horizontal boiler and is now being field tested.

Fuel is fed into the side of the firebox by means of a separate 12" long auger. This layout allows the fuel bin to be considerably lower, making for easier fuel loading. The simplified control system is again being used.

Tuyeres feed turbulent combustion air into the firebox, approximately 1.5 inches above the grate, to intensify combustion and shorten the flame path. Tests on a modified version of the domestic hot water heater with the 4" x 3" grate showed that heat outputs of 4000 BTU/in^2 of grate, double that previously attained, were possible with this method of air injection.

Considerable interest is being shown in these small units as they cover the output range needed for modern, heavily insulated residences. The miniaturization possible because of the small output and the low fuel consumption makes for a very low cost, easily operated unit. The domestic hot water heater required only about $300 in materials while the 50,000 BTU/hour unit, which is providing space heating, contained only $450 of materials.

Fuel Processing and Handling

A pilot scale wood chip fuel processing facility has been set up. Chips are now delivered in 14-16000 lb loads from an 18 foot truck body (approximately half the length of a standard van body). The chips are unloaded from the truck by means of a moving headboard pulled back by a 1/4 hp electric winch which provides 10,000 lb pull on the headboard. This pull is marginal for a 16,000 lb load, indicating that a pull of at least 1500 lb/ton of chips should be allowed in design of this type of unloader.

Screw auger conveyors are used to deliver the chips into storage or drying bins. Screws are at least 2 inches less diameter than the tubes in which they run, to prevent jamming of chips between the screw and the tube wall.

A small pneumatic bin/truck loader, arranged rather like a snow blower, is also being evaluated.

For trouble-free furnace operation chips need to be screened for removal of long slivers which tend to clog conveyors. Rotary baffled screens are used in the processing facility for this purpose.

When the development of wood chip burners began, the intent was to provide a replacement for oil burners which would use a lower cost, locally produced fuel. A fuel supply and burner service infrastructure similar to that for oil was envisioned. Users would store around a 3-4 week fuel supply in small bins on their premises, frequent deliveries would be made and the fuel supplier would provide burner service. This was thought to be particularly appropriate when oil burners were being used as igniters for the chip burners which replaced them. Such a delivery service has been established, with a price for chip delivery in the Orono area of $45/green ton of hardwood, double the van load price and equivalent to oil at 70¢/gallon.

This price disadvantage, along with the difficulty of handling frozen green chips and the lowered combustion efficiency with wet chips led to work to determine whether green chips could be economically dried with winter ambient air at a rate to keep pace with use.

Rate of movement of the drying layer through a deep bed of chips was found to be closely related to air flow rate, with approximately 2.5 inches of movement per day for each 10 cfm per sq ft, e.g. 25 cfm/ft^2 through the mass would produce a layer of approximately 6.25 inches of dried chips per day. Moisture content of the dried material was found, as expected, to be closely related to relative humidity of the air entering the chip mass. Unheated January air produced chips around 20% moisture content (wet basis) while solar tempered summer ambient air produced chips around 8% moisture content.

A 4'x8'x8' high bin with a self emptying bottom was constructed. Ventilation at 25 cfm/ft^2 under fall conditions dried a 5 ft deep batch of chips to 18% moisture content in 7 days. Pressure in the plenum under the bin floor was 0.85" SWG. A bin of this type and size could supply air dry chips at a sufficient rate to heat a typical Maine residence in the depth of winter. Fresh fuel would be delivered periodically into the top of the bin while dry fuel was removed from the bottom as needed. However, when chips were removed daily from this bin during a winter run holes formed in the layer of frozen chips at the top of the mass causing very uneven ventilation. After two attempts at winter drying the idea of a small top feed/bottom removal drying bin was deemed impractical for areas with subfreezing temperatures.

A system of two identical 4'x8'x4' high bins, each with ventilation through an air duct on the floor of the bin has proved very satisfactory. One bin was ventilated while the other batch of chips was being used. The twin unit was used successfully through the 1982-83 winter.

A heated air drier was also tested. The unit consisted of a plenum over which was an 8'x8'x4' deep tray with a perforated base. The tray was arranged to tip for emptying. Air heated by a 70,000 BTU/hour chip furnace, plus the flue gas, was blown into the plenum and passed through the chips. Several batches were dried during the 1982-83 winter on this unit with airflows varying from 5-14 cfm/ft^2. Rate of movement of the dryer layer was again related to airflow with final moisture content related to RH of the ventilating air. Final moisture contents of 6% (wet basis) were achieved - considerably lower than necessary. Drying efficiencies averaged 35% because of the loss of sensible heat in the exhaust from the top of the tray. Heated air batch dryers are probably best used to remove sufficient moisture from a batch to develop an overall moisture content of 20% which can be produced by immediate mixing of the overdried and wet layers.

SUMMARY

Woody biomass in chip form has been successfully used over several years in automatically controlled and ignited burners from 25,000 - 750,000 BTU/hour output. Fuel handling and drying techniques have been developed. Ventilation in deep beds with ambient air provides satisfactory drying.

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SMALL SCALE STORAGE OF WOOD CHIP FUEL

by

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ABSTRACT

Storage of wood chips for fuel in lots up to 14,000 lb is being investigated. Ventilation with ambient air at airflows ranging from 4-10 cfm/ft^2 is being used to dry chips for storage. Fungal growth is being evaluated and measures for reducing fungal contamination are being developed.

The original concept for fuel supply to small scale wood chip burners was for frequent deliveries into small holding bins on the customers' premises.

A businessman in the Orono area became interested in the University of Maine wood chip project and began installing chip burners and supplying green hardwood chips as fuel in 1980. However his mark-up for making small deliveries of around 300 ft^3 almost doubled the standard van load cost of $22-25 per green ton. This made the wood chip fuel almost as expensive as coal, $4.70 per million BTU against $5.00 per million BTU for coal. By comparison, oil sold for approximately $8.50 per million BTU. A further disadvantage to the green wood chip fuel was the high moisture content, 40% wet basis. The chips could be burned at this moisture content, but could not be stored outdoors as they froze together under winter conditions. Storage indoors for periods over 2 or 3 weeks resulted in mold formation. Allergic reactions to the molds among some users were found in a companion project in New Brunswick, Canada.

During the winter of 1981, when two companies were negotiating to manufacture the burners, there was considerable interest among homeowners and businesses throughout the state. The difficulty of obtaining fuel frequently in small lots and the increase in price over standard bulk loads led a number of would-be users to consider receiving chips in standard van loads, 2500 ft^3, approximately 25 green tons, roughly one season's fuel for a large residence. This method of fuel delivery and handling would greatly increase the possibilities for use of wood chip furnaces so three storage/drying experiments were set up in the summer of 1982.

At one location chips are being dried, in the van in which they were delivered, by air blown through a plenum formed by pallets covered with hardware cloth which were placed on the bottom of the van before the chips were blown in. At a second location a 27'x8' lean-to chip bin was attached to the building to be heated and a small blower moved air through the 8' depth of chips at approximately 10 cfm per ft^2. Air was supplied 24 hours/day and the bin of chips was dried to around 20% moisture content between July 1st and mid August for an electricity cost of $38.

A pilot scale drying bin, with the roof used as a solar collector to temper the ventilating air, was used on the University of Maine campus. Ventilation of a 14,000 lb batch of chips loaded to a 5 foot depth with 7 cfm/ft^2 of solar tempered air reduced overall moisture content from 40% to 11% in 24 days of 24 hour/day operation. Wet and dry bulb temperatures of incoming and outgoing air were monitored to evaluate moisture removal rates from the chip mass. Some drying took place at all times for the first few days. However as the drying layer moved through the chip mass it appeared that moisture was being put back into the chips during the early morning hours. Continuous ventilation was carried out in spite of this as an inflated solar collector was being used. It was thought that this might suffer wind damage if it was not pressurized. A graph relating moisture removal to time agreed quite well with the overall reduction in moisture content. 460 Kwh of electricity were used to remove 4230 lb of moisture from the chips, i.e. 1 BTU was provided per 2.7 BTU used for evaporation.

A second 14,000 lb batch was dried in the same building with ventilation at 4 cfm/ft^2 for only 10 hours/day (10 am - 8 pm) with no apparent damage to the solar collector while it was not inflated. After 23 days of operation, moisture content in the mass of wood chips varied from 6.8% where the air entered to 34.2% near the air exit. Moisture removal was 3520 lb, bringing the overall moisture content of the batch to 21.7%, sufficiently dry to prevent molding and freezing, and dry enough for very easy electric ignition in furnaces. 132 Kwh of electricity were used to power the ventilating fan, indicating only 1 BTU of energy provided per 7.8 BTU used to evaporate moisture.

This illustrates the value of timed ventilation and the economy with which batch drying of chips can be achieved.

A second experiment in a 'bunker silo' with uneven depths of chips indicated that average flow rates of 4 cfm/ft^2 did not provide sufficient air flow in all parts of the bin for successful storage drying with ambient air. Mold growth outpaced drying in the deeper sections.

Nine drying boxes with perforated floors, each holding approximately 21 ft^3 of wood chips were ventilated in February 1983 with ambient air. Flow rates were 4, 6, 8 and 10 cfm/ft^2 with two control bins, one sealed and the other open to allow natural convection. Chips from debarked logs were used. Initial moisture content was 43.2% wet basis. Wet bulb and dry bulb readings were recorded on a daily basis and the weight loss for each box was recorded weekly. The boxes were ventilated for a period of 28 days. The weight loss per week for airflows of 4, 6, 8 and 10 cfm/ft^2 is shown in figure 1.

At the end of 28 days the boxes having airflows of 6,8 and 10 cfm/ft^2 had reached equilibrium, whereas the 4 cfm/ft^2 box was still losing weight. Equilibrium for the 10 cfm/ft^2 and 8 cfm/ft^2 airflows occurred respectively during the second and third week of ventilation.

Samples for moisture content were taken at the surface and then every 6" until the plenum screen was reached; samples for spore counts were taken at depths of 24" and 12". Visible fungal growth was found throughout both control boxes; in the 4 cfm/ft^2 box from just below the surface layer to

12" above the plenum screen; in the 6 cfm/ft^2 box, from 1" below the surface layer to 18" above the plenum screen. No visible fungal growth was observed in either the 8 cfm/ft^2 or 10 cfm/ft^2 box.

Moisture contents for the wood chips having 6, 8 and 10 cfm/ft^2 airflows were constant throughout the container at 9.5%. Airflow of 4 cfm/ft^2 produced moisture contents of 9.5% (0" to 12"), 10.5% (18"), 24% (24"), 41.5% (30"), and 27.5% (surface). The number of spores present was inversely related to airflow (Table 1).

Table 1
EFFECT OF AIRFLOW ON FUNGAL GROWTH

Airflow cfm/ft^2	Spore Count x 10^6	
	Depth	
	12"	24"
0	330	530
4	310	530
6	155	265
8	120	210
10	120	205

The predominant types of spores found were various species of Gonatobotryum. Effects of moisture content, temperature, and various chemical treatments on fungal growth were also investigated. Wood chips were dried at 150°F to various moisture contents and then placed in an 18°C (64.4°F) incubator. Other samples were placed in different environments: 25°C (77°F), and 7°C (44.6°F). Simple chemical treatments which could be easily used by homeowners were also evaluated and included: baking soda 0.4g to 200g chips, 0.09g Captan to 200g chips, and 8 ml Chlorox (diluted 25 parts water: 1 chlorox) to 200g chips. Samples were incubated for 50 days.

Reducing the initial moisture content prior to incubation reduced the number of spores produced. Initial moisture content of 36% resulted in spore counts of 2000 x 10^6 whereas a moisture content of 13% resulted in spore counts of only 83 x 10^6. Innoculation with baking soda reduced fungal growth, the spore count was 893 x 10^6, while Captan reduced the spore count to 174 x 10^6. The Chlorox treatment reduced fungal growth as the spore count was 386 x 10^6.

Further investigation of ambient air drying without chemical treatment using 6 cfm/ft^2, 8 cfm/ft^2, 10 cfm/ft^2 will continue so that the effect of seasonal changes can be observed. Chemical pre-treatment prior to and during storage will be done at all air flows to see if the amount of fungal growth can be further reduced.

SUMMARY

Wood chips in 14,000 lb batches have been successfully dried during winter months with ambient air at flow rates as low as 6 cfm/ft^2 with minimal fungal contamination. Small lot testing indicates that simple chemical pretreatments to reduce fungal growth may allow drying with even lower air-

flows, which will decrease both equipment and operating costs.

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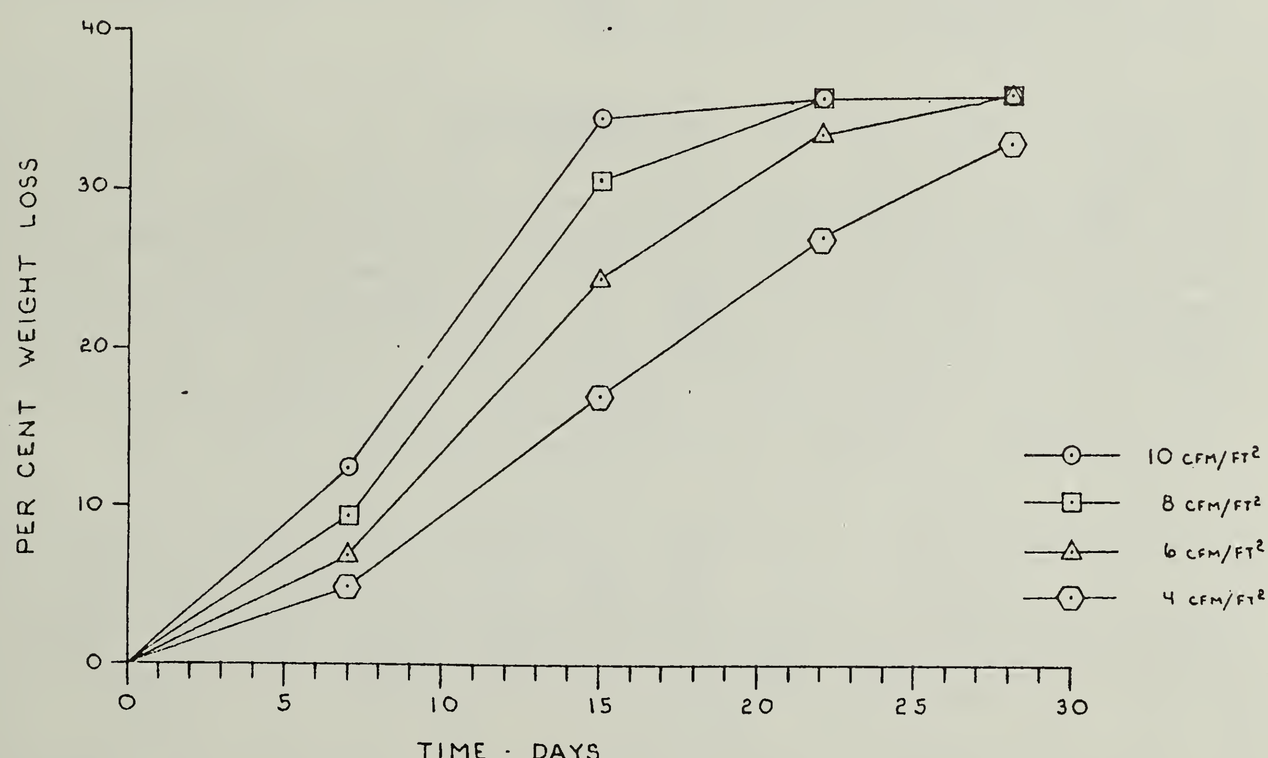
FIGURE 1

WEIGHT LOSS FOR WOOD CHIPS AT VARIOUS VENTILATION RATES USING AMBIENT AIR DURING FEBRUARY 1983



IN-HOME PERFORMANCE OF WOOD STOVES

by

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ABSTRACT

In-home tests have been conducted on wood stoves to measure their overall operating performance and define factors which influence performance. All tests were conducted in-home to represent as closely as possible the actual use patterns of homeowners. Results indicate that in-home operating efficiencies are as high as those obtained in laboratory tests. However, in operation, flue temperatures vary greatly and some stoves may have much greater creosote buildup potentials than others. The results have been compared with the in-home performance of fireplaces which have much lower efficiencies than wood stoves. Wood stoves and fireplaces were shown to allow similar air losses when cool unless dampers or other means of reducing air losses are used.

INTRODUCTION

The laboratory performance of wood burning units has been well documented (e.g. Maxwell, et al., 1979; Shelton, 1976). The authors were curious as to what extent the operating habits of homeowners may alter these performance characteristics and thus they conducted performance tests on wood burning units as installed and operated in homes. Such characteristics as efficiencies, flue temperatures, air losses, and burning rates were observed. For all tests, homeowners were requested to leave their units adjusted as the units were normally operated.

Eleven wood stoves, as described in Table 1, were tested. All except two (#S1 and #S2) were airtight--that is, stoves having precise draft controls and tight fitting seams. Of the airtight stoves, one (#S3) was a convective heater with the remainder being radiant heaters. Three of the radiant heaters (#S9, #S10, and #S11) were fireplace inserts, while the others were free standing units.

PROCEDURES

The main criterion in performing the tests was to define as closely as possible the performance of the wood burning units as actually operated by homeowners. The pattern of operation of a wood burning stove is usually continuous or burning for relatively long periods of time. Tests were conducted with wood added to cool stoves early in the morning and then measurements were taken throughout the day until the wood was consumed and the stoves cooled to near the temperature at the beginning of the test.

Measurements included the rate and temperature of air passing through the flue, and indoor and outdoor temperatures. Measurements were taken before the fire was started, immediately after the fire was lit, and continuing at five minute intervals for about 20 or 30 minutes, and then at increasingly longer intervals.

Calculation of wood stove efficiencies from flue temperature measurements introduces errors associated with incomplete combustion and flow measurements. Thus, the efficiencies obtained in these tests must be considered as the maximum possible and are probably high. Efficiencies calculated on the basis of the difference between flue and room temperatures are referred to herein as unit efficiencies, whereas those based on the difference between flue and outdoor temperatures are referred to as effective efficiencies.

All wood was purchased from a single source. The wood was lodgepole pine with the bark removed. The moisture content averaged near 10% dry basis with little (±1%) variation between samples. For this study, the heat value of wood at 10% moisture content was taken as 7930 BTU per lb.

RESULTS

The most notable performance characteristic observed was the low average flue temperatures. Only two units (#S5 and #S6) had average flue temperatures greater than 300°F while about half operated at temperatures that never reached 300°F for even a short period, as indicated by the maximum temperature attained (Table 2). Creosote formations are usually considered to become serious when chimney surface temperatures are less than 250°F to 300°F (Maxwell, et al., 1980; Shelton, 1979). This would indicate that the homeowners whose stoves we tested were generally operating their stoves (probably very unknowingly) in such a manner as to create serious creosote deposits. The recommendations of smaller fuel loads, with greater air supplies and more frequent refueling (e.g. Shelton, 1979) to achieve more complete combustion would be appropriate for nearly all of these homeowners. However, it should be pointed out that within the ranges in which these stoves were operated, lower flue air temperatures were associated with higher air flow rates whereas the stoves with the lower air flow rates attained high flue air temperatures. Previous tests of fireplaces, which have much higher flow rates than stoves tested here, produced lower flue air temperatures than for the stoves (Pochop, et al., 1981). In general, it would appear that the temperature in itself may not be what controls creosote formation but more important is the amount of air supplied to the fire and the degree of combustion that occurs. It is interesting to note, however, that in the case of fireplaces which have essentially unrestricted air flow the higher air losses occurred with higher flue air temperatures.

The average heat production rate of the eleven stoves was calculated to be about 20,000 BTU/hr. The lowest rate was about 10,000 BTU/hr whereas the highest was near 28,000 BTU/hr. These rates are the minimum that should be able to be maintained on a continuous basis, since the test period included a cooling down period. These rates are based on the measured efficiencies which may be somewhat high as explained earlier.

Two of the stoves tested (#S1 and #S9) had considerably lower efficiencies than the other stoves. Stove #S1 was a non-airtight radiant heater while stove #S9 was a fireplace insert without a fan and without proper caulking of the insert into the fireplace. This does indicate that installation of the stoves is important and that improper installation can significantly reduce performance.

The performance of the wood stoves were compared to that of fireplaces which were tested earlier (Pochop, et al., 1981). The highest effective efficiencies attainable for fireplaces were near 50% with most averaging near 30%. The higher efficiencies were for units with heat exchanger units while open units had efficiencies near 20%. In all cases, fireplaces consumed wood at a rate of two to three times that of the wood stoves. Fireplaces while operating had air losses that average about four times higher than the average air loss from the wood stoves, with wood stoves averaging about ½ air exchange per hour for an average size home. One important consideration is that air losses from the wood stoves when cool and not operating were greater than for fireplaces with glass doors closed. Without glass doors the fireplace air losses when cool were about three times of those for cool wood stoves, probably reflecting the larger chimney sizes used for fireplaces.

SUMMARY

Most homeowners appear to operate wood stoves in such a manner as to create serious creosote problems. Simple changes in their operational habits could greatly reduce their creosote accumulations. Considerable performance differences do exist from one wood stove to another as installed and operated by homeowners. The efficiencies of wood stoves as measured in operation by homeowners appear to be comparable to laboratory tested efficiencies. The efficiencies are much greater than those obtained by homeowners operating fireplaces, and stoves are not as sensitive to outside weather changes as fireplaces.

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Table 1. DESCRIPTION OF STOVES

Test	Description
S1	Radiant, non-airtight
S2	Glass carousel, damper controlled air flow
S3	Convective, w/o fan, airtight, thermostatically controlled draft
S4	Radiant parlor type, airtight
S5	Radiant box heater, airtight with manual draft control
S6	Radiant box heater, airtight, thermostatically controlled draft
S7	Radiant, with baffles, airtight
S8	Radiant, with baffles, airtight, thermostatically controlled draft
S9	Fireplace insert w/o fan, airtight with manual draft control
S10	Fireplace insert with fan, airtight with manual draft control
S11	Fireplace insert with fan, airtight with manual draft controls

Table 2. SUMMARY OF STOVE TESTS

Test	Weight of Wood (lbs)	Duration of Test (hrs)	Wood Use* per Hour (lbs)	Average Indoor Temp (°F)	Unit Efficiency (%)	Average Outdoor Temp (°F)	Effective Efficiency (%)
S1	16.9	3.0	5.6	70	55	23	44
S2	20.7	4.0	5.2	76	79	23	68
S3	14.6	4.0	3.7	60	78	21	59
S4	8.8	5.0	1.8	66	75	29	68
S5	22.6	7.5	3.0	74	71	27	65
S6	31.5	7.5	4.2	65	-	26	86
S7	21.8	5.0	4.4	77	79	42	68
S8	30.4	6.0	5.1	65	75	35	68
S9	21.3	5.7	3.7	66	72	28	48
S10	24.9	5.5	4.5	73	84	31	76
S11	18.4	6.0	3.1	66	76	35	66

*This approximates the minimum wood use.

