SAMPLE - DO NOT REMOVE

16th

ONTARIO INDUSTRIAL WASTE CONFERENCE

Proceedings

JUNE 1969

SPONSORED BY

THE

ONTARIO WATER RESOURCES COMMISSION

16th

ONTARIO
INDUSTRIAL WASTE
CONFERENCE

JUNE 15 - 18 1969

SHERATON BROCK HOTEL

NIAGARA FALLS

ONTARIO

CONTENTS

Page

PREFACE

D. S. Caverly,
General Manager,
Ontario Water Resources Commission,
Toronto.

Conference Chairman

Each year, the Industrial Waste Conference, sponsored by the Ontario Water Resources Commission, gains momentum. This is true both with respect to the attendance and the interest which the conference engenders. The 1969 conference, again held in Niagara Falls, was no exception.

Sixteen of these conferences have been held, to date, and whether you were a newcomer this year or have attended these meetings on previous occasions, I trust that you found this year's conference informative and worthwhile.

The success of a conference of this type may be attributed to a number of persons - those who deliver the technical papers, those who raise questions and spark discussions, those responsible for the physical arrangements. To all of these people I wish to register my sincere thanks. It may be said, however, that the success of these industrial waste conferences over the years has been due, most of all, to the growing awareness of the vital importance of maintaining a clean environment. As we become more and more industrialized, the problems related to industrial waste disposal take on a new degree of urgency and importance. Attendance at a conference of this type, therefore, assumes a new level of priority. For this reason, I hope that we may have the pleasure of welcoming you back again next year.

I am pleased to forward to you a copy of the 1969 Proceedings. It will serve to remind you of the various discussions which took place at the conference as well as provide you with a useful reference in the years ahead.

Conference Chairman

CONVENTION HEADQUARTERS
HOTEL SHERATON-BROCK

REGISTRATION

THE AMERICAN FALLS

MR. D. J. COLLINS
CHAIRMAN
ONTARIO WATER RESOURCES
COMMISSION

MR. D. S. CAVERLY
GENERAL MANAGER
ONTARIO WATER RESOURCES
COMMISSION

BANQUET NIGHT

REV. GEORGE GOTH
METROPOLITAN UNITED CHURCH
LONDON, ONTARIO

BANQUET SPEAKER

DR. K. L. MURPHY
DEPARTMENT OF CIVIL ENGINEERING
McMASTER UNIVERSITY
HAMILTON, ONTARIO

"SOME PROBLEMS OF INDUSTRIAL WASTE DISPOSAL FROM A FERTILIZER PLANT"

BY

J. H. FORSTER
ERCO ENGINEERING DEPARTMENT
ELECTRIC REDUCTION COMPANY OF CANADA, LTD.
TORONTO, ONTARIO

1. INTRODUCTION

The production of wet process phosphoric acid and the subsequent operations involved in manufacturing phosphatic fertilizers give rise to a number of waste products that are potential environmental pollutants. The main emissions consist of gaseous and particulate fluorides which are reduced to acceptable levels by scrubbing with water thereby giving rise to a fluoride containing effluent. This effluent, together with the gypsum cake discharged from the acid plant, constitute a major disposal problem in a phosphatic fertilizer operation.

The purpose of this paper is to present information on the effluent disposal system used originally by ERCO at the Port Maitland plant, outline some of the difficulties encountered and describe some of the changes made to improve the system.

2. GENERAL OUTLINE OF PROCESS

The ERCO fertilizer complex is located at Port Maitland near the mouth of the Grand River and was commissioned in 1961. It presently consists of an expanded conventional Prayon wet process phosphoric acid plant producing 30% P_2O_5 from Florida phosphate rock and sulphuric acid - a by-product from an adjacent zinc sulphide roasting plant which is also equipped to burn elemental sulphur.

The initial phosphoric acid concentration facilities installed were Ozark-Mahoning submerged combustion units to produce 54% P_2O_5 from a 30% P_2O_5 feed. These units have since been supplemented by a Swenson single-stage vacuum evaporator.

Part of the 54% acid produced is defluorinated and used to produce feed grade dicalcium phosphate, part is clarified and sold as phosphatic fertilizer solution (pfs), and the remainder is converted to ROP triple superphosphate in a conventional den system. The den is also used to make ROP single superphosphate by reacting sulphuric acid and phosphate rock. A large proportion of both single and triple superphosphate ROP is subsequently converted into a granular form in a common granulation plant.

3. SOURCES OF EFFLUENT

The original source of all fluoride found in wet process phosphoric acid and phosphatic fertilizers derived from phosphoric acid is the basic raw material used in the processes, phosphate rock.

Typically, phosphate rocks found in North America are sedimentary deposits containing approximately 3 to 4% fluorine, principally as the mineral francolite, a carbonate fluorapatite, $Ca_{10}F_2(PO_4)_6$ X. $CaCO_3$. The fluorine content of the main deposits in the United States is shown in Table 1 from which it can be seen that the F range is very similar irrespective of source.

3.1 Phosphoric Acid Process

The first step in producing phosphoric acid is to react the ground phosphate rock with sulphuric acid to form a slurry of calcium sulphate dihydrate or gypsum and phosphoric acid. During this digestion process significant quantities of gaseous fluorides are emitted as HF and SiF_4. The reactions occurring can be represented very simply by the equations (1) to (5) given in Table 2.

The main reactive impurity is calcium carbonate which is attacked by sulphuric acid (equation (2)).

In many rocks the fluoride content exceeds the amount required for fluorapatite and the excess can be considered to be calcium fluoride giving more HF per equation (3).

Reactive silica or metal silicates in the rock are attacked by the hydrogen fluoride to give fluosilicic acid, and some of this fluosilicic acid volatilizes as silicon tetrafluoride as represented by equations (4) and (5).

The gypsum and phosphoric acid slurry is filtered to remove the gypsum which is washed countercurrently with water to remove P_2O_5 prior to discharge from the pan filter. The product acid is then concentrated from 30% P_2O_5 to 54% P_2O_5. This latter step is a major source of fluoride emission resulting in liquid effluent containing both P_2O_5 and fluoride for disposal.

The distribution of the fluorine in the phosphate rock between the various parts of the acid process is shown in Table 3. With vacuum evaporation, approximately 40-50% is evolved as gaseous fluoride from the reactors and evaporators while the remainder is distributed almost equally between the gypsum and the 54% P_2O_5 product. Using submerged combustion evaporators the split approximates to two thirds as gaseous fluorides, and the remaining third in the gypsum and acid product.

The quantity of gypsum formed usually approximates 1.5 to 1.6 tons/ton of rock digested, or 4.6 to 5.2 tons/ton P_2O_5 produced, or approximately 500 tons/100 tons P_2O_5. In addition, the washed gypsum cake discharged from the filters can contain 18-35% water and significant residual quantities of P_2O_5 and fluoride, typically 4% P_2O_5 (60% insoluble), 0.6% F.

3.2 Superphosphate Process

Normal superphosphate is produced by reacting phosphate rock with sulphuric acid in accordance with equation (6).

The fluorine evolved from this process can vary from 11 to 42% of the fluorine in the rock fed. SiF_4 is the major fluorine compound obtained, formed by the HF attacking the rock and is removed by scrubbing.

Triple superphosphate is obtained by reacting phosphate rock and phosphoric acid (54% P_2O_5) and is simply represented by equation (7).

Again the gaseous fluoride evolved is mainly SiF_4 formed by the HF attacking the rock. About one third of the fluorine initially in the feed is evolved and removed by scrubbing.

After curing for approximately four weeks in a storage building, the ROP (run of pile) superphosphate can be granulated. A further major gaseous fluoride evolution occurs at this stage necessitating an additional scrubbing operation.

3.3 Effluent Discharges

The quantities of raw effluent to be handled from the various parts of the process are illustrated in Figure 1 from which it will be seen that the total flow amounts to some 3,500 IGPM containing 27 TPD P_2O_5, 68.7 TPD F, and 2,400 TPD gypsum.

4. EFFLUENT TREATMENT AND DISPOSAL

As water was readily available, the original design of the plant was based on a once through system without any recycle. The effluent was treated with lime to neutralize the P_2O_5 and fluorides, settled to remove the precipitated phosphates and fluorides together with the by-product gypsum and the clarified effluent discharged into the Grand River.

The large quantity of gypsum produced from wet process acid plants requires a considerable acreage for disposal. As a rule-of-thumb, approximately 1 acre-foot of gypsum will be accumulated annually for every daily ton P_2O_5 produced, and usually 0.5 acre/daily ton P_2O_5 is provided for disposal of gypsum for a new plant. A dyked area to act as a lagoon was, therefore, constructed in the low lying ground along the river bank, immediately adjacent to the plant at Port Maitland. The neutralized effluent was conveyed to the lagoon as a 5-7% slurry via FRP and wood-stave pipelines. The initial pond was approximately 50 acres and this was later increased to 130 acres by the addition of a second pond.

5. OPERATING PROBLEMS

After a few years of operation, it became apparent that the system was not entirely satisfactory and a number of problems arose:-

1. The control and operation of the neutralizing facilities was erratic with over-treatment and under-treatment being obtained under certain conditions.

2. The retention time in the neutralizing system became too low with increasing plant production and reaction continued in the pipeline and, to some extent, in the lagoon itself.

3. Difficulties were experienced in maintaining good pond management. Exposure of the settled gypsum surface to winter conditions caused decrepitation of the crystals and consequent "dusting" from the exposed surface. One way of preventing this is to keep the pond completely flooded, but problems are then experienced with wave action breaking down the dyke, causing high solids content in the discharge. Dyke repair costs are also increased substantially.

The limits set by the Ontario Water Resources Commission for the effluent discharge, and the range of ERCO experience, are shown in Table 4. From these figures it can be seen that, in general, some difficulty was experienced in exercising adequate control over the discharge.

6. RECYCLE SYSTEM

In addition to the difficulties mentioned above, the annual cost of operating the system was substantial, approximately 80% being the cost of lime and 20% operating costs. A study of operating a recycle system indicated that significant annual savings could probably be achieved, perhaps as high as $500 to $1,000 per daily ton.

It was also likely that an increased recovery of P_2O_5 would be achieved and calculation confirmed the figure of approximately 1% additional recovery usually quoted for plants operating with recycle water systems in Florida.

Preliminary studies indicated a probable capital cost of $250,000 to $300,000 for conversion to a recycle system. For the annual savings anticipated this gave an acceptable return on the investment and a short enough payout period.

6.1 Project scope

The project was approved early 1968 for \$270,000 and construction started July 1968 with completion expected by the end of the year. Due to problems with the weather and some equipment failures at start-up, the system was, in fact, not finally commissioned until April 1969.

The scope of the project was essentially that of providing new pumping capacity to return the settled clarified effluent to the plant and distribute the water to the various points of use. The fact that the plant is an operational one meant it was virtually impossible to replace the existing steel pipelines, and the new FRP distribution lines were, therefore, run in parallel to avoid major interference with production.

While it was hoped that the effluent discharge could be eliminated completely, it was also realized that out-of-balance conditions would arise and changes in pond levels would have to be made from time to time. Provision was therefore made in the project for neutralizing and settling facilities to handle a nominal discharge of up to 500 GPM. The installation of the neutralization equipment was delayed initially until operating experience was obtained, but it is now in progress and will be completed this summer.

6.2 Operating Conditions

Experience with similar recycle systems, particularly in the United States, has shown (5) that the concentration of fluoride in pond water apparently approaches a limit of 3,000 to 5,000 ppm. This is a result of adsorption of fluoride by the gypsum and the formation of insoluble complexes with calcium and silica. After three to five years' operation, typical figures have been quoted (4) of 5,000 ppm fluoride, 10 to 12,000 ppm phosphate with pH of 1.0 to 1.5. In our case we have not been operating long enough to reach equilibrium, but the predicted levels are expected to be quite similar.

The residual dissolved fluoride in the pond water exerts significant partial pressures of the order of 0.0008 mm Hg for HF, and 0.00007 mm Hg for SiF_4 (5), and this raises the question of vapour losses. Under high wind conditions, losses from ponds can be significant in terms of pounds per day, but it is believed that concentrations in the air will be of the order of 1 part per billion or less, an acceptable level from the fumigation point of view.

The predicted behaviour of the system is based on achieving a degree of cooling in the ponds and the design was based on the expectations of a 85°F water return temperature being realized under summer conditions.

The anticipated changes in the water flow pattern under recycle conditions is indicated in Figure 2. The operation of this system has necessitated a basic change in operating philosophy. Whereas previously the main concern was to minimize the P_2O_5 escaping in the effluent, now the emphasis is on maintaining a balanced system and avoiding the addition of water which can be regarded as a "contaminant". Present indications are that a balanced system can be maintained except for the effluent originating in the fertilizer plant. This is a flow of about 200 GPM which will have to be neutralized, settled, and the clarified effluent discharged to the river, a far cry from the 3,000 to 4,000 GPM effluent previously released.

TABLE 1

FLUORINE CONTENT OF U.S. PHOSPHATE ROCKS (1)

Source	% Fluorine
Florida	3.3 - 3.9
Tennessee	2.9 - 3.7
Western U.S.	2.9 - 3.8

TABLE 2

CHEMICAL REACTIONS

(1) $$\underset{\text{Fluorapatite}}{Ca_{10}(PO_4)_6\,F_2} + \underset{\text{Sulphuric Acid}}{10H_2SO_4(aq)} + 20H_2O(l) \longrightarrow \underset{\text{Gypsum}}{10CaSO_4.2H_2O} + \underset{\text{Phosphoric Acid}}{6H_3PO_4(aq)} + \underset{\text{Hydrogen Fluoride}}{2HF\ (aq)}$$

(2) $$CaCO_3 + H_2SO_4(aq) + 2H_2O\ (l) \longrightarrow CaSO_4.\ 2H_2O + H_2O\ (l) + CO_2\ (g)$$

(3) $$CaF_2 + H_2SO_4\ (aq) + 2H_2O\ (l) \longrightarrow CaSO_4.\ 2H_2O + 2HF\ (aq)$$

(4) $$6HF\ (aq) + SiO_2 \longrightarrow H_2SiF_6\ (aq) + 2H_2O\ (l)$$

(5) $$H_2SiF_6\ (aq) \longrightarrow SiF_4\ (g) + 2HF\ (aq)$$

(6) $$\underset{\text{Fluorapatite}}{Ca_{10}(PO_4)_6\,F_2} + \underset{\text{Sulphuric Acid}}{7H_2SO_4} + 3H_2O \longrightarrow \underset{\text{Mono Calcium Phosphate}}{3Ca(H_2PO_4)_2.H_2O} + \underset{\text{Gypsum}}{7CaSO_4} + \underset{\text{Hydrofluoric Acid}}{2HF}$$

(7) $$Ca_{10}(PO_4)_6\,F_2 + 14H_3PO_4 + 10H_2O \longrightarrow 10Ca(H_2PO_4)_2.H_2O + 2HF$$

TABLE 3

DISTRIBUTION OF FLUORINE IN WET PHOSPHORIC ACID PROCESS

	% TOTAL F IN PHOSPHATE ROCK			
	Typical Range	Typical Values		ERCO
From reactors	4-7	5	5.5	5
From evaporators	35-45	40	41.9	60-65
In gypsum	25-30	30	27.8	20-25
In 54% P_2O_5 product	20-30	25	24.8	10
REFERENCES	(3)	(2)	(6)	ERCO

TABLE 4

EFFLUENT DISCHARGE QUALITY

	Limits set by O.W.R.C.	ERCO Experience Range
Phosphate (as PO_4) ppm	25	-
(as P_2O_5) ppm	18.8	1 - 210
Fluoride (as F) ppm	25	10 - 35
Solids (due to process) ppm	15	5 - 312
pH Range	5.5 to 10.6	3.2 - 10.4

FIGURE 1

SOURCES OF EFFLUENT

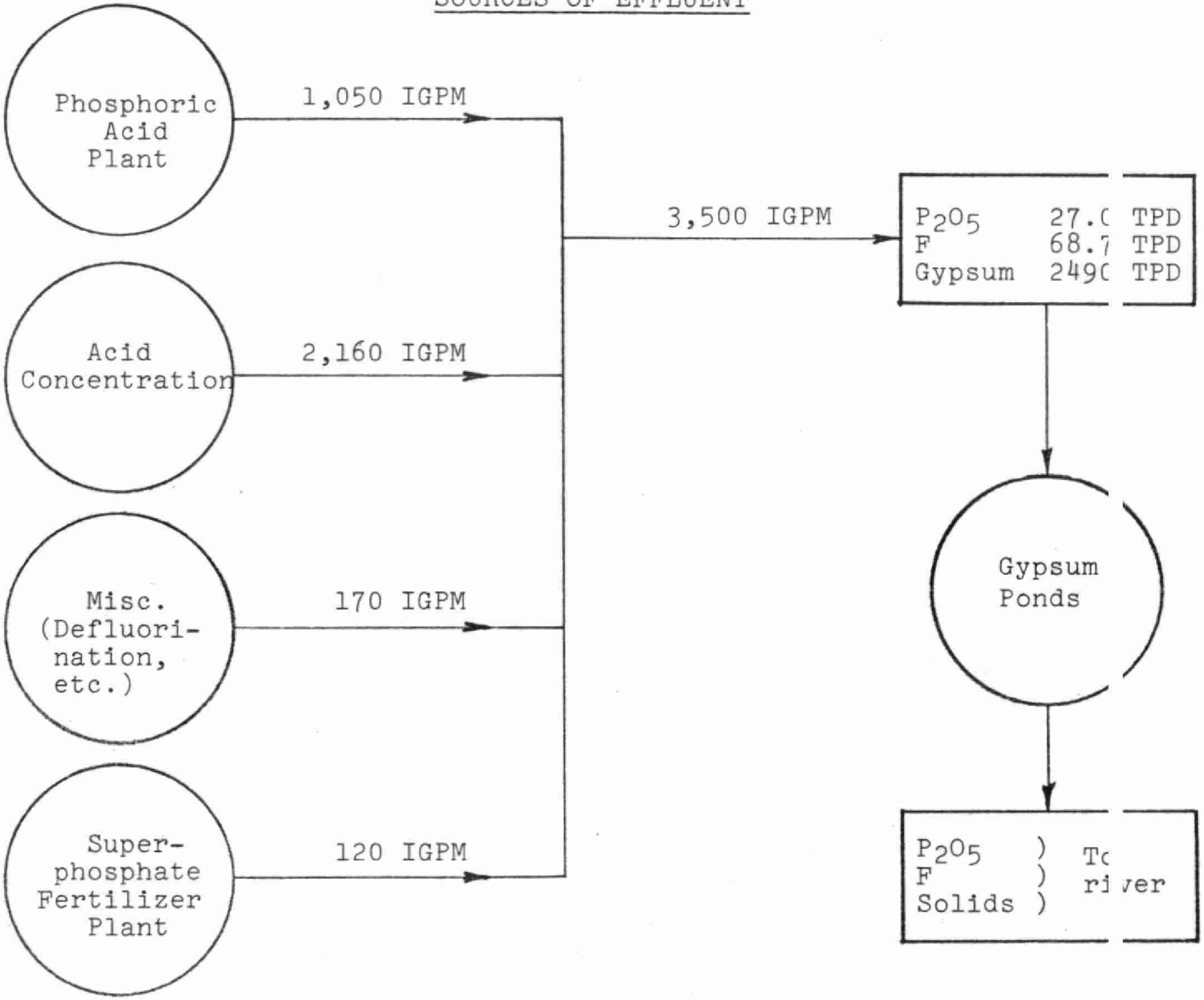
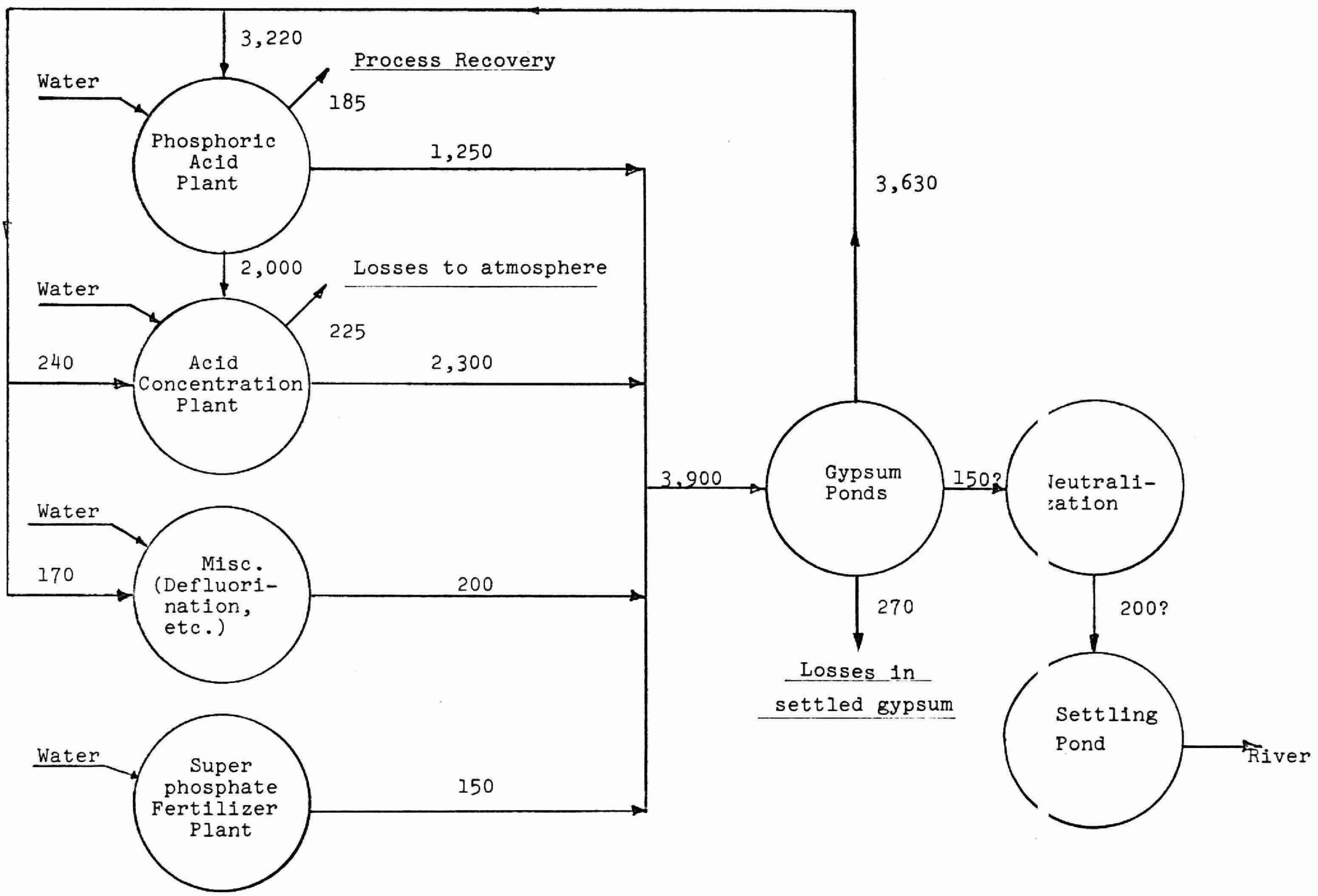


FIGURE 2

EFFLUENT RECYCLE FLOW RATES (IGPM)



REFERENCES

(1) W.L. Hill in "Superphosphate, its History, Chemistry and Manufacture," U.S. Government Printing Office, Washington D.C., 1964, pp. 218-221.

(2) E.J. Fox, J.M. Stinson, G. Tarburton, "Superphosphate," U.S. Dept. of Agriculture and Tennessee Valley Authority, 1964, p. 237.

(3) W.A. Lutz and C.J. Pratt, "Fertiliser and Technology Series - Vol. 1, Phosphoric Acid," edited by A.V. Slack, Marcel Dekker, Inc., 1968, pp. 191-197.

(4) K.K. Huffstutler, ibid. pp. 727-739.

(5) A.J. Teller, ibid. pp. 741-763.

(6) M.D. Sanders, ibid. pp. 765-778.

K. C. DEAN

"UTILIZATION AND STABILIZATION OF SOLID WASTES"

BY

K. C. DEAN, PROJECT COORDINATOR

R. HAVENS, SUPERVISORY METALLURGIST

E. G. VALDEZ, METALLURGIST

SALT LAKE CITY METALLURGY RESEARCH CENTER
BUREAU OF MINES
DEPARTMENT OF THE INTERIOR
SALT LAKE CITY, UTAH

ABSTRACT

Solid mineral wastes from mines, mills, and smelters are potential or active contributors to air and water pollution and, together with accumulations of automobile scrap, detract from the beauty of our landscape. U. S. Bureau of Mines researchers are seeking means for utilizing or stabilizing the mineral waste and for recycling or economic usage of automobile scrap.

Utilization studies have been directed to (1) producing copper from dump leach solutions using shredded auto scrap as a cementation medium, (2) recovering zinc from foundry dusts, (3) recovering additional values from copper and uranium mill wastes, and (4) producing ceramic and construction materials from waste products.