Table 3. AIR USED BY WOOD STOVES DURING TYPICAL BURNING RATE

Test	Flue Area (ft^2)	Air Volume (ft^3/min @ 70°F)	Time for one* Air Change (min)	Avg. Flue Temp. (°F)	Max. Flue Temp. (°F)
S1	0.349	131	61	250	535
S2	0.349	49	164	300	650
S3	0.643	178	45	115	165
S4	0.196	39	205	220	340
S5	0.136	37	212	325	525
S6	0.349	26	304	385	475
S7	0.889	110	73	180	225
S8	0.267	81	99	240	460
S9	0.642	218	37	110	130
S10	0.229	37	218	210	235
S11	0.918	122	66	180	275

*Air change is for 1000 ft^2 house having 8 ft ceilings.

AUTOMATED WOOD CHIP GASIFIER-COMBUSTOR FOR DIRECT CROP DRYING APPLICATIONS

by

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ABSTRACT

This research is directed toward improving the control of two-stage combustion of biomass in which a clean exhaust is desired for direct crop drying applications. The two-staged combustion of biomass was mathematically modeled for steady state operation to develop a control algorithm for microprocessor control of the combustion temperature and for output modulation. The control algorithm will be applied to a wood chip gasifier-combustor in 1983.

INTRODUCTION

One of the most energy intensive operations on the farm is crop drying. Much of the corn crop and several other crops including tobacco, soybeans, rice and peanuts are typically dried with LP or natural gas. Crop drying in the United States requires the energy equivalent of 15 million barrels of crude oil per year. Development of reliable and efficient biomass combustion processes will promote the use of alternative fuels; therefore, reducing the farmer's and our country's dependence on fossil fuels.

This research is directed toward development of the technologies employing separate gasification and combustion steps, ie., two-stage combustion. Several configurations of two-stage combustors have been researched for providing heat for crop drying or processing (Bozdech, 1980, Payne et al., 1981a, Morey and Thimsen, 1981, Richey et al., 1980, Richey et al., 1981). These combustors, if properly controlled, have the ability to simultaneously provide both clean combustion and output modulation. The mechanical configurations of the above cited two-stage combustors are different, although, the chemical processes are very similar. Complete combustion of the gas from a two-stage combustor under controlled conditions can yield an exhaust low in particulates (Payne, 1980; Barrett et al., 1981; Bozdech, 1980) and hydrocarbons (Payne, 1980). Complete combustion of the gas is achieved structurally by proper design of the secondary combustion chamber and operationally by maintaining proper levels of excess air.

The control of the secondary combustion chamber temperature with proportional controllers is excellent after the system is operational. However, during startup, shutdown or large process interruptions the proportional controllers are inadequate. This inadequacy stems from four factors: (1) proportional controllers are designed for linear responses and the air flow response through a damper is by no means linear. (2) Placing two proportional controllers in series to control secondary combuston chamber temperature and burner output may result in "hunting". (3) A proportional controller tries to reduce air flow into the secondary combustion chamber when the temperature is below the set point. During startup, shutdown and process interruptions this is not always the desired response since rich as well as lean mixtures can have a low temperature. (4) The output of two-stage combustors can be modulated, but the rate of change is finite, because of the thermal inertia of the system, especially for updraft gasifiers.

The development of microcomputer control would significantly improve the ability to monitor and control a two-stage combustor which is coupled to drying, curing or heating operations. Low cost sensors can be used with a microcomputer to give the necessary information for accurate combustion control. Anticipated results of this research will be the successful integration of two-stage biomass combustors into agricultural applications and a reduction of the chance of crop contamination.

METHOD

The goal of this research is to develop a microcomputer based control algorithm for gasification-combustion of particulate agricultural fuels. The development of the algorithm will require the combination of a mathematical model of the kinetics of gasification and combustion and a physical model of mass flow through the equipment. To simplify the approach, gasification and combustion are assumed to be at steady state with the system being continuously fed with fuel.

The criterion for development of the control algorithm is that for a specific deviation of a property (temperature, O_2, CO_2) from a set point the response necessary for correction (via damper adjustment) must be calculable by a simple equation. The gasifier-combustors have two control points; 1) the damper on the secondary air which controls the secondary combustion chamber temperature and 2) the damper in the fan exhaust which controls the thermal output. Thus, for example, the angular change in the secondary combustion chamber damper, $\Delta\theta_s$, required to correct a deviation in the secondary combustion chamber temperature, ΔT, is estimated from the equation

$$\Delta T = \frac{\partial T}{\partial \theta_s} (\Delta\theta_s) \qquad (1)$$

The model for steady state combustion is complicated and does not yield the "simple equations" needed for the control algorithm.

Determining a control algorithm reduces to determining the relationship of $\partial T/\partial \theta_s$ from a mathematical model of the system in terms of the primary functional parameters which would be available to the microcomputer. Then a simple regression equation can be determined which can be used by the microcomputer instead of the lengthy mathematical model.

RESULTS

The relationship between the secondary air damper and the combustion temperature as a function of damper angle, exhaust flow and biomass moisture content was obtained from the model. A simple regression equation of this relationship can be used for microcomputer control of the secondary air damper. The regression equation will be of the form

$$\frac{\partial T}{\partial \theta_s} = f(\theta_s, \dot{m}_e, X_m).$$

The details of the development of this model were reported by Payne and Dunlap (1982). These relationships will be used to determine the coefficients to a linear feedback controller which will be tested on a wood chip gasifier combustor in the summer of 1983.

A microcomputer capable of measuring temperatures and setting damper positions of the gasifier will execute a controller program to regulate the process heat of the system. The controller will adjust secondary air intake to maintain a combustion temperature set point, and will adjust exhaust flow rate to regulate the process temperature. Time lag of the gasification rate with respect to primary air flow changes and the lag of exhaust temperature due to thermal capacitances within the gasifier are the dynamic elements with which the controller will be modeled.

SUMMARY

The use of a microcomputer to control the two-stage combustion of biomass will improve process control and reduce chances for contamination of agricultural products. The steady state model of an updraft gasifier combustor has been developed and is being used to obtain the coefficients to a linear feedback controller. The control algorithm will be tested in 1983 on a wood chip gasifier combustor.

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Design and Operation of a Two Stage Wood Burner for Crop Drying [1-4].

by

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ABSTRACT

A portable wood-fired hot water heating system for crop drying was designed, constructed, and installed on a southeast Virginia farm in 1981. The 500,000 BTU per hour two stage fire tube heater uses a water-jacketed combustion chamber with refractory base similar to a residential design developed at the University of Maine. The unit was locally constructed to provide supplemental heat of 12°F temperature rise for peanut drying in an 8 trailer arrangement and 38°F temperature rise for grain drying in a 3,000 bushel in-bin system. Hot water is forced from the 500 gallon boiler by thermostatically controlled pumps at three different locations through heat exchangers mounted on the inlet side of the crop drying fans.

In 1981, the wood-fired boiler provided all heat for drying peanuts in a 4 trailer unit. In 1982, the heater provided heat for residential heating, corn drying, and peanut drying. Data was collected during peanut drying for two week periods in both 1981 and 1982. In a one-hour test period, more than 700,000 BTU were provided by the heater for peanut drying in 2 4-trailer arrangements. Approximately 2/3 cords of wood were used per day during the data collection period. The heater operated at high efficiency with ignition in the second stage when fired at full capacity. Uniform and frequent firing was observed as necessary for optimum output and efficiency.

TREE GROWTH AND ENVIRONMENTAL EFFECTS OF COAL-ASH AS A SOIL AMENDMENT FOR FUELWOOD SILVICULTURE

by

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ABSTRACT

The poorly-drained sandy soil of a small watershed in North-Central Florida was amended with 125 dry ton/ha of coal-ash, bedded at 2 m spacing, and planted to seedlings at 1 m intervals. First-year growth of Casuarina cunninghamiana was better than on the non-amended control. The exceptional freeze of the winter of 1982 killed about 70% of the trees but surviving individuals continued significantly improved growth rates. Replanting with Eucalyptus viminalis showed no better growth than the control. Dissolution of bases from the ash neutralized the normally acid soil and runoff water. As a consequence, concentrations of heavy metals were diminished.

INTRODUCTION

Changes in the economics and policies of energy production have led to a significant increase in the use of coal as an energy source (Adriano et al., 1980). As a result, coal-ash and slag production increased from about 60 million tons during 1974 to 68 million tons by 1977 and an estimated 90 million tons by 1980. Ash utilization in the United States is less than 20 percent. Most use is for construction materials and roads, with less than 1 percent for soil amendment. Utilization of coal-ash on forest lands reduces the chance of toxic metals entering the human food chain. Weathering of ash minerals provides for a slow-release nutrient supply. However, the effects of such a treatment on tree species, soil, and water are little known and need to be evaluated for Florida conditions. The objective of this study was to test the growth of Casuarina cunninghamiana on ash-amended soil of a fuelwood plantation, and to assess the effects of such a silvicultural practice on soil and water.

PREVIOUS WORK

Utilization of coal-ash for soil amendment has been tested in terms of survival, growth and yield of a variety of crops (Adriano et al., 1980). In general, amendments with modest amounts of weathered ash (less than 2% of the plow layer weight) improved plant productivity. Unweathered ash applications usually caused boron toxicity. Less than half of woody species planted on weathered fly-ash showed reasonable survival and fair growth (Scanlon and Duggan, 1979). Interestingly, two of the four reports showed a good response by black alder (Alnus glutinosa), which is a nitrogen-fixing species.

Casuarina or australian pine is a hardwood native to Australia widely planted for its rapid growth, dense wood, and nitrogen-fixing capabilities. Growth of forest stands in south Florida averaged more than 10 ton/ha/yr (Rockwood et al., 1983). Wood density is about 0.63 g/cm^3 comparable to that of oak (Wang et al., 1982). Symbiotic nitrogen fixation by Casuarina has been estimated to range from 58 to 200 kg/ha/yr (Torrey, 1978). C. cunninghamiana has some frost tolerance, does well on a range of soil conditions, and sprouts readily. Stand establishment requires effective weed control. Seedlings should be inoculated with Frankia, an actinomycete found in litter, topsoil or crushed root nodules of existing stands (McCluskey and Fisher, 1983). Fertilization caused excessive weed growth, counteracting the improved growth potential for Casuarina seedlings (Rockwood et al., 1983). However, a 15 ton/ha sewage sludge application 6 months after planting improved growth of survivors by 60% and a 30 ton/ha application tripled the growth response. Casuarina is susceptible to root rot caused by Phytophthora and Clitocybe, especially in neutral soils.

PROCEDURES

A poorly-drained flatwoods soil (siliceous hyperthermic arenic ultic Haplohumod) on the Austin Cary Forest of the University of Florida near Gainesville, FL, was used. The pine forest had been harvested and cleared by windrowing during 1978. Two small watersheds (WS7: 0.68 ha; WS8: 0.15 ha) were isolated by a plastic wall about 1 m deep in the soil. Each watershed plot had a long-throated recording flume with an automatic water sampler. Precipitation and other climatic data were recorded at a weather station about 0.5 km distant.

Unweathered fly-ash was spread on WS7 at the rate of 125 ton/ha dry weight and disked into the soil. Both plots were then bedded with beds 2 m apart and about 30 cm high. The beds were treated with 3% 2,4-D plus Roundup herbicides three weeks before seedlings were hand-planted at 1 m intervals during July, 1981. C. cunninghamia seedlings were grown to a height of 20 cm in Frankia-inoculated soil root plugs by a commercial nursery. Chemical analyses of soil and water samples were made using standard analytical procedures.

RESULTS AND DISCUSSION

Growth of the C. cunninghamiana seedlings was about twice as rapid on the ash-amended soil, reaching about 1.0 m height within the first 6 months. Toxicity effects were apparent from tip-browning, poor survival, and stunted growth occurring on spots with more than average coal-ash. An exceptional two-day freeze during the winter of 1982 killed about 70% of the seedlings on both plots. Surviving trees were concentrated on four beds containing only Casuarina seedlings and on three beds interplanted with new *Eucalyptus viminalis* seedlings. The remaining beds of each watershed were planted to *E. viminalis*.

Growth of *Casuarina* on the coal-ash amended soil after 18 months was superior averaging 1.9 m height vs. 1.1 m on the control. Growth of the new *Eucalyptus* plantation after 8 months averaged 1.0 m on the ash-amended plot and 1.1 m on the control. The average coefficient of variation for all trees was 35%. A higher incidence of root rot associated with *Phytophtera* was evident in the *Casuarina* seedlings of the ash-amended soil. *Eucalyptus* seedlings showed no disease symptoms. Toxic effects of ash on *Eucalyptus* were apparent from leaf burns and more shrub-like growth. A planting trial of slash pine (*Pinus elliottii*) on ash-amended soil showed severe toxicity symptoms and poor survival, even with a low ash application rate of about 60 ton/ha.

The main site effect of the ash treatment was a significant increase of the soil pH by one unit due to the addition of mainly calcium (J. J. Street, unpublished data). A similar liming effect was evident for runoff waters (Table 1). The substantial increases of pH and conductivity were due to a large increase of base elements. Interestingly, the pH during the second year was significantly higher while base element concentrations dropped. Similar observations have been reported for leaching experiments of columns of soil-ash mixtures (Gaasch and Law, 1977). Presumably the base-saturation of the exchange complex in the soil exhausted the supply of available hydrogen ions.

Table 1. Average annual runoff water quality.

Year and Treatment	Acid pH	Cond mmho	NO_3N	TKN	PO_4P	TP	K	Ca	Fe
			ppm						
1981 Ash	6.04	303	0.08	0.77	0.012	0.023	6.2	53.2	0.4
1982 Ash	6.41	176	0.05	0.78	0.018	0.033	2.7	22.1	0.2
Control	4.66	83	0.02	0.82	0.009	0.024	1.0	1.8	0.4

Progressive fixation of soil phosphorus by the amorphous ferro-alumino silicate minerals of coal-ash has been reported by others (Adriano et al., 1980). However, the data of Table 1 show increased phosphorus levels in runoff from the ash-treated watershed during the second year. Whether or not this is a real trend of phosphorus weathering and leaching is uncertain at present. Analyses for iron in runoff water showed a significant decrease from 0.4 ppm in the control to 0.2 ppm in the ash-amended watershed during the second year. Unpublished analyses of other heavy metals showed increased levels to rapidly return to below-detection limits within one year. It will be of interest to continue monitoring nitrogen levels of the soil and water as the *Casuarina* stands fix more nitrogen.

CONCLUSION

The use of coal-ash as a soil amendment for Casuarina cunninghamiana fuelwood production is promising for the infertile poorly-drained acid soils not used for agriculture or rangeland. However, a frost-free climate, rigorous weed control, and bedded soils are required for stand establishment. Root-rot disease from planting stock or from local origin has to be controlled. Environmental effects include a neutralization of the originally acid soil and associated waters by the liming effect of added bases.

ACKNOWLEDGEMENTS

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PRODUCTION AND PRICE OF WOOD RESIDUES FOR BIOMASS ENERGY IN GEORGIA, 1980-1981

by

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ABSTRACT

A survey of more than 250 sawmills and other wood-using firms in Georgia revealed that the average weekly production of most wood residues was statistically unchanged from 1980 to 1981, however, the commercialization of these residues significantly increased during that time. Prices of potential wood fuels also rose dramatically during the period. These increases ranged from 15% for hardwood sawdust which sold for $4.82/ton, to 261% for mixed hardwood residues which sold for $10.00/ton FOB the source in 1981. These results would tend to indicate that the demand for wood fuels continues to grow while supply has not increased fast enough to keep up. This trend is expected to continue until supply can satisfy the demand. If the situation persists, it could one day allow the entrance of logging residues and whole tree chip into the biomass fuel market.

INTRODUCTION

Wood residue is becoming increasingly important as a source of biomass energy for industrial purposes in certain parts of the country which have substantial forest products industries. It is not surprising that the wood products industry itself is a major user of these formerly discarded materials as an alternative energy source. However, as the price of fossil fuels continues to increase, other industries are beginning to investigate the use of wood residues for industrial fuel. A number of firms in the state of Georgia are currently using wood biomass to meet their energy needs.

This study focused on the production of residues available as by-products of wood-using industries. Commodities in this category include bark, sawdust and mixed residues. Some varieties of low-grade wood chips may also be included in a list of potential fuels, although these are not technically residues.

About 250 selected wood products firms throughout the state of Georgia were surveyed in 1980, and again in 1981. The large majority of these firms were sawmills, but veneer plants, chipmills, furniture manufacturers and other wood products industries were also contacted. This paper will concentrate on two aspects of the larger study which are of major concern to users of wood fuel -- prices and production. Only state averages will be reported and compared. Price and production figures for pulp chips will also be reported for comparison. The means for each year were tested by the Wilcoxon rank-sum method to determine whether they were significantly different from one another (1).

AVERAGE PRODUCTION

The ratio of average softwood to hardwood production -- 65 to 35% -- showed no significant change. Output capacity for lumber remained statistically unchanged, although there was a slight decline in hardwood production. The average weekly production of seven of the ten commodities listed in Table 1 increased in 1981, while three declined. However, only two of these changes were found to be statistically significant. The production of softwood bark showed a significant increase of 56% over 1980. The average production of mixed residues provided the most dramatic increases, with hardwood production experiencing a change of 77%. None of the other commodities listed in Table 1 changed significantly during the period.

Part of the apparent increase in production can be attributed to a greater awareness of the demand for wood residues which has lead to more complete utilization. As evidence of this, the surveys revealed a major shift in the utilization pattern for wood residues. In 1980, roughly 34% of the respondents reported that they sold their residues. By 1981, however, commercialization had increased to 69%. Stockpiling, dumping, and incineration declined proportionately, thus providing an incentive to keep better records of the production of residues.

AVERAGE PRICES

The average price of softwood bark rose 117% between 1980 and 1981, a highly significant increase (Table 2). Softwood sawdust also showed a substantial price change, increasing by nearly 55%. The commodity which experienced the greatest price increase was mixed hardwood residues; the average price of this potential fuel rose by 261% in one year. Both types of clean chips went up significantly in price. The 153% increase in the price of dirty hardwood chips was also important. These results indicate that the demand for wood residues has continued to expand. However, this demand pressure has apparently triggered sharp price increases.

SUMMARY

The annual surveys of wood-using industries in Georgia in 1980 and 1981 revealed some interesting contrasts in the average production and price of wood residues at the state level during a period of economic stress in the forest product industry. The average weekly production of most residue commodities showed an increase. The most significant increases were recorded by commodities of interest to wood fuel users -- mixed residues and softwood bark. Reported declines in hardwood bark, sawdust and shavings production were not statistically significant.

Prices, as expected, demonstrated substantial increases, with the most dramatic rises occurring among potential wood fuels. Mixed hardwood residues, dirty hardwood chips, softwood bark, and softwood sawdust all experienced significant increases ranging from 55 to 261%. By comparison, the average price of clean hardwood chips rose 22%, while clean softwood chips went up by only 8%. These price increases would make the delivered cost of biomass energy considerably higher in 1981, and since stockpiling has declined these increases will probably continue until production catches up with demand. If this situation persists, it could make the processing of logging residues and the production of whole tree chips economically feasible, which would substantially broaden the base of the biomass fuel market.

Table 1. Average Weekly Production of Wood Residues by Mills in Georgia, 1980 and 1981.

Commodity	1980	1981	Percent Change[a]
	--- tons/week ---		
Bark			
SW	156	243	+ 55.77*
HW	55	40	- 27.27
Sawdust			
SW	164	170	+ 3.66
HW	65	43	- 33.85
Other/Mixed			
SW	185	351	+ 89.73
HW	65	115	+ 76.92*
Shavings			
SW	88	137	+ 55.68
HW	32	29	- 9.38
Clean Chips			
SW	866	1,028	+ 18.71
HW	169	200	+ 18.34
All Fuel[b]			
SW	249	363	+ 45.78
HW	93	99	+ 6.45

a. *=change is significant at the 0.05 level, **=change is significant at the 0.01 level by Wilcoxon rank-sum method.

b. All Fuel = (Bark + Sawdust + Other)

NOTE: Although zero is a valid production figure, such values were not included in the calculation of the means reported here in order to provide a more accurate representation of production by mills which actually produced that commodity.

Table 2. Average Prices for Wood Residues in Georgia, 1980 and 1981.

Commodity	1980	1981	Percent[a] Change
	--- dollars/ton ---		
Bark			
SW	3.42	7.42	+ 116.96**
HW	3.81	5.78	+ 51.71
Sawdust			
SW	3.88	6.01	+ 54.90*
HW	4.18	4.82	+ 15.31
Other/Mixed			
SW	6.97	5.29	- 24.10
HW	1.66	5.99	+ 260.84**
Shavings			
SW	10.21	9.93	- 2.74
HW	11.20	6.89	- 38.48
Clean Chips			
SW	18.21	19.67	+ 8.02**
HW	11.97	14.62	+ 22.14**
Dirty Chips			
SW	5.27	9.00	+ 70.78
HW	3.95	10.00	+ 153.16*

a. * = change is significant at 0.05 level, ** = change is significant at the 0.01 level by Wilcoxon rank-sum method.

NOTE: Prices are in dollars per ton FOB the source. In the 1980 survey only a single price was recorded for each commodity class -- bark, sawdust, etc.; whereas in 1981 the commodities were broken-down into sub-classes -- softwood bark, hardwood bark, etc. The softwood and hardwood prices reported here for 1980 are averages derived by subdividing the data set into three groups -- those firms producing only softwood, those producing only hardwood, and those producing both. The mixed category is not reported here because it could not be assumed that mixing did occur.

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BTU COST FOR WOOD FUELS IN GEORGIA, 1980-1981 [1-2]

by

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ABSTRACT

Factors such as moisture content, bulk density, combustion efficiency, distance hauled, transportation cost, and price all affect the value of wood residues as industrial fuel, and complicate the determination of delivered cost. A computerized model was developed to help wood fuel users determine the least-cost fuel with regard to delivered cost per million useable BTU's. As a demonstration, several wood residues were compared with natural gas, fuel oil, and coal using this model to determine the lowest priced energy source based on state-wide average prices for 1980 and 1981. In this instance, softwood bark was found to be the least expensive and most widely available fuel in both years, although the relative rankings of other fuels changed during the period. With the aid of such a model, consumers can use localized data to make more meaningful price comparisons.

INTRODUCTION

Consumers of wood fuels have a choice between various wood residues when selecting industrial biomass fuels. Firms which may be considering a switch to wood energy will want to know how these fuels compare to the fossil fuel they are currently using. One of the primary considerations involved in choosing the least-cost fuel for a given situation is the delivered cost per useable BTU. As energy prices rise, the determination of this cost becomes even more critical to the consumer.

The calculation of this cost entails the solving of a rather complex mathematical equation. In addition, the values of some of the factors in this equation are not widely known. With this in mind, a simple cost comparison model, which can be run on a small computer, was developed to aid consumers in the selection of the least expensive fuel. Although state-wide average prices were used in the comparison presented here, the buyer would want to substitute localized prices into the model to produce a more accurate assessment of his situation.

The price and transportation data presented here were derived from two surveys of wood-using industries in Georgia conducted during 1980 and 1981 (1). The information concerning BTU values was taken from the literature and from limited testing, conducted during the study, of wood fuels samples from north and central Georgia (2, 3). Data concerning fossil fuels were obtained from DOE sources, and represent average prices paid by Georgia Power Company during 1980 and 1981 (4).

BTU VALUE AND MOISTURE CONTENT

The BTU and moisture content of wood residues are highly variable. For instance, BTU content ranged from 5965 to 8917 BTU's/lb (oven-dry basis), while moisture content ranged from 24.3 to 59.9% moisture (fresh weight basis) for samples collected from one fuel pile in east central Georgia. The value of these variables depends on the nature and species composition of the material, as well as age and storage conditions. For the sake of comparison, all wood fuels were assumed to have a gross BTU value of 8,600 BTU's/lb (2, 3). Table 1 lists the typical moisture contents, useable BTU's per ton and the combustion efficiences for wood fuels used in this comparison.

TRANSPORTATION

Transportation charges for wood residues vary according to the distance hauled, and cost per loaded mile. The delivered cost per BTU also depends upon the moisture content and particle size distribution of the material, which affect the bulk density and truck capacity. The surveys revealed that average hauling distances ranged from 50 miles for sawdust to 115 miles for dirty hardwood chips. A weighted average distance of 65 miles was used in the calculations presented here. The statewide average transportation cost was roughly $1.50/loaded mile in both 1980 and 1981.

DELIVERED COST PER MILLION USEABLE BTU'S

The formula used to model the delivered cost per million useable BTU's (Table 1, columns 6 and 7) is:

$$DC = \frac{CT + [(CM)(MI) \div TC]}{[(BT \div (100+MC))100]CE}$$

Where: DC = delivered cost/million useable BTU's; CT = cost/ton, FOB the source; CM = transportation cost/loaded mile ($1.50); MI = transportation mileage (65 miles); TC = truck capacity in tons; BT = BTU's/oven dry ton (17.2 million); MC = moisture content (dry weight basis); and CE = combustion efficiency. The numerator of this equation represents the delivered cost per unit (Table 1, columns 1 and 2), and the denominator represents the number of useable BTU's per unit (Table 1, column 5). By solving this equation for each potential fuel a cost comparison can be developed, and the least-cost fuel determined.

COST COMPARISON

The results of such a cost comparison are given in Table 1. State wide, softwood bark was found to be the least-cost fuel in both 1980 and 1981, even though it underwent a 50% price increase during the period. Using

Table 1. Cost Comparison and Indifference Index for Fossil and Wood Fuels in Georgia, 1980-1981.

Fuel	Delivered Cost per Unit		Typical Moisture Content[d]	Combustion Efficiency[e]	Useable[f] BTU's/Unit	Delivered Cost/Mill. Useable BTU's		Price Change	Index of Energy Cost/Mill. BTU's	
	1980	1981				1980	1981	1980-1981	1980	1981
	-dollars-		-percent-	-percent-	-mill. BTU's-	-dollars-		-percent-	(sftwd.bark=1.00)	
Fossil Fuels:[a]										
Coal (Ton)	35.59	40.69	N/A	70.0	16.73	2.13	2.43	+ 14.1	2.42	1.84
Fuel Oil[b] (Bbl.)	36.08	45.11	N/A	82.5	4.79	7.53	9.42	+ 25.1	8.56	7.14
Natural Gas (10^3 ft^3)	2.38	3.16	N/A	80.0	0.82	2.90	3.85	+ 32.9	3.30	2.92
Wood Fuel:[c]										
Softwood Bark (Ton)	7.85	11.85	40.0	72.8	8.95	0.88	1.32	+ 50.0	1.00	1.00
Softwood Sawdust (Ton)	9.30	11.43	80.0	67.6	6.49	1.43	1.76	+ 23.1	1.63	1.33
Softwood Shavings (Ton)	16.71	16.43	15.0	76.1	11.42	1.46	1.44	- 1.4	1.66	1.09
Dirty Hardwood Chips (Ton)	8.38	14.43	100.0	65.0	5.59	1.50	2.58	+ 72.0	1.70	1.95
Clean Softwood Chips (Ton)	22.64	24.10	90.0	66.3	5.97	3.79	4.04	+ 6.6	4.31	3.06

a. Averages for 11 Georgia Power powerplants as reported by DOE.

b. Includes both #2 and #6 Fuel

c. Delivered cost includes average price per ton, FOB the source, plus transportation charges for 65 miles at $1.50 per loaded mile, assuming a truck capacity of 22 tons for bark and chips, 15 tons for sawdust, and 13 tons for shavings per 40 ft. van.

d. Dry weight basis.

e. Percentage of useful heat per unit when heat of vaporization of water is subtracted.

f. Includes adjustment for average combustion efficiency.

this fuel as the basis, an index of energy cost per million BTU's was calculated. According to this index, softwood sawdust was second in 1980, and third in 1981. Softwood shavings was third in 1980, but because its price remained virtually unchanged, it moved up to second in 1981. Dirty hardwood chips placed fourth in 1980, but dropped to fifth in 1981 due to a 72% price increase that year. Coal was the most competitive of the fossil fuels, ranking fifth in 1980 and fourth in 1981. Natural gas was sixth, and fuel oil was the most expensive industrial fuel relative to the cost of softwood bark in both years.

AVAILABILITY

Wood residues suitable for use as fuel are most readily available in certain parts of the country, such as the Southeast, which support a substantial wood products industry. Even in these areas certain residues, such as shavings, may only be available in small quantities due to limited production. Other potential biomass fuels, such as clean softwood chips, may be priced out of the energy market due to high demand for other uses. Bark and sawdust, however, continue to be available in sufficient quantities to be considered for use as boiler fuel. These residues are also widely available in mixed form, but the high variability of the BTU content for these mixtures precluded their inclusion in this comparison. Their average price is usually lower than that of either of the constituents when sold separately.

SUMMARY

A number of factors must be considered when choosing the least-cost industrial fuel. Probably the single most important consideration is delivered cost per BTU, which includes the effects of BTU value, moisture content, combustion efficiency, hauling distance, and transportation cost. In this demonstration using state-wide averages, softwood bark and softwood sawdust were determined to be the least-cost fuels compared with the six other energy sources we tested. Local conditions affecting supply and demand may produce different results, and consumers should therefore be able to determine the least-cost fuel for themselves.

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METHANE FROM CAGED LAYER MANURE

by

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ABSTRACT

This research effort is being undertaken to evaluate methane yield from caged layer manure using 5.0 liter continuous anaerobic digesters. Loading rates will range from 1.4 to 3.2 g VS/l-day, with feed concentrations of 7 to 11% TS and hydraulic retention times (HRT) of 15 to 40 days. Ultimate methane yield (lCH_4/g VS) is being determined in 2.0 liter batch digesters. The data will be used to develop a mathematical model for prediction of methane yield.

Introduction

Methane production of caged layer manure is receiving more attention today, but not much research has been performed in comparison to swine, beef, and dairy manure. Poultry manure has a lower C/N ratio, a higher solids concentration as produced, grit, and feathers.

Gramms, et al. (1971) performed some of the initial work on poultry manure. Converse, et al. (1980) evaluated a farm size digester under several different loading rates and hydraulic detention times. Morrison, et al. (1980) evaluated poultry manure using a prototype digester. Hill (1983a, 1983b) calibrated the model of Hashimoto and Chen using available layer manure digestion data, including the field study data.

The primary objective of this study is to evaluate methane yield over a wide range of feed concentrations and retention times, but with a consistent manure and with identical digesters. The resulting model will be free of the manure-to-manure and digester-to-digester variation of currently available data. This study also includes examination of ammonia inhibition and evaluation of digester stability.

Equipment

Each of the three 5.0 liter digesters has an inside diameter of 0.14 m, a depth of 0.46 m, and a conical bottom. Two feed tubes extend through the digester lid and side into the liquid, with sampling valves in the bottom and sides. Intermittent mixing is provided by a variable speed (0 to 400 rpm) motor connected to a shaft with four propellers. A thermoswitch-controlled heating tape maintains the digester at 35°C. Gas is collected in a 7.5 liter plastic bottle which floats in brine.

Sampling and Analysis

Daily procedure for each digester consists of recording the volume of gas produced, withdrawing the desired volume of digester contents while the mixer is at high speed, then feeding diluted manure. Gas methane content is measured using a Fisher 1200 gas partitioner. To overcome difficulties in obtaining a representative subsample for solids analysis, the entire effluent sample, as well as a 167 ml feed sample, is analyzed for total and volatile solids three days per week.

On alternate days, the effluent sample is mixed and split for chemical analysis. A portion is centrifuged to yield supernatant for determination of alkalinity (to pH 5.75 and pH 4.3) as well as volatile acids. The volatile acids subsample is frozen for biweekly analysis with a Perkin Elmer Model 3920 gas chromatograph. A second portion of the effluent is homogenized, acidified to pH 2, diluted, and stored at 4°C for ammonia and total Kjeldahl nitrogen analysis according to the method of Bremner and Keeney (1966). A third portion is refrigerated at 4°C for total organic carbon (TOC) analysis. The sample is later adjusted to pH 11 with NaOH, then autoclaved and homogenized to break down particles which would otherwise be filtered out by the TOC injection syringe. The sample is then diluted, acidified to pH 2, sparged with nitrogen gas, and analyzed using a Beckman Model 915 TOC analyzer.

Digester Operation and Data Presentation

Poultry manure was initially obtained from a manure pit beneath caged layers on a commercial farm. It was mixed, subdivided, and frozen. Digesters 1 and 2 were seeded with digester effluent obtained from a cage layer digester. Following 113 days of operation, the gas production, alkalinity, and volatile acids data indicated that both digesters had reached steady-state. Average steady-state data for the next 35 days are presented in columns 1 and 4 of Table 1. The digesters were then slowly supplemented with ammonium carbonate to raise ammonia levels to 4000 mg/l as N. Data for the "spiked" operation are presented in columns 3 and 5 of Table 1. Digesters 1 and 2 are currently being raised to ammonia levels of 6000 mg/l.

Digester 3 was seeded with effluent from Digesters 1 and 2 and operated at a 30 day HRT to replicate base line operation of Digester 1. Following 51 days of operation, Digester 3 reached a steady-state condition which is described in column 2 of Table 1. Digester 3 is currently operating in a "decant" mode with a 20 day HRT but an increased solids retention time. This is achieved by decanting supernatant three days each week prior to mixing, rather than withdrawing the usual well-mixed sample. Data are presented in column 6 of Table 1.

Results and Discussion

Table 1 gives the average values for the digesters. Influent concentrations averaged from 6.8 to 7.0% TS for the various trials with loading rates ranging from 1.29 to 2.05 g VS/l-day. Methane yields ranged from

195 to 265 ml/g VSA (volatile solids added) with VS destruction ranging from 47 to 61%. Converse, et al. (1980), with loading rates of 1.65 to 2.29 g VS/l-day and HRT of 36 to 40 days, reported methane yields of 230 to 354 ml/g VSA and methane yields of 0.39 to 0.75 l CH_4/l-d. Morrison, et al. (1980) reported loading rates of 1.6 to 4.6 g VS/l-day with methane yields of 0.30 to 1.68 l CH_4/l-d for HRT of 70 to 10 days respectively. Loadings were done weekly and biweekly.

Digester 3 gave very similar results to Digester 1 even though it was not run at the same time, thus indicating that replication of all runs will not be necessary. The shorter HRT gave higher daily gas yields but lower methane yield based on ml/g VS destroyed. Spiking the digester to increase the ammonia concentration from approximately 2400 mg/l as N to about 4000 mg/l as N increased the percent of methane slightly but had very little effect upon methane production. Volatile acids and alkalinity increased in the spiked digesters from the unspiked digesters with pH remaining relatively unchanged.

Decanting at 20 day HRT increased VS destruction from 47 to 61% and increased biogas production by 30%. The percent of methane changed from 55 to 57%. Methane yield increased from 0.40 to 0.54 l CH_4/l-d.

Studies are continuing at higher ammonia concentrations and higher loading rates. Ultimate methane yields are being determined.

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Table 1. Summary of Inputs and Outputs of the Digesters Under Various Conditions

Reactor	1	3	1	2	2	3
Period	11/1-12/3	12/1-12/31	2/13-3/12	11/1-12/5	2/13-3/12	2/13-3/12
HRT, days	30 (base line)	30 (replicate)	30 (spiked)	20 (base line)	20 (spiked)	20 (decant)
Feed TS, %	7.0	7.1	6.8	7.0	6.8	6.8
Feed VS, %	4.3	4.2	4.0	4.3	4.0	4.0
Feed TKN, mg/l	3,840	3,985	---	3,840	---	3,707
Feed NH_3-N, mg/l	2,130	2,080	---	2,130	---	2,115
Effluent TKN, mg/l	3,720	3,750	5,400	3,691	5,190	3,920
Effluent NH_3-N, mg/l	2,420	2,370	4,020	2,370	3,890	2,590
Effluent pH	7.8	7.7	7.9	7.7	7.8	7.7
Effluent Alkalinity @ mg/l $CaCO_3$ pH 4.3	10,050	9,590	13,560	9,500	15,250	9,960
Vol. Acids, mg/l	514	524	774	1,313	2,095	752
Loading - g VS/l-day	1.36	1.29	1.34	2.05	2.02	2.02
VS destruction, %	52	53	51	47	48	61
Biogas, ml STP/day	2,840	2,890	2,720	3,660	3,420	4,740
Methane fraction, %	56	55	59	55	58	57
Methane - l/l-d	.32	.32	.33	.40	.40	.54
Methane - ml/g VSA	234	246	235	196	195	265
Methane - ml/g VSD	451	464	461	416	403	436

Methanol Production From Food and Agricultural Wastes

by

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ABSTRACT

Innovative techniques for producing methanol from food and agricultural wastes are proposed and investigated. Methanol can be produced from organic wastes by several methods: 1) Anaerobic digestion of organic wastes followed by partial oxidation of methane to methanol; The methane can be converted to methanol either by biological oxidation using methane-utilizing bacteria or by the Imperical Chemical Industries (ICI) low pressure catalytic process; 2) Hydrolysis of pectin into methanol and galacturonic acid from food wastes such as citrus peel; and 3) methanol fermentation of food wastes.

Introduction

Growing concern about environmental pollution and increasing energy prices have presented a severe economic threat to the food and agricultural processing industries. Approximately 400 million tons of organic waste are generated from agricultural crops and food processing in the U.S. each year. Conventional treatment of wastes is not only nonproductive but also costly especially for small scale plants. Innovative techniques for conversion of wastes into process fuels such as methanol will provide an effective and feasible solution for the waste and energy problem facing food industry.

Traditionally, methanol was obtained from destructive distillation of wood. However, in 1927, the synthetic process was introduced and today, most methanol is made by passing a synthesis gas or natural gas over a catalyst under pressure and at elevated temperature. Production of SYN gas/Methanol through thermochemical gasification/liquification of coal, wood and municipal solid wastes has been studied many years. However, thermochemical process is not feasible for treating food/agricultural wastes, especially those with high water content. As shown in Figure 1 methanol can be produced from food/agricultural wastes through the following ways: 1) anaerobic digestion of organic wastes followed by partial oxidation of methane into methanol; 2) hydrolysis of pectin-containing substances such as citrus peel into methanol and galacturonic acid, and 3) direct methanol fermentation. This paper discusses the feasibility of methanol production from food and agricultural wastes through these three methods based on our experimental results as well as literature data.

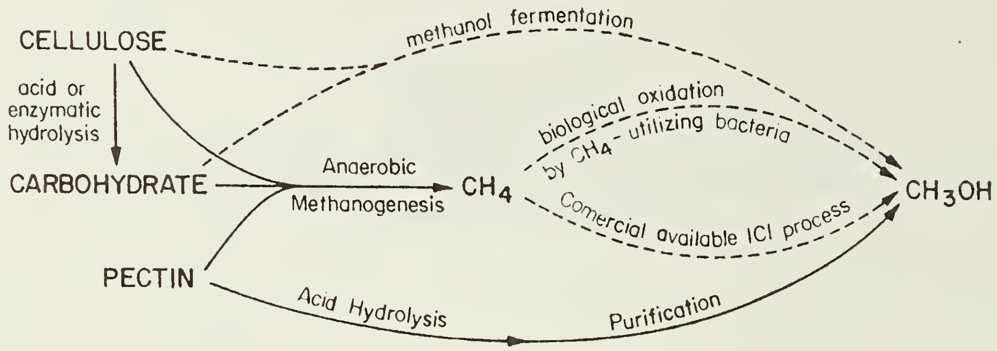

Figure 1. Possible Routes for Producing Methanol from Liquid Biomass.

Anaerobic Digestion of Organic Wastes

The microbiology and biochemistry of the anaerobic methanogensis has recently been extensively reviewed. In general, three groups of microorganisms are involved in the anaerobic methanogenic process. They are acid formers, H_2-producers, and methanogens. All the known methanogens use H_2 and CO_2 as energy source. Four species can use formate, only a few species can use acetate and methanol as a substrate. However, about 70% of methane produced in anaerobic methanogenesis comes from acetate. The interspecies H_2 transfer reactions provide a symbiosis for H_2-producers and methanogens and is the key to allow the complex organic matters completely degraded to CH_4 and CO_2. Unfortunately, the growth of methanogens is much slower and more susceptible to the environmental changes than others. By immobilizing the microbial cells onto solid support, the greater stability as well as methane production rate were obtained. A two-phase process can provide optimal growth conditions for both acid formers and methanogens and thus allow them to grow at their own optimal conditions.

Using pre-defined seeding culture for methane fermentation of food wastes can provide several advantages: 1) shorten start-up period, 2) provide stable and fast fermentation since process is controlled, and 3) avoid the undesired fermentation products such as propionic acid which is toxic to methanogenesis. In addition, pre-defined fermentation systems can be easily modified to produce products other than methane if desired. Various defined mixed cultures for methane fermentation of whey lactose have been developed and evaluated. Lactose is first converted into lactic acid by homo-lactic acid bacteria (S. lactis, S. cremoris). Lactic acid is then converted into acetic acid via homo-acetate fermentation (C. formicoaceticum, A woodii). Methane and CO_2 are finally formed from acetate via methanogenic bacteria such as M. barkeri and M. mazei. Similar cultures can also be used for producing methane from glucose, fructose, pectin and other carbohydrates. Cellulose can be easily degraded into acetate, methane, CO_2 and ethanol by coculture of C. thermocellum and M. thermoautotrophicum. The produced methane can be either used for on-site energy needs or converted into methanol via biologically or chemically catalyzed oxidation.

Oxidation of Methane to Methanol

Methanol can be produced from methane through two routes: 1) biological oxidation of methane using methan-utilizing bacteria, and 2) partial oxidation of methane to methanol using catalyst at high temperature. Many methane- and methanol-utilizing microorganisms have been studied from the viewpoint of a protein source since 1905. Extensive reviews on these types of microorganisms have been made recently. The methylotrophic bacteria utilize single carbon compounds such as methane and methanol to form biomass and carbon dioxide through the following route: CH_4 -> CH_3OH -> HCHO -> HCOOH -> CO_2. The methane oxidation is catalyzed by a membrane-bound oxygenase as found in Pseudomonas methanica and Methylomonas methanooxidians. The methanol dehydrogenase which requires phenazine methosulfate (PMS) and ammonium ions for activity is capable of catalyzing the oxidation of methanol, formaldehyde and many normal aliphatic alcohols. A mutant of Pseudomonas AM1 which had lost PMS-linked methanol dehydrogenase activity has been isolated. It is thus possible to produce methanol via biological oxidation of methane and preventing the further oxidation of methanol by properly inhibiting methanol dehydrogenase. This may provide a biological route of producing methanol from carbohydrate and other complex organics since methane can be easily derived from organic matters via anaerobic digestion.

Methanol can also be obtained by hydrogenation of carbon oxides: $CO + 2H_2$ -> CH_3OH and $CO_2 + 3H_2$ -> $CH_3OH + H_2O$. When the feed is synthesis gas, a mixture of carbon monoxide and hydrogen, a gas shifting step is usually taken to bring the H_2:CO ratio to 2:1. When the feed is natural gas, steam reforming methane is first made to generate CO and H_2, $CH_4 + H_2O$ -> $CO + 3H_2$. CO_2 is also added into the gas stream since excess hydrogen is formed from the steam reformer. The next step involves converting the gas by a low pressure process. Copper based catalysts are used. Feed gas is thoroughly treated to remove sulfur to avoid poisoning of the catalyst. However, in many agricultural wastes little sulfur is present and the CO_2 produced anaerobically along with the methane has found to enhance catalyst life. Operating temperature and pressure are 270^{o}C and 750 psig, respectively. The crude methanol formed contains few impurities, because few side reactions take place in the converter due to low temperature and high selectivity of the copper-based catalyst.

Methanol from Pectin Contained Substances

Pectic substances occur without exception in all higher plants. One of the richest sources of pectin is lemon or orange rind which contains about 32% of this polysaccharide. Pectins consist of a mixture of methyl esterfied galacturonan, galactan and araban varying in proportions in pectins from different sources. Total hydrolysis of pectin yields D-galacturonic acid, methyl alcohol and small amounts of galactose and arabinose. In natural pectins about 20-60% of its carboxyl groups are esterfied with methyl groups. Most natural pectins contain about 12% ester methoxyl. Pectin can be extracted by mild acid or alkaline. A longer reaction time of treatment at higher concentration causes extensive decomposition and demethylation of the pectic substances. Food processing wastes which contain large amounts of pectin are derived from trimming and washing operations, blanching, culled products and by-products In general, 10-30% of the incoming fruits and vegetables are usually disposed of due to lower quality or to trimmings. In the citrus juice industry, 40 lbs of peel, pulp, rag and seed are left from 90 lbs of citrus processed. This waste contains 22.5% solids. More than 30% of the solid content is pectin. Approximately 90% of 16.5 million tons of citrus annually produced in the U.S. is processed into juice, with the sizable waste either dried to make animal feed or dumped. This waste product represents a potential annual energy source of 10^{13} BTU. More than 20% of the energy used in concentrating the juice could be obtained by hydrolyzing the pectic substance and separating the methanol. Similar situations also exist for tomato, apple and other fruit and vegetable industries. Acid hydrolysis of citrus (lemon, grapefruit and orange) peel which contains 20-40% of pectin yields 2-5% of methanol. The remaining components of fruit wastes can be converted to methane/methanol via anaerobic digestion and partial oxidation of methane to methanol.