Stabilization studies employing physical, chemical, vegetative, and combination techniques also have been made. A 34-acre uranium waste accumulation has been stabilized using an elastomeric polymer and a calcium-magnesium lignin sulfonate as chemical stabilizers. Ten acres of copper mill tailings also have been effectively stabilized using a resinous adhesive compound in conjunction with selected vegetation in a combination chemical-vegetative method.

INTRODUCTION

Mine, mill, and smelter wastes aggregating billions of tons are scattered across the country as unattractive barren piles that detract from the natural beauty of the land. As the population of the United States increases and the demand for land intensifies, populous centers are slowly encroaching on these formerly isolated wastes. Encroachment sharply intensifies the importance of controlling the air and water pollution derived from natural weathering of such wastes. Use or stabilization of these wastes comprises the only viable means for minimizing pollution.

The Federal Bureau of Mines program on mineral wastes encompasses a broad spectrum of materials and problems. In addition to 20 research grants and seven contracts negotiated with different universities, research foundations, and private industries for special solid waste studies, research on mineral wastes is conducted at five Bureau of Mines Research Centers.

The work at the Salt Lake City Metallurgy Research Center, which is the principal subject of this report, is concerned with both utilization and stabilization of a wide variety of metallic and nonmetallic mine, mill, and smelter wastes obtained from 45 different mineral waste accumulations. Utilization is preferable to stabilization because full use would both eliminate the waste and broaden the mineral resource base. Only rarely can such low-grade material be reprocessed to extract additional minerals at a profit. Some mineral wastes are suitable for disposal as mine fill, railroad and highway road ballast, and land fill. Similarly, some mineral wastes can be utilized as raw materials for making brick, rock wool, concrete, and ceramic products. The accumulated mineral waste piles and the currently generated wastes are so large that only a small part is likely to be fully used; hence, stabilization is possibly the principal means for minimizing air and water pollution problems.

Several means exist for stabilization of relatively fine wastes, which constitute the chief sources of air and water pollution. These include physical, chemical, and vegetative stabilization, and combinations thereof. Massive coverings of coarse slag, concrete, and soil may be used to prevent erosion of waste piles. A variety of chemicals can be used to bond particles of fine waste into a relatively inert mass. However, the most promising method of producing an esthetically appealing storage site is vegetative stabilization. Numerous species of plants can germinate, grow, and reseed in waste materials which have been adequately prepared to support plant life.

UTILIZATION OF SOLID WASTES

The current utilization research effort is focused mainly on (1) producing copper from leach solutions using shredded auto scrap as a cementation medium, (2) recovering zinc from flue dust generated in foundries using automotive iron scrap, (3) recovering additional values from copper and uranium mill wastes, and (4) producing ceramic and construction materials from waste products.

Copper Cementation Using Shredded Auto Scrap

Discarded automobiles are accumulating across the landscape of the country as the demand for such scrap decreases with the conversion from open-hearth to basic oxygen steel furnaces. Hence, means were sought to utilize some of this scrap by methods other than recycle to steel mills. The development of automobile shredders capable of producing clean, relatively light gage and small size steel fragments enhanced this possibility.

Shredded automobile steel scrap has been successfully used in a rotating tumbler for the precipitation of copper from leach solutions. The tumbling action in the rotary drum continuously abrades the cement copper and presents a cleaner iron surface to the copper-bearing solution, thus materially increasing reaction rates compared with those obtained using conventional shredded tin cans in launders. A cost evaluation indicates that readily available shredded auto scrap at $32 per ton is competitive as a cementation medium with the launder and other methods using relatively high-cost shredded cans at $55 per ton.

Zinc and Lead from Foundry Flue Dust

One of the waste byproducts from foundries melting scrap automobile metal is flue dust (baghouse dust). Two samples received from Los Angeles and Seattle were similar in metallic element content, and both ostensibly represented 25-ton-per-day citywide accumulations. These daily accumulation tonnages of dusts, if extrapolated to a national basis for all similar type foundries, would indicate a production of 500 tons daily of such material.

The samples of flue dust ranged in percentage content from 30 to 35 zinc, 4.7 to 4.9 lead, 21 to 22 iron, and 0.2 to 0.3 copper. Methods tried for recovering zinc and lead included fuming, acid leaching, and acid or ferrous sulfate baking followed by water leaching.

Fuming tests showed that 95 percent of the zinc can be recovered by heating a pelletized dust and carbon charge at 925° C and sweeping the vapors with natural gas. The product recovered contained 97 to 98 percent zinc and the lead, manganese, iron, copper, and carbon impurities were all 0.1 percent or less. When sodium chloride was added to the charge and heated to 1,000° C, 99.6 percent of the zinc and 86 percent of the lead fumed off.

Hydrometallurgical treatments were relatively ineffective for extraction of the values. Selective leaching of the zinc from the dusts by the gradual addition of sulfuric acid to produce progressively lower pH's appeared to be the more practical chemical treatment. These tests showed that 75 to 80 percent of the zinc could be selectively leached at a pH of 3.0. The zinc extraction was increased at lower pH's, but the leach solution extracted increasing quantities of iron, copper, and manganese, thus complicating zinc recovery procedures. Sulfating roasts at 650° C with sulfuric acid, ferrous sulfate, and pickle liquor additives had the same disadvantage of producing impure leach liquors.

The amount of dust accumulated in any one city is probably economically insufficient for construction of zinc-processing plants in the individual cities. Therefore, methods also were developed for briquetting the dusts to permit shipment to commercial zinc-fuming smelters. Bonding agents were added in varying amounts to a mixture, in percent, of 5 carbon and 95 dust. This mixture was formed into briquets under a pressure of 9,000 psi and the resultant briquets subjected to empirical shatter tests and fuming tests. The shatter tests indicated that a resinous adhesive chemical and bentonite in quantities of 6 gallons and 20 pounds per ton, respectively, produced the better briquets. Fuming tests on these briquets demonstrated zinc extractions of 95 to 97 percent were obtainable from both briquets, but an undesirable condensate was derived from the resinous adhesive briquet. The purity of the zinc recovered from the preferred bentonite briquets ranged between 92 and 97 percent.

Recovery of Additional Values From Copper and Uranium Mill Wastes

Bureau of Mines research for utilizing copper mill tailings is aimed at (1) making a bulk concentrate of the sulfide minerals, principally pyrite; (2) roasting the sulfide minerals to convert the sulfur to SO_2; (3) leaching the calcine to recover residual copper, (4) reductive roasting of the pyrite cinder to a metallic iron product suitable for copper cementation; and (5) using the sulfide-free tailings for ceramics.

Flotation mill tailings from six western copper producers were treated by flotation for recovery of sulfide minerals. Bulk rougher concentrates recovered ranged in percentage content from 12.4 to 48.4 sulfur, 13.5 to 39.5 iron, and 0.28 to 5.0 copper. Fluidized-bed roasting tests were made on one of the concentrates to sulfatize the copper and oxidize the excess sulfur to sulfur dioxide. The resulting calcine was leached and over 92 percent of the copper was extracted in water-soluble form. Reductive fluid-bed roasting of the iron-rich residue produced a material containing approximately 70 percent metallic iron, suitable for precipitating copper from solutions in leach-precipitation-flotation circuits.

Old tailings from several uranium mills contain 0.3 to 0.5 percent vanadium. These tailings include the following: Foote Mineral Co. tailings at Durango, Colo., Shiprock, N. Mex., and Naturita, Colo.; Climax Uranium Co. tailings at Grand Junction, Colo.; and Union Carbide Corp. tailings at Rifle, Colo. Sulfuric acid leaching tests were made on a typical tailings sample, assaying 0.33 percent V_2O_5 and 0.045 percent U_3O_8, to obtain data for a cost study on the recovery of these elements. An acid cure was made in which pulp containing 80 percent solids was prepared by pugging with 100 pounds H_2SO_4 and 20 pounds CaF_2 per ton of tailings, holding for 5 days, and water leaching. This treatment solubilized 65 percent of the vanadium and 78 percent of the uranium.

Ceramic and Construction Materials

Ceramic work at the Bureau of Mines has demonstrated the feasibility of using copper mill tailings from six different sources for making building bricks by a dry press method. Tailings containing 1.5 percent or less of sulfides were used as received, whereas those of higher content were desulfided.

Dry tailings were mixed with 0.5 to 1.0 percent calcium lignin sulfonate (for green strength) and sufficient water to produce 3 to 6 percent moisture. The bricks were formed in the laboratory at 5,000 psi pressure and fired for 3 hours at 2,100° F. Several color variations were achieved without altering physical properties by addition of iron oxide, manganese oxide, and calcium oxide. Competent bricks were produced on a pilot-plant scale at the Coal Research Bureau of the West Virginia University. A cost evaluation made by the Coal Research Bureau indicated that the total cost for 1,000 of these bricks would be about $32. Work continues on the production of bricks from copper tailings using the extrusion process and on the production of steam-cured bricks from miscellaneous wastes.

The ceramic engineering group of the University of Utah, under a grant from the Bureau of Mines, is studying the possibilities of producing the following: (1) Plaster for wallboard from waste gypsum of the phosphate industry, (2) nucleated glasses from phosphorus furnace and copper mill wastes, (3) ferrites from mill scale, and (4) ladle brick from phosphorus furnace and asbestos wastes. A combined effort is being expended on the production of wall tile from the asbestos and phosphate industry wastes and on refractories from the asbestos wastes.

STABILIZATION

Stabilization of mine, mill, and smelter wastes presents problems of varying magnitudes. Coarse mine and smelter wastes are less subject to erosion than the fine materials in mill tailings. Similarly, wastes that are near populous centers are more of a nuisance than wastes located in essentially uninhabited areas. The aridity of certain sections of the country when compared with areas of high rainfall and accompanying lush vegetation also produces widely differing problems. In some areas, tailings piles that have been stabilized by various means are more attractive than the surrounding countryside. Thus, in gauging the seriousness of mineral waste problems, cognizance should be taken of the surroundings involved. The choice of method to alleviate a specific waste problem will depend upon the circumstances of individual waste accumulations. Physical, chemical, vegetative, and combination methods are practical stabilization procedures. Preplanning of waste disposal, which was often ignored in times past, is now a usual practice for many companies initiating new milling operations.

Physical Stabilization

Many materials have been tried for physical stabilization of fine tailings to prevent air pollution. Other than water for sprinkling, perhaps the most used material is rock and soil obtained from areas adjacent to the wastes to be covered. The use of soil often has a dual advantage in that effective cover is obtained and a habitat is provided for local vegetation to encroach.

Crushed or granulated smelter slag has been used by many companies to stabilize a variety of fine wastes, notably inactive tailings ponds. On active tailing ponds, however, the slag-covered portions are subject to burial from shifting sands. Slag has the drawback, unlike soils or country rock, of not providing a favorable habitat for vegetation. Furthermore, suitable slag, like soil and rock, must be locally available.

Other physical methods of stabilization evaluated include (1) the use of bark covering, (2) the harrowing of straw into the top few inches of tailings, (3) the placement of windbreaks, and (4) the spreading of a mixture of limestone chips and sodium silicate as a coating. The use of bark and straw has proved beneficial at the Anaconda, Mont., copper operations, and reed windbreaks were successfully employed in South African[1] gold and uranium operations, especially in combination with vegetative plantings. The limestone-sodium silicate mixture has not been considered successful by those testing that material.

Chemical Stabilization

Chemical stabilization involves reacting a reagent with the waste to form an air- and water-resistant crust or layer. Chemical stabilization of fine-grained mill tailings is complicated in that the surfaces of tailings piles seldom are homogeneous. Sections of slimes frequently alternate with sections of sands. The permeability, reactivity, pH, and salt content of the surfaces vary considerably. Hence, tests were conducted on several samples of acidic, neutral, and basic mill tailings of varying salt content which were segregated into sand, slime, and combined fractions to evaluate the effectiveness of various reagents on differing surfaces. As the amount of moisture in the tailings affects the bonding characteristics of the reagents, this variable was also investigated by moistening the tailings to various degrees prior to adding the chemicals. The coherency of the tailings surfaces after treatment was determined by using air and water jets to simulate wind and water erosion.

Optimum conditions and effective rates of application for all materials tested have not been determined and testing is continuing. The chemicals are listed in order of effectiveness based upon the cost in cents for the amount of reagent required to stabilize one square yard. An overlapping of costs resulted as some of the reagents were required in greater quantities to stabilize the various tailings. Thus, although only comparative data are available, the general conclusions presently derived are as follows:

---

[1] James, A. L. Stabilizing Mine Dumps With Vegetation. Endeavour 96, v. XXV, London, England, 1966, pp. 154-7.

1. Coherex,[2/] a resinous adhesive furnished good wind-resistant tailings surfaces when applied in quantities costing as little as $0.01 per sq yd, but good resistance to water jet testing was not achieved until reagent costing about $0.10 per sq yd was applied.

2. Calcium, ammonium, and sodium lignin sulfonates, as well as redwood bark extracts, were all effective surface stabilizers at costs of about $0.02 per sq yd.

3. Cement and milk of lime additives were effective in stabilizing surfaces when applied at a rate costing $0.03 per sq yd.

4. Paracol S 1461 (a blend of wax and resin) and Paracol TC 1842 (a resin emulsion) were effective as stabilizers in quantities ranging in cost from $0.04 to $0.10 per sq yd on various tailings samples tested.

5. Potassium silicates having SiO_2-K_2O ratios of 2.5 were effective stabilizers when applied at a reagent rate costing $0.07 to $0.15 per sq yd.

6. A cationic neoprene emulsion and Rezosol, an organic polymer, effectively stabilized the tailings at costs approximating $0.08 per sq yd.

7. Sodium silicate applied in quantities of 4.5 pounds per sq yd and at a cost of $0.11 per sq yd was an effective stabilizer. Calcium chloride was an effective additive to the sodium silicate, whereas ferrous sulfate was not. Addition of 6 percent by weight of $CaCl_2$ to the sodium silicate permitted reduction of the cost of sodium silicate used from $0.11 per sq yd to $0.02 per sq yd.

8. Peneprime (a bituminous base product), selected amines, dicalcium silicate, and the elastomeric polymers (Compound SP-400, Soil Gard, and DCA-70) produced wind- and water-resistant surfaces at costs of $0.10 per sq yd and up.

9. Pyrite treated with sulfuric acid, Aerospray Binder 52 (a synthetic resin), Landscape (solution of

---

[2/] Reference to trade names is made for identification only and does not imply endorsement by the Bureau of Mines.

combined sulfur in water soluble oil), or Water Mate (an organic, non-ionic product) were ineffective stabilizers on the tailings used in the testing.

Vegetative Stabilization

The successful initiation and perpetuation of vegetation on fine wastes involves ameliorating a number of adverse factors. Mill wastes usually (1) are deficient in plant nutrients, (2) contain excessive salts and heavy metal phytotoxicants, (3) consist of unconsolidated sands that, when windblown, destroy young plants by sandblasting and/or burial, and (4) lack normal microbial populations. Other less easily defined problems also complicate vegetative procedures. The sloping sides of waste piles receive greatly varying amounts of solar radiation depending on direction of exposure. Recent studies by Gates3/ have indicated that, contrary to popular belief, photosynthesis of plants is not continuous while the sun is shining; under high temperature conditions, photosynthesis may almost completely stop. Furthermore, most accumulations of mill tailings are light in color and may reflect excessive radiation to plant surfaces, thus intensifying physiological stresses. For these reasons, vegetation that may be effective on northern and eastern exposures may not be suitable for southern or western exposures.

Ideally, vegetative stabilization should produce a self-perpetuating plant cover directly or foster entrapment and germination of native plant seeds which will form a self-regenerating community. In the latter case, an ecological succession would be established leading to a vegetative covering so completely in harmony with the environment that irrigation or special care would be unnecessary. If the area were not cropped or grazed, only an initial fertilization should be required because the essential nutrients would be largely cycled in place.

Tailings at the Miami Copper Co. at Miami, Ariz., were covered with about 4 inches of country soil obtained from areas adjacent to the tailings. This country soil was of darker color than the tailings and provided some protection from heat reflection and offered a favorable environment for germination and seeding establishment.

3/ Gates, David M. Radiant Energy, Its Reception and Disposal. Meteorological Monograph 28, v. 6, 1965, pp. 1-26.

The Miami researchers seeded this material with mixtures of seeds representing scores of species so as to obtain diversity. Seedlings or sprouts of various trees and shrubs also were placed by hand. Such practices resulted in vigorous growth of planted species and the rapid encroachment of native species onto the stabilized sites. Eventually such natural succession will produce a cover capable of self-perpetuation without irrigation or fertilization.

Vegetative Testing

Bureau of Mines research at the Salt Lake City Metallurgy Research Center and at the Utah State University is designed to develop improved methods for achieving better initial germination and more rapid growth than is now common on mill tailings. Bureau work is concerned with selecting proper vegetation, studying the interaction of fertilizers with residual heavy minerals and salts contained within the wastes, improving the structure of the wastes to enhance vegetative growth, and developing a combination chemical-vegetative procedure to obviate the problems of highly reflective surfaces and sand blasting. Utah State University under a Bureau of Mines grant is conducting research concerned with leaching of tailings for salt removal, determination of fertilizer requirements, and defining problems associated with acidity derived from the decomposition of sulfides. Pertinent studies conducted at the Salt Lake City Research Center are described as follows:

Species Selection

Seeds of many species were tested for germination and growth in representative samples of various types of tailings. Both domestic and wild plant species were evaluated in as-received tailings and with various fertilizer amendments. Almost always, the domestic species were more reliable germinators than wild species and thus easier to test. Plants that showed considerable promise include the following: Sweet clover, various varieties of alfalfa, winter wheat, rye, barley, various wheatgrasses (western, crested, intermediate, tall, pubescent), other grasses (sorghum, love, Kentucky blue, orchard, etc.), and shrubs such as big sagebrush, rubber rabbit brush, and

Siberian pea tree. A special barley, Charlottetown 80 (grown on Prince Edward Island), has been effectively grown in acidic wastes at a pH as low as 3.0.

Microvegetative Stabilization

Stabilization tests were initiated in which various microscopic plant forms such as algae, lichens, and mosses, rather than the macroscopic forms of vegetation were evaluated as soil stabilizers. Lichen and moss crusts were collected from Canyonland National Park; greasewood and sand dune areas near Delta, Utah; and black sage and shadscale areas near Ely, Nev. These crusts were used to inoculate tailings from the Utah Copper Division of the Kennecott Copper Corp. A comparative control plot of building sand was also inoculated. Preliminary investigations show relatively profuse growth on the control plots and virtually no growth on the Kennecott tailings. Test plots on tailings other than Kennecott's were initiated to determine if the high salinity of the Kennecott tailing is the main deterrent to cryptogamic plant growth.

Effect of Salinity

Considerable difficulty was encountered in growing vegetation in tailings from Kennecott's Utah Copper Division. To determine the reasons, plantings were made in (1) normal tailings, containing considerable water-soluble salts and 0.05 percent copper, and (2) a simulated tailing containing little soluble salts and 0.25 percent copper. Seeded test plots were watered with tap water and tailings effluent water. Germination and growth were adversely affected when effluent water was used. For plots watered with tap water, germination and growth were much better in the simulated tailing material. These tests indicated that the toxicity was due primarily to the high salt content of the water and tailings.

Supplementary tests were made to determine which salts or organic reagents in mill tailings and solutions most affected plant growth. The reclaimed water was compared with a solution simulating organic-free effluent and one containing the organics used in the mill. Water hyacinths were used as the test plant. Hyacinths in the artificial solution with organic agents thrived for several weeks with no visible harm. Plants in mill effluent or in artificial solutions with sufficient inorganic salts added to produce an osmotic concentration comparable to organic-free mill water wilted immediately. The measured osmotic concentrations of the latter two solutions were 2.36 and 2.46 atmospheres. The osmotic gradient between the plant fluids and the environment around the roots presumably caused the plants to become dehydrated. A control test was run in which a hyacinth was placed in a nonreactive mannitol solution having an osmotic concentration of 2.4 atmospheres. The hyacinth wilted as rapidly as in the mill effluent, indicating that death of the test plants was due more to the salt content than to either toxic organic compounds or metallic elements. The principal salt in the mill effluents is sodium chloride, but testing indicates that dehydration is produced with all types of salts at the osmotic concentrations considered.

To determine the effect of salinity on germination, tomato seeds were treated with mannitol solutions at osmotic concentrations ranging from 0 to 5 atmospheres in increments of 0.5 atmosphere. The germination rate dropped with increasing concentration until there was almost no germination at 4.5 atmospheres. In other tests, seeds of several species were planted in copper tailings containing sufficient salts to produce osmotic concentrations between 2.2 and 2.5 atmospheres. These tests indicated that such osmotic concentrations will not materially hinder initial germination of most plants, but will limit growth unless the tailings are leached to remove the soluble salts.

A series of plant growth tests was made on several uranium mining wastes. Tests on samples of stripped overburden from the Federal Partners Mine at Gas Hills, Wyo., showed that a growth of yellow sweet clover, crested wheat, and tomatoes could be established, but salts solubilized by watering are brought to the surface by evaporation and after a month inhibit or destroy growth.

Considerable research was conducted to devise means of overcoming the deleterious effects of salts and acids within mill tailings. Three methods were considered: (1) Percolation leaching of the salts from the tailings, (2) stratification of the sand and slime fractions of the tailings during deposition, and (3) solar orientation of mounds of tailings to produce differential concentrations of salt on shaded and sunlit sides of the mound.

A minimum of work was done on percolation leaching, since Dr. A. L. James[4] had apparently devised a satisfactory means of leaching highly acidic tailings because (1) prolonged flooding compacts the materials producing conditions unfavorable for plant growth, and (2) when flooding is halted, evaporation brings the acid to the surface again. James' investigations indicated that the downward movement of acidity can be encouraged by an extremely fine spray of water which forms a mist over the surface and retards evaporation. If the spray of water applied does not exceed the rate at which it can penetrate the fine slimes, high acidity can be moved to a sufficient depth to permit vegetative growth within a period of 3 to 4 weeks.

Studies made in the Bureau indicated that stratification and mounding of tailings were effective in ameliorating salinity problems. Comparative vegetative growth tests were made (1) in unstratified plots of tailings material, and (2) in "as deposited" tailings capped with a layer of sands overlain by a stratum of slimes. Both plots were permitted to dry thoroughly, then were watered once with sufficient salt-free water to force the "wetting front" several feet into the underlying tails. Subsequently water was added only when plants showed signs of wilting. Appreciably more profuse and healthy plant growth was obtained in the stratified plots. Apparently the sand layer hindered the migration of salts to the upper slime layer in which most of the vegetative growth took place. When tailings were piled in long mounds (approximately 12 inches high) oriented in an east-west direction, vegetative growth was manyfold greater on the northern slopes of the mounds than on south-facing slopes where increased evaporation had concentrated the soluble salts. In this testing, similar to that of Bains and Singh[5] five mounds were established with saline copper tailings from Kennecott Utah Copper Division having a soil solution with an osmotic concentration of about 2.4 atmospheres. The mounded tailings were then planted in April with tall wheatgrass, yellow sweet clover, and Ladak alfalfa in two rows each on north and south slopes of the mounds and one

---

[4] Work cited in footnote 1.

[5] Bains, S. S. and K. N. Singh. Utilization of Solar Radiation in Desalinization of Ridged Plantbeds on Saline Soils. Nature 212 (5069), 1966, pp. 1391-2.

on the top. These tests showed that plant germination and survival after 9 weeks was three times greater on the north slope than on the south slope and that the topmost row of vegetation on the mounds showed poorer growth than that on either slope. The tops of the mounds were subject to more solar radiation than even the south slopes and plant growth suffered commensurately. Samples were taken from the surface inch of the mounds near the planted rows on the northern and southern exposure and leached to determine soluble salt content 15 weeks after planting. The results showed 30 percent more salts on the south than on the north slopes. After 28 weeks, the survival rate of vegetation on the north slopes was 17 times greater than on the south slopes.

In an attempt to reduce the rate at which the mounds erode, five different chemical stabilizers were applied to newly erected and seeded ridges. Results of these trials indicate that the stabilizers do influence erosion rates, and also the germination and survival of plants. Chemical stabilizers tested included Coherex (a resinous adhesive), Orzan A (ammonium lignin sulfonate), Rezosol, DCA-70 (elastomeric polymers), and a cationic neoprene emulsion. After 28 weeks, seedling survival counts showed that almost 40 percent more seedlings grew on the Coherex-treated plots than on the control. In comparison, the cationic neoprene emulsion treatment supported only 50 percent as many seedlings as the control plot; Orzan A, 70 percent; and Rezosol and DCA-70, 90 percent. Thus, Coherex appears to aid seedling establishment and survival in saline waste.

Effect of Heavy Metal Salts on Seed Germination

The presence of copper sulfides in tailings was not as deleterious as originally supposed. Additional plant growth tests made in tailings, containing 0.07 and 0.2 percent copper, indicated that copper content in the sulfide form was not a significant factor. To ascertain if soluble metal salts are toxic copper, nickel, zinc, and composite salts of these elements were added to test plots and tomato seeds planted. Tomato was used as a relatively quick-growing plant that is sensitive to heavy metal phytotoxicants. These tests showed that 1,000 ppm copper had little effect, nickel concentrations above 100 ppm were toxic, and zinc concentrations above 10 ppm were toxic. When using a composite of these elements, toxic effects became evident at 10 ppm and became pronounced at about 100 ppm. The effect achieved with the low concentrations tested indicate toxicity to be independent of osmotic pressure.