Methanol Fermentation

Some methanol is found in many plants and animals, and bacteria exist which can consume methanol, it is also conceivable that bacteria exist which could decompose the more complex natural organic materials down to methanol in a fashion analogous to the fermentation of carbohydrates to ethanol. This could potentially provide a convenient method of energy production for food industry once suitable microorganisms are found or genetically engineered. Although, no such processes are being used or apparently even known at present. Some of the methanogens may have the potential to produce methanol from hydrogen and carbon dioxide since methanol is the substrate of one methanogen (M. barkeri) and its existance as an intermediate during hydrogenation of carbon dioxide is recently proposed. Through appropriate metabolic regulation, the methanogen may produce methanol instead of methane, thus methanol could be obtained directly from anaerobic fermentation.

SUMMARY

Defined methane fermentation of food/agricultural wastes is superior to conventional anaerobic digestion due to the controlled fermentation can provide stable, fast and reliable process. Culture for methane fermentation of whey lactose have been developed and evaluated. The chemistry for methanol production from methane is well known. Commercial low-pressure production systems are available and their economics are well documented. Thus, organic wastes can be converted into methane gas and then methanol. Biological oxidation of methane to methanol is possible by using mutants of Pseudomonas AM1 or by properly inhibiting methanol dehydrogenase. However, more work is necessary to prove this idea. 2-5% of methanol can be obtained from hydrolysis of citrus wastes. The rest components can be converted to methane via anaerobic digestion. Direct methanol fermentation of food wastes is speculative. Isolation and/or genetically engineering of such a microorganism is required.

245 METHANE FERMENTATION OF DILUTE DAIRY CATTLE WASTE AT LOW TEMPERATURE AND SHORT RETENTION TIME [1-3].

by

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ABSTRACT

Methane fermentation of dilute dairy cattle waste from a screen separated, water flush waste disposal system was performed at low temperature (20, 30 and 40°C) and short retention time (1,2,4,6,8 and 10 d). Fermentations were performed in tubular, unagitated fermentors (505-liter) that were fed once daily. Methane yields ranged from 0.19 to 1.24, 0.28 to 1.20 and 0.29 to 1.09 liter/liter influent day at 20, 30 and 40°C, respectively.

INTRODUCTION

The fermentative conversion of animal waste into energy in the form of methane has been reported. Similarly, upgrading this gaseous fuel, transportation requirements and utilization schemes are well underway to being a field applicable technology. However, additional effort is needed to increase methane yield per: unit of input; fermentor volume and time. Basic research directed at understanding the microbial interactions and biochemical pathways involved in methane formation are needed. This research would result in enhanced methane yield and improved fermentor design, which can reduce capital investment costs and provide a more efficient backup energy system for crop drying, electricity generation and other uses on the farm. The work reported is an initial experiment directed at obtaining methane yield data and fermentation characteristics of dilute dairy cattle waste at low temperature and short retention time. This data will be used for comparative purposes in additional experiments aimed at evaluating microbial cell adhesion and immobilized cell culture characteristics of similar waste.

MATERIALS AND METHODS

Liquid and fines (LF, liquid waste stream passing through an inclined solids separating screen,1.0 x 6.0 mm pore size) from a water flush waste disposal system were collected daily from lactating cows housed outside on concrete floors. The LF were hydraulically transferred and mixed in a 1000-liter tank prior to distribution to pilot-scale (505-liter) tubular fermentors operating at 20, 30 and 40°C without mechanical agitation. Single daily feedings equivalent to hydraulic retention times (HRT) of 1,2,4,6, 8 and 10 days were performed for each temperature condition. At theoretical steady state conditions (5xHRT), samples were collected and analyzed by standard methods. Gas volume, gas composition, and total, volatile and fixed residues at fermentor inlet and outlet were determined daily. Chemical oxygen demand, volatile and non-volatile fatty acids were determined at theoretical steady state.

RESULTS AND DISCUSSION

The characteristics of the liquid and fine from the coastal plains dairy farm are presented in table 1. Theoretically, an estimated 1.4 liters of methane/liter of influent could be obtained if the COD were totally reduced. The farm could, therefore, produce an estimated 101 ± 6.6 m^3 of methane/day from the liquid and fines waste fraction.

Due to the large volume of LF produced daily and the high capital construction and operational costs of conventional fermentation systems, a low cost tubular fermentor system operating at low temperature and short retention time was studied. The yield of methane at various theoretical retention times and temperatures is presented in table 2. Methane yields at a 10 day HRT were similar for the temperatures studied. However, at HRT less than 10 d, methane yield at 20°C was reduced when compared with similar fermentations maintained at 30 and 40°C temperatures. Methane yields at 30 and 40°C were comparable throughout the study.

The data demonstrate that methane can be produced at low temperatures and at short retention times in an economical, tubular fermentor. A fermentation study currently in progress is aimed at improving methane yield at retention times less than 10 days by evaluating microbial adhesion characteristics and population densities.

CONCLUSION

Methane fermentation of liquid and fines from a dairy water flush waste disposal system is feasible at low temperatures (20-40°C). Methane yield was not affected by temperature at a 10 day theoretical hydraulic retention time. Methane yield at a 10 day retention time was 78 to 89 percent of theoretical. Methane yields at 30 and 40°C were comparable from 1 thru 10 day retention times.

Table 1. Characteristics of liquid and fines at the University of Georgia, Coastal Plain Experiment Station, dairy farm.

Liters/day	72500.0 ± 4700.00
Chemical oxygen demand, COD (mg/liter)	4005
Total residue (mg/liter)	2847.1
Volatile residue (mg/liter)	2158.8
Theoretical methane yield (liter/liter input)[a]	1.40

[a] 1 gm COD reduction equivalent to 0.35 liters methane at STP (McCarty, P. L. 1978. Anaerobic process, Birmingham short course on design aspects of biological treatment. Int. Ass. Water Pollution Res., Birmingham, England)

Table 2. Methane yield from dairy waste liquid and fines fermented in tubular fermentors.

Methane Production	Temperature (C)	Theoretical retention time (day) 1	2	4	6	8	10
liter/liter influent day	20	0.19	0.30	0.38	0.54	0.47	1.24
	30	0.28	0.49	0.62	0.75	0.66	1.20
	40	0.29	0.55	0.62	0.68	0.61	1.09

245

PRE-TREATMENT METHOD FOR SPECIFIC CROPS TO INCREASE REDUCING SUGARS CONTENT FOR POTENTIAL METHANE PRODUCTION.*

100 F. le Grand**

INTRODUCTION

Past experimentation with screening of crops produced solely for biomass yield indicates that napier grass (elephant grass), forage sorghum, saw palmetto, saw dust of soft woods, and water hyacinth show possible promise for use as feedstock to produce methane by fermentation.(1) The selected crops produce a high yield of lignified biomass per acre, but also contain a limited amount of water-soluble reducing sugar, causing a slurry to be introduced into a digester requiring a long retention time to complete conversion into methane.

Pre-treatment of harvested materials from the selected crops is an attempt to increase the water-soluble content of reducing sugar, and consequently to reduce retention time for digestion of these crop materials.

Effective pre-treatments necessitate the use of only small quantities of catalyst for hydrolysis and a relatively low steam pressure, because methane from biomass must be produced for $6.00 or slightly higher per million BTU to remain competitive with natural gas and other alternative fuel resources.(2)

The use of rather small quantities of acid and low temperature heat should successfully convert moderately liginified biomass like sorghum and napier grass, but a satisfactory conversion rate of highly lignified saw dust into significant quantities of mono-pentoses appears unlikely.

Fortunately, pentoses appear to be suitable for serving as feedstock for digestion by methane producing organisms; the result of conversion rates for the specified crops into reducing sugars (whether pentoses or hexoses) are reported hereinafter.

METHODS AND PROCEDURES

All materials from the specified crops were treated and analyzed on dry basis to facilitate uniform reporting and comparative interpretation. Exactly one gram of material, dry basis, was hydrolyzed, and hence the actual quantity of material used for treatment was adjusted for the predetermined moisture content.

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Weighed material was placed in long pyrex tubes which were hydrolyzed in a specially built pressure vessel, with saturated steam from a laboratory boiler.

Five milliliters of distilled or acidified distilled water were added to each sample in the pyrex tube prior to hydrolyzing in the vessel. The added distilled water measured pH 5.2, and was either pH 3.0 or pH 1.0 after acidifing with sulphuric acid. Hence, three levels of acidity were used for hydrolyzing. The hydrolysis process for each crop was carried out at five time durations, at three levels for acidity, and at two levels for temperature (saturated steam at 50 and 75 psi, respectively). Hydrolysis at different time durations may be important kinetically; the formation of reducing sugars may be determined over time, and possible destruction of sugars over time can be observed.

After hydrolyzing, the resulting aliquot was neutralized with calcium carbonate to 6-7 pH, was filtered, and the glucose content in the filtrate was determined with a YSI Model 27, Industrial Analyzer. Total reducing sugars (hexoses and pentoses) in the filtrate was determined by the titrimetric Schoorl method. Results from the determinations were expressed as milligrams of glucose and milligrams of total reducing sugars per gram of dry plant material, respectively.

In all cases samples were boiled at atmospheric pressure for a few minutes and the glucose and total reducing sugars were determined. These values express the quantities of the sugar components naturally present in the specific crop. When substracting the values for glucose and total reducing sugars from the same values reported after hydrolyzing, one can regard the difference as gain in sugar components due to the hydrolyzing process.

RESULTS AND CONCLUSIONS

Results from hydrolyzing different crops are summarized in Table 1. From the obtained results the following conclusions may be summarized:

1. Hydrolyzing as a pre-treatment with saturated steam which has been moderately acidified with sulphuric acid optimizes the conversion of fiber into reducing sugars.

2. A pressure of 50 psi for saturated steam optimizes the formation of reducing sugars for 5-30 minutes duration.

3. Destruction of reducing sugars occurs when steam of 75 psi is applied for hydrolysis during the stated time periods.

4. Time required for hydrolysis to optimize the formation of reducing sugars is not constant, and hence the specific time required to optimize the hydrolysis process is dependant on the type of plant

material treated.

5. Forage sorghum and napier grass yielded a favorable increase in reducing sugars when hydrolyzed as pre-treatment. In contrast, content of reducing sugars in water hyacinth was only slightly enhanced by hydrolysis as a pre-treatment.

DISCUSSION

Pre-treatment with a mild hydrolysis process under moderate steam pressure and a short time lapse appears highly successful for forage sorghum and napier grass, yielding 43.6 and 34.2 percent of reducing sugars in dry plant material, respectively. When assuming about 2% for total nitrogen content in dry plant material for these species,then the C/N ratio after hydrolysis will be about 22 and 17 for forage sorghum and napier grass. These values compare favorably with C/N= 30, a reported optimum value for maximizing methane productiom over time.

In a pilot plant operation the hydrolysis operation may be carried out when using a plugged reactor vessel. The hydrolyzed material continuously exits the plugged vessel as a slurry containing an elevated quantity of dissolved reducing sugars and a non-water soluble residue consisting mostly of still lignified alpha cellulose. After adjustment for pH the slurry may be introduced into a methane fermenter. Most of the organic fibrous residue will be converted over time, possibly leaving lignin as partial residue for removal from the digester. The latter may be used, after drying to 60% moisture, as fuel in a wet-boiler to energize the hydrolysis process.

Finally, the bonds between lignin and alpha cellulose are possibly weakend by the hydrolysis pre-treatment, and consequently the time required for conversion of alpha cellulose into methane may be considerably shortened.

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2. Anonymous. Estimation by GRI/IFAS cooperative team during a special seminar in 1982.

ACKNOWLEDGEMENTS

Appreciation is due to Mr. Ned Stevens, Chemist II, and to Mr. Ian Jackson, Biologist, for their assistance with analyzing the numerous plant samples and with the computation of the results.

Table 1. Highest Quantity of Total Reducing Sugars Obtained After Hydrolysis At 50 and 75 psi Steam Pressure When Using Three Levels of Acidity And Five Time Durations

Plant species	Pressure, psi. 50	75	Acidity, pH	Time, min.	After hydrolysis, mg reducing sugars/g dry plant material*	Unhydrolyzed, mg reducing sugars/g dry plant material*	Increase due to hydrolysis, mg of reducing sugars/g dry plant material*
Water	X		1.0	15	158	80	78
hyacinth		X	1.0	10	218		138
Forage	X		1.0	30	436	69	367
sorghum		X	1.0	30	350		281
Napier	X		1.0	30	342	83	259
grass		X	1.0	5	307		224
Saw	X		3.0	10	248	105	143
palmetto		X	1.0	15	258		153
Pine	X		1.0	5	327	141	186
sawdust		X	1.0	10	281		140

* Percent of reducing sugars in plant materials, dry basis = value of mg/g x 0.1.

ANAEROBIC FERMENTATION OF BEEF-CATTLE MANURE AND CROP RESIDUES

by

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ABSTRACT

A two-stage fermentation system involving a high-rate fermentor (HRF) to convert beef-cattle manure to methane, and a straw fermentor (SF) to convert slowly degraded organic material to methane began operating on July 29, 1982. The first trial was completed on November 13, 1982, and the second trial began on December 6, 1982, and is currently in progress. Results from these trials show that methane can be produced in the SF; and that injection of anhydrous ammonia apparently releases previously unavailable substrate for fermentation to methane.

INTRODUCTION

The overall objective of this project is to evaluate the economic feasibility of converting manure-crop residue mixtures to methane. Within this context, the project purposes to develop optimum design criteria for a two-stage fermentation system that allows rapid conversion of easily degraded compounds to methane, and long-term fermentation for more slowly degraded compounds.

The advantages of the proposed two-stage fermentation system are: thermochemical pretreatment or size reduction of the crop residue are not required; the crop residue is handled only at the beginning and end of fermentation (i.e., materials handling problems associated with mixing and pumping crop residue slurries are minimized), and the system will selectively ferment the easily and less degradable compounds.

SYSTEM DESCRIPTION AND PROCEDURES

The first-stage high-rate fermentor (HRF) had a total volume of 5.7 m^3 with a working volume of 5 m^3. It was insulated with 3 cm of polyurethane foam. Four baffles were equally spaced around the inside of the tank. The HRF was mixed with a 1.5 kW variable-speed motor and two, three-blade, stainless-steel marine propellers on a stainless steel shaft rotating at 220 rev/min. An external, double-tube heat exchanger was used to maintain a 55°C fermentation temperature using hot water heated to 65°C.

Starting on day 87, 1 m^3 of K was pumped to the top of the SF and an equal amount of KS was pumped to the fermentor. No manure was fed to the fermentor at this time. This procedure was followed until day 108.

Trial 2

The SF was loaded with 479 kg of the same straw used in Trial 1. On day 1 (December 7, 1983), 1 m^3 of K was pumped into the SF. This was continued through day 11 and then on day 13 when the level reached the full working volume of the SF. From day 9, the liquid from the SF was pumped through the heat exchanger to maintain the average SF temperature between 32°C to 37°C. On days 22 through 29, cold weather and storm related power failures caused the average tank temperature to fall below 30°C. On day 29, an additional 1 m^3 of K was added to the SF to raise the level to the full level. This was necessary mostly due to the compaction of the loose (hand packed) wheat straw.

RESULTS

Figure 1 shows the TVA for K and KS during Trial 1. The TVA for K steadily increased from about 1 kg/m^3 on day 0 to 3.2 kg/m^3 on day 36. The reason for this increase in TVA was assumed to be salt accumulation in the HRF, since KS was the only source of make-up liquid. After the HRF was diluted and tap water was used to dilute N an H, the TVA decreased to about 0.5 kg/m^3. The TVA in KS remained at about 1.5 kg/m^3 for the first 40 days of operation then decreased to about 0.5 kg/m^3 when the TVA of K decreased. The increase in TVA in KS after day 80 was attributed to the substrate released after ammonia treatment.

Figure 2 shows the biogas production of the SF for Trials 1 and 2. The low biogas production during the first 50 days of Trial 1 was attributed to a faulty gas meter. After a new gas meter was placed in operation, the measured biogas production was similar to that of Trial 2. The break in biogas production from day 70 to 76 in Trial 1 was the period when the SF was drained, and anhydrous ammonia injected into the SF. The increase in biogas production after day 76 was attributed to the substrate released after ammonia treatment. The total amount of biogas produced during the first 75 days of Trial 2 was 314 m^3 (162 m^3 CH_4). Anhydrous ammonia treatment of the straw in Trial 2 is in progress.

SUMMARY

Two trials have been completed on the two-stage fermentation system. These trials have shown that methane can be produced in the SF; therefore, there is no need to recycle KS to the HRF. In fact, the results from Trial 1 indicate that it is detrimental to recycle KS as the only make-up liquid, since salt accumulation inhibited methane production. Injection of anhydrous ammonia into the SF apparently released previously unavailable substrate for fermentation to methane.

The second-stage straw fermentor (SF) was a 16.8 m^3 steel tank, insulated with 7.6 cm of polyurethane foam. The working volume of the tank was 14.2 m^3. An expanded steel screen was placed 0.3 m above the floor of the tank to support the straw and to prevent plugging of the outlet. Another screen was placed 3.5 m above the lower screen (4.0 m above the floor) to prevent floating straw from plugging the gas outlet pipe. The volume packed with wheat straw was 13.0 m^3. Influent slurries entered through a 7.6 cm pipe at the top of the tank, while effluent drained from the bottom of the tank. The biogas produced was collected at the top of the tank and passed through a temperature-compensated gas meter and a pressure-relief valve. The temperature was monitored using three thermocouples at the top, middle, and near the bottom of the working volume. The SF temperature was an average of these three readings. In Trial 1, the temperature was not controlled.

The manure (1-10 days old) used in this study was gathered daily from steers housed on partially-roofed, concrete-floored pens. The steers weighed from 340 to 570 kg. Their ration consisted of 85% yellow corn, 13% corn silage, 1.6% soybean meal, 0.2% limestone, 0.1% each of dicalcium phosphate and salt, and trace minerals and vitamins A, D and E. The manure was transported by a small front-end loader and dumped into a mixing-degritting tank, diluted to 10-12% VS, and mixed with a 1-kW variable speed mixer.

Wheat straw, from hard-winter wheat (Bennett) grown in Clay County, Nebraska, was baled in large round bales (approximately 400 kg) and stored in an open-front barn.

Trial 1

At the start of Trial 1, 381 kg of straw was placed in the SF. The tank was then sealed and filled with tap water. On day 1, the manure placed in the mixing-degritting tank was diluted to 10-12% VS using the effluent (KS) from SF. Depending on the VS analysis of this slurry (N), a given amount was weighed and mixed with more (KS) to make a 6% VS slurry (H) for feeding the HRF. HRF effluent (K) was then pumped to the top of the SF to bring it back to the full level. H was heated to 50°C and then pumped into the HRF. This procedure was followed for 36 days.

On days 38, 39, and 40, the HRF was diluted with 1 m^3 of water each day. On days 42 through 47, the fermentor was fed manure mixed with water only (not KS). Also, 1 m^3 was fed to the SF and an equal amount pumped from the SF tank to the HRF. The HRF was maintained at 5-days HRT, and H of 6% VS. However, the SF was loaded with K only on days 58 and 64, and left to ferment the rest of the time.

On days 71 and 72, the SF was drained of all liquid. Anhydrous ammonia was injected slowly into the bottom of the SF beginning on day 74 and for the following three days, a total of 29.9 kg of ammonia was injected into the SF. On day 78, 1 m^3 of K was pumped into the SF. This was continued daily until day 85, when the SF was again full.

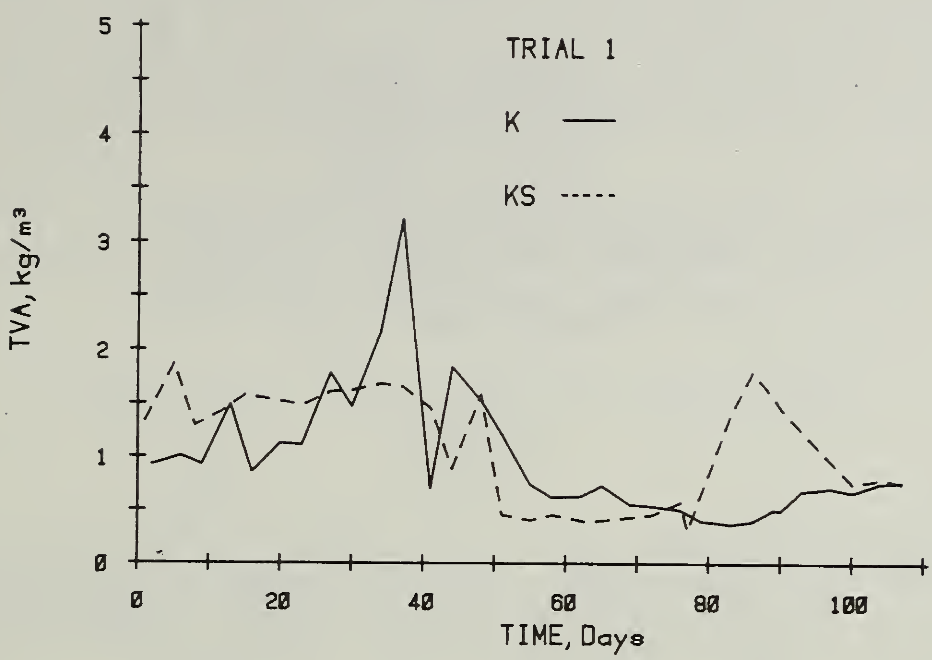

Figure 1. Total Volatile Acid (TVA) Profile of High-Rate Fermentor Effluent (K) and Straw Fermentor Effluent (KS).