Interactions of Fertilizers and Heavy Metal Minerals

Contradictory results were derived from initial tests wherein nitrogen, phosphorus, and potassium fertilizers were added to test plots of copper flotation tailings from different mills. Addition of fertilizers enhanced germination and growth on some tailings, whereas the opposite effect was achieved on other tailings. These opposing effects were deemed to depend principally on two factors: First, if salt-containing tailings produced an appreciable osmotic concentration when watered, the fertilizer appeared to increase this concentration with deleterious effect on the plants. Second, if components of the heavy-metal-containing minerals were easily solubilized by the ammonia in the fertilizer, the metal ions hindered plant growth.

Preliminary tests on several types of mineral wastes indicated that the addition of 45 pounds per acre of urea and calcium treble superphosphate provided sufficient fertilizer to stimulate growth of most plants. As subsequent tests revealed that use of this much urea apparently inhibited germination of legumes, a series of tests was made to determine the effect of urea and calcium treble superphosphate on various legume and grass seeds in quantities of 25, 45, 75, and 120 pounds per acre of each. Comparable tests were run also in which ammonium sulfate and ammonium nitrate were added as sources of nitrogen. In all instances the legumes showed a progressive decline in germination as the quantity of nitrogen added was increased regardless of the form in which the nitrogen was present. At 75 pounds nitrogen per acre, most of the legume seeds failed to germinate; and at 120 pounds per acre, legume germination was zero. The grass seeds conversely did not show any inhibition of germination when fertilizers were added in these quantities. The addition of phosphate fertilizer only in quantities up to 120 pounds per acre had no adverse effect on germination.

Modification of Tailing pH

Both basic and acidic tailings present conditions adverse for plant growth. In some instances, both conditions are present in one tailing accumulation. At Anaconda, Mont., the pH of the first of several successive tailings ponds is over 10.5, whereas the pH of the final pond is less than 3.0, presumably due to oxidation of the pyrite in the tails. The acidity and basicity of tailings can be neutralized by adding lime and sulfuric acid, respectively, but problems arise if the amount required is appreciable. Impervious crusts are sometimes formed if the neutralizing agent interacts with the acidic or basic causative agent. Limestone is less reactive and cheaper than lime and thus would be a preferred compound for many acid neutralization needs. The use of a fine water spray, described earlier, provides another technique which may be effective for eliminating excess acidity.

Several samples from various locations would not support vegetation without neutralization. Among these were uranium tailings from Wyoming and Colorado which had respective pH's of 2.3 and 4.5; 70 and 6.7 pounds of lime, respectively, added to the top 2 inches of tailings per acre, changed the pH level to sustain plant life. Vitro Minerals & Chemical Co. of Salt Lake City, Utah, has both acidic uranium tailings (pH 3.6) and basic vanadium tailings (pH 8.5). These were mixed in equal portions to produce a material of pH 6.3 in which seeds readily germinated. Fertilization, however, was necessary to sustain adequate plant growth.

Physical Modifications of Tails

Several methods were tried for increasing particle aggregation of tailings to provide better root environment and soil aeration thereby improving vegetative growth. Effective pelletizing and agglomerating procedures were developed. One of these procedures consisted of pelletizing tailings to minus 8- plus 35-mesh size with 2.5 percent asphalt, hardening the pellets by baking at 250° C, and spreading the pellets over the surface of the tailings to a depth of 1/2 inch or mixing the pellets with an equal quantity of tailings to form a 1-inch-deep covering over normal tailings. A similar pellet was achieved, without the baking step, by pelletizing with 3 to 4 percent Peneprime (a commercial asphaltic bitumen product cut with white kerosine). Another procedure not requiring pelletization encompassed (1) seeding the tailings, (2) watering the tailings, (3) raking the wet tailings to form small-size agglomerates, and (4) spraying the agglomerates with Coherex and/or Soil Gard, an elastomeric polymer, to preserve the pelletized form. Plant growth was improved in all instances where a granular, soil-like texture was achieved by these agglomerating methods.

One segment of vegetative stabilization research, that of making a simulated soil from tailings and municipal waste, could be considered as a utilization practice. However, as the growth of vegetation on such simulated soils is the best evidence of success, this phase of research is considered a stabilization approach.

Two types of municipal wastes were tested as additives to tailings. One was a commercial compost made from municipal refuse, and the other was sewage sludge. Both are bulky organic materials which can, when mixed with soils, furnish soil textures conducive to providing better soil, air, and water relationships. Plots prepared with Kennecott Copper tailings and 5 tons per acre of each of the two waste-derived products indicated the additives to be beneficial to both vegetative germination and growth. The sewage sludge produced better growth than the commercial compost, and plots treated with either material demonstrated much better growth when additional fertilizer was added. The preferred conditions for making simulated soils will be determined by additional testing.

Studies also may be made to determine if compost or sludge can be added to the final tailings discharged from a mill to be abandoned to determine if suitable mixing and deposition of the compost and tailings can be obtained thereby decreasing the cost of application.

Dewatering Research

Another facet of the research involved attempts to hasten dewatering of Florida phosphate slime wastes through the use of plants. Dusts blowing from the mineral wastes in the arid west present air pollution problems, but the main problem connected with Florida phosphate slimes is that of excess water. The phosphate slimes are discharged at approximately 2 percent solids and after years of storage have thickened to about 30 percent solids.

Research was directed toward biological dewatering of the slimes. In a preliminary dewatering experiment, a single water hyacinth was planted in a cylinder filled with a 19.7 percent solids slurry. Initially, additional slime was added through the bottom of the cylinder to maintain the slime level at the top of the cylinder as evaporation and transpiration proceeded. After 18 weeks, addition of new slime was halted and the hyacinth was permitted to dewater the slime for another 10 weeks. At the end of the test, the top 3 inches of slime contained 57.3 percent solids, and the average percent solids for the entire cylinder was 35.1 percent. From a total of 217 pounds of pulp, 95 pounds of water was lost by transpiration and evaporation.

Hyacinths planted in more dilute slurries were equally as effective and a higher percent of solids was achieved in 10 to 20 weeks than is normally obtained after years of ponding. Test plots showed 14.2 percent more water was lost by combined evaporation and vegetative transpiration than by evaporation alone in 4 weeks' time. This percentage rose to 17.6 after a 7-week interval. Water mint and water cress also proved effective dewatering agents in trials conducted at the Salt Lake City Metallurgy Research Center. The use of water mint as a biological dewatering agent with possible commercial harvesting as an inducement may prove a more practical solution to the dewatering problem than that offered by water hyacinth.

Combination Chemical-Vegetative Stabilization

Perhaps the most innovative study of the Bureau of Mines has been the development of a combination chemical-vegetative stabilization method. The use of proper chemicals in conjunction with vegetative growth can have several advantages. The chemical can be of benefit by (1) preventing sand blasting of the plants, (2) retaining moisture in the tailings by decreasing evaporation, (3) aiding in germination by absorbing heat, (4) adding organics, and (5) preventing reflection of the sun's rays back onto the plant.

Several chemicals that effectively stabilize tailings were evaluated as to beneficial effect when used with vegetation. Testing during the winter was accomplished in an indoor laboratory using Grow-lux lamps augmented with infrared lamps to more nearly approximate the sun's rays. Summer testing was conducted outdoors under natural sunlight conditions. The results obtained from indoor testing appeared to be compatible with those obtained under harsher outdoor conditions.

A series of indoor tests was made in which ranger alfalfa, crested wheat, yellow sweet clover, rabbit brush, sagebrush, and Marglobe tomatoes were planted in leached and unleached Kennecott Utah tailings which had been treated with several chemical soil stabilizers. The group planted in leached tailings included a control and four plots treated with Coherex, Soil Gard, Peneprime, and Compound SP-400. The group planted in unleached tailings included a control and two plots treated with Coherex and Soil Gard. Coherex and Soil Gard stimulated germination and sustained plant growth; Peneprime and SP-400 hindered germination under the conditions tested. On leached tailings, the effects of Coherex and Soil Gard were nearly the same; on unleached tailings, Coherex performed better than Soil Gard. The respective germination and survival rates were as follows, in percent:

	Coherex		Soil Gard	
	Germination	Survival	Germination	Survival
Leached.....	64.1	61.0	54.7	52.6
Unleached...	30.5	16.0	14.5	5.6

Other indoor tests were made in which the germination and survival rates of barley, yellow sweet clover, alfalfa, crested wheat, and Marglobe tomatoes were tested in leached and unleached Kennecott tailings treated with Coherex, fertilizer amendments (P_2O_5 and urea), and combinations of the three. With the leached tailings the effect of

Coherex plus fertilizer was pronounced. Germination rates (after 12 days) were 40 to 56 percent, while with fertilizer alone only 4 percent germinated. In unleached tailings, the germination rates were highest (20 to 34 percent) in the plots treated with Coherex plus fertilizer.

Outdoor tests initiated during July tended to corroborate the indoor test results with some exceptions. There was no observable difference in the longevity of plant growth on leached or unleached tailings that were otherwise treated similarly. Germination rates indoors were much greater for the Coherex-treated samples but outdoor-germination rates were more nearly equal to those of the untreated control samples. Presumably this was due to the great amount of heat available outdoors which offset the advantage accruing to the darker-colored Coherex plots in the cooler indoor test areas.

A combination system involving vegetation and an application of Coherex to stabilize the surface against sand blowing until the plant cover was able to take over that function itself was ultimately developed from knowledge acquired from the laboratory and field plot trials. That system was applied to a 10-acre plot of Kennecott's McGill, Nev., tailings in mid-September of 1967. The McGill tailings are located in a climatically harsh site for vegetation. The growing season is short, the temperature range is wide, and precipitation is only 8.37 inches per year. Different proportions of western, pubescent, crested, intermediate, and tall wheatgrasses, Russian wild rye, Ladak and ranger alfalfas, yellow sweet clover, winter wheat, and Siberian pea tree seeds were mixed and planted by drill seeder at a rate of about 35 seeds per square foot. Prilled urea and superphosphate fertilizers were added to the seeding mixture at a rate of about 45 pounds per acre each of P_2O_5 and nitrogen. The mixture was planted in furrows 10 inches apart. (This field test was conducted prior to discovering that nitrogen in this quantity tends to inhibit legume germination.) A week after the area was seeded, Coherex diluted with 4 parts water was applied over the entire area at rates of 0.18 to 0.66 gallon of dilute solution per square yard.

A germination count of the plants was made 1 month after seeding. This count showed that 24, 12, and 52 percent of the legumes, grasses, and winter wheat, respectively, had germinated. The seedling plants were vigorous and healthy ranging up to 5 inches in height. One week later, a killing frost destroyed most of the legumes which were still in the cotyledon (earliest leaf) stage.

The seeded area was resurveyed the following year, on May 14 and September 5, 1968. These surveys, especially the latter, indicated that the primary objective was attained--the area was stabilized against wind erosion, and native plant species were encroaching onto the stabilized plots. The Siberian pea tree was the only one of the 11 species originally planted that either did not germinate or failed to survive to the September 5, 1968, survey. Eleven wild species had encroached and were growing. Table 1 furnishes a summation as to the seeds planted with germination and survival rates. Table 2 gives the complete list of plants extant on the plot as of September 5, 1968.

TABLE 1. - Seeds and plants per square foot

Item	Date	Perennial grasses	Legumes1/	Winter wheat	Total seeds or plants	Percent of total planted
Planted......	9/14-15/67	23.1	12.2	1.7	37.0	100.0
Germination count.......	10/17/67	2.86	2.89	.89	6.64	17.9
Plant count..	5/15/68	2.40	.17	.47	3.04	8.2
Do.........	9/5/68	1.41	.02	.51	2/1.94	5.2

1/ Includes Siberian pea tree planted at rate of 1 seed per 2.7 sq yd.

2/ When wild species are included in the count, the total amounts to 2.40 plants per square foot.

TABLE 2. - Existing plants on September 5, 1968

Common name	Scientific name
Winter wheat	*Triticum aestivum*
Russian thistle	*Salsola kali tenuifolia*
White sweet clover	*Melilotus alba*
Intermediate wheatgrass	*Agropyron intermedium*
Tall wheatgrass	*Agropyron elongatum*
Crested wheatgrass	*Agropyron desertorum*
Russian wild rye	*Elymus junceus*
Pubescent wheatgrass	*Agropyron trichophorum*
Western wheatgrass	*Agropyron smithii*
Indian ricegrass	*Oryzopsis hymenoides*
Alfalfa[1/]	*Medicago sativa*
Halogeton	*Halogeton glomeratus*
Shadscale	*Atriplex confertifolia*
Wild barley	*Hordeum jabatum*
Bassia	*Bassia hyssopifolia*
Prostrate knotweed	*Polygonum aviculare*
Big rabbit brush	*Chrysothamnus nauseosus*
Sagebrush	*Artemisia tridentata*
Greasewood	*Sarcobatus vermiculatus*
Bee plant	*Cleome serrulata*

[1/] Plants could not be differentiated as to type (Ladak or ranger).

Horses, rabbits, pocket gophers, and other animals have invaded the area acting as disruptive influences, but the tailings appear to be completely stable. The rabbits have chewed off the tops of most of the wheatgrasses and legumes; ultimately this should prove beneficial by hastening tillering of the plants. On the other hand, the rodents cut off all the flowering heads of wheat prior to seed maturity, thus preventing reseeding. The rodents have established extensive burrow systems in the tailings.

Many violent windstorms have passed through the McGill area during the year of test without raising dust clouds from the stabilized plot. The Coherex satisfactorily maintained the surface until the vegetation grew and the chemically and vegetatively stabilized tailings now appear fully resistant to wind erosion. No irrigation was applied to the plot during the year, but growth was deemed as excellent for the conditions. Eight different nitrogen, phosphate, and potash fertilization regimes plus limestone amendments were applied to different parts of the vegetated area in October 1968. The results of the different fertilization treatments will be compared with control plots when plant counts are made in 1969.

An accounting was kept of material and application costs associated with treatment of the 10-acre plot. The Coherex was applied in quantities ranging from 0.18 to 0.67 gallon per square yard to determine comparative stabilization achieved. During a year of observation, no appreciable differences were noted in the stabilization of plots treated with the Coherex. This would indicate that the preselected quantity of 0.25 gallon per square yard of dilute Coherex solution could be reduced with a resultant savings in cost. Table 3 presents the costs based on application of 0.18 gallon Coherex per square yard. The estimated cost of $1,355 for the 10 acres could probably be reduced if larger acreages were treated or if proper equipment were readily available.

TABLE 3. - Cost of stabilization procedure per 10 acres

Item	Application rate	Cost
Seeds......................	37 seeds per sq ft......	$ 56
Calcium treble superphosphate............	45 pounds P_2O_5 per acre.	51
Prilled urea...............	45 pounds N per acre....	62
Coherex:		
At 20 cents per gallon...	0.18 gallon per sq yd[1].	348
Freight at 8¢ per gallon.	....	140
Labor, at $3 per hour......	3 men for 3 days........	216
Equipment expense:[2]		
Seeder and grader........	Seed 10 acres.........	100
Water truck..............	Water 1/4 inch and apply chemical to 10 acres..	382
Total..		$1,355

[1] Coherex solution diluted with 4 parts by volume of water.

[2] Equipment costs estimated.

MR. D. JONES
MANAGER
TECHNICAL SECTION
CANADIAN PULP AND PAPER ASSOCIATION
MONTREAL, QUEBEC

R. N. FARVOLDEN

"HYDROGEOLOGIC FACTORS IN LANDFILL DESIGN"

BY

R. N. FARVOLDEN
ASSOCIATE PROFESSOR OF GEOLOGY
UNIVERSITY OF WESTERN ONTARIO
LONDON, ONTARIO

G. M. HUGHES
ASSOCIATE GEOLOGIST
ILLINOIS STATE GEOLOGICAL SURVEY
NAPERVILLE, ILLINOIS

Introduction

Just a few years ago, conferences of this sort were held for the purpose of alerting the public to the pollution problem, and getting support for legislation in waste disposal. The overwhelming success of this campaign is a tribute to the efforts of some of our conservation minded officials and to the power of the mass media. There are few subjects on which the public is so united as that of water resources and pollution. While we acknowledge the work of these people we must recognize that simple repetition of the fact of pollution is no longer enough, and our concern now must be for solutions to specific problems in all aspects of the matter. Proper landfill design is one of the effective ways of averting pollution from waste disposal.

One of the best ways of disposing of wastes is by burial in the shallow subsurface. For the large volumes of waste from any large urban area, it is by far the most economic method of disposal, and has the added advantage of finality in that there is no further handling. But, because of the volumes involved, old sites are rapidly being filled and new sites are required. The appraisal of a site for waste disposal always raises some controversy.

First there are economic and political considerations. Local disposal may be prohibited by zoning regulations or by severe restrictions on the actual disposal operation. If the only alternative is long transport, the economic advantage of landfills may be lost. Some restrictive regulations are based on misconceptions or ignorance of the pollution hazards, and thus the cost of disposal is increased. Most regulations, most literature, and most research on landfills deals with the collection, transport, and implacement of waste, and on the processes of decomposition. Very little research has been done on the groundwater pollution hazard. The physical characteristics of the subsurface into which the waste is being dumped are usually dismissed with the stipulation that there be no pollution of groundwater. While this is very admirable, usually the only steps that are taken to prevent pollution are to require certain design and operation procedures, some of which are based on misunderstanding of natural phenomena. Further, pollution is only recognized when an existing well is affected because rarely is a special monitoring system installed.

The uncertainty of the effect of refuse landfills on the groundwater resources led to our investigation in northeastern Illinois. This investigation was supported by the Illinois State Geological Survey, the University of Illinois, and the Illinois State Health Department, and funded in part by a grant from the U.S. Public Health Service.

Our conclusions are that the landfill method can be used safely for the disposal of wastes, almost anywhere, provided that proper design and operational techniques are followed to suit the conditions at the site.

Design Objectives

Wherever wastes are buried in contact with the ground we must expect that at least some volume of the earth, that in direct contact with the fill, will be contaminated. Although we cannot eliminate this completely, our objective must be to ensure that the envelop of contamination is acceptable in every respect. This requires a design and operational procedure based on the physical or hydrogeological environment of the site. By hydrogeologic environment we mean the physical and chemical properties of the subsurface, the medium, and also the groundwater in storage and transit through the medium.

Water in the subsurface moves according to Darcy's law, which may be written:

$V = ki$ where:

v = velocity, (cm/sec.)
k = permeability of the medium, (cm/sec.)
i = hydraulic gradient, (dimensionless).

From the equation it is obvious that if there is a finite permeability and a gradient then there must be some water movement. The movement is in the direction of the maximum gradient on the groundwater head. Water levels in wells are a measure of the head; this is the reason they are important data in groundwater-flow studies.

Contaminants from waste disposal sites move with groundwater as dissolved solids, so a very effective way of restricting these contaminants to the disposal site is to keep the fill in an unsaturated state. This is quite feasible in an arid climate where there is always a soil moisture deficiency. Under these circumstances the saturated zone is rather deep and infiltrated rain does not reach it. Thus refuse may be buried in the unsaturated zone where it will not be leached (University of Southern California, 1954). In the humid climates of the midwest and Ontario, there is sufficient rain for groundwater recharge. The saturated zone is thus close to the surface over much of the area, and refuse will be leached whether it is buried above or below the water table.

Our proposed design objectives and techniques are based on the assumption that a highly contaminated leachate will be produced in the fill by water that has infiltrated from precipitation or water that is in movement through the ground. We propose three sorts of design objectives, depending on the hydrogeology of the site. They are: 1) to allow for predicted and acceptable migration of the contaminants from the site, 2) to allow for migration and subsequent collection of the contaminants, and 3) to retain and collect the leachate within the fill. Any combination may be a suitable objective at a particular site.

1. Design to allow for predicted and acceptable migration.

Leachate will migrate from any landfill if the gradient is downward or outward. This is usually the case in an upland area where the gradient is away from the fill in all directions. A landfill may leak leachate to the groundwater flow system but because the flow lines diverge the leachate is diluted and the hazard is reduced. If the earth material is clay, movement will be slow and contamination will be restricted to a narrow zone adjacent to the fill, a situation which cannot be regarded as alarming. At the old DuPage county landfill in Illinois, studied in this project, leachate is migrating downward through about 30 feet of clay till toward a permeable, heavily pumped, aquifer. The closest well is only about 200 feet from the fill, and pumps nearly one million gallons per day. The combination of slow percolation of the leachate and high pumping rate of the well provides a dilution factor that eliminates any hazard.

Leachate from a landfill may migrate to a natural zone of discharge such as a stream or lake. Again, dilution may overcome any hazard whereas concentration may aggravate the hazard.

2. Design to allow for migration and subsequent collection of leachate.

In order to achieve this objective, the landfill must be located so that groundwater flow lines that pass through the refuse converge farther on at a place where the fluid can be collected. A favorable location would be near a natural groundwater discharge zone where the leachate from the landfill will reappear at the surface and can be easily collected. Examples include a slope near a stream, valley, or kettle hole. If flow lines do not converge naturally to allow easy collection of leachate, they can be made to do so by creating an artificial discharge zone by ditches, tile drains, or pumping wells. The success of this scheme will depend upon keeping the volume of water to be handled within manageable limits. Two obvious sites to avoid are major discharge areas such as the flood plain of a river and areas over shallow permeable aquifers.

3. Design to retain and collect leachate within the fill.

The leachate generated within the refuse of a landfill is effectively retained if the fill is in thick, relatively impermeable clay, a condition rather common over wide areas of Ontario. Where refuse must be disposed of in permeable materials such as sand and gravel, regulations may require that a clay liner be emplaced for the purpose of retention. Usually such regulations neglect two very important considerations. First, there must be some migration of contaminants if there is a finite gradient and permeability, and second, if the leachate is not allowed to migrate in the subsurface then it must spill out on the surface, for the water that infiltrates must also be discharged. Both of these possibilities can be averted by draining of the leachate within the fill so that the gradient is always into the fill. Again, a well or tile drains are required.

All three of these design objectives are directly affected by the quantity of leachate produced. Quantity in turn is a function of the rate of infiltration of precipitation into the fill. Infiltration is easy to reduce by proper grading, draining, and choice of cover materials. This is seldom considered in landfill design. On the contrary, most landfills are completed in such a way that maximum infiltration is assured.

Irrigating the landfill cover, and injecting liquid wastes, supplements natural recharge. The additional fluid helps raise the refuse to field capacity and adds to the quantity of leachate moving from the site.

Operational considerations in site selection

The design objectives all concern protection of groundwater from pollution so are naturally based on hydrogeology. Hydrogeology is also the factor that limits choice of operational methods and ultimate land useability. All landfill operations require some sort of excavation, either to provide space for refuse, or to provide cover material, or both. The type of materials and the groundwater conditions will determine how and where this excavation is to be carried out; whether the refuse is to be buried in trenches or piled on the ground surface; whether cover material can be obtained on the site or must be hauled in. It is hydrogeologic conditions which control how the landfill operation can be conducted most economically and still meet the requirements of sanitation.

In this respect too, a river flood plain has obvious disadvantages, such as excavating in saturated silt, dumping in a water-filled trench, and contending with a polluted pond in the excavation. These can be avoided by not excavating but then there will be no cover material on the site and it will have to be hauled in. Lack of cover material is also a disadvantage when using existing excavations such as quarries and gravel pits.

It is becoming more and more common to plan a landfill site for ultimate use as a recreational facility. This is particularly true in metropolitan areas. Piling the refuse into hills is commonly part of this plan. While there are obvious advantages to this procedure, there are some disadvantages which are not so obvious. Again, spoil to cover the refuse during the daily operations must be hauled to the dumping face at the top of the hill, which is much more expensive than having it piled adjacent to the dumping face as in the trench and fill method. Also, we have found that the flow of groundwater in the vicinity of the site is controlled by a groundwater mound that developes under the refuse hill (Hughes, Landon, and Farvolden, 1968). This groundwater mound has the same characteristics as natural groundwater mounds and one of these is the occurrence of springs on the surrounding slopes, where the water table intersects the land surface. These springs of objectionable leachate should be anticipated in every case where refuse is being piled high in hills. The mound will not start to form until infiltration has brought the fill up to field capacity, which in Ontario requires about one year for each ten feet of fill (Remson, et al, 1968). The draining and collection techniques already described are suitable ways of dealing with this problem, if they are considered in advance and incorporated into the design and operational plan. Provision must also be made for coping with the obnoxious and explosive gases produced by decaying refuse.

At present, the operators of many of the true sanitary landfills follow the practice of laying a final cover of earth over the site, grading and seeding it to grass. The result is quite pleasing in appearance and the site is then suitable for recreational uses. However, a grass cover is one of the most favorable for high infiltration rates and therefore this practice promotes high production of leachate in the fill.

Conclusions

Our research indicates that landfill disposal is a very satisfactory method of coping with the problem of solid wastes. The safety from pollution depends on meeting a design objective compatible with the hydrogeology of the site. The economy depends at least in part on adapting the operation to the hydrogeologic environment. It is unrealistic to prohibit disposal in any particular environment because at least one of our design objectives can be met at almost any site. Whether or not it is economic to do so should be a decision for the operator who wants to use the site. The regulatory agency need be concerned only that acceptable objectives are met.