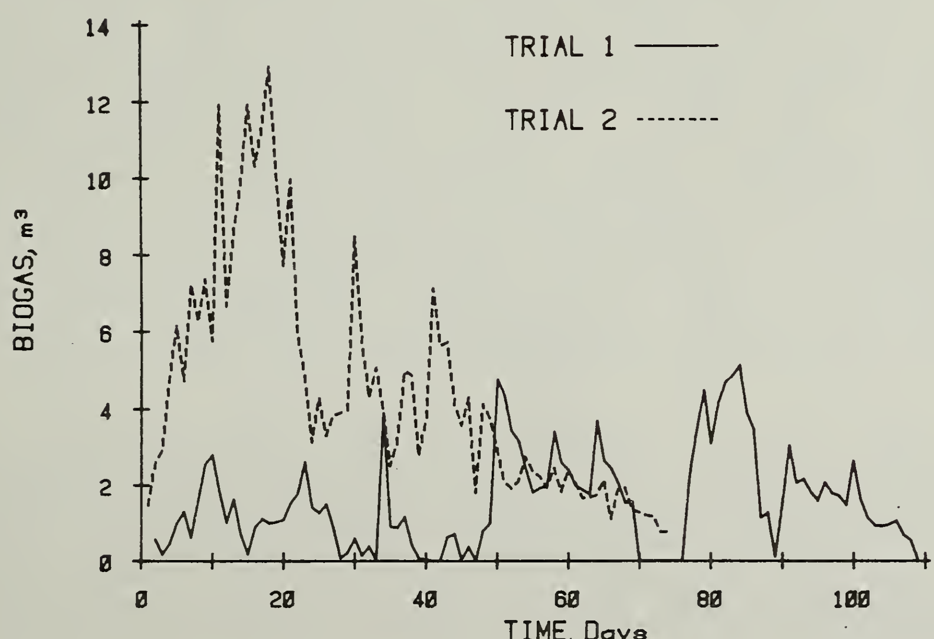

Figure 2. Biogas Production During Trials 1 and 2.

ENERGY INTEGRATED DAIRY FARM -- A PROJECT UPDATE

by

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ABSTRACT

The Energy Integrated Dairy Farm (EIDF) project by Georgia Tech at Mathis Dairy Farm is briefly described. This is a review of the current status of the project on the evaluation of alternate energy and energy conservation technologies on a southeastern dairy.

Introduction

The Department of Energy program in Energy Integrated Dairy Farm has as its primary goal the evaluation and utilization of alternative energy technologies which can replace or supplement conventional farm energy sources (electric utilities and fossil fuels). The Georgia Institute of Technology has teamed with R.L. Mathis Dairy as one of the eight EIFS projects. Initially, the team efforts were directed toward characterizing the energy requirements of the Mathis Dairy Farm, inventorying the resources available at the farm site which could be used for energy production, and establishing potential on-site energy production. The next step was the solicitation of actual quotations from vendors for equipment to comprise the energy systems being evaluated. By soliciting quotations, capital costs, operating and maintenance costs, service capabilities of the equipment manufacturers could be evaluated. Subsequent phases of the Georgia Tech/Mathis Dairy Energy Integrated Dairy Farm (EIDF) project involve the installation, operation, and monitoring of the energy systems.

The Mathis Dairy Farm is located near Social Circle, Georgia, approximately 50 miles east of Atlanta. It is one of only two certified raw milk dairies in the United States. When the dairy reaches its full capacity, it will have approximately 550 milking head in two freestall areas and will provide a feeding area for the support and hospital herds. Milker average weight is 1,350 pounds per animal with an expected production of 60 pounds of milk per cow per day.

The farm covers over 700 acres, of which 490 acres are cropland with sorghum and corn silage as the primary crop.

Energy Consumption Patterns

Table 1 lists the major annual energy inputs and cost at the dairy farm. The majority of the diesel fuel was consumed during the spring and fall harvesting and planting. The gasoline is used primarily for the dairy feed truck, silage hauling trucks, and the farm pickup trucks. The LP gas was used for the dairy parlor hot water heater, parlor space heating, and farm residence heating.

The electrical input is primarily (75%) used for the milking operations, with the balance for the various residences and farm equipment.

Table 1

MAJOR ANNUAL ENERGY INPUTS FOR MATHIS DAIRY
1981-1982

Input	Unit	Amount	Cost	% of Total Cost	Energy Value 10^6 Btu/yr
Diesel Fuel	Gallons	15,355	$17,630	14.0	2,147
Gasoline	Gallons	34,185	41,820	33.1	4,239
LP Gas	Gallons	9,415	6,740	5.3	861
Electricity	kWh	443,320	25,910	20.5	1,516
Nitrogen Fertilizer	Tons	22.8	34,150	27.1	1,563
TOTALS			$126,250	100.0	10,326

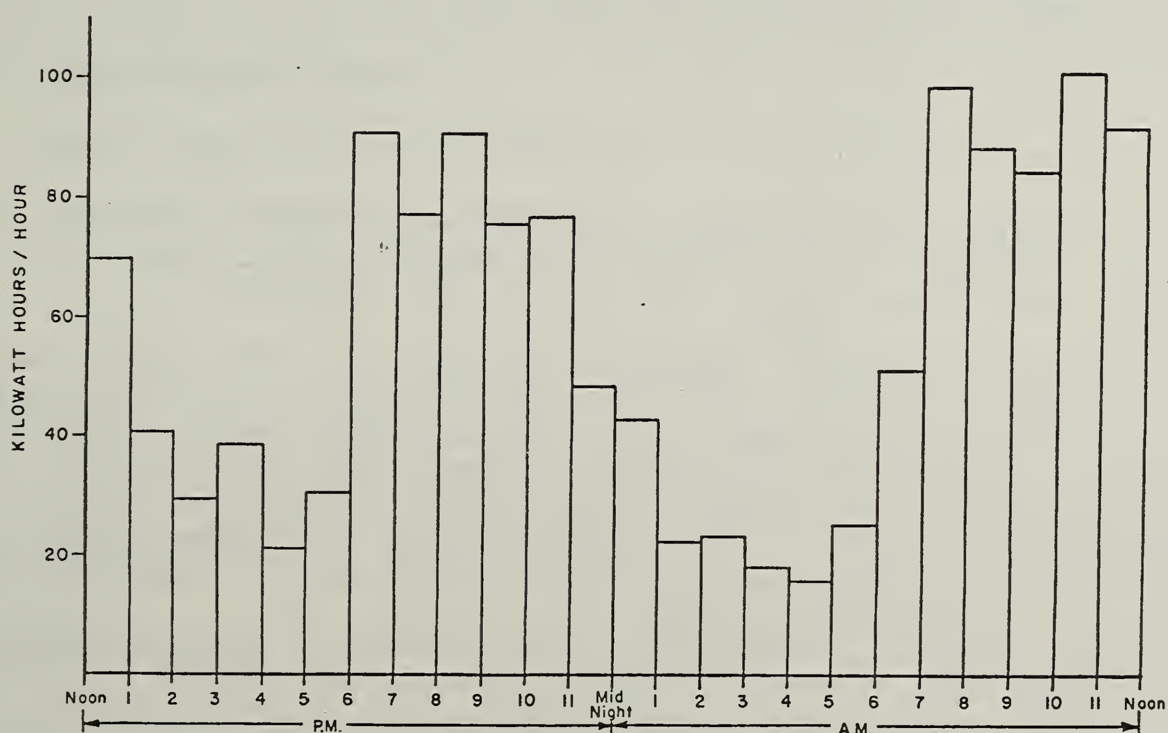

Figure 1. Milk Operation Electrical Consumption
Mathis Dairy Farm, Feb. 19, 1982

Figure 1 shows the daily power consumption in the milking parlor, including the water pumping. The daily total is 1,350 kWh, for an average requirement of 56 kWh per hour. The load is concentrated in the two milking periods each day of about 6 hours each or 12 hours total with the power requirement for the other 12 hours being quite low. During the two 6 hour periods of heavy load, the energy consumption averages about 85 kWh/hr.

A portion (16%) of the electrical consumption is in the operation of the water pumps. Current estimates are that about 95,000 gallons of water per day are used for parlor and freestall flushing, parlor spray grid, pre-milk prepping, milk line and tank cleanup, and miscellaneous uses. Some 53% of the 95,000 gallons or over 50,000 gallons per day is used for the flushing of manure from the freestall areas. This water use above requires over 220 kWh per day to pump the water from the deep well to storage, storage to flush tanks, collection sump to storage tank, and storage tank to either a holding pond or through the irrigation system. When the pond water is used in irrigation, it requires additional pumping to move it through the system.

Energy System Evaluation

Several alternative system options were reviewed for technical and economic feasibility including:

- o anaerobic digestion of an estimated 51,000 pounds of recoverable raw dairy manure (at 12.7% TS) to produce biogas;
- o biogas conversion including cogeneration, direct combustion, and high compression for vehicular use;
- o solar energy applications for dairy thermal energy demands;
- o on-farm production of fuel grade alcohol for farm use; and
- o energy and resource conservation practices including minimum tillage, refrigeration waste heat recovery, waste utilization, water conservation, and electric load management.

Five anaerobic digester companies responded to a bid request specifying only digester feedstock characteristics. The bids varied significantly in price ($141,000 to $277,000), and reflected a wide range in digester system concepts: mesophilic, plug-flow to thermophilic, mixed reactor. A subsequent technical and economic review, based on individual digester biogas production estimates and life cycle costing, determined the choice of a mesophilic, plug-flow digester to be installed at the dairy Spring 1983.

A similar bidding process for engine generator sets for cogeneration yielded two bids in the price range of $50,000 for units in the 70 kW to 85 kW range. With an anticipated biogas production of 28,000 SCF per day, biogas cogeneration is expected to yield 49 kW of electricity and 312,000 Btu/hr of thermal energy on a continous basis. The recovered thermal energy will provide hot water to satisfy parlor requirements for hot water and space heat and to maintain proper digester temperatures. Cogeneration is the preferred biogas conversion method on this site because of the low degree of utilization from direct combustion for hot water production and cost and range of operation limits posed by high compression for vehicular use.

Production costs of over $2.00 per 190 proof gallon of alcohol and restricted land area for raising an appropriate feedstock made farm produced fuel alcohol economically and practically unviable. Solar energy for parlor hot water production, while economically feasible compared to an LP gas-fired hot water system, was not as attractive as producing hot water from the cogeneration or direct combustion of biogas.

Energy conservation methods to be implemented include minimum tillage which has the added and possibly more important benefit of soil conservation. Refrigeration heat recovery is already practiced at the dairy, however, will be improved. Water conservation, due primarily to a 70% reduction in flush usage, will result in a considerable savings in electricity for numerous pumpings in the water supply and wastewater removal cycle. Waste utilization includes recovery of digester effluent solids with a separator for subsequent use as a freestall bedding or a possible marketable bagged fertilizer product. Proper utilization of the separated liquid fraction as cropland fertilizer is also to be investigated.

SUMMARY

Table 2 illustrates anticipated annual energy and resource savings from the integrated energy system once operational. Installation and startup of the system will take place over the next year with a subsequent two years of monitoring by Georgia Tech.

Table 2

EIDF ENERGY AND RESOURCE RECOVERY ESTIMATES

	Amount	Value ($ 1982)
Energy Production (Cogeneration)		
Electricity	4.1×10^5 kWh	$26,300
Thermal (hot water and space heat)	2,200 gallons LP gas	1,600
Energy Conservation		
Minimum tillage	700 gallons diesel	800
Heat recovery	4,600 gallons LP gas	3,300
Water conservation	55,700 kWh	3,600
Waste Utilization		
Solids recovery (bedding)	248 dry tons	20,000

PHYSIOLOGY AND BIOCHEMISTRY OF THE INTERACTIONS OF METHANOGENIC BACTERIA WITH FATTY ACID PRODUCERS AND UTILIZERS AS AN APPROACH TO INCREASING THE RATE AND YIELD OF METHANOGENESIS

by

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ABSTRACT

The aim of this research is to study the fatty acid oxidizing microorganisms (acetogens) and the acetate utilizing methanogens with the goal of increasing both the rate and yield of methane formation from biomass. This overall objective will be accomplished by (1) isolating new types of these organisms and studying their nutritional requirement for optimum growth, (2) studying the physiology and biochemistry of the organisms involved, (3) attempting to co-culture them (acetogens and methanogens) and establishing the parameters for optimum growth, and (4) validating the test tube results in fermentors.

Physiology and biochemistry

Since hydrogenase is one of the key enzymes in the microorganisms which are responsible for the degradation of cellulosic materials into methane, a thorough investigation of its structure and function is essential for the understanding of the interspecies hydrogen transfer phenomenon. We have purified and characterized the hydrogenases from three species of *Desulfovibrio*, bacteria which are the direct partners of the methanogens. All three proteins contain non-heme iron centers but only two were found to have redox active nickel. Since the stability of these enzymes toward O_2 is also an important factor, it is interesting to note that these hydrogenases are all very stable to oxidation. Although our knowledge of the structure of the enzymes has considerably increased, three important questions still remain to be answered:

1. What is the center which is responsible for hydrogen activation?
2. What is the cause of oxygen stability of certain hydrogenases?
3. Is there another transition metal, besides iron, which replaces nickel in the proteins which lack this metal?

Two hydrogenases from *Ms. barkeri* strain 800 and 804 have also been purified and characterized. The reason of the choice of these two strains is that their nutritional behavior is not the same: The first grow better on $H_2 + CO_2$ and acetate while the second grows better on methanol. Indeed much less vitamin B_{12} (an essential component of the methyl transferase) has been found in 804 than in 800. The *Ms. barkeri* 800 hydrogenase contains non-heme iron, FMN and nickel. So far, no nickel has been found in strain 804. Experiments are still in progress to determine whether this metal has been replaced by another element.

In the course of the purification of D. desulfuricans strain 27774 hydrogenase we have found a flavodoxin which possesses a semiquinone form, very stable to oxidation by air. In collaboration with Professor Schlegel's group in Germany and Thomas in France we have utilized this new protein in the chloroplast/hydrogenase system and found that it is then possible to obtain hydrogen evolution without the utilization of an oxygen trap such as the glucose/glucose oxidase system. This result clearly shows how difficult it is to separate the problem of H_2 and CH_4 production in the field of biological solar energy research.

In collaboration with Dr. Melvin H. Czechowski the iron requirement for different species of Desulfovibrio has been quantified. Large differences appear between them. For example, D. vulgaris has been shown to exhibit optimal growth in the presence of 0.2 ppm of iron (this corresponds to trace iron found in our initial medium "depleted" with iron). D. gigas and D. desulfuricans grow poorly under such conditions requiring the equivalent of 2.0 ppm iron.

The ferredoxin system of D. gigas is now very well characterized. Ferredoxin II contains a single [3Fe-3S] cluster while Ferredoxin I contains a [4Fe-4S] cluster. In collaboration with Professor A. Xavier's group in Portugal we have shown that biological interconversion of Ferredoxin II to Ferredoxin I is possible. This system can be interpreted as a regulatory mechanism by which minimal amounts of iron are utilized by the bacteria (a 3Fe cluster is also present in D. gigas hydrogenase). When ferredoxin became even more depleted it can be replaced by flavodoxin, an FMN containing low potential flavoprotein.

Microbiology

Fatty acid oxidizers

Four strains of sulfate reducing fatty acid oxidizers are presently being studied. Two of these are gifts of Professor N. Pfennig and F. Widdel from Germany. These are: D. saporovans strain lpa3, isolated on Na Palmitate but which can also utilize soluble fatty acids down to butyrate, and D. baarsii, which carries out the oxidation of monocarboxylic acids from formate to stearate. Neither organism requires vitamins. The two other stains are more recent isolates: The first one is a gram negative motile bacilla, isolated on propionate. The second one was also isolated on propionate from microbial mat enrichments. Morphologically it is a motile vibrio species similar but somewhat smaller than D. gigas which can develop on lactate in the presence of sulfate, malate, succinate or pyruvate.

These four strains will be masse cultured for biochemical studies and also cocultured with pure acetate-utilizing methanogens or methanogenic enrichments on acetate from diverse sources.

Methanogens

A Sarcina type acetate-utilizing methanogen is being purified from our enrichments of mud. A short rod type methanogen capable of association to form filaments is also usually present. In mud enrichments of low acetate concentration, the rod type seems to out compete the sarcina type. Both organisms are resistant to vancomycin (6 μl/ml) or a mixture of penicillin G (2 μg/ml) and D-cycloserine (0.1 μg/ml), the antibiotics used for their selection.

Fermentation

The fermentation of cellulose to methane inoculated with mud is being studied. Using 2 liter fermentors the effects of vitamins, sulfate, pyrophosphate, polyphosphate glasses and cellobiose on both the rate and yield of methane production are tested. The effect of these different treatments on the microbiol population is also studied.

SUMMARY

We have now four strains of sulfate-reducing fatty acid oxidizers which physiology and biochemistry will be investigated. They will be studied for their nutritional requirement and for their ability to carry out acetate production from various substrates. They will be cocultured with acetate-utilizing methanogens in pure culture and in enrichments. The stimulation of methane production by pyrophosphate will be tested in these cultures.

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BIOMASS ELECTROCHEMISTRY [E-4].

by

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in relation to

ABSTRACT

The research objectives are to select the most relevant biomass-derived substrates which can benefit from electrochemical processing, improving the economics of fuel production from biomass sources. Electrochemical processing is being applied to biomass and derived materials to (1) upgrade their energy content, thereby generating fuels and fuel additives (octane or cetane boosters); (2) generate petrochemical substitutes from renewable resources; (3) increase the reactivity and value of the lignin fraction of the wood for a variety of applications of the polymeric materials, therefore generating alternative patterns of utilization of this by-product that can lead to an overall favorable economics of fuel production from biomass sources; and (4) investigate innovative ways of separation of fermentation substrates for subsequent electrochemical processing.

We have completed functional group characterization, infrared spectroscopy, ^{1}H and ^{13}C nuclear magnetic resonance analyses (90 MHz instrument), and molecular weight distribution of the ethanol-extracted explosively-depressurized aspen lignin (EEEDAL). We have also submitted EEEDAL to electrolysis at constant potential -2.6 V vs. Ag/ AgCl reference electrode on mercury cathodes in methanol and observed the reduction of carbonyl groups as well as cleavage of side chains in the lignin molecules. The reduced materials have also been characterized. We plan to correlate structure of these well-characterized materials with the properties of the polymers. Replacing phenol with the lignin-derived materials in a thermosetting resin is one possible application.

INTRODUCTION

The application of organic electrosyntheses to biomass-derived compounds has been reviewed recently.[1] In organic electrosyntheses, in addition to the normal variables common to all chemical reactions (medium, temperature, catalyst, pressure, pH, and time), the electrode potential, the nature of the electrode, the applied current density, and the cell design are also variables. As a result, a variety of novel reactions can be accomplished, in addition to the common reactions performed by simple oxidizing and reducing agents. One of the inherent advantages of these electrochemical processes is that they are pollution free. The electrons are the chemical reactants, and the potential at which they are generated (reductive processes) or consumed (oxidative processes) commands the observed reactions. Many good reviews of these processes are included in Ref. 1.

One of the major disadvantages of the electroorganic syntheses is the consumption of costly electricity, which depends upon the specific synthesis. The electricity requirements of one such synthesis are a direct function of the cell voltage (V) needed to accomplish the desired reactions at a suitable rate (includes thermodynamic and kinetic terms as well as solution resistance to be overcome). The second major parameter is the current efficiency (C.E.) for the production of the desired product, with a molecular weight M and consuming n faradays per mole of product formed. These terms are related as follows: power usage (kWh/kg) = (26.8 V × n)/(M × C.E.). Common numbers are 1-8 kWh/kg. Research decreasing the power consumption through catalysts and the use of electrocatalytic processes can lead to processes with much smaller electrical requirements.

At SERI we have performed organic electrochemical research during the past three years in a program which involved a number of collaborators. Our pioneer efforts in biomass electrochemistry have contributed to an increase in the awareness of industrial and university researchers in this promising area in the U.S. and abroad. We have organized a number of workshops and symposia in the area with an excellent response from the scientific and technical communities. SERI is the only national laboratory investigating organic electrosynthetic processes.

SUMMARY OF OUR RESEARCH AND FUTURE PLANS

1. Lignin. (D. Johnson, M. Ratcliff, S. Black, H. L. Chum)

The ethanol-extracted explosively depressurized aspen (<u>Populus tremuloides</u>) lignin has been characterized with respect to its functional group composition and electrochemical reduction reactions in a methanol/tetraethylammonium perchlorate solvent system. The statistical representation of this irregular polymer in terms of functional groups is $C_{9.0}H_{6.7}O_{1.2}(O_{CO})_{.3}(OH)_{1.2}(OCH_3)_{1.2}$. A fractionation procedure has been developed in order to recover a large fraction of lignin by differential solubility in aqueous acid solution. Two different types of lignins are isolated under these conditions prior to electrolysis: (1) an acid-insoluble material with a phenolic OH content ~10% smaller than that of the original EEEDAL, and similar aliphatic OH content (this material has a higher double-bond equivalent number and appears to be more condensed than the acid-soluble fraction); and (2) an acid soluble fraction which has a phenolic OH content close to one/C_9 formula and a similar aliphatic alcohol content. After electrolyses, the amount of the low-molecular weight acid-soluble material increases. This material has a higher phenolic OH content and aliphatic alcohol content than the acid-soluble material obtained by fractionation only. The main electrochemical reactions are carbonyl reduction to hydroxy group, and cathodic cleavage of β-O-4 alkyl aryl ether bonds, which are activated for reduction by the presence of adjacent α-carbonyl bonds.[2] These reactions are responsible for consuming about 2/3 of the charge utilized in the electrolyses. The molecular weight distribution of all of these lignin fractions, as well as lignins from other pretreatments, was investigated by high-performance gel permeation chromatography,[3] in cooperation with M. Himmel and K. Oh (Biotechnology Branch). The fractionated acid-soluble materials clearly show paucidispersity (monomer, dimers, trimers, and tetramers can be distinguished). The acid-insoluble materials are polydisperse and have a higher weight-average molecular weight than the acid-soluble fractions.

We are presently completing the chemical characterization by the evaluation of the C-C and C-O bonds content of the various lignin samples, in cooperation with Prof. W. Glasser, Virginia Polytechnic Institute and State Univesity. An EEEDAL derivative obtained by reaction with formaldehyde was isolated and partially characterized. Replacement of 25% phenol in a phenol-formaldehyde thermosetting resin was very successfully achieved (in cooperation with H. Schroeder and K. Wallace, Colorado State University).

Research is in progress to replace the successful but impractical mercury cathodes with metal amalgams (Zn/Hg was shown to be suitable). However, hydrogen evolution consumes a higher fraction of the current in this new cathode. A new cell (packed bed) was constructed to test this reaction. We are evaluating oxidative processes for their ability to lead to demethoxylation and demethylation reactions which would increase the suitability of the material in the resin application, as well as degrading it partially into monomeric fragments and recondensing it by oxidative couplings under some conditions.