References

Hughes, G. M., Landon, R. A., and Farvolden, R. N., 1968, Hydrogeology of solid waste disposal sites in northeastern Illinois: Progress Report to the Department of Health Education and Welfare, Cincinnatti, Ohio, 137 pages.

Remson, Irwin, Fungaroli, A. Alexander, and Lawrence, Alonzo, W., 1968, Water movement in an unsaturated sanitary Landfill: Journal of the Sanitary Eng. Div., A.S.C.E., Vol. 94, N.SA2, Proc. Paper 5904, April, 1968, pp. 307-317.

University of California, Los Angeles, Sanitary Engineering Research Laboratory, 1954, Final report on the investigation of leaching of a sanitary landfill: California Water Pollution Control Board, Pub. 10, Sacramento, California, 92 pages.

D. D. MCLEAN

"SUBSURFACE DISPOSAL OF LIQUID WASTES IN ONTARIO"

BY

D. D. MCLEAN
RESERVOIR ENGINEER
DEPARTMENT OF ENERGY AND RESOURCES MANAGEMENT
TORONTO, ONTARIO

PAPER READ BY: D. A. SHARP
SUPERVISOR
PETROLEUM RESOURCES
DEPARTMENT OF ENERGY AND RESOURCES MANAGEMENT
TORONTO, ONTARIO

Note - The following is presented as highlights extracted from a report prepared by the author and published as Departmental Paper 68-2. Copies of the report may be obtained from the offices of the Ontario Department of Energy and Resources Management, 880 Bay Street, Toronto 181, Ontario.

INTRODUCTION

Pollution of our streams and lakes with industrial waste has become a matter of grave concern to all levels of government throughout North America. The general public is increasingly alarmed and many process industries themselves are concerned.

The problem will intensify dramatically over the next few decades as the population expands - Ontario, alone will see the number of people living within its boundaries increase from 6½ million to possibly 20 million after the turn of the century - Increased competition for the use of our fresh water will make it necessary to place rigid and costly controls on the use of surface waters for waste disposal.

Industry will be forced to seek more efficient and economical methods for treating and disposing of its wastes. Under specified and clearly defined conditions, the subsurface has been a convenient receptacle for such products.

Much of our knowledge concerning the subsurface disposal of fluids is derived from the petroleum industry. For many years oil field brines have been injected into the subsurface through normal disposal operations, or more often, in conjunction with secondary recovery operations.

The process industries did not make use of the concept for waste disposal until the early 1950's and today, only 140 disposal wells exist, of which 120 are in the United States, 16 in Ontario (of which 11 are operating) and four in Saskatchewan (Figure 1).

The ensuing comments of this discussion were derived, essentially, from a departmental report which was prepared to aquaint the process industries in Ontario with the concept of subsurface disposal, to provide information as to suitable locations in the province, and most importantly, to note the many pitfalls that could plague this type of operation.

Formation Evaluation

In determining an area suitable for subsurface disposal of liquid wastes, the geological and hydrological conditions are the primary considerations. An industry considering subsurface disposal must determine if an underground formation will accept fluids, at what rates and pressures and how the injected fluids will move within the formation.

Geological Considerations

Sedimentary rocks are, in most cases, selected for subsurface disposal although fluids have been injected into metamorphic complexes with varying degrees of success.

Ideally, the sedimentary formation should possess the following characteristics. The formation should:

(a) be a uniform sandstone, limestone or dolomite or under favourable conditions, a fractured shale;

(b) be of a large areal extent;

(c) be of sufficient thickness;

(d) have high porosities and permeabilities;

(e) possess adequate overlying and underlying impermeable strata or aquicludes;

(f) have a low pressure;

(g) be well below and separated from fresh water horizons;

(h) be salt-water filled and artesian in nature;

(i) possess waters which are of no economic value either now or in the forseeable future;

(j) possess fluids and rocks which are compatible with the injected fluid; and

(k) have no unplugged wells that penetrate the formation in the vicinity of the disposal well.

Structural conditions in the receiving formation as an anticline or dome may be considered for the retention of fluids having a specific gravity lighter than that of the formation waters. However, since these structures are widely used for gas storage, they should normally be reserved for that purpose at least within proximity to populated areas. Further, pressure buildup in the formation and dispersion of injected fluids could detrimentally affect nearby hydrocarbon deposits, and assurance must be made that disposal is not conducted near these accumulations or near areas that could contain hydrocarbons.

The presence of faults or fractures in the region of a disposal operation and for that matter, the presence of unplugged wells, must always be considered. The effect of these situations is illustrated in Figures 2 and 3.

A variety of pump tests have been developed by ground water hydrologists to determine where faults or other barriers exist or where there is a pervious cap rock. These tests, however, usually involve observation wells. Also, pressure buildup tests have been developed in the discipline of petroleum engineering to detect the presence of barriers or faults within the region of the well bore. If a region is suspected of possessing barrier conditions or pervious confining rocks, these tests should always be considered to assure a long-term success of the disposal operation.

Hydrological Considerations

One of the most important and perhaps the least understood considerations with respect to subsurface disposal is the question of what happens to the waste once it is injected into the receiving formation or aquifer.

In the past, effluents have occasionally been injected into what appear to be suitable formations with little concern as to where and how the fluid was dispersing, what possible damaging effects such foreign fluids would have over long periods of time and, especially, what effects pressure distribution or buildup would have in the formations.

The concept of disposing of fluids into a water-bearing rock may, at first, be difficult to visualize. Basically, the waters in the aquifer are compressed by the injected wastes in an ever-increasing or expanding cylinder away from the well bore. Water at bottom hole pressure is only slightly compressible (3×10^{-6} unit volumes per p.s.i.), and as such, an aquifer must be of a large areal extent to distribute the increasing pressure. If the formation is confined, or affected by faulting in the region of the disposal well, a very limited area would be available for compression of the formation water and pressures would rapidly build up or injection rates decline to the point where the operation became impractical.

Research in petroleum engineering and ground water hydrology has produced a number of useful equations for evaluating the hydrology of the receiving formation. Using these equations, an estimate of the injection rates and pressures can be calculated from data obtained from nearby wells. The pressure effect developed in the formation with time and distance for various injected volumes can also be calculated. However, because of the many local factors which can affect the performance of a well, actual testing must be made at the well to measure the injection capacity.

The concept of radial flow in an artesian well is illustrated in Figure 4. Figure 4 shows the expanding cylinder concept for a homogeneous and infinite aquifer of equal thickness. An expression of the dynamic pressure surface is illustrated where the greatest pressure or potential exists at the formation face of the well bore - decreasing exponentially away from it. This pressure surface is the reverse of the cone of depression which results as water is withdrawn from a water well.

This figure illustrates also, how this equation can be utilized to calculate the approximate minimum injection pressure at the wellhead. Further, it is seen that the injection rate is directly proportional to the formation capacity (permeability x thickness).

Therefore, as the capacity increases so does the injection rate at any given pressure differential. Other equations exist, as well, expressed in dimensionless units which can be utilized to compute the bottomhole injection pressure as a function of time, and to measure the pressure effects of other disposal wells in the vicinity.

One of the most important, and possibly least understood, considerations with respect to subsurface disposal is the pressure effects at various distances from the well bore, for given times and volumes of fluid injected. Where legal situations may develop, or where disposal is conducted in formations that have other potentially valuable minerals in the area, this factor becomes very important. In addition, this information is most useful in predicting long range reservoir performance and design of injection equipment, pumps, tubing, and the effect in unplugged wells in the vicinity.

Many oil field formulae have been developed to evaluate similar situations and can be applied under certain situations. However, some of the formulae provide for fluid withdrawal as well instead of a normal waste disposal situation where such relief is non-existant.

The ground water industry has developed equations as well to describe fluid withdrawal from a water well. These equations can be used in reverse to describe injection into a formation. The rate at which the pressure increases in the formation and the distances that the pressure moves radially out from the injection well for a specific injection rate can be computed from non-equilibrium equations. If equilibrium flow conditions are attained or approached, however, these equations are no longer applicable. As water is continuously pumped into a homogeneous, uniform aquifer of infinite areal extent, the pressure radius will increase but at a decreasing rate because of the expanded storage area available as the "cylinder" enlarges.

As illustrated in Figure 5, a non-equilibrium formulae is shown which can be used to calculate the pressure-distance-time relationship for given injection rates and values of permeability, under certain uniform reservoir conditions. The permeability concept in this equation is described as a coefficient of transmissibility expressed in gallons per day per foot.

The coefficient of transmissibility is defined as the rate at which water will flow through a vertical one foot wide strip of the aquifer under a 100% hydraulic gradient. The coefficient of storage is defined as the volume of water taken into storage per unit of surface area per change in head.

Transmissibility can be computed from the drawdown curve following an injectivity test, however an observation well is necessary to calculate the coefficient of storage. If an observation well is not present, an assumed value for a normal limestone reservoir would be in the order of 10^{-4}. However, the dangers of such assumptions are obvious and it must be remembered, that the valves calculated for transmissibility and storage only apply to the immediate area of the well bore and that core analysis of other wells in the area will greatly assist in evaluating the validity of the calculations.

If the disposal aquifer is nearly homogeneous and of uniform thickness the effluent will move out radially from the well bore neglecting the effect of natural hydraulic gradient movement. Surprisingly, a very large volume of fluid can be placed near the well bore. As shown in Figure 6 for a typical disposal situation of 100 g.p.m., over a 50 foot thickness of aquifer of 20% porosity, the effluent moves out only one-half mile from the well bore in 50 years, and usually within the boundaries of the plant disposing.

DRILLING, COMPLETING AND TESTING OF DISPOSAL WELLS

Great care must be exercised in the drilling and completing of an injection well. One of the most important considerations is the protection of fresh water sources and other valuable minerals. Figure 7 illustrates the completion of a typical disposal well in which the surface casing is usually cemented and in all cases, the injection string will be cemented to surface.

The size and weight of the casing is important depending upon the pressures and depths encountered and the volumes to be injected. Larger injection strings will have the effect of reducing wellhead injection pressures. However, over-size holes are costly and often unnecessary. Proper casing and tubing sizes should always be calculated for the maximum anticipated volumes to be injected.

Where favourable conditions exist, the use of the cable tool to drill disposal wells is often preferred because of the lesser chance of damaging the disposal formation as in the case of mud using rotary equipment. However, rotary equipment can be equally effective and if possible, clean water or air should be used to drill out the aquifer. The open hole completion method is certainly preferred where consolidated and uniform formation conditions exist. The use of packers on the tubing will depend, among other things, on the corrosiveness of the effluent. In any event, the annulus should be filled with an inhibited water or kerosene and monitored at the wellhead to detect any detrimental change in the operation. Plastic coated tubing should be used where highly corrosive fluids are disposed. However, great care must be exercised in placing such tubing in the hole.

The rate of injection can often be greatly increased by stimulating the formation with various chemical or mechanical methods which effectively increase the porosity in the critical region of the well bore and reduces the chance of plugging. The use of such methods will depend on the chemical and physical nature of the formation as determined from core, sample and log analyses.

In order to design adequate surface equipment and pumping equipment, and to accurately evaluate the hydrologic properties of the disposal formation, as described previously, injectivity tests should be run. If possible, the test should be run to a critical input pressure, or the point at which the formation starts to part. This point will determine the maximum safe injection pressure. Usually this value ranges from 0.5 to 1.5 p.s.i. per foot of depth. Assuming a value of 1.0, the injection pressure will range from 0.65 to 0.8 p.s.i. per foot at the formation face.

The success of any disposal operation is dependent not only upon proper completion and testing of the well, receiving formation and equipment, but also upon the compatibility of the effluent with the formation brine and the rock itself. Compatibitibility tests should be conducted in the laboratory on both the core and brine samples under assimilated reservoir conditions.

If the effluent is incompatible with the formation waters or rock, plugging can take place relatively quickly and increase the injection pressures to the point that the operation becomes uneconomical. Common causes of plugging are from suspended solids as resins and hydrocarbons in the waste; various ions as barium, iron manganese etc., which can cause precipitates under certain environments; organic materials which may form an environment for microorganisms, oxygen and CO_2 which could develop corrosion products. Although many of the causes of plugging result from the incompatibility of the fluids, certain effluents will re-act vigourously with the rock itself, or cause swelling of any clays present. Ideally, the waste should have a pH slightly below that of the formation brine.

The results of such tests may involve costly surface treating facilities which could feasibly make the project impractical. On the other hand, prior purchase of costly equipment that may be unnecessary could be avoided through proper testing procedures. If some incompatibility still exists after treating, a buffer of clear water could be injected ahead of the first slug of effluent.

The continued performance of a disposal operation must include a properly designed monitor program in order to detect failure of various well components as the packer, casing, cement, or sudden plugging or rupturing of the formation.

The monitor program at specified intervals should include the injection pressure, rate of injection, chemical composition of the effluent, annulus pressure, and a measure of the injectivity index (input rate/p.s.i. increase in bottom hole pressure) which should remain constant unless such things as plugging develop.

The validity of an observation well or wells may be questionable in certain reservoirs with respect to monitoring the waste travel, however, such a well is a necessity if the disposal area is near fresh water environments or areas containing valuable minerals. The well also serves as a check on the calculated pressure-distance-time plots, and future reservoir performance. An important consideration with respect to an observation well drilled into the receiving aquifer is that it can also serve as a stand-by well in the event of failure in the main well and where the plant operation is dependent upon continuous injection. Very often an observation well will be drilled into the deepest overlying fresh water zone especially if highly toxic wastes are being disposed.

Legal Considerations

There does not appear to have been a case documented where subsurface trespass has been contested. Nevertheless, the possibility must be considered. With the knowledge available today in the fields of hydrology, a plaintiff will have little difficulty proving trespass should the occasion arise.

Although trespass in itself would unlikely be a cause for legal recourse, destruction of valuable resources such as hydrocarbons, brines or mineable minerals would definitely be a cause for damages.

Damage suits are more likely to arise from failure in the well itself through improper construction or maintenance, which allows waste fluids to migrate into horizons other than the disposal aquifer, especially into fresh water sources.

Although the role of the regulatory agencies in Ontario is to assure that all disposal operations are properly engineered, and that damages of the nature described are avoided, the permit so issued does not alleviate the legal responsibility of the operator.

Conditions in Ontario

The sedimentary area of Southwestern Ontario is encompassed by the northern rim of the Appalachian Basin and the eastern rim of the Michigan Basin. As shown in Figure 8, these rocks range in age from Upper Cambrian to Upper Devonian and constitute only 25,000 square miles of land area. The overall thickness of these sediments ranges from zero feet north of Lake Simcoe and Kingston to 5000 feet at Sarnia. These sediments thicken to about 20,000 feet in the basinal areas.

The Eastern Ontario Basin is about 4500 square miles in areal extent with a maximum thickness of 3000 feet - mostly Ordovician sediments with a thin basal deposit of Cambrian sediments. The Eastern Ontario Basin possesses a number of major faults which affect the entire sedimentary sequence.

Because of the relatively thin sedimentary area in Southwestern Ontario, very few formations can be considered for disposal of industrial waste. As shown in Figure 8, only the Cambrian formations, Guelph formation and the Detroit River Group can be considered as potential disposal aquifers. Locally in certain areas, the Bois Blanc and Bass Islands may have possibilities.

Isopach and structure maps of the Cambrian and Guelph formations and a structure map of the Detroit River Group are included in Report 68-2 and outline favourable and unfavourable areas for disposal, based on the frequency and quantity of water recoveries for these formations, and the proximity of hydrocarbon accumulations, possible potable water areas, outcrop areas or areas of possible faulting. The delineation of some areas could, feasibly, alter depending upon the results of further drilling. Some areas are, of course, completely lacking in data.

The Cambrian formation has potential over a widespread area of its distribution. However, prolific oil pools have been found in this sequence, having accumulated in the fault complex of the Chatham sag or in a pinchout trap. The occurrence of such areas must be considered in formulating plans for disposal into the Cambrian formations in the Appalachian rim area of Southwestern Ontario.

The Cambrian formations consist of basal sand, a middle formation of interbedded quartz sandstones and dolomites, and an upper formation of buff dolomite with sandy interbeds.

Water records are sparse, but indicate the formations to have, generally, 200,000 to over 400,000 p.p.m. of total dissolved minerals. Careful consideration must also be given to possible occurrence of valuable minerals in the Cambrian waters. A value of 5000 p.p.m. of total dissolved mineral in the brine is usually considered as the upper limit of potable water, although livestock can tolerate concentrations of up to 10,000 p.p.m. Porosities in the Cambrian range from 5 - 15% and often up to 30% in sands and 10% in dolomites, and permeabilities of less than one m.d. to over 250 m.d. - the average between 50 m.d. and 60 m.d.

The Cambrian shows good potential for disposal in Essex County and part of Lambton County, with possibilities in Elgin, Norfolk, Haldimand, Welland and Lincoln Counties and parts of Wentworth and Brant. Recently two wells were completed in the Cambrian for the disposal of steel mill effluent in the Buffalo area, and from tests conducted, the wells appear to be successful. The Cambrian appears to be the only possibility in the Hamilton area. However, the formations are quite thin and volumes would be limited. Unfortunately, the thin Ordovician cover in the Toronto area offers little hope for this method of waste disposal. A few old and scattered wells drilled east of the Escarpment had indications of fluid flow from the basal Ordovician and Precambrian rocks, but were of an isolated nature.

The Guelph formation is characterized by areas of pinnacle, patch and barrier reefs. The lithology varies generally from a grey medium crystalline fossiliferous dolomite in the lower limit to a grey crystalline argillaceous dolomite in the middle unit and finally, to a brown, argillaceous finely crystalline dolomite in the upper unit.

Water recoveries have been recorded chiefly in the upper and middle units. Few analyses exist for Guelph waters - however, in the Lambton County area values of over 300,000 p.p.m. of total dissolved minerals are recorded. The Guelph formation has porosities in the order of 5 - 15% and permeabilities in the 10 - 50 m.d. range, often with streaks greater than 250 m.d.

The Detroit River Group, and specifically, the Lucas formation comprising the upper part of the Group, is the only formation used at present for the disposal of industrial wastes. The formation outcrops eastward near Ingersoll and westward in Essex County, and so confines its potential for disposal to Lambton, parts of Elgin, and Kent Counties. The Lucas formation encompasses the former sandy limestone Columbus formation, and is generally made up of crystalline limestones, dolomites and granular dolomites. The Amherstburg or lower formation of the

Detroit River, in certain areas, will accept fluid, and is generally made up of dark brown, finely crystalline to sucrose dolomites and limestones. Core analyses data is generally sparse for all formations in Ontario, but the Lucas formation appears to have a porosity ranging from 8% to 20% in the Lambton County area, and permeabilities ranging from 10 m.d. to 50 m.d., with locally high permeability streaks in the order of over 200 m.d. Considerably lower values exist in other areas. The formation averages around 200 to 250 feet in thickness in the western part of Lambton County.

The Detroit River waters contain generally, over 100,000 p.p.m. of total dissolved minerals in Lambton County, 40,000 p.p.m. in Elgin County, and 5000 p.p.m. in Huron County. From Figure 1, the rate of injection for a given injection pressure can be quite variable within a small area. Any disposal designs that involve this formation should consider the variable nature of the formation and plan an adequate injection test program.

THE ROLE OF GOVERNMENT

The responsibility for regulating the subsurface disposal of industrial wastes in Ontario rests with the Petroleum Resources Section, Department of Energy and Resources Management, and the Industrial Wastes Division, Ontario Water Resources Commission.

The Department of Energy and Resources Management (herein referred to as the Department) regulates the drilling, completing, testing, operating, monitoring and abandonment of disposal wells. The Ontario Water Resources Commission regulates surface installations, other than the wellhead equipment, to assure that surface contamination does not occur and that ground waters are protected. Permits for disposal are required from both of these agencies before injection is permitted.

The role of the Department, with respect to subsurface disposals of wastes, is to provide those individuals considering disposal, with all available geological and hydrological data for any given area or formation being contemplated, and to assist them in any way it can. The Toronto office makes available all pertinent geological and completion data on nearby wells, core analyses, water analyses, updated well maps, various computer programmes, and relevant data on existing disposal operations in the province.

The Department has offices at the Geological Survey of Canada in Ottawa where all drill cuttings and a large quantity of core are maintained and are available for study.

The Department requires a feasibility study on all disposal proposals. The onus is on the applicant to provide in the study sufficient information to indicate that the operation will be adequately engineered to safeguard all valuable mineral resources and potable water supplies, and that the injected fluids will be confined to the receiving formation. With specific types of waste disposed of in certain areas, lateral confinement of the waste may have to be assured, but generally this is not a requirement.

The drilling, completing and subsequent operation of disposal wells in Ontario is regulated by The Energy Act, 1964, and the regulations thereunder.

The Appendix of Report 68-2 outlines extensively, the requirements of the feasibility study, testing programs and data to be submitted upon the completion of the well.

Once the data are reviewed by the Department, a permit may be issued to dispose and will be subject to various limitations with respect to wellhead pressures, injection rates, monitoring procedures, and, of course, a stipulation that further limitations or cancellation can be imposed if such is found to be in the public interest.

CONCLUSIONS

There are two schools of thought regarding subsurface disposal - one that encourages the scientifically planned use of the subsurface for the containment of toxic or odoriferous wastes, and one that would not interfere with the subsurface under any conditions. One can allow some validity to the latter position - individuals who hold this view can visualize the surface pollution damage produced under what is sometimes referred to as "controlled conditions" and suspects an equally damaging effect in the subsurface. Report 68-2 attempts to show that where prescribed procedures are strictly adhered to such damage is minimal or non-existent.

The storage capacity of potential aquifers, although considerable in certain areas, is nevertheless limited if long-term or continuous disposal is considered. If wastes are essentially non-toxic, the volumes relatively small and such wastes can be economically treated on the surface, the surface installation should be employed and the subsurface retained only for those wastes which are, for the most part, untreatable.

Unquestionably, extensive research must be conducted in the field of subsurface disposal, with a view to better understanding many of the problems mentioned previously, especially those of hydrology and the chemistry of the waste, and to operate present and future disposal systems more efficiently.

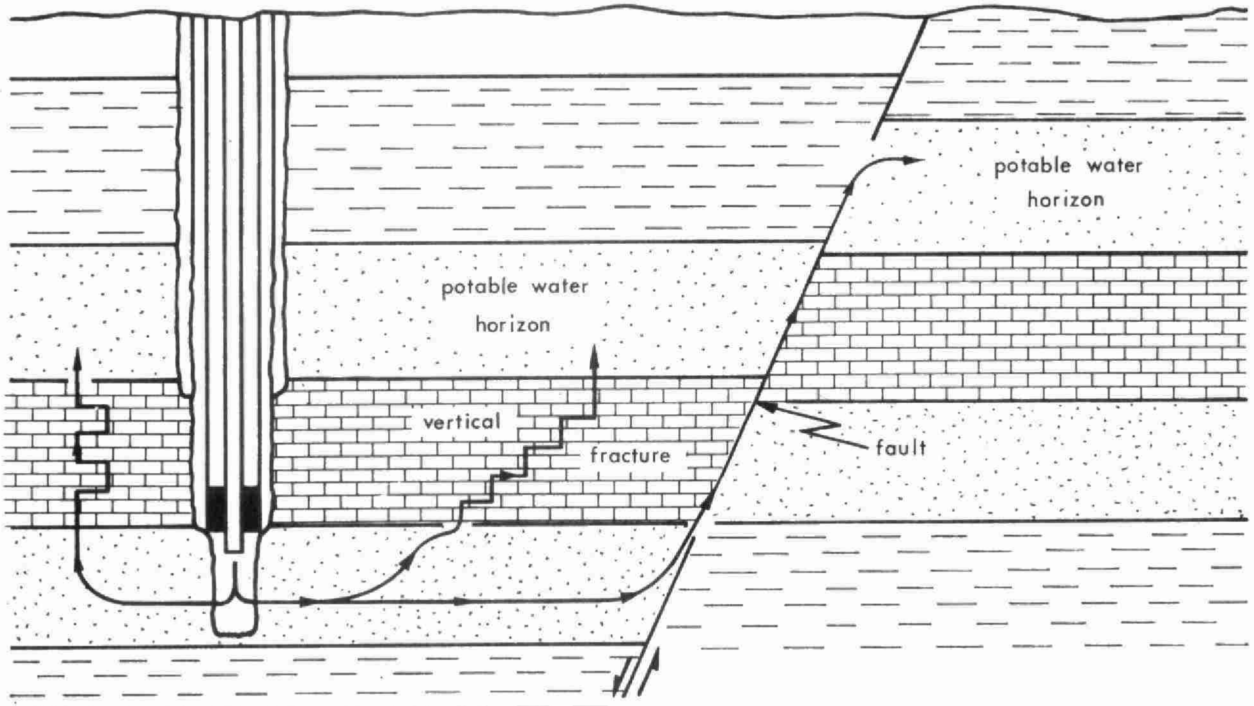
Hydrological equations encompassing the pressure-distance-time relationships must be developed to extend the concept of subsurface disposal to those areas where the aquifer conditions are less than ideal. Present equations can be utilized only where the aquifer is homogeneous and the reservoir unlimited.