2. Carboxylic Acids. (D. Johnson, F. Posey, M. Ratcliff, H. Chum)

The electrolysis of valeric acid on graphite electrodes is under investigation. A parallel-plate flow cell for electrolysis has been built and three gas-liquid disengaging systems have been constructed (cyclones and demistors). This reaction generates in the low molar concentration, compatible with fermentation reactions, butene-1 (major), butene-2 (cis and trans), hydrogen, and carbon dioxide in the gas phase. The organic phase of the two-phase electrolyte is composed of butanol-2 (major) and butanol-1. We are set up for complete analysis of the liquid and gaseous products.

The photoelectrochemical investigation of levulinic acid on undoped platinized anatase powders was completed.[4] These processes do not use electricity but sunlight illumination of slurries of semiconductor electrodes. The reaction of lactic acid is under investigation.[5] In this case, two major pathways have been observed: decarboxylation to acetaldehyde and hydroxy group oxidation to pyruvic acid followed by decarboxylation to ethane. Electrolytic work on valeric acid continues. The aim is to find catalysts that will decrease the overvoltage needed to carry out such electrolyses, and therefore make them more attractive from an economic standpoint for the production of fuels.

SUMMARY

Electrochemical processing is being applied to biomass and derived materials to upgrade their energy content thereby generating fuels (or additives) or petrochemical substitutes, or increasing their reactivity and value for a variety of applications of the polymeric materials. We are addressing the utilization of the following:

- Lignin polymers, which are not suitable substrates for anaerobic digestion to fuels and chemicals. Our approach is to investigate relatively simple lignin derived materials which, in principle, can be produced in large quantities, and serve as models for the behavior of more complex materials. The lignin of choice is derived from a hardwood such as aspen (Populus Tremuloides), which has been pretreated by explosive depressurization (steam explosion) and is ethanol extracted.[2] We aim to change the degree of polymerization[3] of these materials, and to increase their suitability as a replacement of phenol in thermosetting resins.
- Carboxylic acids, which can be obtained by suppressing the methane formation in anaerobic digestion processes. Our approach is to develop new separation methods for the carboxylic acids and innovative ways of electrochemically processing dilute solutions to gaseous and/or water-insoluble products.
- The upgrading of waste streams from biomass (terrestrial and aquatic) processing, electrochemically or photoelectrochemically. The waste streams under consideration include those from acid hydrolysis, fermentation, and alkaline treatment (e.g., kraft pulping), which contain a variety of polyfunctional carboxylic acids, amenable to electrochemical processing.[4,5]

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PROGRESS REPORT (12/82 - 3/83): NUTRITIONAL STIMULATION OF METHANOGENIC BACTERIA

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S.E.R.I. Contract #XK-2-02139-01

ABSTRACT

Greatly increased iron additions have resulted in high average acetate uptake rates (AUR). Average AUR of 17 to 22 gm/l-day have been maintained in three digesters receiving increased iron additions for periods of 40 to 70 days. Addition of desiccated liver resulted in an AUR average of 33 gm/l-day for six weeks and 66 gm/l-day for the past week.

1.0 OBJECTIVE

The objective of this research project is to identify organic and/or inorganic nutrients and their appropriate concentrations which are capable of stimulating the growth of methanogenic bacteria. Such stimulation will be reflected in higher rates of methane production from anaerobic digesters being fed biomass when the rate-limiting step is acetate conversion to methane. Stimulation can be based upon volumetric loading rates or methane production rates as well as upon specific acetate utilization activity of the microorganisms mediating the conversion. Conventional high rate digestion is considered to be 200 pounds of volatile solids per 1000 ft^3 per day (3.3 gm/l-day), which is approximately 1.3 volumes of methane gas/ volume of digester per day. We also observe specific acetate utilization activity of the methanogens to be in the range of 2 to 4 gms of acetate per gm of methanogens per day (gm/gm-day). Increased volumetric loading rates can be realized in two different manners:

1. by increasing the concentration of microorganisms in the reactor.
2. by increasing the specific acetate utilization activity of the microorganisms in the reactor.

Anaerobic digesters treating industrial wastewaters in Europe have had volumetric loading rates as high as 40 gm/l-day by achieving a volatile solids concentration (a measure of microorganisms concentration) of 40 gm/l - resulting in a rather low specific acetate utilization activity of 1 gm COD/gm VSS-day. Thus, while the volumetric loading rate was very high, the unit specific activity was rather low, possible due to a large fraction of non-methanogenic microorganisms consuming the high carbohydrate organics. Our objective in this research is to achieve both an increase in microorganisms and an increase in the specific acetate utilization activity of the microorganisms by nutritional stimulation.

1.1 REASON FOR RESEARCH

Reactors for bioconversion of biomass to methane are large and costly - resulting in a significant cost component for amortization of the capital facility per 10^6 BTU of methane produced. Process stability is also a key consideration in any biomass to methane project. Nutritional stimulation identifies key nutrients. This also allows increased loading rates which reduces the size requirement for the bioreactor and simulataneously increases process stability.

1.2 SIGNIFICANCE TO S.E.R.I. BIOMASS PROGRAM

The S.E.R.I. Biomass Program has as part of its mission the development of economical, reliable conversion of biomass to methane. One of the key facets of this mission is the methanogenic bacteria which mediate the biological conversion of acetate to methane. It is crucial to the success of the program that the methanogenic bacteria perform efficiently and reliably. Identification of the nutrients which stimulate methanogenic bacteria will thus enable optimum efficiency and reliability of this facet of bioconversion of biomass to methane.

2.0 ACCOMPLISHMENTS

In the previous budget year, nutritional stimulation to a short, temporary peak of 51 gm/l-day and specific activity of 7.8 gm/gm-day was achieved when no phosphate was supplemented. On two other occasions, nutritional stimulation to short, temporary peaks of 34 and 36 gm/l-day and unit specific activities of 15.4 and 12.8 gm/gm-day respectively, were achieved also when no phosphate was supplemented. With daily phosphate addition, the acetate utilization rate was stimulated to between 20 and 30 gm/l-day for an extended period of 25 days with a corresponding unit specific activity of approximately 10 gm/gm-day. In the absence of nickel in the Supplemented Acetic Acid Feed, the specific acetate utilization activity was limited to the range of 2 to 4 gm/gm-day and did not exceed 4.6. The inclusion of nickel in the Supplemental Acetic Acid Feed (with no daily addition of 100 mg/l-day of yeast extract) resulted in unit specific activity rates of 10 gm/gm-day. When 100 mg/l-day of yeast extract was supplemented once daily directly to the reactor and nickel was included in the Supplemented Acetic Acid Feed, specific acetate utilization rates as high as 12 to 15 gm/gm-day were observed. Daily phosphate addition appeared to be required in order to prevent the abrupt "crash" in high acetate utilization rates and VSS levels. However, omission of daily phosphate supplementation seemed to be associated with achievement of the maximum acetate utilization rates (40-50 mg/l-day) observed. Iron and cobalt were included in the Supplemented Acetic Acid Feed. It appeared that nickel, iron and/or cobalt must be supplemented to achieve high microorganism concentrations. With yeast extract supplementation only, the highest VSS observed was 1800 mg/l. When nickel, iron and cobalt only were supplemented, the highest VSS observed was 3000 mg/l. When nickel, iron, cobalt and yeast extract were all supplemented, the highest VSS observed was 7000 mg/l.

In order to realize stimulation of the acetate utilization rate (AUR), the soluble phosphate concentration must be below 10 to20 mg/l as (PO_4). Excess phosphate in the inoculum can be precipitated with additions of $FeCl_2$. Subsequently the AUR starts to increase within a period of two weeks and has temporarily reached AUR rates of 30-40 gm/l-day. Thereafter the rate was not sustained and declined precipitously.

2.1 ACCOMPLISHMENTS AND SIGNIFICANCE DURING THIS REPORTING PERIOD.

The major thrust of the research has been to sustain the high AUR. The average AUR background level of the inoculum for the first two weeks for 15 different start ups was 4.2 $\pm$ 1.6 gm/l-day. Therefore, this is the base level for comparison of stimulatory nutrients. Stimulation in noted after approximately two weeks reaching a maximum of approximately 30 - 40 gm/l-day within 25 to 30 days after start up. The AUR characteristically declines to less than 10 gm/l-day by about Day 40.

We have reduced the SRT and HRT from 40 to 20 days. This washes the organisms out of the system twice as fast, but also inputs twice the volume of Drexel media to the system.

The most significant improvements we have noted in this period has been:

A. The stimulation which results from daily additions of: 13 mg/l $FeCl_2$ (as Fe).
B. Dessicated liver 325 mg/l-day

The supplemented HAc contains 500 gm/l HAc, 15 gm/l NH_4Cl, 2 gm/l $MgSO_4 \cdot 7H_2O$, 250 mg/l $FeCl_2 \cdot 4H_2O$, 10 mg/l $CoCl_2 \cdot 6H_2O$, 10 mg/l $NiCl_2 \cdot 6H_2O$ and 10 mg/l Na_2MoO_4. Therefore, the amount of these chemicals added is in direct proportion to the AUR. At 30 gm/l-day, approximately 3.5 mg/l-day of Fe is added. Daily slug additions of 13 mg/l of Fe is therefore a large increase. (These digesters also receive 100 mg/l-day of yeast extract.) Slug additions of Fe have not eliminated the cyclic AUR excursions but have resulted in high average AUR over extended periods. Three digesters have operated as follows:

Digester	AUR	Duration days
7	22	60
8	22	70
13	17	70

All of these digesters have cycled between a low of less than 10 to a high of about 30 gm/l-day AUR. The period of the cycle is about three weeks.

The inclusion of a daily addition of 325 mg/l of desiccated liver plus

13 mg/l-day Fe and 100 mg/l-day yeast extract has resulted in a dramatic stimulation in Digester #9. For a six week period, it has averaged 33 $\pm$ 17 gm/l-day. For the past week, it has averaged 66 $\pm$ 13 gm/l-day. The maximum daily AUR was 84 gm/l-day. For the six week period, the three-day running average has been below 20 gm/l-day only four days.

Desiccated liver contains many vitamins and amino acids. Perhaps notable is that it is a rich source of B_{12} also. The stimulatory component(s) of desiccated liver can only be speculated. However, it is noteworthy that the liver has elevated the minimum excursion on the cyclic variation to about 20 gm/l-day and elevated the maximum excursion to 84 gm/l-day. Organism concentrations as high as 15,000 mg/l (VSS) were recorded.

Molybdenum was added to the Supplemented Acetate, but no definitive stimulation has been verified. Daily additions of selenuim did not result in stimulation of the AUR. Addition of the chelators EDTA and EDDHA elevated the soluble iron concentration but resulted in decreased AUR.

The specific acetate utilization rate has varied from 2 to 5 gm HAc/ gm VSS-day.

3.0 FUTURE PLANS

Riboflavin, B_{12}, and dessicated liver will be assayed more extensively.

4.0 PROBLEMS AND VARIANCES

Cyclic excursions of the AUR still occur even though the average rate is quite high for extended periods. It could be related to the population outgrowing the rate at whcih an essential nutrient is being supplied.

5.0 LITERATURE CITED

None

6.0 PUBLICATIONS AND MEETINGS

None

A STUDY OF METHANOGENS BY GENETIC TECHNIQUE

by

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ABSTRACT

This program is in its second year and concerns the genetic study of two species of methanogenic bacteria: *Methanococcus voltae* (*M. voltae*) and *Methanobacterium thermoautotrophicum* (*M. thermoautotrophicum*). This will be accomplished by: a) Continued isolation and description of nutritional and metabolic inhibitor resistant mutants of these bacteria. b) When satisfactory mutants are obtained, tests for conjugation and/or DNA transformation. c) Search for bacteriophages capable of infecting methanogenic bacteria.

BACKGROUND

In nature a major end product of anaerobic respiration is methane. The production of methane is the terminal step in the degradation of organic matter in the absence of oxygen (and sulfate) and is carried out by a special group of organisms referred to as methanogens.

Methanogens are among the most difficult microorganism to culture. They require absence of oxygen and very low redox values. They use a limited array of growth substrates (H_2, formate, acetate, methanol, and methylamines). Recent biochemical studies have shown that these bacteria are strikingly different from other bacteria and have assigned them a special taxonomic position.

The study of mutants has been indispensable in the analysis of biochemical pathways in a variety of organisms and is expected to also extend the understanding of methanogens. It may be that these organisms, unique in several of their biochemical pathways, will turn out to also possess unique genetic characteristics. The application of genetics to methanogenic bacteria may prove beneficial in the long run if it should lead to increased population tolerance to environmental stresses, to expanded range of methanogenic substrates, to higher effectiveness of certain bacterial associations, and possibly to the construction of bacteria capable of synthesizing other useful products.

RESULTS

Methanococcus voltae

To date we have six U.V. induced mutants of M. voltae. These are temperature sensitive nutritional mutants which are unable to grow in minimal medium at 41°C. Further study of these mutants has shown that they will eventually grow under the non-permissive conditions (elevated temperature-minimal media), presumably because of a high frequency of reversion. Also, at the elevated temperature (41°C) they and the wild type strain have a greater tendency to lyse than at 30°C. For these reasons, this set of mutants does not seem to be appropriate for use in selection.

Since autolysis is a rather common occurrence with cultures of M. voltae (and also of M. vanniellii), we have made several attempts towards controlling this process. We have recently found that we can block autolysis by frequently feeding the culture with H_2/CO_2 during and after active growth. We would tentatively propose that autolysis occurs when H_2/CO_2 become limiting, when some other nutrient (ammonium? phosphate?) is still present in excess. Other alternatives are open, however, and are being investigated.

We worried about the possibility that these bacteria may not have the capability of taking up many organic molecules, amino acids for example. If that were the case, it might really be difficult to isolate good nutritional mutants. With this in mind, we tested specific amino acid analogues such as ethionine, para-fluorophenyl alanine, and 5-methyl-tryptophan (MTP), and these were found to be inhibitory.

In the case of MTP, resistant mutants, mtp^R, were demonstrated and isolated. They are stable upon transfer in the absence of the analogue. Since they are rather common (10^{-4} in a wild type culture), the MTP-resistance character does not allow for a very strong selection.

From our bes^R mutant (resistant to BES, bromoethane sulfonate, and described in last year's report), we have isolated a mtp^R mutation: we thus have a doubly marked strain, bes^R mtp^R, that can be used in certain selection experiments. We have tested, for example (unfortunately with negative results to date), whether M. voltae and M. vanniellii would recombine conjugationally. M. voltae requires acetate for growth, M. vanniellii does not. A mixed culture of M. vanniellii wild type and of M. voltae bes^R mtp^R was plated at very high concentrations on agar lacking acetate and containing both BES and MTP (to which M. vanniellii is, like wild type M. voltae, fully sensitive). While no recombinants were found, the selection was absolutely tight (no survivors on the selective agar) and will allow the use of even higher bacterial concentrations in future experiments.

We described last year the peculiar shape of UV survival curves for M. voltae, indicating that the killing rate becomes extremely small at survivals below 10^{-5}. While several possible explanations are still open for this phenomenon, we worried that it might be due to the presence in the suspended culture of inorganic microprecipitate particles to which some bacteria may adhere and be protected from non-penetrating radiation. If this were the case, it would be extremely hard--technically--to treat bacteria in sufficiently large numbers with sufficiently high mutagenic doses. We have started, therefore, some new mutagenesis experiments with M. voltae cultures heavily irradiated with the penetrating gamma radiation from ^{60}Co.

M. voltae is known to require isoleucine and leucine. Cysteine, which is added routinely to anaerobic cultures, is known to interact with the regulation of isoleucine synthesis in other microorganisms. We wanted to exclude this possibility in the case of M. voltae. We found, in fact, that the growth requirements of our strain were not affected by a substitution of D-cysteine for L-cysteine.

Methanobacterium thermoautotrophicum

We have found that M. thermoautotrophicum is slightly more sensitive to UV than M. voltae. Like M. voltae, M. thermoautotrophicum UV survival curve flattens at higher doses of irradiation. We have yet to check if the flattening of the curve is due to a genetically UV resistant subfraction of the original population. (In M. voltae, no genetically resistant subpopulation was found.) At the present time we have not succeeded in isolating any UV-induced nutritional mutants of M. thermoautotrophicum. We do have a bes^R strain of M. thermoautotrophicum and we will shortly start to test for analogue sensitivity in M. thermoautotrophicum as we did in M. voltae.

Bacteriophage

In order to help characterize the genetic system of methanogenic bacteria one needs mutants and a means to transfer DNA between bacterial strains. We have initiated the search for bacteriophages in methanogenic bacteria. We have collected 40 rumen samples representing different animals, from different geographic locations. Each sample was first screened to remove the large particulates. Then centrifuged at 3000 xg to remove suspended solids and finally recentrifuged at 40,000 xg to concentrate phage-size particles. In addition, from some rumen samples methanogenic strain have been isolated using antibiotic resistance and fluorescence as tentative indicators of the presence of methanogenic bacteria. This procedure has proven to be somewhat laborious and we are now investigating procedures that will reduce the time and effort in isolating methanogenic strains.

Following tentative identification, the isolates are grown in liquid culture and analyzed for the presence of methane by Gas Chromatography. At present, we have isolated six strains of methanogenic bacteria. We are continuing to isolate new bacterial strains and when a sufficient number have been obtained, they will be tested for susceptibility (plaque formation) to phages that may possibly be present in the rumen high speed concentrates.

SUMMARY

Presently we have 6 UV-induced temperature sensitive nutritional mutants, one bes^R mutant, one mtp^R mutant and one double mutant resistant to both BES and MTP in *M. voltae*.

Autolysis in *M. voltae* can be suppressed by overfeeding of the culture with H_2/CO_2.

Several unsuccessful attempts at isolating *M. thermoautotrophicum* nutritional mutants have been made. Efforts in this direction will continue and will be supplemented with analogue studies as done with *M. voltae*. The search for bacteriophage in methanogenic bacteria has started. Presently we have isolated six new methanogenic strains. Bacteriophage testing will commence when a sufficient number of different isolates have been recovered.

KINETIC ENHANCEMENT IN CONTINUOUS CULTURE ANAEROBIC DIGESTION

by

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ABSTRACT

Agricultural materials can be converted to methane by anaerobic digestion. Reaction kinetics are slow, requiring large reactor volumes. This study involves the investigation of three methods of decreasing reactor volume: increasing the feed solids concentration, employing cell recycle and using culture enhancement. Experiments are being conducted to measure the improvement in kinetics and yield that these methods offer over standard anaerobic digestion cultures utilizing corn stover. Data for these experiments are presented and the effect of these methods on reactor volume is discussed.

INTRODUCTION

The reaction kinetics of the anaerobic digestion of lignocellulosic materials to methane are quite slow. For example, the batch digestion of corn stover to methane requires about 60 days to give a 40 percent carbon conversion. A retention time of 100 days is required to reach 70 percent conversion in a single continuous reactor.

These slow reaction kinetics are reflected in high capital costs for reactors in large-scale methane facilities. For a plant producing 50 million ft^3 of methane per day, the capital costs for the reactors represent almost 60 percent of the total capital costs. Significant improvements of the process economics in continuous anaerobic digestion systems can only be achieved by improving the reaction kinetics and decreasing reactor volume.

For a given methane production level, the two factors that could have a positive effect on decreasing the reaction volume would be an increase in the biomass fraction in the feed and an increase in the reaction rate constant. This study focuses on evaluating the kinetics at increased solids feed concentrations and improving the reaction rate constant by culture enhancement and cell recycle. Improvements are measured by comparison with standard anaerobic digestion cultures.

STANDARD CULTURE ANAEROBIC DIGESTION

Data for continuous culture digestion of corn stover are obtained in agitated three-liter reactors, which are fed semi-continuously. The reactors are agitated at 80 rpm and maintained at 37°C. A ten percent (weight) mixture of corn stover (20 mesh) in water is fed once per day. Retention times are varied periodically and the gas concentrations and volumes are measured daily. The pH, ammonia-nitrogen and phosphate levels are monitored as needed.

The reaction rate and carbon conversion are computed at steady state. The solid lines in Figure 1 and 2 represent these data for the standard cultures. The ultimate biodegradability of corn stover is 78 percent (Fig. 1) and the first order kinetic coefficient is .045 $days^{-1}$ (slope - Fig.

2). These lines fit the data with a correlation coefficient of .946. Other data from the high solids, recycle and enhancement studies are also shown on these same plots for comparison.

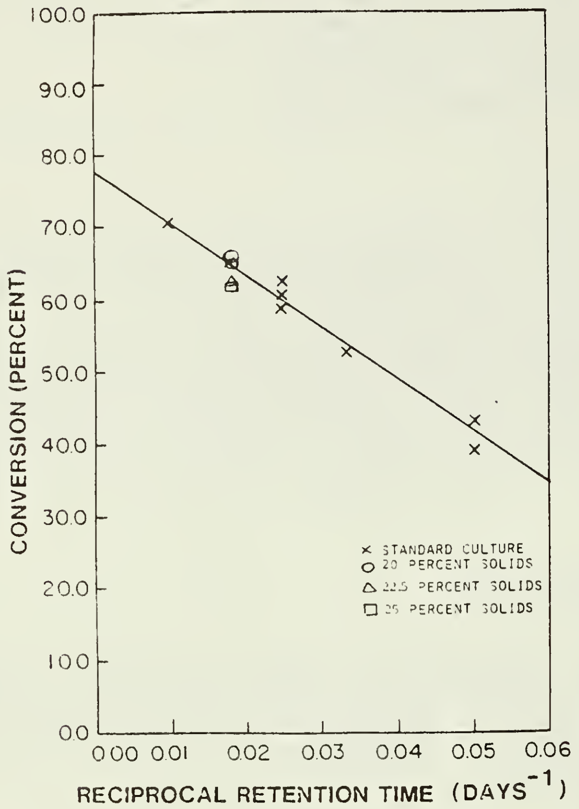

FIGURE 1. CORN STOVER CONVERSION IN ANAEROBIC DIGESTION

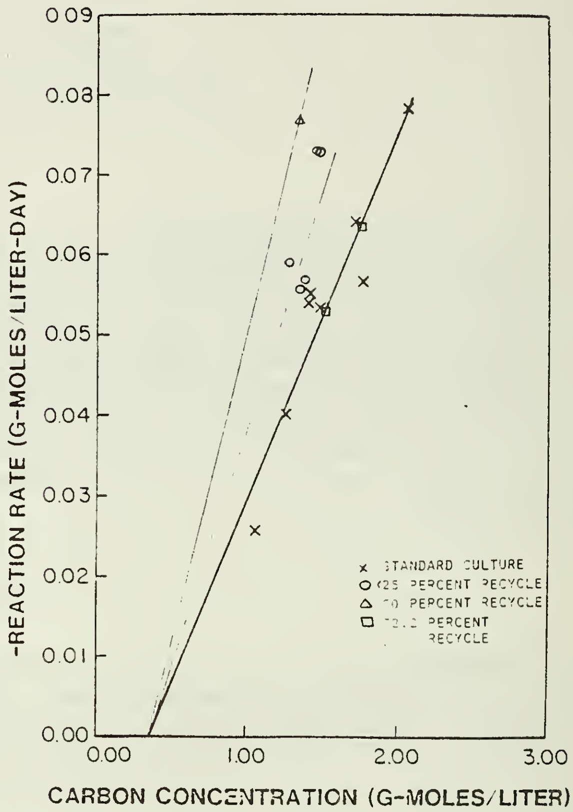

FIGURE 2. REACTION KINETICS OF CORN STOVER DIGESTION

ANAEROBIC DIGESTION IN IMPROVED REACTION SYSTEMS

Each of the three systems under study to improve the economics of anaerobic digestion by reducing reaction volume: high solids studies, cell recycle studies and culture enhancement studies; will be briefly described and kinetic data presented.