All these problems could be better understood through co-operative research by the process industries, or industry supported research at the university level, through carefully designed requirements of the regulatory bodies, and through publication of data on existing operations.

INDUSTRIAL SUBSURFACE DISPOSAL WELLS IN ONTARIO

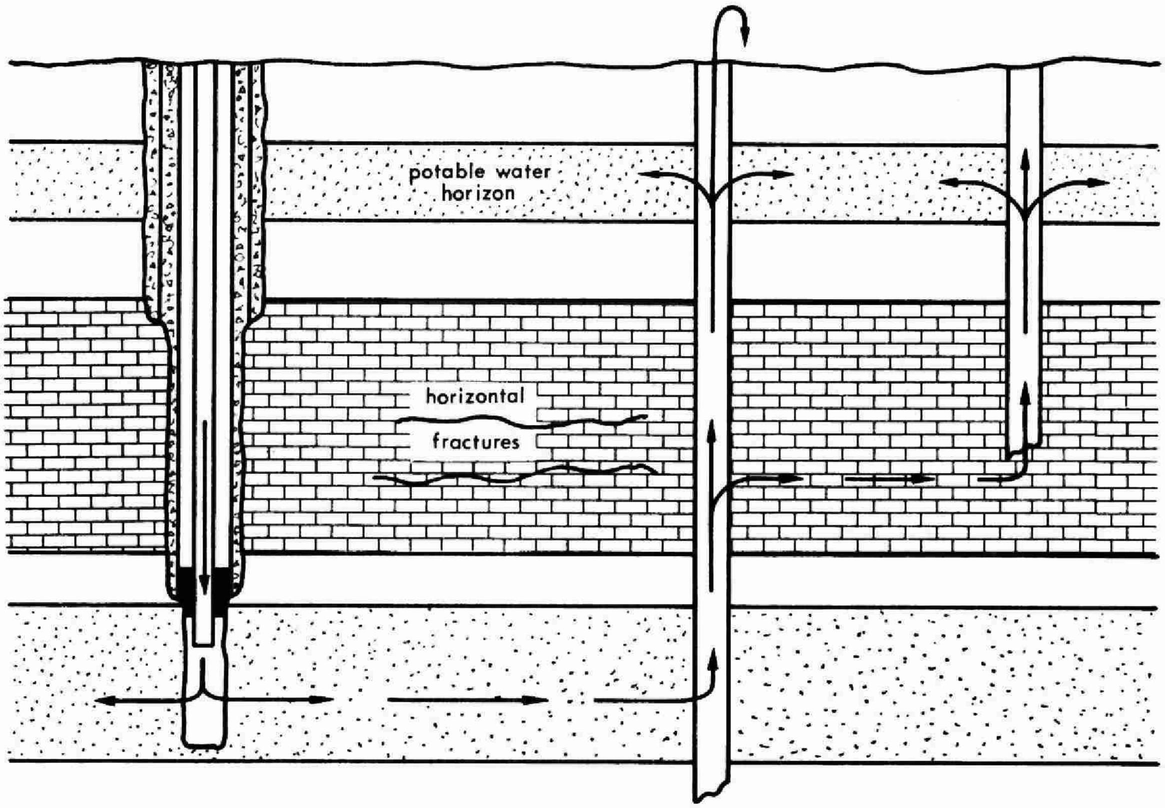
Company	No. Wells	Waste Description	Township	Formation	Disposal Depth	Injection Pressure PSIG	Injection Rate U.S. Gal/Min	Total Injection M.M. Bbls.	Date of System
A	1	Spent Refinery Caustic	Sarnia	Detroit River	900′	420	36[1]	0.6	1961
B	5 OBS	Spent Refinery Caustic	Sarnia	Detroit River	700′	300-350	10-30	20.9	1958-60
C	1	Spent Refinery Caustic	Sarnia	Detroit River	800′	225	50	1.2	1965
D	2	Phenols	Moore	Detroit River	800′	180 130*	80 Nil	1.9	1965
E	3	Waste Oils	Sarnia	Salina Salt	1,900′	Vacuum	—	0.004	1968
F	2	Steam Condensate Water With Ammonia and CO_2	Sombra	Detroit River	800′	380	90	0.5	1968
G	1	Hydrocarbon-Chlorides Hydrocarbon-Ethers Phenols	Moore	Detroit River	800′	Vacuum	30	—	1964
H	1	Spent Caustics and Sulphuric Acid	Enniskillen	Detroit River	850′	275	4[1]	0.03	1965

* STATIC PRESSURE
1 INTERMITTENT



HAZARDS OF SUBSURFACE DISPOSAL
IN FRACTURED AND FAULTED AREAS

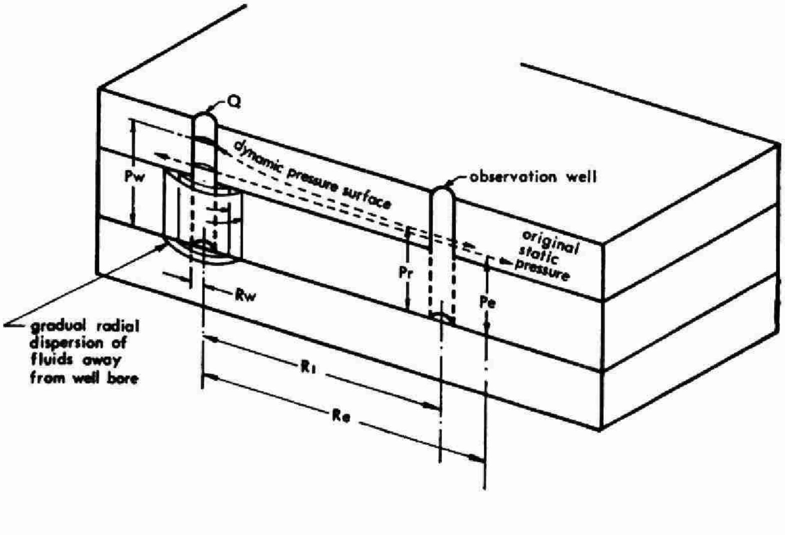
Figure 3



HAZARDS OF SUBSURFACE DISPOSAL IN AREAS OF UNPLUGGED WELLS

Figure 4

RADIAL FLOW IN AN ARTESIAN WELL



1 radial flow equation = $\triangle P = \dfrac{Q\mu \operatorname{Ln}\frac{Re}{Rw}}{7.07\,Kh}$

where Q = flow in barrels per day
K = permeability in Darcys
h = formation thickness in ft.
$\triangle P$ = Pr = pressure differential to cause radial flow in psi
μ = fluid viscosity in centipoise
Re = effective radius of formation in ft. at static pressure = Pe
Rw = radius of well in ft.

2 equation to calculate minimum injection pressure at well head = $Pi = Pf - Ps + P_I + Pr$

where Pf = formation fluid pressure
Ps = pressure of fluid column
P_I = friction loss in tubing
Pr = $\triangle P$ = pressure required to maintain radial flow

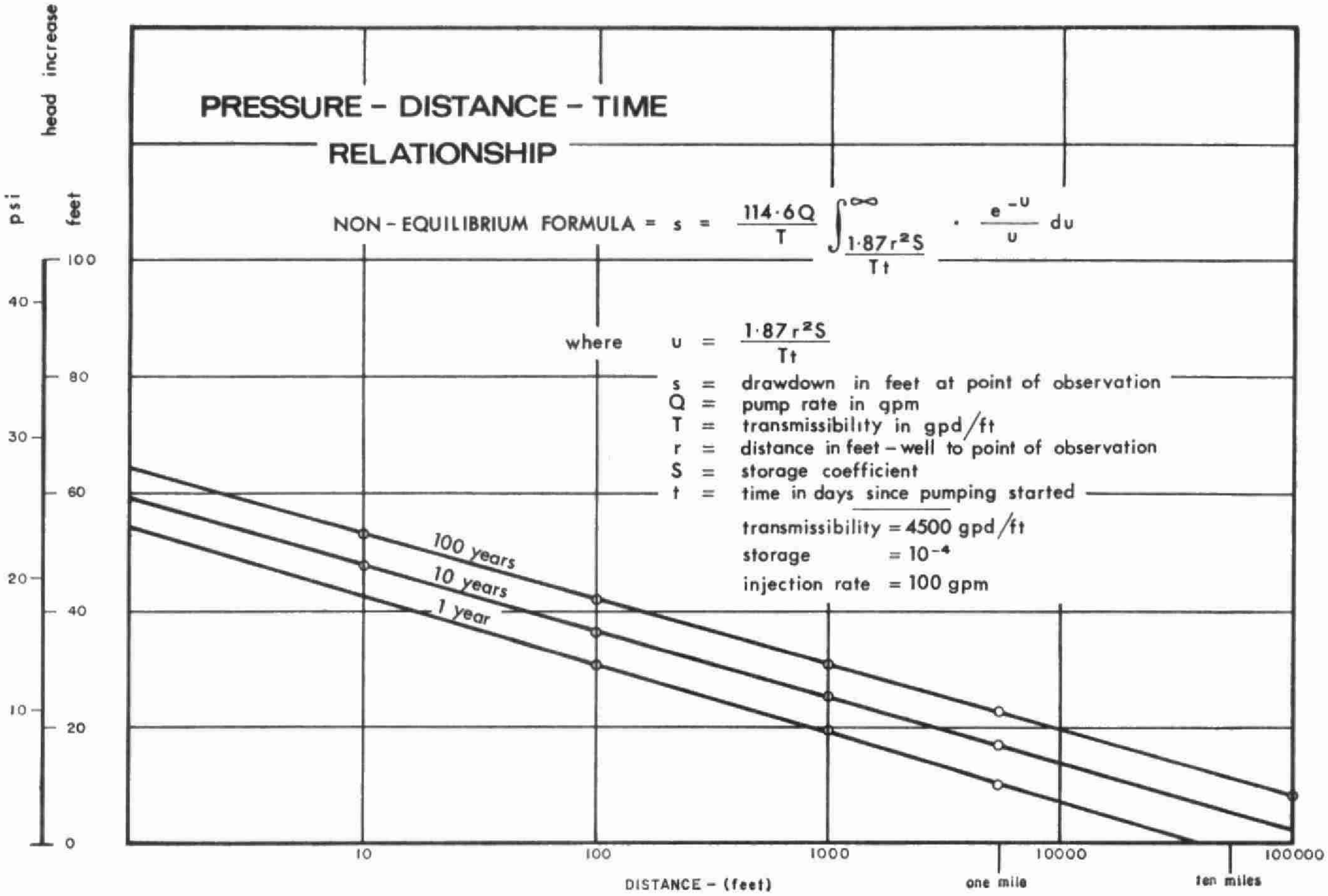


Figure 5

WASTE TRAVEL

$$re = 0{\cdot}0236\sqrt{\frac{Q}{h} \times \frac{t}{\emptyset}}$$

where re = radius of waste travel in miles

Q = injection rate in thousand gallons per day

h = effective thickness of aquifer

t = time in years

Ø = porosity

example Q = 100 gallons per minute

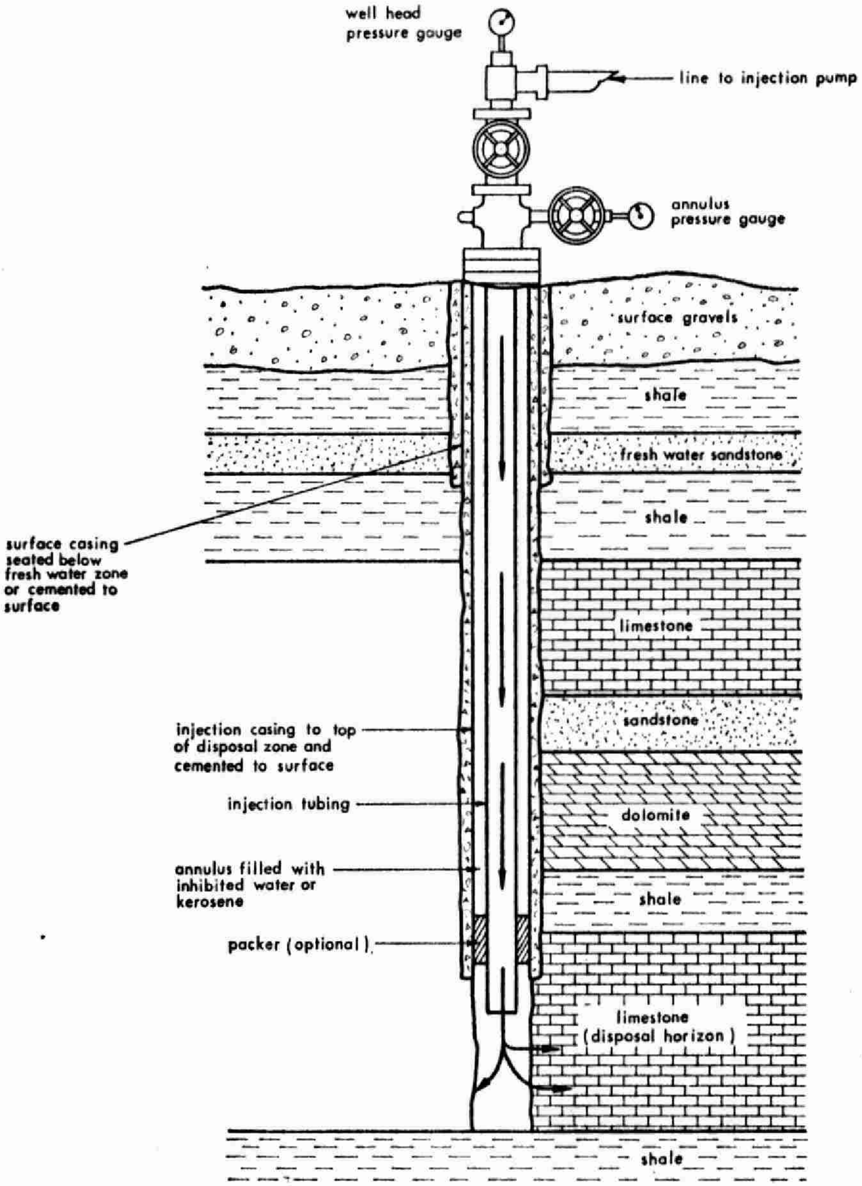
h = 50 feet

t = 50 years

Ø = 20%

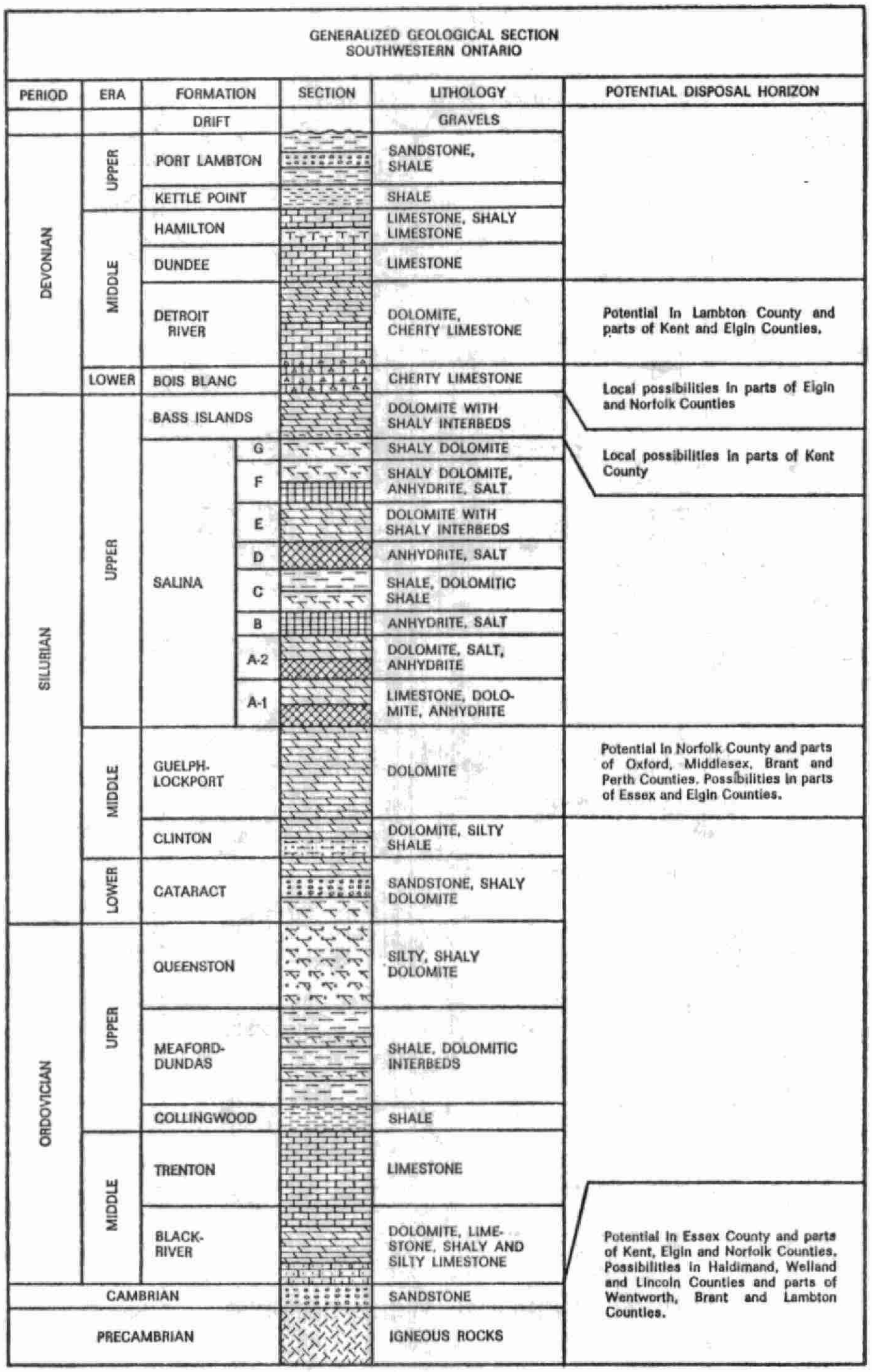
re = 0·6 miles

Figure 6



TYPICAL DISPOSAL WELL CONSTRUCTION

Figure 7



GENERALIZED GEOLOGICAL SECTION
SOUTHWESTERN ONTARIO

PERIOD	ERA	FORMATION		SECTION	LITHOLOGY	POTENTIAL DISPOSAL HORIZON
		DRIFT			GRAVELS	
DEVONIAN	UPPER	PORT LAMBTON			SANDSTONE, SHALE	
		KETTLE POINT			SHALE	
	MIDDLE	HAMILTON			LIMESTONE, SHALY LIMESTONE	
		DUNDEE			LIMESTONE	
		DETROIT RIVER			DOLOMITE, CHERTY LIMESTONE	Potential in Lambton County and parts of Kent and Elgin Counties.
	LOWER	BOIS BLANC			CHERTY LIMESTONE	Local possibilities in parts of Elgin and Norfolk Counties
SILURIAN	UPPER	BASS ISLANDS			DOLOMITE WITH SHALY INTERBEDS	
		SALINA	G		SHALY DOLOMITE	Local possibilities in parts of Kent County
			F		SHALY DOLOMITE, ANHYDRITE, SALT	
			E		DOLOMITE WITH SHALY INTERBEDS	
			D		ANHYDRITE, SALT	
			C		SHALE, DOLOMITIC SHALE	
			B		ANHYDRITE, SALT	
			A-2		DOLOMITE, SALT, ANHYDRITE	
			A-1		LIMESTONE, DOLOMITE, ANHYDRITE	
	MIDDLE	GUELPH-LOCKPORT			DOLOMITE	Potential in Norfolk County and parts of Oxford, Middlesex, Brant and Perth Counties. Possibilities in parts of Essex and Elgin Counties.
		CLINTON			DOLOMITE, SILTY SHALE	
	LOWER	CATARACT			SANDSTONE, SHALY DOLOMITE	
ORDOVICIAN	UPPER	QUEENSTON			SILTY, SHALY DOLOMITE	
		MEAFORD-DUNDAS			SHALE, DOLOMITIC INTERBEDS	
		COLLINGWOOD			SHALE	
	MIDDLE	TRENTON			LIMESTONE	Potential in Essex County and parts of Kent, Elgin and Norfolk Counties. Possibilities in Haldimand, Welland and Lincoln Counties and parts of Wentworth, Brant and Lambton Counties.
		BLACK-RIVER			DOLOMITE, LIMESTONE, SHALY AND SILTY LIMESTONE	
CAMBRIAN					SANDSTONE	
PRECAMBRIAN					IGNEOUS ROCKS	

Figure 8

"AN ECONOMIST'S APPROACH TO THE PROBLEMS OF WATER POLLUTION

BY

J. H. DALES
PROFESSOR, DEPARTMENT OF POLITICAL ECONOMY
UNIVERSITY OF TORONTO
TORONTO, ONTARIO

My purpose in this paper is to discuss with you a few of the main principles of economics as they apply to a variety of policies designed to reduce water pollution. Economics is essentially a simple subject based on a few common sense assumptions and propositions. If one wishes to go into the fine points of <u>any</u> subject, the argument is, of course, likely to become complicated; but my wish -- and my promise to you -- today is to deal only with major points and to keep the argument simple. Nevertheless, we may have a communication problem. Time and time again I have found that the greatest barrier to communication between economists and non-economists arises from the fact that nearly everyone thinks he knows something about economics. Probably everyone <u>does</u>, but you know as well as I do how dangerous a little knowledge can be, and you know as well as I do that nothing muddies the clear waters of discussion like a half-truth, or a quarter perception, or an eighth analogy. May I ask you, then, to do your part in reducing the communication barrier during the next half-hour, by trying to forget anything you think you know about economics. If you can do that successfully, we can start from first principles and propel the argument by common sense and simple logic that is unpolluted by preconceptions. Let us also agree not to let views about what is and what is not "practical politics" divert us from the argument. I know that we are, all of us, great experts in the field of practical politics -- and that we would, therefore, disagree violently about what is politically practicable! But my concern in this paper is to get the economics of pollution straight. Let us therefore leave for another occasion pronouncements about the political possibility of different plans for pollution control. And now to work!

. . . .

The first proposition of economics is that nothing that is valuable is free; everything that is worth something costs something. The cost may be expressed in terms of money, or effort, or foregone enjoyment of some goods or service. It is the last way of expressing value, or cost, and this offers the most direct route to understanding. If, you, as an individual, with a given income (resulting from a given expenditure of effort), buy more carrots you must buy less of something else. And as a nation, too, we cannot grow more carrots or spend more money on space flights unless we reduce our output of something else. We could grow one hell of a lot of carrots if we put our minds to it -- but, of course, we don't want to maximize our output of carrots. The name of the game is to maximize enjoyment, or welfare, and this we do by seeking an optimum balance between the output and consumption of different goods and services. In the attempt to maximize our welfare, we always keep adjusting -- more of this and less of that, or more of both this and that and less of something else. But more of this is always bought at the expense of less of that. I am sure you all agree on the truth of this statement. If it were not so, there would be no economics, no choices to make, and all the challenge of life would disappear.

Very well. You can now conclude that more pollution abatement can only be bought by producing and consuming less of something else. Because the welfare you get from enjoying natural water, and the increased welfare you would expect to get from enjoying less polluted natural waters, does not appear in the statistical compilation we call Gross National Product, we can put our conclusion in rather more dramatic form. If we buy more pollution abatement our Gross National Product and our Standard of Living, as measured, will necessarily fall. Our real standard of living will, of course, rise if, by giving up, say, $100 worth of commercial goods and services, we obtain say, $120 worth of increased welfare from cleaner water. But let us not be deceived. The unavoidable price of cleaner water is a lower aggregate consumption of existing goods and services, and therefore a lower aggregate output of those goods and services. How do you like them apples, Mr. Citizen? I am personally not convinced that as a citizenry we *do* want less pollution, despite what we say. Indeed there is a good deal of evidence to suggest that both we and our governments want *more* pollution? Don't you think that population and industrial growth are good things? *I* don't. But I suspect that you do, and I am certain that governments do. Despite my misgivings, I am forced to assume that the electorate *does* want to reduce its standard of living, as conventionally measured, in order to reduce pollution. I am forced to assume this purely for reasons of mental health, for if the assumption were false, you and I would both be wasting our time here. I don't know about you, but the cost to me of being here is considerable. I would much rather be fishing in a stream where the D O is still greater than zero. So I have to keep telling myself over and over again that we really *are* serious about pollution abatement. So now that I have repressed my doubts once more, let us push on.

. . . .

Pollution abatement is a rather tricky sort of commodity. Most of the goods and services we are accustomed to are "individual" goods, such as shirts, which can be "consumed" by a single individual. Because the enjoyment from the consumption of a shirt accrues primarily, and mainly, though not exclusively, to the individual who owns it, our legal system provides for exclusive use of a shirt to the man who buys it -- unless, of course, he has teen-aged sons. But there is a very important set of goods, which we shall call "social" goods for which a great variety of technological and social reasons, it seems sensible *not* to provide for exclusive use by one individual, but on the contrary to make their services available to all individuals. Parks, road systems, elementary education, radio and television broadcasting, national defence, and pollution abatement, are all examples of "social" goods in our society. I must not allow myself to be diverted into explanations of why some goods are social goods in almost all societies, and why others are social goods in some societies and individual goods in others. You must allow me to be a little dogmatic at this point and to assert, without much explanation, that there are two ways in which social goods differ from individual goods from the standpoint of economics. Let me hasten to assure you, though, that what we said about valuable things being procurable only at the cost of foregoing some quantity of other valuable goods and services, is every bit as true of social goods as it is of individual goods.