High Solids Studies

Because the liquid and solids are usually mixed together to form a fluid mixture prior to feeding into a stirred tank reactor, previous studies have been limited to a maximum feed fraction of 10% solids. However, if the solids and liquids are fed separately, the only limit on feed concentration is the fluidity of the reactor contents. Thus, if a 30% feed fraction were used with a conversion of 66%, a reactor volume of only one-third that with 10% feed would result. Clearly, there is economic incentive to operate at high solids; however, experiments are necessary to determine whether the reaction rates or yields are impaired under these conditions.

Experiments with increased solids feed concentrations have been conducted and data are shown in Table 1 and Fig. 1. As noted, conversions over 66% are obtained for both data points at a 60-day retention time and 20% solids feed, which matches the standard culture performance. However, as the feed concentration is increased further to 25%, the conversion decreases slightly to a level of 60%. The data above 20% solids are somewhat preliminary at this point; however, the reaction slurries are very viscous and the problem appears to be a mass transfer limitation. Heavier duty agitators are needed in the laboratory reactors at these high slurry concentrations. Retention times have been extended to 80 days, where the reactor slurries should be less concentrated, to determine whether higher feed solids levels can be reached.

Table I
Kinetic Data for High Solids Feed Concentration Studies

Retention Time (days)	Percent Feeds Solids	Gas Production L/day	C_i gmoles/l	C_o gmoles/l	Reaction Rate gmoles/L·day	Conv. %
60	20.0	5.38	7.26	2.456	0.0801	66.2
60	20.0	5.44	7.26	2.403	0.0810	66.9
60	22.5	5.58	8.17	3.186	0.0830	61.0
60	25.0	6.15	9.08	3.584	0.0915	60.5

Cell Recycle Studies

The kinetics of continuous cultures is limited by the microorganism concentration. Cells are continually discharged with the reactor effluent. The liquid portion of the effluent would contain a large fraction of these discharged microorganisms. Separation and recycle of the liquid fraction would substantially increase the cell population and, consequently, should enhance the reaction rate. Also, less substrate should be required to maintain cell growth, so that more substrate is available for methane production. Liquid recycle reduces fresh water requirements and reduces the effluent treatment volume. Offsetting these advantages is the need for a separator and the possibility that the concentration of toxic materials could build up and impair the fermentation or make the reaction less stable.

Laboratory data for reactors employing cell recycle are presented in Table II. Data for 25, 50 and 72.2% recycle are presented. Conversions range from 51 to 65%, increasing with recyle rate from 25 to 50% and then decreasing at 72.2%. The recyle rate data are plotted with the standard rate data in Fig. 2. To obtain first order rate constants, the data have been extrapolated to the same intercept on the abcissa. The constants from the slopes, are 0.059 days^{-1} at a 25% recycle, 0.074 days^{-1} at 50% recyle, and 0.045 days^{-1} at 72.2% recycle. Toxic materials probably build up, negating any enhancement at 72.2% recycle. Stable reactions could not be sustained at retention times less than 30 days, due to pH problems. Apparently, the recycle liquid contains an unbalanced proportion of acidogenic bacteria which cause pH problems at high flow rates.

Enhanced Culture Studies

The standard culture, because of its bacterial source, has been found to be deficient in cellulolytic activity. Organism maybe added to the standard culture to enhance the reaction rate. Clostridium butyricum has been particularly promising in batch culture, showing a 20% improvement in reaction kinetics. An inoculum of this culture has been introduced into the standard culture to determine the improvement in the kinetics in continuous culture.

The results of five culture enhancement experiments are shown in Table III. As noted, the conversions ranged from about 50-80% over a retention range of 20 to 100 days. The slope of the first-order rate plot gives a constant of 0.053 days^{-1}, or an 18% improvement over standard kinetic model.

Table II
Reactor Performance of Cell Recycle System

Retention Time days)	%[1] Recycle	Gas Production L/day	C_i gmoles/l	C_o gmoles/l	Reaction Rate gmoles/L.day	Conv. %
30	<25	4.87	3.63	1.456	0.0725	59.9
30	<25	4.88	3.63	1.451	0.0726	60.0
40	<25	3.77	3.63	1.385	0.0561	61.8
40	<25	3.98	3.63	1.260	0.0593	65.3
40	<25	3.84	3.63	1.347	0.0571	62.9
30	50	5.12	3.63	1.346	0.0761	62.9
30	72.2[2]	4.25	3.63	1.755	0.0625	51.7
40	72.2[2]	3.51	3.63	1.541	0.0522	57.5

1 Percent of feed liquid that is recycled
2 Maximum possible recycle

Table III
Kinetic Data for Culture Enhancement Studies

Retention Time (days)	Gas Production L/day	C_i gmole/l	C_o gmole/l	Reaction Rate gmole/L·day	Conv. %
20	9.572	3.630	1.923	0.0854	47.0
40	6.672	3.630	1.351	0.0570	62.8
40	3.814[1]	3.630	1.359	0.0568	62.5
60	2.797	3.630	1.133	0.0416	68.8
100	3.163	3.630	0.847	0.0282	76.7

1 Smaller reactor system

THE EFFECTS OF IMPROVEMENTS ON REACTOR VOLUME

The effects that each of the reaction modifications has upon the reactor volume is shown in Table IV. With increased solids concentration to 20%, the reactor volume can be decreased 50%, since the reaction rate or conversion does not decrease. However, at a 60-day retention, only a 38% volume reduction can be achieved when using a 25% solids feed, due to the decrease in conversion. Perhaps at longer retentions, no impairment in kinetics will result. Also, higher solids concentrations, perhaps to 30%, are expected with an improved agitation system in the reactor.

Table IV
Volume Decreases with Anaerobic Digestion Improvements

Process	Percent Decrease in Reactor Volume
1. Increased solids concentration	
20 percent solids	50
25 percent solids	38
2. Cell recycle	
25 percent	24
50 percent	39
72.2 percent	0
3. Culture enhancement	15

The reactor volume can be reduced by 24% at a 25% recycle, and by 39% at a 50% recycle. No improvement is seen if the recycle rate is increased to 72%, probably because the benefits of recycle are negated by the build-up of toxic materials. Culture enhancement can decrease the reactor volume by 15% by increasing the reaction rate constant to 0.053 $days^{-1}$.

AG RESIDUE TO DIESEL FUEL - R&D TASK

by

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ABSTRACT

A research and development task was established to examine the overall process of converting an agricultural waste material into potentially useful chemicals and liquid fuels. The complete process is composed of unit processes and operations such as drying, grinding, first-stage hydrolysis, second-stage hydrolysis, neutralization, filtration, toxic compound removal, concentration, fermentation, identification and separation of products and purification of products.

Bagasse was selected as the agricultural waste to be examined in this study. A two-stage hydrolysis reaction apparatus was designed and built to study the production of furfural and reducing sugars by the action of acid on the waste cellulose and hemicellulose in the sugar cane bagasse.

Objective and Purpose

The objective of this task is to provide bench-scale testing of an agricultural residue hydrolysis process that is designed to produce aliphatic compounds and fuel substitutes. This work is being done to examine and verify a processing concept for the conversion of waste agricultural materials into useful chemicals and fuels such as furfural, butanol, acetone and other potentially valuable substances.

Discussion

This study began with an examination of the hydrolysis of biomass in an existing high-temperature, stainless steel tube reactor. Experimentation with this small equipment showed that the dilute acid was leaching nickel out of the particular stainless steel. Nickel is a known catalyst for various reactions in the production of furan derivatives. However, because little control could be exercised over the nickel concentration, the tube reactor was abandoned in favor of an all glass reactor. Glassware equipment was assembled in the laboratory and several hydrolysis runs were made. These runs produced furfural from the hemicelluloses and sugars from the celluloses. However, yields of these products were low. These low yields were partly the result of an inability to obtain sufficiently high reaction temperatures in the glass equipment and partly because of product decomposition. Cellulose crystallinity must be broken in order to produce the reducing sugars. This can be accomplished by adjusting three principal factors, i.e., temperature, acid concentration and time. These factors are interdependent. Low temperatures can be used for the hydrolysis steps, if high-acid concentrations and long-reaction times are used. These conditions, of course, cause product decompositions because of the high-acid concentration. What is really desirable is low-acid concentration, high temperatures and short reaction times. Conditions such as these optimize the yields and prevent decomposition of the products.

A run in the glass equipment at high-acid (80%), low-temperature (100°C), and long-reaction time (24 hours) produced a sugar solution of approximately 5% concentration. This high concentration of acid was responsible for a low overall yield of 1% and caused decomposition of the formed sugars as well as the production of toxic phenolic compounds. These bio-toxic compounds had to be removed before subjecting the sugar solution to fermentation. An activated carbon treatment was used to prepare the material for the bio-operation.

Because of the inability to obtain the optimum temperature conditions for the hydrolysis reaction in the glass equipment, a new and modified metal reactor was designed and assembled. This new reactor consists of a thick-wall, 304 stainless stell shell fitted with the following ancillary parts: steam inlet line, popoff valve (set at 100 psi), thermocouples for temperatures of the reactor condenser, vacuum pump, steam generator, steam super-heater, liquid nitrogen trap, and various valves and insulation.

Use of this new equipment has allowed the attainment of temperatures from 149° to 193°C (300° to 380°F). The ability to obtain higher operating temperatures has shown that the hydrolysis acid concentration can be reduced to as low as 0.5%. A run using the low acid, high-temperature conditions has produced a sugar solution with a 10% yield (from original cellulose). The low acid concentration also reduces the decomposition of the sugars once they are formed.

Water is the main problem in the hydrolysis of biomass. Although it is an essential ingredient, it causes many problems among which are high dilutions and excess energy that must be supplied to the operation to accomplish the following: to hydrolyze the cellulose (acid is used as a catalyst); and to give mobility to the solids (pumping, distilling, neutralizing and filtering). Since water is the reaction media, it is also the heat transfer material. It uniformily wets and causes swelling of the cellulosic components so that the gluoside chains can be ruptured to produce the sugars.

In an effort to reduce this high energy dependence based on a water reaction media, a solvent system was examined to replace or supplement this complete dependence on water. Several potential solvent systems have been examined as well as those which were indicated in the literature. A class of solvents was discovered that is completely misable with the furfural produced from the hemicellulose hydrolysis and appears to meet most of the requirements for a desirable reaction liquid media. An added advantage of this class of materials is their inertness and high-temperature stability. With this high-temperature capability and excellcent solubility for furfural, surplus water can probably be reduced in the hydrolysis operation. By removing the products of the hydrolysis, as they are formed, an increase in overall yields should result. Less decomposition and resin formation will also occur and the energy required to separate the products will be reduced.

SUMMARY

Various apparati have been assembled and tested for the two step acid catalyzed hydrolysis of biomass. The hydrolysis of biomass (bagasse) has produced furfural from the first step hydrolysis and reducing sugars from the second step. A pressure reactor appears to be the most practical method of obtaining the conditions for the most efficient operation of the system.

Additional major chemical products that can be produced by these methods include: furfural, butanol, acetone, acetic acid and methanol. Experimentation has shown that biologically toxic components are produced during the hydrolysis operations. These can be controlled by the conditions used during the operations or by removal with activated carbon after formation.

An important discovery was made when it was found that the furfural produced from the hemicellulose could be extracted with a stable solvent as it was being formed. This promises to prevent product decomposition, reduce the normal energy requirements and lower the waters of dilution. A more efficient operation should result if it can be shown that trace amounts of the solvent are not harmful to the biological fermentation step.

HYBRID SOLAR SYSTEM FOR YOUNG PIGS

by

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ABSTRACT

Operation of a swine nursery field unit equipped with a hybrid solar system during three winters showed that good facility design coupled with an in-floor heat distribution-storage system and hovers enables all supplemental heat required by nursery pigs to be provided by solar energy except under conditions of extended sub-normal temperatures and insolation levels. Laboratory studies (3) verified: 1) the importance of turbulent flow to achieve good heat transfer; 2) effective utilization of collected solar energy with the in-floor heating system; and 3) the role of warm floor surfaces in reducing heat losses from the pigs. A stochastic model based on a Markov chain using historical daily maximum and minimum temperatures and relative humidities shows good potential as a tool to predict insolation levels.

INTRODUCTION

Temperature requirements for just-weaned pigs range from 29 to 35^{o}C depending upon group size, pen design and air velocities through the animal zone. Whole-building heating and mechanical ventilation are typically used to provide an environment suitable for these small animals (4 to 10 kg). This three-phase project was designed to determine the feasibility of utilizing a non-mechanically ventilated modified-open-front building, zone heating and solar energy to provide the necessary environment. A field unit was monitored for three years. Separate blocks of field and laboratory data were used to develop and verify models to predict system and animal performance. The third phase was a stochastic model to predict insolation levels as a design aid.

FIELD UNIT

Description

The field unit was located in south central Nebraska (40^{o}24'N, 98^{o}11'W) on a commercial swine farm. The southward facing 35.4 x 7.0 m non-mechanically ventilated building had a monoslope roof (3:12 slope), openable translucent panels on the south wall (to allow use as both a passive collector as well as ventilation openings), insulated openable panels on the north wall, a well insulated ceiling (R 3.3 to 3.8) and sidewalls (R 2.3 to 2.6) made of 1.2 m high insulated concrete sandwich panels and frame construction.

air to the concrete blocks. In the first study changing the airflow through the 20 x 20 x 41 cm (nominal) 2-core concrete blocks from laminar (9.4 L/s per block, Re<2300) to turbulent (28.3 L/s per block, Re>6000) resulted in a three-fold increase in the heat transfer coefficient.

The second study, using computer simulations, showed that 59% of the heat transferred into the IFHDS system is released into the animal sleeping zone. The remaining heat is lost to the surrounding soil. Overall results compared favorably with data from the field unit. The model allows evaluation of various collector-to-storage mass ratios and levels of enveloping insulation.

Animal response to a warm floor was investigated in the third study. Estimates of the pig's ability to utilize floor heat were developed into a model by combining the body core temperature, skin conductance and size of the nursery pig with thermal properties and temperatures of the air and floor in contact with the pig. Assuming a constant body core temperature of 39°C, conductance of skin in contact with a floor can be 20 times the conductance of skin in contact with air. An increase in both air and floor temperature results in greater efficiency of the pig to retain energy for weight gain. However, the pig is three times more sensitive to an increase in floor temperature than air temperature. Thus showing floor heat to be an efficient means to provide heating requirements for the nursery pig.

COMPUTER MODELING

A stochastic model based on a first-order Markov chain and using a five-state transition matrix for each month of the heating season was developed to predict solar insolation. For improved results, work was undertaken to complement this model with historical daily maximum and minimum temperatures and relative humidities. This phase of the project is not complete but shows promise of providing a reliable means to predict solar insolation. This capability will augment the system design models developed as part of the laboratory studies.

Modification of the AGNET SOLSWINE model to allow prediction of swine performance with a "continuous flow" (as contrasted to "all-in/all-out") management regime was the final phase of the project. This approach provides a better fit to management practices found in the field.

Integration of the stochastic model into SOLSWINE for producer useage is in progress. Implementation is anticipated in the next 12 months.

SUMMARY

A 3-phase study including field and laboratory investigations and computer modeling has proven the feasibility of utilizing energy-efficient non-mechanical ventilation and solar energy as the primary environmental modification tools for nursery pigs. Models developed as part of the project will continue to find use as system design aids. Animal zone warm floor heating and non-mechanical ventilation combined to yield reductions in annual operating expenses exceeding 98%. Construction costs yielded

Twenty-five pigs were housed in each of 22-0.3 x 6.1 m pens (total capacity = 550 head). Pen partitions were cast-in-place concrete except over the 0.9 m wide open flush gutter and along the service alley.

The in-floor heat distribution-storage (IFHDS) system was positioned under the sleeping area at the north end of the pens. Cores in five 20 x 20 x 41 cm (nominal) concrete blocks were aligned to form air passageways. Thermal storage was provided by the concrete blocks, an 18 to 25 cm sand layer and the concrete floor. The IFHDS system was enveloped by extruded foam insulation (R 0.7 to 0.9) on both sides and the bottom.

Heated air from a 1 m high flat plate active collector positioned at ground level across the front of the building was conducted to the IFHDS system through insulated PVC pipes. A closed-loop airflow pattern was used through the active collector, conveyance tubes and in-floor heat distribution system to reduce fouling in the system (Figs. 1 and 2).

Results

Solar energy provided 100% of the required supplemental heat during the first two winters (1979-80 and 1980-81). Insolation levels averaging 30% below normal and sub-normal temperatures (4th coldest January in over 100 years of record keeping) made use of heat lamps for newly weaned pigs in five pens necessary for four weeks during the third winter (1981-82).

Resultant heating costs or costs for operating the active solar system fan plus heat lamp operation (in year three) were 10, 18 and 55 dollars for the three years, respectively. These costs represent savings of 98 to 99% when compared to heating costs for mechanically ventilated, raised deck nurseries. The savings are based on both engineering estimates and comparisons with other field units. The non-mechanical ventilation system provided savings estimated at $600 to 700 per year. Additional savings were realized from construction costs which were $58 per pig for the total system. This compares with costs of $85 to 100 per pig for "conventional" nurseries.

Animal performance was measured in a similar 300-pig field unit and compared favorably with performance in conventional nursery units. Feed conversion ranged from 1.85 to 2.33 kg feed per kg gain while daily gains ranged from 0.31 to 0.35 kg per day for pigs between 4 and 18 kg. Death losses in the first field unit have been less than 0.5% since operation began in October 1979.

The stability of floor surface temperatures within the pigs' sleeping area above the IFHDS system and beneath the hovers is shown in Fig. 3. The warm sleeping area allowed good animal performance despite ambient temperatures as low as 12^{o}C in the feeding and dunging areas.

LABORATORY STUDIES

Three separate but related laboratory studies were conducted. A critical aspect of the IFHDS system is the transfer of heat from the solar heated savings in the range of 30 to 40%.

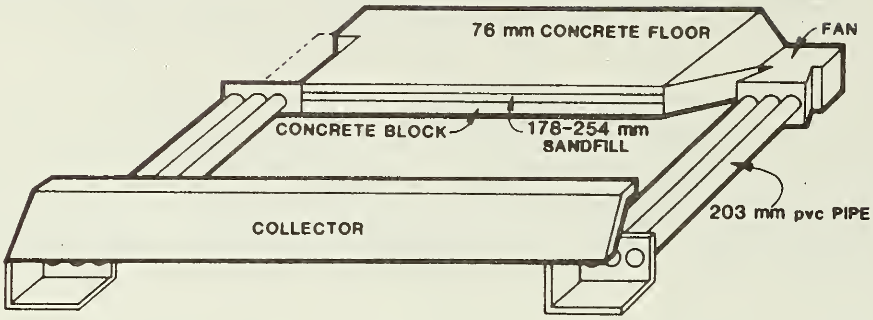

Fig. 1. Schematic of the active solar collector system, including the in-floor heat distribution-storage system.

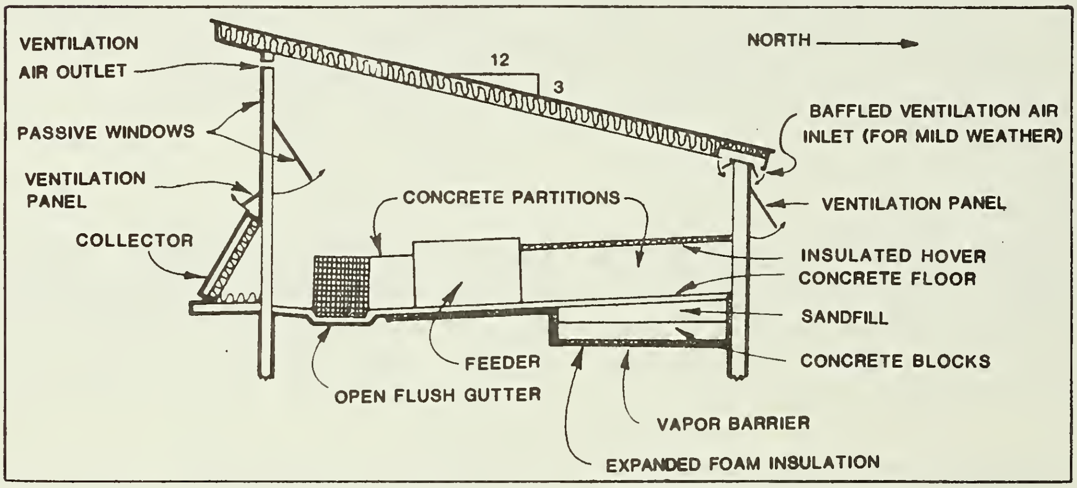

Fig. 2. Cross-section of solar modified-open-front non-mechanically ventilated swine nursery. (Some details omitted for clarity.)

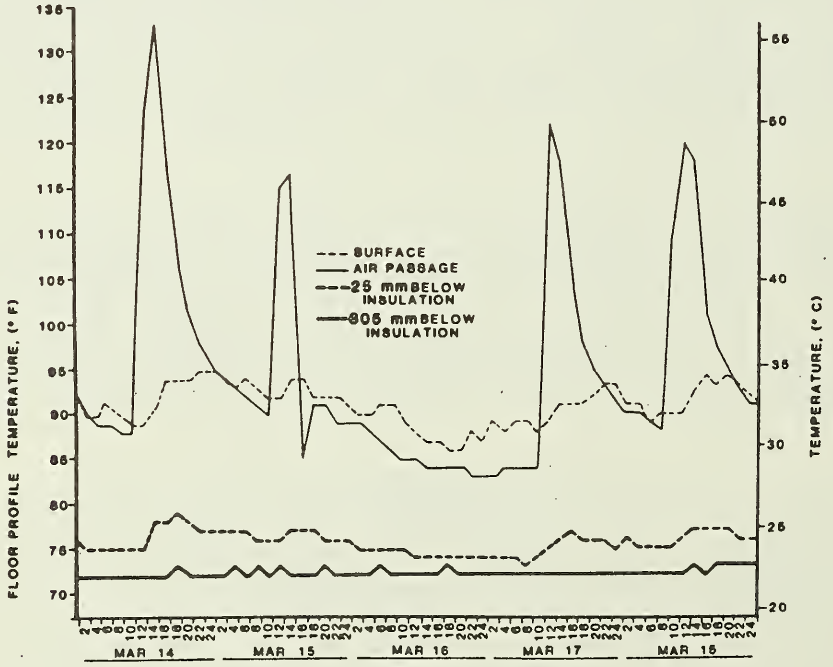

Fig. 3. Floor profile temperatures at the inlet end of the in-floor heat distribution-storage system.

INCREASING CROP MATURATION PERIOD IN ALASKA AND IMPROVING MOISTURE RETENTION AT SPRING RUN-OFF BY ACCELERATING SNOW MELT

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ABSTRACT

This research was conducted by the University of Alaska Geophysical Institute and AES personnel over an eighteen month period encompassing the spring breakup of 1982. The snow melt was accelerated by lowering the snow pack albedo with surface darkening agents such as lampblack. Although melt conditions were relatively adverse during the 1982 break-up, the snow pack on plots dusted with various materials and mixtures disappeared at times earlier than adjacent untreated plots, clearly demonstrating that soils could be cleared of snow earlier. When the soil is thus exposed, it absorbs radiation at a rate eight to ten times that of snow. Subsequent thawing of the soil was observed vs. time at these sites. Rapid thawing following the accelerated snow melt and subsequent infiltration of moisture would allow field operations to begin earlier, resulting in a longer season. Fertilizer mixed with lampblack appears to be the most efficient albedo altering mixture from the standpoint of early melt, but further work must be done to determine if fertilizer used in this manner may be lost to runoff. Soil moisture was closely monitored during the snow melt and soil thawing period. These observations show there is a direct relationship between melt water retention in the soil and time of snow pack disappearance, i.e., the earlier the disappearance, the greater the retention of melt water.

Introduction

There are several millions of acres of virgin land in interior Alaska that have been identified as potentially usable for agricultural purposes. As elsewhere, large scale cereal grain farming in Alaska is a risky venture, made even more so by marginal climatic conditions. A large portion of the potentially arable land in Alaska is in what is called the Interior, having a semi-arid continental climate. The growing season in Interior Alaska though intense is short (~ 110 days) and precipitation in the form of rainfall averages less than 10 inches. Although crops may be developed through advances in biotechnology to withstand such harsh climatic conditions, agricultural engineering technology can contribute to improvement in agricultural development in Alaska. This research was initiated to study the feasibility of lengthening the growing season and improving soil moisture retention by artificially increasing the spring melt rate.

Experiment

Generally there is a high degree of solar insolation during the period of spring breakup in interior Alaska. Reflection of radiation from the snow at this time is high, delaying breakup until snow albedo increases from recrystallization by warm air temperature or even rain. When breakup does occur, it proceeds rapidly. At this time the frozen soil is relatively impervious to moisture transport so that much of the melt water is lost to runoff.

Darkening of the snowpack with solar radiation absorbing materials will lead initially to alteration of snowpack, rapid melting of snow and early exposure of small patches of soil covered with melt water. Such water will tend to be immobilized overnight in the early part of the breakup by subfreezing temperatures and radiation cooling. This water will act as a reservoir of heat allowing thawing of the soil beneath. Thus, not only will the snowpack be melted at an earlier time by dusting with materials such as lampblack, but also a significantly higher retention of runoff water should be expected.

Experiments to quantify the effects of accelerating the snowmelt in terms of timing of application, soil temperature and soil moisture were undertaken during Spring, 1982 on agricultural land with varying slope. Temperature measurements were made periodically in the snowpack and soil to a depth of 50 cm through the winter and spring breakup period using strings of thermistors. Snowpack albedo and surface temperature measurements were made with radiometers. Moisture profiles of snow and soil were determined using a combination of neutron probe and gravimetric measurements. Snow and soil samples for gravimetric analysis were taken by digging pits or by coring methods throughout winter and melt and several days after breakup. Measurements of depth of thawed soil after breakup using a rod were also made.

The effects on the snowmelt of varying application rates and using different mixtures of materials were also studied. The materials studied included lampblack, lampblack-coated urea fertilizer and coal ash in varying concentrations and combinations.

In summary, the data included albedo measurements, snow and soil temperatures, snow and soil moisture content and depth of thaw taken prior to, during and after breakup on plots dusted with light-absorbing materials and untreated control plots.

Results and Conclusions

Although meteorological conditions during spring, 1982 did not favor a dramatic difference in breakup between dusted and undusted plots, the timing of events clearly showed (1) the dusted plots were clear of snow and workable by machinery 5 to 10 days before undusted plots and (2) there was a greater entrainment of moisture in the soil of dusted plots.

The neutron probe measurements calibrated against the gravimetric measurements showed the moisture entrained within the first 2 ft. (~ 50 cm) of soil, a few days after all test plots were totally free of snow, to be about twice as much in the treated as the untreated plots (about 5.5 cm versus 2.5 cm of integrated column moisture). This is a very significant difference in soil moisture which can be made to occur just prior to the very critical time of plant germination.

Because the dusted plots were exposed earlier, the temperatures near the soil surface on these plots tended to be much warmer at an earlier time than those of the undusted plots. However, even a few days after exposure, the temperature profiles to a depth of 50 cm were similar for all plots. The differences in exposure time and moisture entrainment, which govern differences in night time reradiation of stored heat, evaporative cooling thermal conductivity and thermal mass, apparently do not lead to significant long term differences in the temperature profiles. Early exposure, however, does result in earlier thawing of the soil of the dusted plots. The 1982 observations show that the thaw rates after exposure were similar (~ 3 cm/day) in all plots, but that since the dusted plots were exposed much earlier, the thaw depths were correspondingly deeper at any given time.

Observations of the 1982 breakup suggests that, to be most effective, dusting should be done approximately 3 to 4 weeks before the snowpack would normally melt if undisturbed. A mixture of urea coated with lampblack applied at a rate of one to two lbs of lampblack/200 lbs of urea/acre produced the highest melt rates.

In conclusion, dusting agricultural fields with solar-radiation absorbing materials appears to allow lengthening of the growing season and greater entrainment of water in the soil under conditions in interior Alaska. However, these conclusions are based on detailed observations from only one breakup period (1982) and less detailed, unfunded observations of another (1979). Further study of this technique of enhancing available moisture and time for growing crops in Alaska is needed to put it on a sounder scientific basis. In addition, detailed studies should be made of dust application methods, effect on soil conservation and effect on overwintering cereal crops.

We are presently modeling the heat and moisture transport in the snowpack and soil using the data gathered during the 1982 breakup. Such modelling should lead to a better understanding of processes and sequences of events leading to spring breakup and thawing of agricultural soils in Alaska.

SUMMARY

Dusting of snow-covered agricultural plots in interior Alaska with sunlight absorptive materials was undertaken during the spring of 1982 to determine how much earlier crops could be planted and how much more moisture could be entrained in the soil by the acceleration of the snow melt. Observations of this one season indicates 5 to 10 days time could have been gained for the growing season and as much as twice the moisture entrained at this critical time in the growing season over that of untreated plots. Temperature, moisture and thaw depth measurements and overall visual observations of the breakup indicate that the physical reason for greater moisture entrainment is that the snow melt rate is enhanced locally in cells which allows the heat in meltwater to penetrate and thaw the soil more rapidly.

SOLAR AND BIOMASS UTILIZATION IN FOOD PROCESSING

by

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ABSTRACT

A system using solar and biomass to economically replace a substantial fraction of the energy currently used in the processing of foods has been evaluated. Flat plate collectors can be used to heat the food product and provide hot clean up water. Concentrating collects can be used to provide steam for evaporation and pasteurization. Food processing wastes can be converted to process fuels. Novel reactor designs and separation systems incorporating solar energy have been used to convert whey and other dairy wastes into ethanol and into methane to be used in spray drying. Techniques have been developed that will aid in the design of an economical solar-biomass system particular dairy processing facility.

Introduction:

The overall goal of the project is to develop techniques for food processing plants to economically integrate the use of solar energy and food processing wastes into present plant energy needs. The overall objective of the project is to design an integrated solar-biomass process as a means of decreasing the need for petroleum fuels in a given food processing plant. It is felt that a well designed solar-biomass process can supply at least half of the food plants energy needs and potentially save 5×10^{13} Btu/year for the dairy industry. To date, very little work has been done to optimally incorporate solar energy and the energy obtained from food process wastes into food processing systems. This study will undertake to demonstrate the technical and economic feasibility of a solar-biomass system for supplying a signification fraction of an operating plants energy needs.

Techniques, novel to the food industry, have been used in this project for the production and purification of the fuels produced from food processing wastes such as discarded cheese whey. Methane has been generated from microorganism adsorbed to solid supports. The gas formed can be utilized directly in a process. Ethanol has been produced from whey by microorganism adsorbed to solid supports. To facilitate the separation of ethanol from the fermentation media and maintain high formation rates, vacuum conditions have been used. Solar concentrating collectors have been used to produce steam to operate process equipment. An economic analysis has been performed to determine the feasibility of an industrial process. Energy demand data from operating plants have been used to determine the optimum solar-biomass process for a particular plant.

I. Solar System

This section summarizes the findings of the solar related aspects of the project. A brief system description is included to aid the data interpretation as shown in Figure 1. The key components included are: a flat plate and a line focus array, and a storage tank. Several features like the heat exchanger, product storage tank, ect., although not a part of this study, are included for the sake of completeness. The major dimensions of line-focus collectors are 2.79 m x 0.99 m. The receiver tube is of 7/8 in. diameter with a selective volting. The overall dimensions of the double glazed flat plate collector are 1.8 m x 0.90 m. The diameter of bonded tube is 3/8 in. The collector performances have been summarized. The performance correlations are based on varying inlet and ambient conditions. The collector test procedure was based on the NBS and Sandia guidelines. Cost equations used in the system optimization have also been developed.

II. Methane Production From Whey

Four completely mixed anaerobic filters were operated to digest liquid whey with a feed concentration of 0.3%, 0.6%, 1.2% and 2.0% total solids, respectively. The organic loading rate ranged from 0.5 to 30 g COD/l/day. Soluble COD removal efficiency is higher than 80% in most cases studied as shown in Figure 2. The products distribution in the methane fermentation is dependent on fermentation conditions as well as the microorganisms participating in the system. Modeling an undefined methanogenic process is not only complex but also impractical. A completely mixed anaerobic filter is suitable to treat whey for methane production and COD removal. The methane fermentation of whey is economically feasible when the plant scale is not smaller than 8,000 kg/day. Better economic result will be obtained if the process is improved by better control on reactor pH and increasing methanogenic activities in the biorector. Research should be directed to developing an effective defined methanogenic culture as well as reactor design with higher ability of retaining bacterial activities.

III. Ethanol from Whey

A novel two column gas-liquid solid biological reactor has been conceptalized, designed, built and tested. This tubular fermentor separator consists of a co-current 'enriching' column where gas and liquid flow cocurrently upwards followed by a countercurrent 'stripping column' where gas and liquid flow countercurrently. A basic schematic of the reactor-separator is shown in Figure 3. The inlet substrate and gas move cocurrently upwards the first or 'enriching column' during which some fraction of the substrate is converted to a volatile product by the cells. Some of the product moves into the gas phase following gas-liquid equilibrium. The gas phase leaves the top of the enricher while the liquid phase moves to the top of the second or stripping column. In this column the liquid moves down counter currently to the stripping gas. The remaining substrate is converted to product while the product is stripped into the gas phase resulting in a final exhausted liquid feed effluent containing ideally no substrate or product. Thus the reactor-separator both converts the substrate or product, and removes the product from the fermentation broth. The gas phase leaving the ICRS is condensed to recover the product.

The reactor-operator offers several advantages over other simultaneous separation systems advanced in the literature since reaction rates and cell life durations are increased at lower ethanol concentrations; a high output ethanol concentration is obtained from any sugar concentration in the feed; the energy of fermentation is utilized to vaporize the ethanol reducing the need for added heat and eliminating the need for cooling water; and the ethanol-water vapor from the output from the reactor may be distilled directly using the reactor-separation essentially as a reboiler. Results show that a 10.6% lactose whey ultrafiltrate could be fermented to give less than 2% output lactose with a 11 hr residence time. The ethanol produced was moved while 80% of the gas phase. Preliminary economic calculations indicate that for a 500 kg/hr whey stream, 30 kg/hr of 50% ethanol can be produced using 200 kcal/kg of 50% ethanol.

IV. Integrated Energy Use in a Dairy

There is great potential for significant reductions in utility consumption in food processing plants. Energy conservation, waste utilization, and heat recovery trends are evolving throughout the industrial sector. The waste heat recovery designs involve individual unit operations. So far, very little effort has been spent on the integration of the overall processes and systems. The concept of integrating utility systems provides a method for optimal use of energy and other related resources by the integration of utility systems such as electrical power generation; process and plant heating and cooling; and water supply and waste management (treatment and disposal). The overall objective of this study is to integrate all the energy producing sources (generation) and energy consuming systems (sinks) in order to fulfill all the processing requirements of various forms of energy within the operational constraints. This requires a mathematical programming model utilizing the available equipment efficiently, while minimizing the total energy related costs.

The energy use and utility demands in a medium-sized dairy in the mid-west was studied extensively. After tabulating the wasted energy, energy values were expressed as a mathematical model, including energy saving equipment not presently located in the plant. An optimization was performed by using MPOS (Multi Purpose Optimization System). The equipment/utility optimization was performed for a number of alternative sources of energy, such as cogeneration, solar energy generation, and waste treatment for methane production. Each equipment capacity was estimated based upon the use load. MPOS will use fractions of capacity; so, the actual size of the equipment needed is predicted by the program. The total integrated utility system is depicted in Figure 4. Since the dairy uses low temperature steam and hot water, refrigeration system (which is 40% of the electrical demand) is a viable alternative.

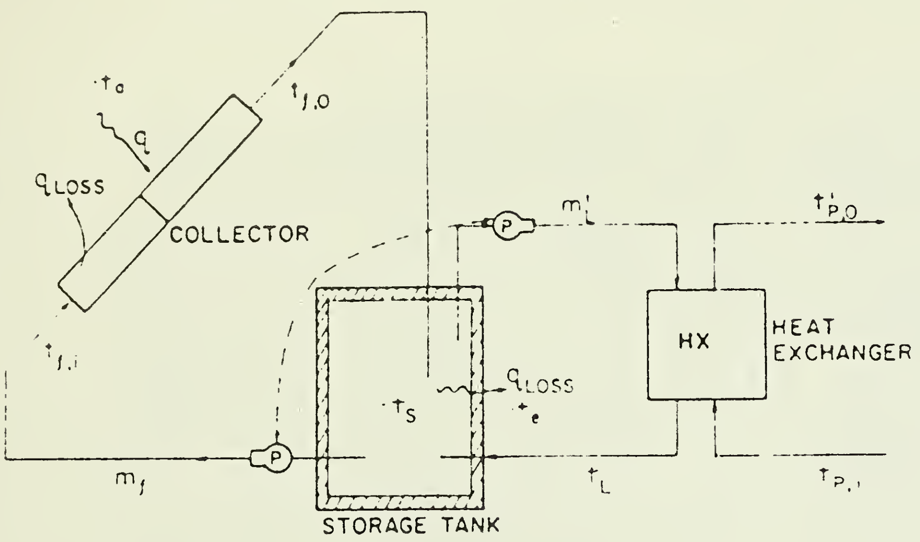

FIG 1 SOLAR SYSTEM

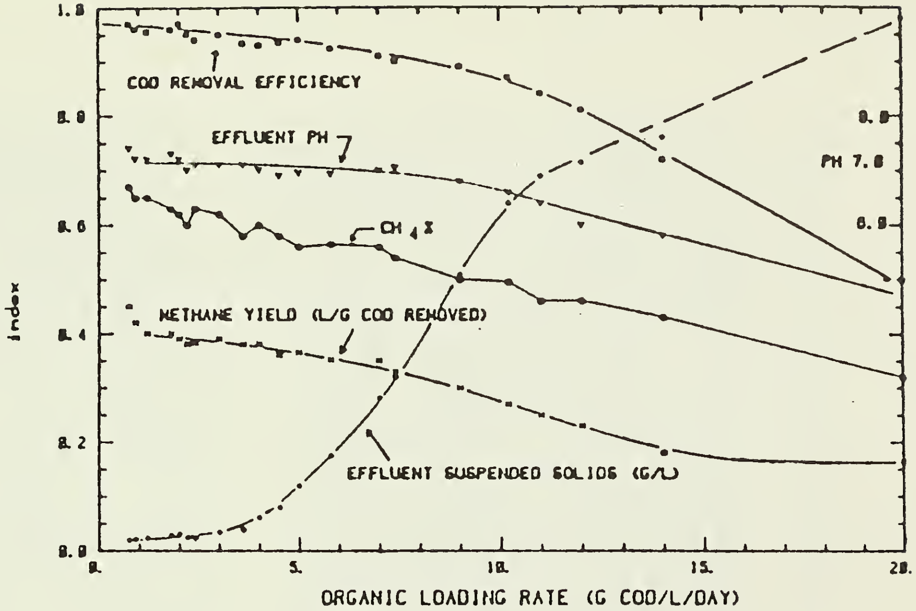

FIG 2 METHANE PRODUCTION FROM WHEY

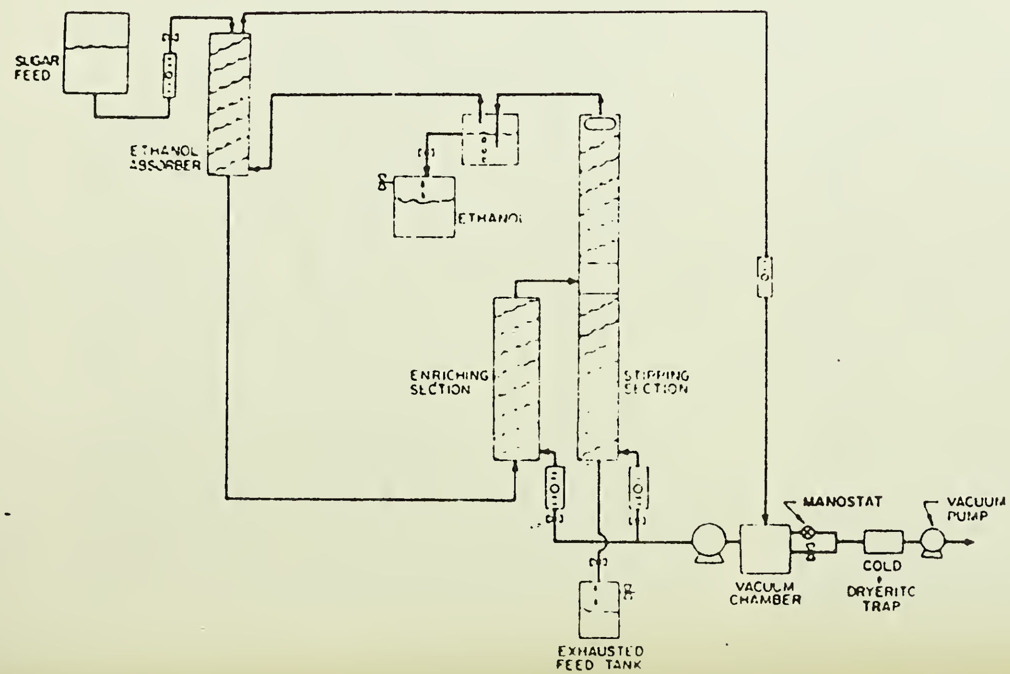

FIG 3 ETHANOL FROM WHEY

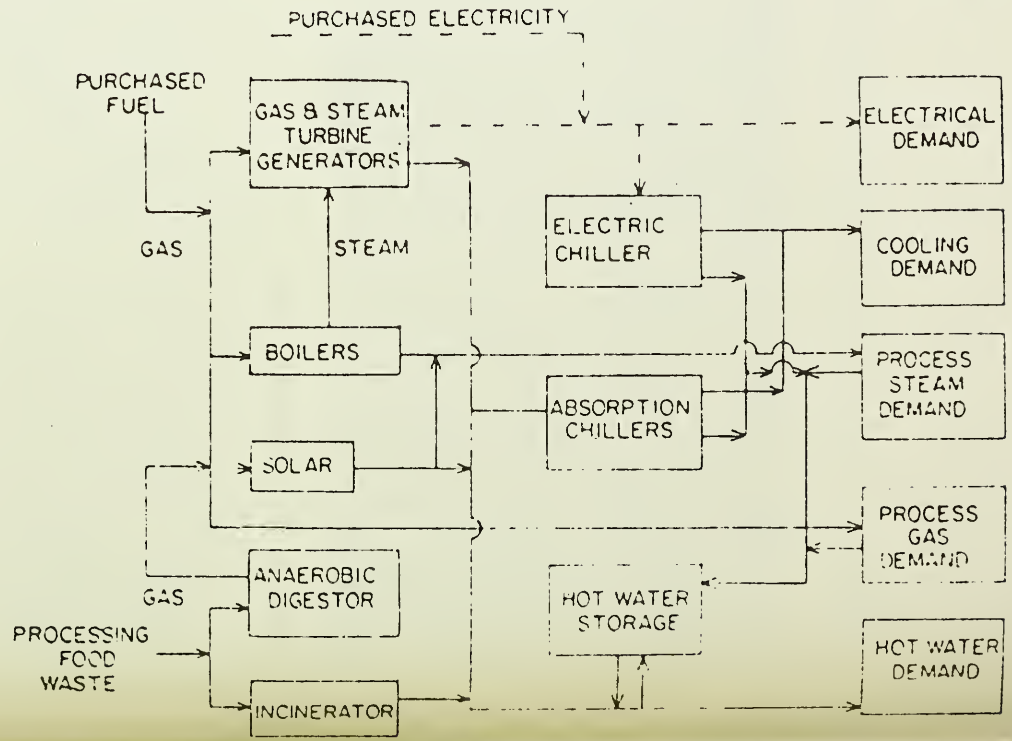

FIG 4 PROPOSED INTEGRATED UTILITY SYSTEM FLOW DIAGRAM

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