Individual goods have a price and therefore an explicit cost to the individual consumer, so that it costs you more money to buy six shirts than to buy five shirts. Social goods usually have a zero price; parks, of course, cost you something, and more parks (for a given population) cost you more than fewer parks; but for any given number of parks the cost to you of six visits per month to your local park costs you no more than five visits per month; and if you never visit your park it still costs you the same amount. The reason for charging a zero price for the use of social goods is often that the cost of collecting fees -- for instance for a stroll through the park -- would be greater than the amount of fees collected. Certainly this seems to be true of cleaner water; there is no practicable way of charging individuals for the enjoyment they receive from cleaner water. Now, private individuals, as you know, only produce a service if they can charge for it, and they can only charge for it if they can prevent people who do <u>not</u> pay for it from enjoying it. It follows that no <u>individual</u> will invest in providing a social good (pollution abatement, for example) because his financial return on his investment would be zero. Thus, no social good will be provided -- and let us remember that social goods make an enormous contribution to our <u>real</u> standard of living -- unless society takes steps to ensure its production. For practical purposes, social action means government action. Our conclusion, then, is that if social goods are to be produced, the government must either produce them or make provision for their production.

The second difference between an individual good and a social good concerns the volume of output of the good. There is an objective criterion for the "best" output of shirts; if shirt producers make more than average profits, more shirts should be, and will be, produced; if shirt producers are making less than average profits, or experiencing losses, fewer shirts should be, and will be, produced. So the government doesn't need to bother its head about how many shirts should be produced. It is quite otherwise with social goods. Because people do not pay <u>directly</u> for these goods (though they certainly pay <u>indirectly</u>), the government does not know how much of each of them should be produced. How much national defence, how many parks, how many roads, how much pollution abatement, do we want? The observation that all of these questions become centres of political controversy indicates that there is no "scientific" or "objective" way of answering them. Debate is only possible when there is no objective way of settling a question; even politicians do not debate about whether water should be composed of 3 hydrogen and 2 oxygen rather than 2 hydrogen and one oxygen. In practice, or so it seems to me, governments are likely to provide national defence, or schools, or pollution abatement, up to the point where the complaints about the cost of these foods exceed complaints about an inadequate supply of them -- but the criterion is obviously very rough in application. Certainly economists can give no objectively defensible answer to the question of how much pollution abatement should be provided; nor, I think, can anyone else. This important question must in practice be answered, more or less arbitrarily, through the political process.

That is a horrible thought to scientists, especially to economists who pride themselves on being able to say, and to say objectively, how many carrots should be produced. But that is my conclusion, much as I dislike it.

. . . .

So far I have stressed that everything that is valuable, not excluding social goods, must be paid for. But I have so far been a little vague about <u>who</u> pays, and about <u>how</u> payment is made for a social good such as pollution abatement. The general answer to the first question is that <u>everyone</u> pays. The portions paid by individuals and/or groups will be unequal; indeed they <u>must</u> be unequal if they are to be equitable. But more of distribution problems later; for the moment the important point is that the cost will be very widely distributed through the population. We shall see in a moment why this is so.

The question of <u>how</u> people pay has two meanings, and must therefore receive two answers. Ultimately, as we have already noted, people "pay" for pollution abatement by reducing their standard of living in terms of other goods and services. But the question of how people pay for pollution abatement may also be interpreted to mean how they pay for it <u>in the first instance</u>, or how the investment in abatement is financed. There are four general answers to this question. Firstly, it may be financed through taxation, the abatement being performed by the government and its total cost being paid for by the people in proportion to the incidence of the additional tax load. Note that if, with the same incomes, people pay more taxes they will have less to spend on privately-produced goods and services so that the output of industry as a whole will fall. <u>Secondly</u>, the abatement may be accomplished through a system of subsidies to industries and municipalities, the subsidies being raised through taxation. If the subsidy is 100%, this technique is in some respects the same as the first one; the total cost is paid through taxation, although the actual abatement operations are performed by firms and municipalities rather than by the senior government itself. If the subsidy is less than 100%, and is voluntary, it will not be accepted and no abatement will take place; if, however, firms and municipalities are required by law to abate, they will accept the subsidy. In this case the cost of abatement arising from subsidies will be paid through taxes; the rest will be paid for, in part, by municipalities and, in part, by industries. Municipalities will have to raise their taxes, and industries will have to raise their prices (or in some cases lower their profits). In any event, the output of privately-produced goods and services will be reduced as the result of both higher levels of taxation and higher prices of goods (or of reduced incomes of shareholders, if profits are reduced). Thirdly, the government may require, through laws and regulations, that industries and municipalities abate their pollution and themselves pay, in the first instance, the entire cost of the abatement. Of course, the cost will be passed on through higher municipal taxes and higher prices of goods and services and, as before, the abatement will ultimately be paid for by people in general, through their reduced consumption of commercial goods and services. Fourthly, the government may tax, or "charge", industries and municipalities for the pollution they create, the charge being based on some estimate of the amount of pollution that each "causes". Again, municipal taxes and the prices of goods and services will rise and, again, the abatement will be paid for by the population at large through a reduced consumption of commercial, or "individual", goods and services.

We were, alas, right the first time. No matter how we wriggle or squirm, we always come up with the same answers; everything that is valuable must be paid for; and no matter how pollution abatement is financed in the first instance, we are all going to share in the cost of paying for it in the final analysis.

. . . .

Having drilled ourselves sufficiently in the first principle of economics, we may now advance to the second piece of common economic sense: individuals, or groups of individuals, will always prefer to pay less rather than more for a given amount of a good or service; or, to put it the other way around, for a given cost, or sacrifice, people will always prefer to have more of a good or service than less of that good or service. Does anybody disagree with that proposition? It turns out to be a much more useful proposition that our first one. All we have really concluded so far is that any pollution-abatement scheme is going to reduce our standard of living as conventionally measured. But in kicking that proposition around, we also noted that there are many types of pollution-abatement schemes; indeed, the number of pollution-abatement schemes is literally infinite. Our second proposition in economics is a very powerful one, because it enables us to pick out, from this infinity of possible schemes, one scheme, or at least one type of scheme that will give us the most for our money -- the most abatement for a given cost, or a given amount of abatement at the least cost. In other words, our second proposition tells us which type of abatement scheme we should adopt on economic grounds. And let me say, in passing, that, while it is always possible that the best scheme on economic grounds should not be adopted because of conflicting social or political considerations that override it, I can see no *a priori* reason why social or political considerations should conflict with the economic consideration of getting the most enjoyment in return for a given sacrifice.

Let us put our second proposition to work. Since it would require an infinite amount of time to evaluate an infinite number of anti-pollution schemes, we must reduce infinity to a finite number of categories -- in this case, three: regulatory schemes, subsidization schemes and charging schemes. We shall discuss two or three examples of each category. We are thus launched on a large scale comparative study. To make things manageable, we must simiplify the situation drastically. I am going to assume that the universe of polluters is composed of two villains: Industrial Establishment (or Municipality) "A"; and Industrial Establishment (or Municipality) "B". I am also going to make two simplifying assumptions about "A" and "B":

(1) I assume that at the present time "A" and "B" each discharge 50 tons of pollution per year into natural waters. I am fully aware that this assumption implies that different types of pollutants can be reduced to some common denominator, in our case, so many "equivalent tons" of pollution; and I am also fully aware, I think, of the value judgements and arbitrary decisions that are implied in measuring pollution in tons or in any other common denominator. But if we are serious about "reducing pollution", we must decide by how much pollution is to be reduced and to decide by how much it is to be reduced, we must be able to measure the damned thing. And if we can't measure it by physical science or economic science, we simply have to measure it by political science. Since political science is not a very exact science, you may regret that this is so; as I said above, I regret that it is so; but I am telling it like it is and not how I would like it to be.

(2) I assume, secondly, that it costs "A" $10 per ton to reduce his pollution by up to 10 tons per year, and more than $10 per ton to reduce his pollution by more than 10 tons per year; and that it costs "B" $5 per ton to reduce his pollution by up to 10 tons per year and more than $5 per ton to reduce his pollution by more than 10 tons per year. These figures are purely imaginary, and for illustrative purposes only. It is very important to note that no outside party is, in practice, able to find out what it costs "A" or "B" to abate different amounts of pollution, if only

because there is no law compelling "A" or "B" to divulge this information if he has it. In all likelihood "A" and "B" themselves do not know how much it would cost them to reduce their pollution by a given amount. The OWRC ought not to feel frustrated that Industry "X" will not tell them how much it will cost to reduce its pollution by 10%; in most cases Industry "X" doesn't know what it would cost. And its managers will never find out until they have an incentive to do so. So our second assumption, apart from being purely arbitary, is extremely unrealistic in principle, since "A" and "B" themselves normally do not know what the correct figures are. The assumption is, however, extremely realistic in the sense that we all know that the costs per ton of abating pollution differ between different establishments or municipalities; and is only the fact of the difference in costs that is important for our present purposes.

Those are the assumptions of our game, which I insist is a reasonable facsimile -- or what is now called a simulation -- of the real world in which we live. How do we decide the winner of the game? We suppose that society in its wisdom has decided that pollution should be reduced by 10 tons. And since we have, I hope, already agreed that it is in society's best interests to achieve its goal at the least possible cost, the question becomes one of how the burden of reducing pollution should be shared between "A" and "B". Or, to put this question another way, which scheme of pollution abatement will lead "A" and "B", taken together, to reduce pollution by 10 tons at the least cost?

It is that word "cost" that must give us pause. How do we calculate it? We cannot, as it turns out, calculate it precisely. It is composed of two parts. The first part we shall define as monetary cost, which is the direct cost to the polluter plus any associated increase in taxes, or minus any associated decrease in taxes. The second part we shall define as the probable costs (which cannot be precisely measured) of administering the scheme. We may distinguish three major administrative costs: the costs of obtaining the information necessary to administer the scheme -- so that the less the information needed the less would be this element of administrative cost; the costs of altering the scheme to adjust to demographic or economic growth; and the costs of enforcing the scheme. We shall assess each scheme according to its total costs, that is to say its monetary costs plus an order-of-magnitude estimate of its administrative costs. The lowest score wins!

If we neglect administrative costs for the moment, you can see that the theoretically correct answer to our game is that "B" should reduce his pollution by 10 tons, the total reduction we have decided on, and that "A" should not reduce his pollution at all. The reason is that for

"B" to reduce his pollution by 10 tons would cost him, or rather the people who buy his goods and services, $50; if "A" were to undertake the whole burden of reducing pollution by 10 tons the cost would be $100, or twice as much; and if "A" and "B" each reduced his pollution by 5 tons the cost would be (5x5) + (5x10) or $75. You may work out every possible combination of sharing abatement between "A" and "B", but in our example it will always work out that the cheapest way for society to reduce its pollution by 10 tons is to force, or induce, "B" to reduce his pollution by 10 tons and not to require "A" to reduce his pollution at all. That is certainly unequal treatment. Is it inequitable? Definitely not! If it costs me twice as much to grow carrots as it costs you, it is generally considered fair and just that you should grow the carrots, not me. Similarly, if the public wants to buy 10 tons of pollution abatement, it has every right to insist that it be bought from "B", not "A". If you want to argue otherwise, you must argue that you should pay more rather than less for a given amount of enjoyment -- and I must rule that argument out of order because you have already agreed that for a given amount of enjoyment you will always prefer to pay less rather than more. O.K.?

Now, suppose society adopts a regulatory scheme to abate pollution, requiring that the polluters themselves pay the shot in the first instance. If the regulator issues his orders in terms of tons of abatement, and we confine ourselves to whole numbers, he has 11 possibilities to choose from -- 10 for "A" and 0 for "B"; 9 for "A" and 1 for "B"; and so on. And since he has no knowledge of the relative cost of abatement as between "A" and "B" (though we do have this knowledge since we devised the game!), he has no basis for choosing among the 11 possibilities. He might as well consult a Ouija board. In our simple example, he will have one chance in eleven of coming up with the right answer; in the real world, with tens of thousands of establishments, his chance of coming up with the right answer will surely not differ significantly from zero. My own guess is that, in practice, regulation works in one of two ways: first, on grounds of a misguided sense of equity, regulations are likely to order all polluters to abate by the same amount or by the same percentage -- a solution that is bound to be incorrect so long as the costs of abatement differ as between polluters; second, I suppose that polluters who are in the weakest position to bargain with the regulator will end up doing most of the abating. Another example of a regulatory scheme is where the regulator issues his orders in terms of dollars rather than tons -- for example, that "A" and "B" must each spend $100, or must each spend 1% of his total costs, on abatement. As you can see, this procedure will result in missing the target of 10 tons of abatement. In our example, if ordered to spend $100, "A" will abate by 10 tons and "B" by more than 10 tons, so that the electorate who wanted to buy 10 tons of abatement ends up by buying more than 20 tons. In practice, the hapless regulator would probably have to experiment for a long time before he came anywhere near the dollar figure that would hit the tonnage target -- and even then we can be sure that the total cost of achieving the 10 tons of abatement would be greater than the least possible cost.

Subsidy schemes have most of the disadvantages of regulatory schemes, plus a few of their own. If the subsidy is voluntary it will not be accepted by polluters unless it is excess of their costs of abatement. In our example, anything less than $5 a ton subsidy would result in no abatement; $5.01 per ton would do the job nicely -- "B" would abate by 10 tons, "A" would not abate at all, and the least cost solution would be achieved. But how can the abatement agency find the magic figure of $5.01 except by a long process of trial and error? Anything greater than $5 a ton would result in too much abatement. It might also result in a lot of strictly unnecessary abatement. Thus, if the subsidy were $7 a ton, "B" would no doubt find ways to increase his output of pollutants that could be abated for $5 a ton in order to collect $7 a ton for doing so. "B" would then have added to his basic business a very profitable sideline in "pollution production and abatement". One can imagine the consternation on the government benches when an Opposition Member caught on to <u>that</u> unintended result of government policy! If subsidies are used in conjunction with a regulatory scheme to defray the costs to polluters of the abatement they are required to perform, this mixed scheme is prey to all the pitfalls of regulatory schemes plus the added disadvantage that the subsidy in some cases may well be above the actual cost of abatement -- in which case, it would again be profitable to produce pollution in order to abate it.

Suppose the anti-pollution agency opts for a "charging" scheme. An across-the-board charging scheme will have exactly the same characteristics as an across-the-board subsidy scheme, with the important exception that no charging scheme can ever induce a polluter to go into the "pollution production and abatement" business. The agency's problem will be to find the right price to charge. In our example, if the charge is less than $5 per ton, it will be cheaper for both "A" and "B" to pay the charge rather than the cost of abatement, and no abatement will occur. At more than $5 per ton, society will overshoot its target, for "B" will abate by more than 10 tons. Exactly $5 -- or $5.01 -- will give the least-cost solution; "B" will abate by 10 tons and "A" will not abate at all. The correct figure, of course, can only be reached by a trial-and-error process. If, however, the agency tries to set different charges for different polluters, the problem becomes hopelessly complex once again. In order to abate by as close to 10 tons as possible, and to get close to the least-cost way of doing so, the agency would again need to know the costs of abatement on a plant-by-plant basis. In addition, this scheme has the following effect; where different charges for different establishments are set below the cost of abatement, so that no abatement occurs, the charges will create changes in the relative prices of the goods produced in those establishments. The effect will be salutary if the pattern of charges is a true reflection of the differential harm done by pollution from different establishments; we note only that, in order to achieve this pattern, the agency needs a whole new set of information -- estimates of the damage caused not only be existing amounts of effluent from each plant in the system, but also estimates of the damage that would be caused by all lesser amounts of effluent from each plant in the system.

. . . .

Of all the schemes we have discussed so far, the best, clearly, is the flat-rate charging scheme of so much per ton of pollution discharged. No plant-by-plant information was needed to apply it, and still it could produce the right answer -- the least-cost solution. Its only disadvantage was that the "right" rate could only be found by a trial-and-error process. That deficiency can easily be remedied. Let the agency set the <u>amount</u> of pollution it will accept ("A" and "B" now produce 100 tons of pollution and the agency decides that the total must be reduced to 90), and let the <u>price</u> that corresponds to this amount be set by an automatic market process. In other words, let the agency create 90 paper certificates, each of which entitles its holder to discharge one ton of pollution per year into the natural water system. A friend of mine has suggested that these certificates should be called Standard Pollution Units, or SPU's for short. Then, after the Government has passed a law making it illegal for anyone to discharge wastes into natural waters in excess of the number of SPU's he holds, the agency can put the 90 SPU's up for auction. "A" and "B" will bid for them, starting, say, at an offer price of $1 per SPU. They both tender for 50 SPU's, but there are only 90 available. Thus, one of them decides to raise the bid. When the price gets to $5, or $5.01, "B" will reduce his tender to 40 because he knows that it will be cheaper for him to abate his pollution by 10 tons than to pay more than $5 per ton not to abate it. Thus, demand and supply of SPU's will be equated at a price of $5.01. The market has automatically, with no fuss or bother, come up with the correct charge; society has bought exactly what it wanted to buy -- 10 tons of abatement, no more no less -- and has bought it at the minimum possible cost. The agency head can go out and play golf, with only one possible worry -- that someone may find out how easy his job really is.

The Government Treasurer will have a problem -- how to use the $450 that he gets as a result of the SPU auction. Let us say he simply reduces general taxation by $450 so that he won't have to go to the trouble of dreaming up some new way to spend money. How have the people fared? Well, the prices of goods have risen so that it would now cost $500 more to buy the total output of "A" and "B", since "A" and "B" have paid $450 for SPU's, and "B" has paid $50 for pollution abatement. As taxpayers, the people have received an unexpected tax refund of $450, but even so, they can't afford to buy all of "A's" and "B's" output. This loss, however, is more than compensated for by the cleaner water that everyone can now enjoy "for free". Either "A" or "B", or both, will have to reduce their output slightly (by $50 worth of goods), and will have to lay off a few men; these men will then take up newly-opened positions in the municipal sewage plant, or the pollution-control agency, or in a new factory producing pollution-measuring devices. So everything works out, and the final result is as expected; the population has bought itself cleaner water by reducing its consumption of other goods and services.

When we consider, briefly, the administrative cost (as distinct from the monetary cost) of various pollution control schemes, the SPU scheme greatly increases its margin of advantage over the others. The enforcement costs of all schemes -- which come down largely to the costs of sampling effluents -- seem likely to be about the same; so SPU has no advantage there. However, SPU does have an enormous advantage when it comes to information costs; no information is needed to operate SPU, while flat-rate subsidies or charges require a lot of trial-and-error experimentation to identify the correct subsidy or charge, and all other schemes require enormous amounts of hard-to-obtain, and therefore very expensive, information if they are to come within a country mile of the least-cost solution. The third element in administrative costs that we have identified is the cost of adjusting to increases in population and industrial output. It is immediately obvious that if society wants to stabilize pollution at 90 tons, abatement efforts will have to intensify as population and output grow. That means that whether abatement is achieved by regulation, or subsidization, or charges, the regulations, or subsidies, or charges will have to be changed every time there is an increase in population or output, if pollution is to be kept under control, i.e., if the 90-ton figure is not to be exceeded. Just when an agency gets its regulations, or subsidies, or charges nicely settled down, a significant increase in population or output is recorded -- and it's back to the drawing board to adjust the whole program to the new situation! The manager of a SPU scheme can go on playing golf; his scheme will adjust automatically to the new situation through the changing market price of SPU's. As population and output increase, the price of SPU's will increase, and as it increases it will pay producers to do more abatement so that they needn't buy so many SPU's, and, as always, the pattern of abatement expenditures among all producers will be exactly that pattern that minimizes the cost of the total abatement performed.

I end with a question. Why would <u>any</u> society that wants to reduce its water pollution try to do so by regulatory commissions, subsidization schemes (which always remind me of the expensive way of killing a cat, namely, by stuffing it with fish), or by cumbersome price-setting agencies, when SPU could do a very much better job at a tiny fraction of the cost? I don't know the answer to that one.

DR. N. E. COOKE
PRINCIPAL CHEMICAL ENGINEER
CANADIAN INDUSTRIES LIMITED
MONTREAL, QUEBEC

"TREATMENT OF BRASS MILL EFFLUENTS AT ANACONDA TORONTO PLANT"

BY

J. J. MCGRATH
METALLURGICAL MANAGER
ANACONDA AMERICAN BRASS LIMITED
TORONTO, ONTARIO

Population growth and industrial expansion have been accompanied by great increases in the amount of waste material produced. Easiest disposal has been to wash away the wastes. But in washing away, they eventually became part of the fresh water supply which requires increased and more varied treatment to remove contamination.

How much better for the community at large if the offending contaminants can be removed at their source. At Anaconda the items which require treatment are the discharged pickle solutions of sulphuric acid and sodium dichromate which have been used to clean copper and copper alloys, and the resultant wash water. Some years ago, these were diluted and discharged into the sewers. Later, the acid solutions which were no longer useful were pumped into tank trucks and hauled away to a dumping area, and now, with the help of Ontario Water Resources Commission and Anaconda research people, we are developing the most efficient methods we can to treat the waste at its source and have a plant whose capital cost is $750,000 to do the job.

The plant consists of collection sump, an equalization basin, iron contact launders, copper settling pits, clarifier, and thickener tank, and a control building. The control building has a main floor and a basement; the main floor houses two neutralizing tanks, a vacuum filter with accessories, a motor control centre and instrument panel, a sulphur dioxide feeding station and a lime storage bin; the basement contains all of the pumps, the sump for collection of mill waste, the lime slurry tanks, and the pH and oxidation-potential electrodes.

Some average plant consumption figures are:

Sulphuric acid	45 tons per month
Sodium dichromate	18 tons per month

Dumping volume of spent acid solution is approximately 3,500 cubic feet annually and of dichromate solution 1,300 cubic feet per week. These account for the acidity and hexavalent chrome content and other inclusions such as copper and other metallics. The rinse waters make up the bulk of the influent which is carried to the treatment plant by gravity through a 12 inch sewer system.

Equalization Basin

From the collection sump the wastes are pumped to the equalization basin which has a holding capacity of 150,000 Imperial gallons. One or both of two centrifugal pumps are used, each with pumping capacity of 200 gallons per minute; a third similar pump is available for standby protection; consequently, total pumping capacity of 600 gallons per minute is available. At present, average flow of waste water into the equalization basin is approximately 175 gallons per minute.

Holding time in the equalization basin is 6 to 8 hours, allowing for uniformity of acidity and metal ion content throughout the basin when influent is mixed and circulated with the contained fluids. For recirculation there are two 800 gallon per minute pumps; mixing is thorough and the effect of pickle dumping is minimal by dilution of the large volume of essentially rinse waters.

Iron Contact Launders

From the equalization basin the waste water flows by gravity to one of two launders. The launders are of wooden tank construction, located side by side and each tank is 80 feet long x 8 feet wide and 4 feet deep. Each launder tank consists of 8 compartments containing wooden baffles to provide an over and under flow for some turbulence. Between the baffles are placed open-slatted wooden baskets each of which carries about one half ton of thin walled iron tube in short lengths - consumption 5 tons per month.

The purpose of the launders is twofold; first for the reduction of hexavalent chromium to trivalent chromium, which is necessary for subsequent precipitation and removal of the chromium contamination from the final plant effluent; secondly for the cementation of copper and ultimate recovery of copper.

During the course of operations we have found that the action of reducing hexavalent to trivalent chromium tends to permit a copper and slime coating to build on the iron, which impedes copper removal and efficiency of the launders. The turbulence developed by baffles and recirculation from copper settling tanks is not sufficient to prevent coating. Consequently, it is necessary to raise the baskets of iron twice monthly and wash the coating off with a hose.

Initially, the two launders were used in tandem, the iron tubing, in longer lengths, was dumped into the compartments without baskets and sulphur dioxide was introduced to aid reduction. Again by experience, we have learned that alternate use of launders, that is, one at a time, and shorter lengths of iron tube in the baskets, has increased the turbulence and copper cementation rate, reduced the frequency of manual washing, and made the task of removing cementate easier and less costly.

Sulphur dioxide introduction was controlled by an oxidation reduction potential electrode; introduction would begin when the oxidation reduction potential of the launder effluent reached 400 millivolts. It has recently been proved that hexavalent chromium reduction does not effectively occur when the pH of the launder fluids rises above 3.0. Therefore, we have provided a controlled application of sulphuric acid at the equalization basin to maintain pH at not greater than 2.8 in the fluid entering the launder. The sulphur dioxide equipment is maintained as supplementary protection.

Copper Settling Pits

These are two tanks in line with the launders; each tank is 25 feet long, 8 feet wide and 10 feet deep. Waste flows by gravity from the launders and can flow at 400 gallons per minute. Part of the flow is recirculated back to the feed side of the launders for a second pass through the iron to further reduce copper content of the waste and hexavalent chromium.

In practice, a relatively small proportion of the copper gets to the settling pits. The greater portion water (clarifier overflow). The coagulant is provided from a pair of 150 gallon tanks to which is added daily 5 to 6 pounds of polymer.

In addition to any turbulence derived from the flow of waste, the neutralization tanks are mechanically agitated.

Clarifier

Neutralized waste flows by gravity to the clarifier tank, 45 feet in diameter and 12 feet of water depth. It performs as a placid settling tank from which clear effluent overflows into a peripheral trough for final disposal.

The metallics precipitated in the second neutralizing tank coagulate and settle to the bottom of the clarifier. Sludge collected in the bottom of the tank is pumped to the thickener before the depth of sludge exceeds three feet.

Any oil or grease which may have collected is continuously skimmed off by a rotary skimmer and directed to a collection pit adjoining the clarifier.

Part of the treated effluent is returned to a 300 gallon storage tank in the basement of the plant building and is used instead of city supply water to feed the lime slurry and coagulant tanks. Of course, city water is automatically available if needed.

A larger portion of the clarified effluent is diverted to the casting department as coolant for water cooled molds, and thence to the storm sewers.

The balance of treated effluent is lost to the municipal storm sewer.

Thickener

Again it is a cylindrical tank 25 feet in diameter and 9 feet deep, and like the clarifier has a feed line to allow entry of the waste below surface level.

The sludge is drawn from the clarifier by two air operated diaphragm pumps. The pump action is controlled first by the quantity of sludge in the thickener, and secondly by the depth of the sludge in the clarifier, which depth should not exceed three feet.

As sludge is pumped from the clarifier and sludge builds up in the bottom of the thickener, the water which is carried over flows very gently over the peripheral weir and is directed back to the clarifier. Most of the sludge itself is pumped to a vacuum cylindrical filter with filtering area of 110 square feet; a small portion is recirculated back to the first neutralization tank to aid in first neutralization of incoming waste.

Vacuum Filter

The vacuum filter is located on the upper floor of the control building.

The sludge, as it arrives in the filter basin, contains about 20 per cent of solids. The vacuum drum removes moisture to provide a filter cake containing about 40 per cent solids. The filter cake falls freely from the discharge side of the filter to a conveyor belt which carries it outside the building for removal to storage and ultimate disposal. The filter drum is 6 feet in diameter and 10 feet long and it rotates once in 5 minutes.

Initially, considerable difficulty was experienced in getting the cake to fall from the filter. By recirculating some sludge from the thickener to the neutralizer tank, the solids content of the sludge going to the filter increased from 5% to 20%, and that of the filter cake leaving the filter increased from 20% to 40%.

The filter operates approximately 20 hours per week and removes about 28 tons of filter cake per month. An analysis of filter cake is as follows:

Iron	11.79%
Copper	4.15%
Chromium	6.43%
Zinc	2.14%
Calcium	1.25%
Sulphate	2.50%
Moisture	55.35%
Total solids	44.65%

Moisture content is determined by loss in weight after drying 16 hours at 100°C.

This analysis compared with one of last September shows a 10% increase in solids, a 2% drop in copper, and a 4% increase in iron; other constituents are about the same. We attribute this to improved launder efficiency and improved sludge densification.

Quality Control

The following routine tests are performed to control the efficiency or effectiveness of the process and to meet requirements.

(a) The pH electrodes are cleaned and checked against a portable pH unit on a daily basis. Particular attention is directed to the electrode controlling the flow of lime slurry to No.2 neutralizing tank. A malfunction could result in unnecessary lime loss by excessive additions or incomplete neutralization and contaminated final effluent.

(b) Daily copper, chromium, iron and hexavalent chromium determinations are made on the clarifier overflow to monitor the effectiveness of the process; sample is composite collected over an eight hour period.

(c) The launders are examined twice weekly for copper cementate build up on the iron and to ascertain the necessity for washdown. Copper determinations are made on the waste fluid entering the launder and leaving the launder, to determine per cent reduction of copper effected within the launder.

(d) Depth of sludge in the thickener is ascertained twice daily to determine the "on" time of the sludge transfer pumps to the thickener and to determine the "on" time of pumps to the filter for removal of excess sludge.

Conclusion:

We have learned by experience and from assistance by Ontario Water Resources Commission Staff. For example, we have learned that no stray lime or neutralized solution should find its way to, or be recirculated to, the launders. The launder function depends on an acidic environment. We have learned that for constant recirculation steam syphoning precludes mechanical failure of pumps on 24 hour service. We have learned that better launder efficiency results from having lighter pieces of iron in the baskets to permit washing and improved contact.

We hope to learn more. Areas under investigation by our Research staff include:

1. Treatment of water soluble oils and their removal by the sludge and filter cake. Currently, solutions up to 10% oils are trucked away to a dumping ground where we presume they become subject to dispersion and eventual inclusion in natural water resources.

2. Improved control and efficiency of copper cementation and chromium reduction in launders.

3. Development of neutralizing methods other than use of lime. Lime is still best.

4. Improved flocculation to reduce further the amount of pinpoint matter in suspension in the clarifier overflow.

5. Further reduction of moisture content in the filter cake or improved efficiency of the filter.

6. Development of use, or market, for the filtered sludge.

We know that our accumulated experience will be of benefit in development of other Anaconda treatment plants. We expect it will be of benefit to others also, and we do have frequent visits from interested parties.

Finally, we offer some quantitative statistics.

Raw Materials Used	Approximate Quantities Used
Coagulant aid X 1633	5 lbs. 10 ozs. per day
Scrap iron tube	5 tons per month
Hydrated lime	22 tons per month

End Products

Treated effluent re-used as cooling water in casting, and as make up water in the treatment plant.

Copper cementate from which copper metal is recovered - 5 tons per month (wet).

Filter cake sludge for which no market has been found - 28 tons per month.

"THE TREATMENT OF LIQUID WASTES FROM AN AUTOMOBILE MANUFACTURING OPERATION"

BY

J. A. WATSON
GENERAL SUPERINTENDENT
PLANT ENGINEERING
GENERAL MOTORS OF CANADA LIMITED
ST. CATHARINES, ONTARIO

General Motors Corporation operates nine plants in Canada, eight of which are located in Ontario, and one in Ste. Therese, Quebec. Early this year these plants were all gathered together under the common name of General Motors of Canada Limited. Previous to that, some had been known as General Motors of Canada Limited, and others under distinctive names of their own.

The plants which this paper deals with were formerly known as Divisions of McKinnon Industries Limited, a wholly owned subsidiary of General Motors Corporation. Two of these plants are located in St. Catharines, Ontario, and one in Windsor, Ontario. The St. Catharines Plants include a modern, continuous pour foundry producing some 2,000 tons of automotive castings per day; an engine plant producing complete V-8 and 6 cylinder engines for General Motors cars and trucks; and an axle and accessory plant producing front and rear axles, starting motors, Delcotrons, and AC components for General Motors cars and trucks. The Windsor Plant produces automatic transmissions for General Motors cars and trucks. It is one of the few plants of General Motors Corporation which produces automatic transmissions outside of the United States. The combined floor space of these three plants is in excess of 3 million square feet, and the combined employment is in the area of 9,000 persons.

A significant portion of the production of each of these plants is shipped to General Motors assembly plants in the United States.

The newest of these three plants is the St. Catharines Plant No. 2. Its Foundry Division began operations in 1952 and its Engine Plant Division began operations in 1954. Plant No. 1 at St. Catharines has mostly been rebuilt since 1936, although parts of it go back previous to the year 1916. Parts of the Windsor facility have been in existence since 1919.

Even this somewhat sketchy history is sufficient to indicate that for the most part these facilities were built before there was any great emphasis placed on matters pertaining to the control of liquid wastes from industrial plants.

As a part of fulfilling its obligations as a good corporate citizen, it is General Motors policy to comply with all regulations concerning the control of pollution, whether it be of air, water, or soil. Accordingly, when in September, 1965, the City of Windsor notified our Company that it intended to implement an Industrial Waste By-law, we began to take a good look at what was necessary to comply with such regulations. We were fortunate in this regard in that we were able to draw to some extent on the resources of General Motors Corporation for guidance in matters of pollution control. General Motors operates some 140 plants in the United States and Canada. More than 100 of these plants have installed industrial waste treatment facilities during the past 25 years. The remaining plants either do not generate pollutants or the effluents which they discharge are acceptable to municipal sewer systems. The Corporation also maintains a staff function in Detroit, known as the General Motors Plant Engineering Section, which, amongst other things, has the responsibility for co-ordinating matters of pollution control within the Corporation and for advising the Divisions on such matters.

In addition, there exists a committee composed of technical personnel from General Motors plants who have had experience in their own plants in the provision of waste treatment facilities. The services of this committee are available to Corporation plants which are embarking on programs of waste control and such plants can get valuable advice from the committee on ways to kick off a waste treatment program. Such advice was sought and obtained by our people in the planning of the waste treatment facility for the Windsor operation on which I would like to elaborate further during this presentation.

One of the elemental facts that came to light in the formulation of a program for control of industrial wastes was that the first line of attack should be to eliminate pollution at its source. In order to do this intelligently, of course, it is necessary to list the sources. So this becomes one of the first steps in the program: survey the complete plant operations listing each user of water and listing pertinent data as to how much water is used in each location, how much is discharged, and what the contaminants are, if any, in the discharge. This exercise often uncovers some processes which can be changed to eliminate pollution, as well as some places where sheer wastage of water is occurring. It is obvious that if sources of pollution or usage of water can be eliminated, the size and complexity of the final treatment plant can be correspondingly reduced.

It also becomes apparent very early in the planning that it is necessary to separate liquid wastes into three general classifications, that is,

(1) sewage and sanitary wastes

(2) cooling and storm water

(3) industrial wastes

The sewage can be discharged to municipal sewage systems or treated in industrial sewage treatment plants. The cooling and storm water can usually be discharged either to

[redacted]

The collection system for the third classification of liquid wastes requires a little closer attention to design. The whole purpose of the separation of liquid wastes into these three classifications is to ensure that no contaminated industrial wastes are discharged into the sewers before treatment. Therefore, this third collection system must be so designed that it will eliminate this possibility whether it occurs by accident or not.

To illustrate this point, there have been recent instances quoted in the news media describing cases where people have accidentally dumped contaminating wastes into floor drains in their plants and these wastes have found their way into sewers or into adjacent streams. One solution to prevent such occurrences is to eliminate floor drains in industrial buildings, but then, what happens if you have a fire and your sprinkler system lets go? You have a flood on your hands. Another solution is to instruct all of your employees that no oil or other contaminated liquid wastes can be dumped into the floor drains. However, mere instructions are not always enough to ensure that someone, sometime, will not intentionally or unintentionally use the floor drains to receive unwanted wastes. It is very difficult to control or police a large industrial operation to entirely eliminate the discharge of unwanted material into floor drains.

We therefore came to the conclusion that the solution which would satisfy all of our requirements would be to leave the floor drains in the floor but to connect them to an underground system which leads to an industrial waste treatment plant and to no other place. Into this system we also connected specific discharges from processes such as soluble oil tanks, industrial washers, etc., which constitute fixed sources of industrial liquid wastes. In this manner, we do not worry if our people get rid of contaminated liquids into the floor drains because they can go to no other place than through the treatment plant before discharge from our property. On rare occasions, where an unexpected event causes a flood of clear water to enter the floor drains (such as a sprinkler discharge or a broken water pipe) no harm is done to the treatment plant other than a temporary increase of hydraulic loading due to the unusual condition.

Some attention is required, when utilizing the existing underground system for this purpose, to be sure that the system is in good physical shape, that it is capable of resisting the types of industrial wastes that may be fed into it, and that the falls are sufficient to ensure adequate carrying away of the liquid wastes. In the case of our Windsor Operations, most of the existing sewers were adequate to handle the liquid wastes involved. In one of our St. Catharines Plants in which we are presently engaged in installing similar separation systems, it was necessary in some locations to replace existing floor drain systems with new systems which would provide for adequate removal of industrial wastes.

So much for the separation systems. Now, let us turn our attention to the treatment of the wastes collected by the industrial waste collection system. In the case of our Windsor Plant, the main types of pollutants in the industrial wastes consist of soluble cutting oils, lubricating and hydraulic oils, effluents from industrial type washers, etc. The soluble cutting oils, in particular, transform the total effluent into a white, milky-looking liquid, which is totally unacceptable for discharge into the sewers in this state.

Generally speaking, the treatment of these wastes is not too difficult and consists of skimming off the free oil, settling out the solid matter, precipitating out the oil in solution, and regulating the pH value. In order to regulate the treatment process, the total liquid effluent from the plant is collected in three holding tanks of approximately 100,000 gallons capacity each. These tanks allow storage of one day's waste ready for treatment. The tanks are emptied alternately. One such holding tank can be treated in eight hours operation of the treatment plant. The process can be explained with reference to the schematic flow diagram shown in Figure 1.

Process wastes from the plant are directed to holding tank No. 1 or No. 3. When tank No. 1 is full, the flow is directed to No. 3. The free oil will float to the top of tank No. 1 and is overflowed into tank No. 2, which is the only tank which contains a skimmer. After the free oil has been removed from the top of tank No. 1, tank No. 1 is agitated with compressed air to create a uniform mixture. Grab samples are taken from this tank and a fast analysis is made of the sample. This analysis determines the treatment for that batch which is done in the remainder of that shift.

The waste is pumped from the holding tank into the bottom of No. 1 alum tank, where alum is added. Sulphuric acid can also be added here if the analysis so dictates. Waste flows by gravity from the alum tank at a rate of about 300 gallons per minute: gravity flows keep turbulence to a minimum and do not break up the floc which is formed by the addition of the alum. In the No. 2 alum mix tank, the pH is finally adjusted and the waste flows from there into the two flotation units. These are large tanks which provide a period of retention time and allow the floc which contains precipitated contaminants in it to rise to the surface.

A portion of the waste water is taken out and pumped through an air saturation tank and reinjected back into the intake end of the flotation units. The air bubbles there rise to the surface of the liquid and help to float the floc to the surface. Skimmer bars at the surface of the flotation units mechanically assist in the removal of the floc. The flotation units discharge over a weir and the effluent flows to caustic mix tanks where the acid is neutralized with liquid caustic soda. The rate of flow of the neutralizer is manually adjusted as each batch is relatively uniform. There are continuously indicating and recording pH meters at the discharge of No. 2 caustic tank. At this point the soluble oils have been removed from the liquid waste along with most of the suspended solids and the pH of the effluent has been corrected to within the limits dictated by the regulatory by-law. The final step in the treatment is performed in the final clarifier which is a 210,000 gallon outdoor tank. The effluent flows from the No. 2 caustic mix tank into the bottom of this clarifier. It overflows around the top perimeter of the tank and discharges to the Windsor sanitary sewers.

The mixture of sludge and scum which is taken out by the holding tanks, the flotation units, and the final clarifier, is heated to about 180° in cookers to help to drive off any moisture that may be in it and the final residue is a black, oily liquid of fairly high viscosity. This is disposed of by diluting it with fuel oil and burning it in our powerhouse boilers. In our case we are doing this without any problem. It is interesting to note, however, that this final step in the solution of a water pollution problem sometimes introduces a problem of air pollution (if the final sludge cannot be burned with perfect combustion). Conversely, the solution of many air pollution problems by entraining the pollutants in water or other liquids can very often give rise to water pollution problems. It is, to say the least, an interesting situation.

The effectiveness with which the Windsor Treatment Plant is cleaning up the industrial wastes is evidenced by the accompanying tables listing the results of a typical day's tests of the operation. Analysis of the influent into the treatment plant, and the effluent from the treatment plant, are listed together with a comparison of the limits of contamination established by the Windsor City By-law. It should be noted that the effluent is well within the limits established by the By-law. Continuing periodic analysis shows results equally as satisfactory.

Although no major problems were encountered in the design and operation of this plant, there are one or two things worthy of mention. Particular emphasis has been placed on reliability of operation with provision being made throughout the system to enable the by-passing of various components for maintenance or repair without jeopardizing the overall operation of the system. In the initial operation of the system it was found that some education of plant personnel was necessary to ensure that undue amounts of clean water were not introduced into the industrial waste system causing hydraulic overload on the treatment plant.

The only real complaint concerning the whole operation was the occurrence of some odor from the exhaust stacks from the cookers under weather conditions with high humidity. This problem has been minimized by improving the operation of the air scrubbers through which this air passes.

The Windsor Treatment Plant officially went on stream on the 17 September 1968, approximately three years from the date on which we first started to look at the liquid waste problem at that plant. Since then it has been successfully treating approximately 100,000 Imperial Gallons of liquid waste each working day. As mentioned above, adequate capacity and reliability have been built into the system and as a result, to the best of my knowledge, there have been no occasions when untreated industrial waste has had to be discharged to the Windsor sewers.

Early in 1967, there were indications that the City of St. Catharines was preparing to implement an Industrial Waste By-law to regulate the discharge of water and wastes into its storm and sanitary sewer systems. In anticipation of the passage of such a by-law, we began at that time to look at the problems of liquid waste disposal at our Plant 1, which is located in the City of St. Catharines.

Following the same philosophy and logic as was used on a smaller scale in the Windsor Operation, we are currently engaged in installing three collection systems to separate sanitary, storm and cooling, and industrial wastes in this plant's operation. When we have these systems installed, we will still be discharging industrial wastes into the City sewers but the points of discharge will have been reduced from 23 in number to 1. We will then be able to, at this point, analyze the industrial effluents both quantitatively and qualitatively for an actual operating period of say two to three months. From the data thus obtained, we will be able to design the most efficient and effective treatment facilities for this operation.

The experiences which we have gone through in our Windsor Plant, and are going through in our St. Catharines Plant, have brought home to us the fact that the installation of treatment facilities in old plants is both disruptive of operations and expensive to undertake. The results of our efforts at our Windsor Plant have, however, been very gratifying and have convinced us that our method of approach has accomplished the desired results, namely, to eliminate the discharge of objectionable materials to waterways or City sewers, and to do our part in helping to eliminate the problem of water pollution.

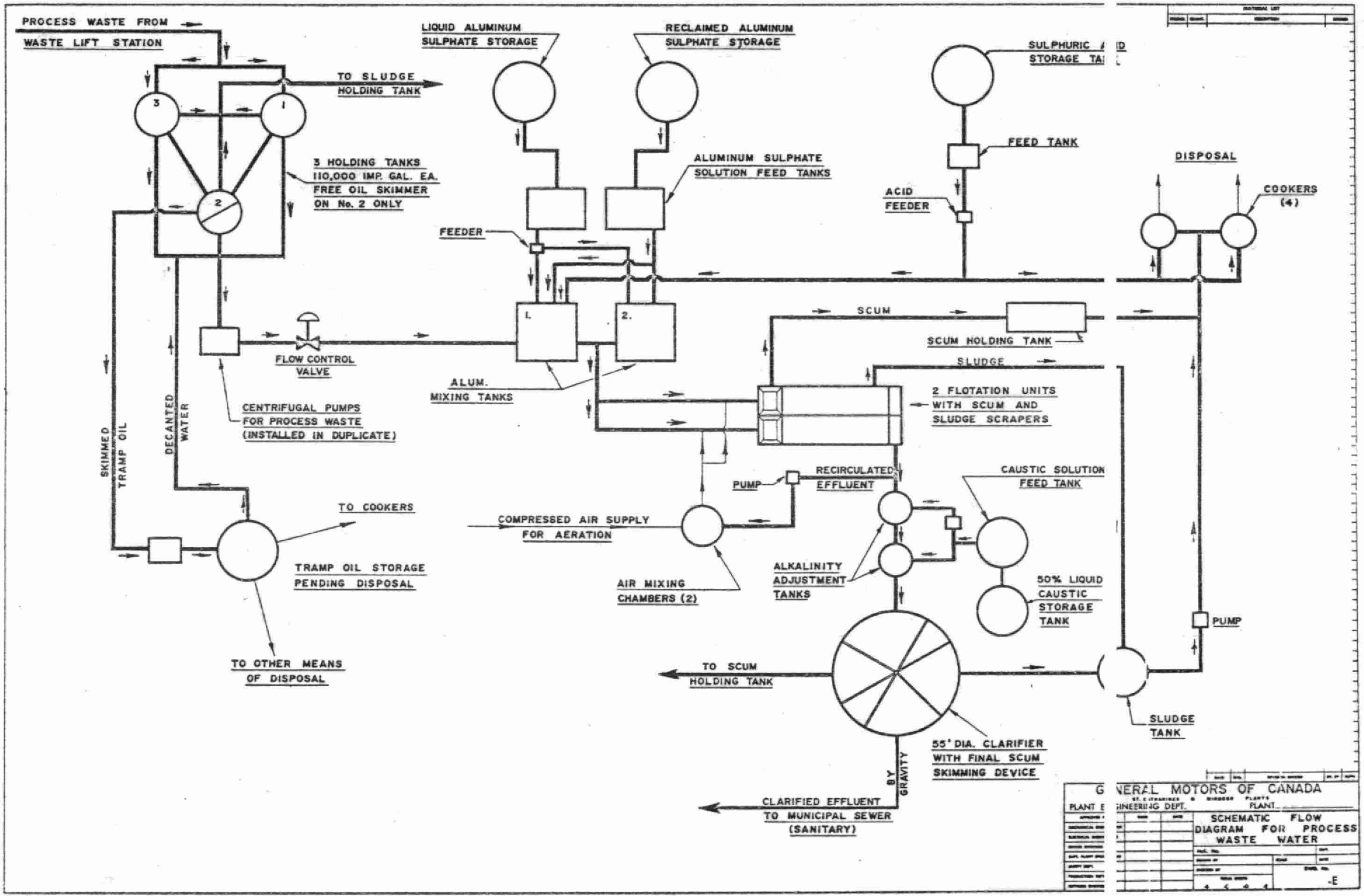
REPORT OF ANALYSIS

GENERAL MOTORS OF CANADA LIMITED
WINDSOR TREATMENT PLANT

Date Taken: February 25, 1969

SAMPLE MARKED: ANALYSIS NO.:	Influent K-4055	Effluent K-4056	By-Law Limits
Total Copper (as Cu)....	less than 0.3	less than 0.3	1.0
Total Nickel (as Ni)....	less than 1.	less than 1.	2.5
Total Chromium (as Cr)..	less than 0.1	less than 0.1	3.0
Total Zinc (as Zn)......	0.7	0.5	10.0
Total Cadmium (as Cd)...	less than 0.1	less than 0.1	1.0
Total Lead (as Pb)......	0.1	0.2	10.0
Phenols (as Phenol).....	0.06	0.03	.05
Cyanide (as CN).........	less than 0.5	less than 0.5	2.0
Sulphide (as H_2S).......	less than 0.1	less than 0.1	5.0
Chloride (as NaCl)......	420.	220.	1500
Sulphate (as Na_2SO_4)....	95.	1350.	1500
Grease (a) Hydrocarbons	1715.	less than 1.	15.0
(b) Fatty Matter	120.	3.	150.0
Suspended Solids (by M.P.)	1450.	12.	600.0
B.O.D. (5 days at 21°C)..	600.	90.	500.0

Note: All results reported in milligrams per litre (mg./l.)


PROCESS WASTE FROM
WASTE LIFT STATION
TO SLUDGE HOLDING TANK
LIQUID ALUMINUM SULPHATE STORAGE
RECLAIMED ALUMINUM SULPHATE STORAGE
SULPHURIC ACID STORAGE TA
3
1
2
3 HOLDING TANKS 110,000 IMP. GAL. EA. FREE OIL SKIMMER ON No. 2 ONLY
ALUMINUM SULPHATE SOLUTION FEED TANKS
FEED TANK
ACID FEEDER
DISPOSAL
COOKERS (4)
FEEDER
1.
2.
SCUM
SCUM HOLDING TANK
SLUDGE
FLOW CONTROL VALVE
ALUM. MIXING TANKS
2 FLOTATION UNITS WITH SCUM AND SLUDGE SCRAPERS
CENTRIFUGAL PUMPS FOR PROCESS WASTE (INSTALLED IN DUPLICATE)
SKIMMED TRAMP OIL
DECANTED WATER
PUMP
RECIRCULATED EFFLUENT
CAUSTIC SOLUTION FEED TANK
TO COOKERS
COMPRESSED AIR SUPPLY FOR AERATION
TRAMP OIL STORAGE PENDING DISPOSAL
AIR MIXING CHAMBERS (2)
ALKALINITY ADJUSTMENT TANKS
50% LIQUID CAUSTIC STORAGE TANK
PUMP
TO OTHER MEANS OF DISPOSAL
TO SCUM HOLDING TANK
SLUDGE TANK
55' DIA. CLARIFIER WITH FINAL SCUM SKIMMING DEVICE
BY GRAVITY
CLARIFIED EFFLUENT TO MUNICIPAL SEWER (SANITARY)
G NERAL MOTORS OF CANADA
PLANT E GINEERING DEPT.
PLANT
SCHEMATIC FLOW DIAGRAM FOR PROCESS WASTE WATER
-E

JAMES E. LUDBERG

"REMOVAL OF PHENOL AND THIOCYANATE FROM COKE PLANT EFFLUENTS AT DOFASCO"

BY

JAMES E. LUDBERG
COKE PLANT SUPERINTENDENT

G. DONALD NICKS
BLAST FURNACE TECHNOLOGIST

DOMINION FOUNDRIES AND STEEL, LTD.
HAMILTON, ONTARIO

During the past several years, Dominion Foundries and Steel of Hamilton, Ontario, has been placing increasing importance on the control of air and water pollution. In 1967, some $2,500,000 was spent on water pollution control for the coke plant alone. Today, I want to describe to you the design and operation of one of the plants installed--the Bacteriological Effluent Treatment Plant.

Formation and Removal of Phenol From Flushing Liquor

Metallurgical coke is made by the destructive distillation of coal in the absence of air. The coal is carbonized in slot-shaped silica brick ovens by being heated to about 2000°F. The bituminous coal charged contains surface water and water of combination. In the coking process, this water is evaporated and then recondensed along with the tar vapour as the gas is cooled in the mains at the battery and in the direct or indirect coolers in the coal chemical plant. The water is then separated from the tar in continuous decanters. The volume of water so obtained is considerable. At the present coking capacity of our two coke plants, it amounts to approximately 75,000 gallons per day. This water, called ammoniacal liquor in the text books, is usually called flushing liquor by coke plant personnel. The chemical analysis of the liquor can vary considerably depending upon the temperature at which the ovens are operated, certain operational practices and other factors. A typical analysis is as follows:

pH	8.8
C.O.D. value	3400 ppm
Total ammonia	2010 ppm
Thiocyanate and cyanide as CNS	185 ppm
Total phenols	1100 ppm
Monohydric phenols	750 ppm

As you know, phenol, and to a lesser extent thiocyanate, constitute a real threat to water purity. Before the advent of the water pollution control program, this flushing liquor was discharged along with cooling water that was very low in water pollutants into the Hamilton bay. Waste water from various other industries, semi-processed sewage from the city of Hamilton and water from the storm sewers of the city also entered it. Because of the large dilution and the reduction of phenol concentration by natural means, there was little evidence of the phenol leaving the bay and entering the lake in sufficient concentration to affect the quality of the water pumped from the lake for domestic use. However, with the increase in the volume of industrial waste water due to the rapid growth of industry on the bay, the importance of phenol control has also increased. Every effort must be made to prevent even small concentrations of phenol being allowed to mix with the drinking water because if the water is chlorinated, chlorophenols are formed that give rise to an objectionable taste. The medicinal taste of chlorinated phenolic compounds is exceedingly penetrating and can be detected at extremely high dilutions of water. Various investigations have indicated that phenol concentrations as small as 1 part in 750 million can give the objectionable taste to chlorinated water.

Before the use of bacteriological treatment of flushing liquor, the two principal means employed to reduce the phenol and thiocyanate concentration were the evaporation of the liquor by spraying it on the incandescent coke or subjecting it to a solvent extraction process. In the quenching of the coke, approximately 1000 gallons of water are evaporated as steam with each quench, so as we quench 239 ovens per day, the 75,000 gallons of liquor could be disposed of easily in this manner. However, this method would contribute to in-plant air pollution and to the corrosion of steel in the vicinity of the quencher station. This method is still in rather wide use in the coking industry, and while it would give a complete solution to the water pollution problem presented by the volume of flushing liquor, we decided that the disadvantages mentioned above would make it unsuitable for us.

In the solvent extraction system, a two-section tower is employed. In the top section, the flushing liquor passes counter-currently to a flow of light oil (a coke plant term describing a mixture of aromatic chemicals--benzol, toluol, xylol, etc. recovered from the coke oven gas by petroleum oil extraction). In the bottom section, the phenolized light oil is brought in intimate contact with a 10% solution of caustic soda and sodium phenolate is produced and recovered. This process has the advantage that phenol can be recovered from the sodium phenolate and the sale of it represents a credit in the balance sheet of the process. However, the capital cost and the operating costs in manpower and chemicals are considerably higher than with the bacteriological process and even more important, the percentage removal of phenol is less, so it was decided to utilize the bacteriological process.

Design of Plant

The Otto Construction Company of New York was given a contract to build and commission a plant to effect the phenol and thiocyanate removal. In preparation for the design of the plant, samples of the liquor in the raw state and treated with copper sulphate with the pH adjusted with phosphoric acid to stabilize the effluent and prevent biological decomposition in transit were sent to the Simon-Carves Laboratory in England. There the samples were analyzed for their chemical content and biological tests were conducted in aeration flasks, Warburg and large flask recording respirometers. From the data collected, the plant as shown diagramatically in Figure 2 was designed. Subsequent pilot plant tests on larger samples indicated that the phenol content of the discharge effluent would be less than 1 ppm and that the thiocyanate and sulphide content would be materially reduced. As a large volume of uncontaminated cooling water from the blast furnace cooling staves was available to dilute the phenol plant discharge effluent before it flowed into the public water of Hamilton Bay, it was felt that the process would more than meet the O.W.R.C. requirements for purity of discharge water.

Anticipating a future addition to the coking facilities, the plant was designed for a total throughput of 133,000 Imperial gallons per day of flushing liquor and the removal of 1000 lbs. of phenol, and space was allocated for the future construction of another aeration tank so that the thiocyanate concentration could be further reduced. The plot plan of the plant is shown in Figure 1. Shown is a storage tank, a two-compartment aeration tank, settling tank, innoculum tank and a steel building to house the electrical gear and the pumps. The total area of the plant is 62' 6" by 161'.

Referring to the flow diagram, Figure 2, the flushing liquor from the two coke plants is introduced into a 200,000 gallon storage tank where the residual tar is separated by gravity and pumped back to a decanter tank. With the storage tank holding more than twice the daily production of liquor, there is a good separation and the contamination of the feed liquor is minimized. Originally the liquor was introduced as a solid flow into the tank, but in order to reduce the temperature and the ammonia content of the liquor in the tank, two ten-spray manifolds were installed on the roof of the tank.

From the tank, the liquor is pumped to a splitter box at the aeration tanks. The rate of flow is checked regularly and adjusted so that the liquor in the tank stays at a uniform high level and the maximum retention time is maintained. The flow from the pump is measured with a rotameter and dilution water is added to the stream at a ratio of about 1:1. The high dilution rate is necessary because of the ammonia content of the liquor. While the literature indicates that ammonia concentrations below 1700 ppm do not inhibit the removal of phenol, we have established the practice of reducing it to about 1200 ppm. The high dilution is also necessary to achieve the proper temperature in the aeration tank in the summer months.

In the splitter box, nutrient phosphoric acid is added at a rate of 1.1 gallons (63% H_3PO_4) per 100 pounds of phenol. The nutrient is necessary because the bacteria needs phosphorus as well as nitrogen and carbon in a suitable form in order to synthesize new cell material. The nitrogen is supplied by the ammonia, the carbon by the phenol, but as no other phosphorus is present it must be added. A stainless steel storage tank feeds a nutrient tank from which a steady drip of acid is taken.

Each of the two aeration tanks measures 30' by 30' x 15' high with a nominal liquid depth of 10' 6" and an effective capacity of 59,000 gallons. With a diluted feed volume of 150,000 gallons per day, the retention time in the aeration tanks is about 19 hours. The tanks can be operated either in parallel or in series, but we have usually operated them in parallel. The oxygen necessary for the growth of the bacteria is supplied by air forced into the bath by electrically driven Simcar aerators. This is a surface aeration device consisting of a fabricated mild-steel cone with a 130° included angle, fitted with 8 vanes consisting of mild steel flats welded on edge to the underside of the cone and arranged tangentially from a central hub situated at the apex of the cone. To enable the intensity of aeration to be adjusted over a wide range, a mechanical lifting and lowering device is incorporated into each unit. Variation of the immersion of the aerator in the liquid produces corresponding variation in the oxygen transfer rate. At the optimum setting, the total oxygen addition obtainable from the two aerators is 156 lbs. per hour. Each aerator is driven by a 30 H.P. motor.

Automatic anti-foam equipment is provided, but has not been used except when the plant was first started.

From the aeration tank, the effluent containing the biological sludge overflows into the 30' diameter by 7' deep concrete settling tank via the energy-dissipating centre well. The sludge settles out and the clarified liquor overflows a peripheral weir into a large lagoon into which the dilution water from the blast furnace empties. The sludge is moved to the centre of the settling tank by a slowly moving scraper and pumped back into the aeration tanks by the sludge pumps. The volume of sludge return is adjusted to equal the volume of the diluted feed entering the aerator.

A 250 gallon steel innoculum tank, equipped with an aerator and immersion heater is also provided to be used to prepare the biological sludge from a freeze-dried culture for starting up the plant the first time and following any period of prolonged shutdown.

Instrumentation consists of the following:

1. Indicating thermometers in the discharge of the storage tank and in each aeration tank.
2. Rotameters to measure the flow of raw feed and the dilution water.
3. Recording flow meters to measure the sludge return to the two aeration tanks and the flow of the treated effluent from the settling tank.

4. pH recording meter to measure the pH of the discharged effluent.

There is no automatic temperature control apparatus, but temperature control has not been difficult. The optimum temperature for phenol oxidizing bacteria is 30°C and the temperature of the aeration tank contents should be maintained within the range of 27° - 33°C. Temperature within the range of 5° - 40°C will not cause damage to the bacteria, but will reduce the rate of phenol destruction. In the winter months, the temperature is maintained at the desired level by the use of indirect steam coils in the storage tank and live steam addition in the aeration tank. Originally, the tanks were planked over, but the planks were removed for safety considerations.

Startup Experience

The first step in the starting of the plant was to develop a proper solution in the innoculum tank. Freeze-dried bacteria, cultured on our flushing liquor in England, was introduced into the tank full of flushing liquor. After seven days, the level of the phenol concentration in the tank dropped from 400 ppm to 30 ppm. At the same time, some activated sludge from the sewage treatment plant was added to one of the aeration tanks filled with flushing liquor diluted to a phenol concentration of 230 ppm. In five days the phenol concentration in the aeration tank was reduced to 20 ppm by the bacteria in the activated sludge. The innoculum tank solution was then added to the aeration tank and a closed circuit circulation was started. A solution was then prepared in the same manner in the other tank, and when the phenol concentration in both tanks was at the proper level, diluted feed stock was introduced into the tanks at half of the design rate.

During the next several days, an attempt was made to increase the rate of feed flow, but we experienced severe foaming that carried away solids and prevented the desired sludge buildup. Also, during this time, a failure of the anti-foam control equipment allowed ten gallons of the anti-foam chemical to enter the tanks as a slug and caused a heavy bacteria kill and the loss of the little sludge that had been developed. After flushing the system of the anti-foam chemical, we started again with a low solids concentration and slowly increased the feed rate. Various chemical additions and changes in practices were tried to improve the situation. Polyelectrolyte and alum were tried to stabilize the solids with little success, tributyl phosphate was added at a rate of 1 ppm as a foam suppressant with more success and the aerators were raised to a maximum freeboard to avoid over-aerating the solids. It was noted that by this time the foam was characterized by a whiter colour and larger bubbles of air, so water sprays were installed to control the foam in those areas of troublesome foam buildup. These sprays worked very well and we have not found it necessary to use any anti-foam chemicals since installing them.

Twelve days after starting to add the diluted feed into the aeration tanks, full feed was established, but the sludge buildup was slow and the phenol removal efficiency rather low. However, soon after that we were able to obtain excess sluge from the Domtar Chemical Company biological treatment plant in Hamilton, Ontario, and the operation of the plant straightened out and has worked well to date.

Control

Samples of the diluted feed, overflow, solution in the aeration tanks and the solution in the innoculum tank are taken six days a week and the following analyses and tests performed:

Diluted feed:

pH

Ammonia, phenol and thiocyanate concentration

Overflow:

pH

Ammonia, phenol and thiocyanate concentration

Suspended solids

(Occasionally the C.O.D. value)

Aeration tank solution:

Suspended solids

% settling test

S.V.I.

Innoculum tank solution:

pH

Phenol and thiocyanate concentration

The analytical methods employed are as follows:

Phenol - 4-aminoantipyrine direct colorimetric method in the presence of potassium ferricyanide. (This method is relatively easy to do and is sufficiently accurate for control purposes, but it tends to give high values at low concentrations. For example, the average phenol concentration of six samples was 1.6 ppm by this control method of determination and only 49 ppb by the standard distillation method. This should be borne in mind when observing the data plotted in Figures 3 and 4.)

Thiocyanate - Modified Aldridge method using ortho tolidine rather than benzidine.

Ammonia - Colorimetric Nesslerization method.

From the results of these analyses and tests, the operator changes the rate of addition of phosphoric acid and the rate of sludge return to the individual aeration tanks. These changes constitute the only control changes necessary to operate the plant other than those necessary to maintain the flow of the raw feed and the dilution water at the proper level.

Figures 3 and 4 show graphically the average results obtained over the past several months. In Figure 3, the weekly averages for a 14-week period are shown, and in Figure 4, monthly averages for a year of operation. As can be seen, there is a minimal reduction of ammonia content as the only ammonia removed is that used by the bacteria for cell growth. The percentage of phenol removal has been constantly high, with the true concentration of phenol in the discharged effluent being well below 1 ppm. However, the thiocyanate removal efficiency has been very erratic for no explainable reason. As seen in Figure 3, this efficiency will vary from one week to another by as much as 40% even though all operating conditions are maintained reasonably steady. Experiments have been carried out in the innoculum tank in an effort to improve the consistency of removal. The principal difficulty lies in the fact that the strains of bacteria that most effectively oxidize thiocyanate function best at a pH lower than that present in the aeration tank solution. The optimum pH for the thiobacillus thiocyanoxidans bacteria is about 7.0 with an allowable range of 6.5 - 7.6 while the average pH of the aeration tank solution is about 8.3. We tried developing a culture in the innoculum tank at the optimum pH and then transferring it to the aeration tanks, but this did not help the situation. It also appears that a longer retention time in the aeration tank is necessary for consistently good removal. This could be accomplished by the building of a second set of aeration tanks to operate in series with the present ones.

Cost of Operation

Operational costs of the process are low. The operators, who have other duties in the area, collect the daily samples, record operating data and make the changes necessary to the flow of the feed, dilution water, phosphoric acid and returned sludge. All of these duties require about 6 hours per 24-hour day. About 3 hours of laboratory time is required per day to make the various analyses. To date, very little maintenance time bas been required--not more than 1 hour per day. The daily electrical requirement is about 1320 KWH, and the cost of the phosphoric acid is $12.

In conclusion, I want to express our appreciation to Mr. E. N. Button, Vice President, Otto Construction Corporation, for his assistance in supplying us with information and to Dominion Foundries and Steel for allowing us to make this presentation.

FIGURE 1

PLOT PLAN

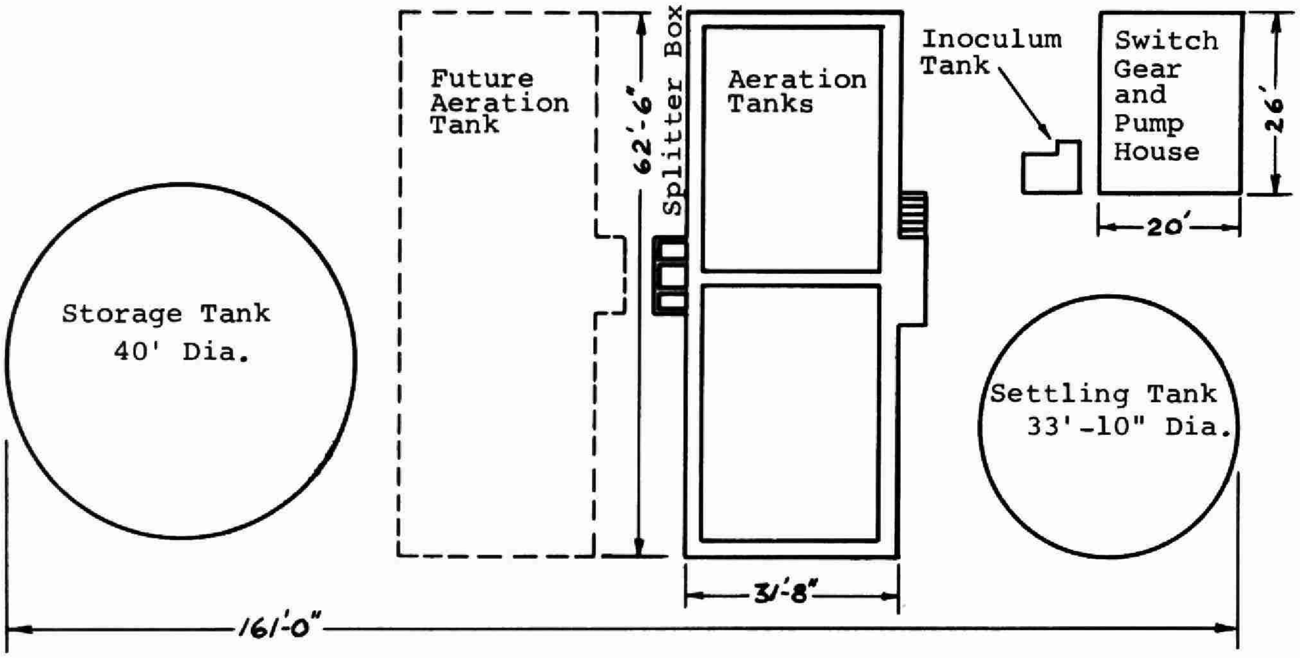


FIGURE 2

FLOW DIAGRAM

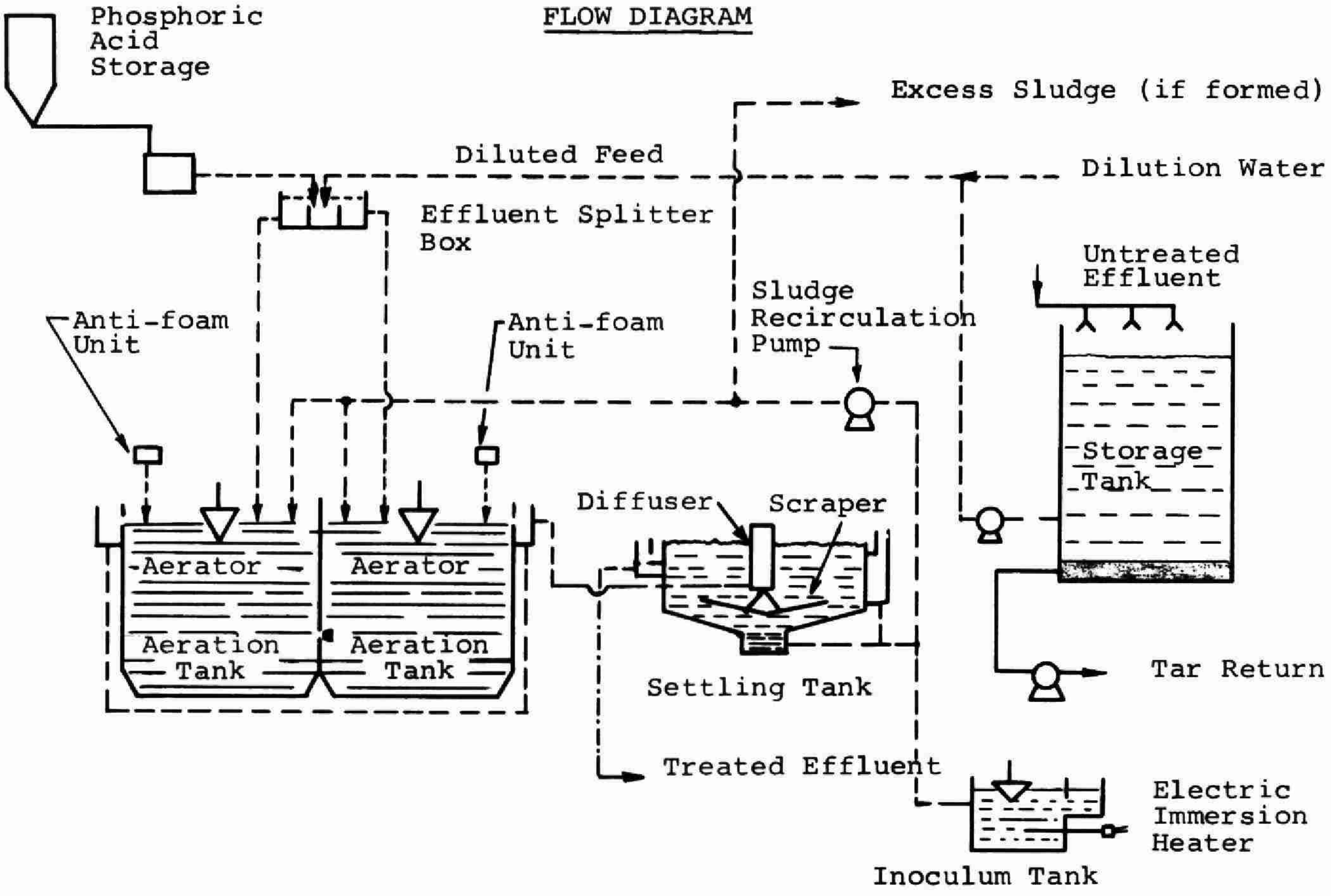


FIG. 3

GRAPH OF CONCENTRATION OF AMMONIA, THIOCYANATE AND PHENOL IN DILUTED FEED AND DISCHARGED EFFLUENT

WEEKLY AVERAGES

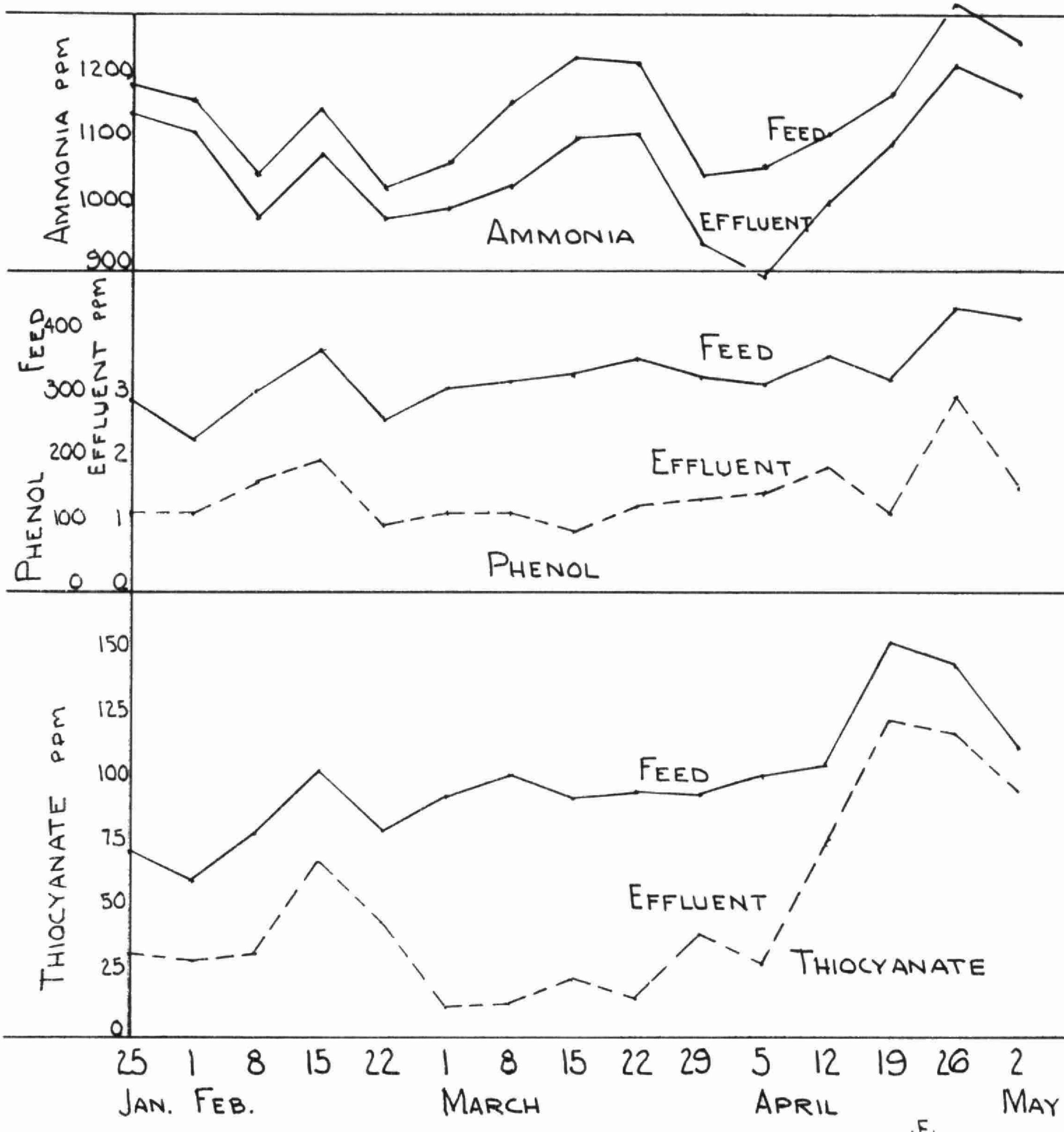
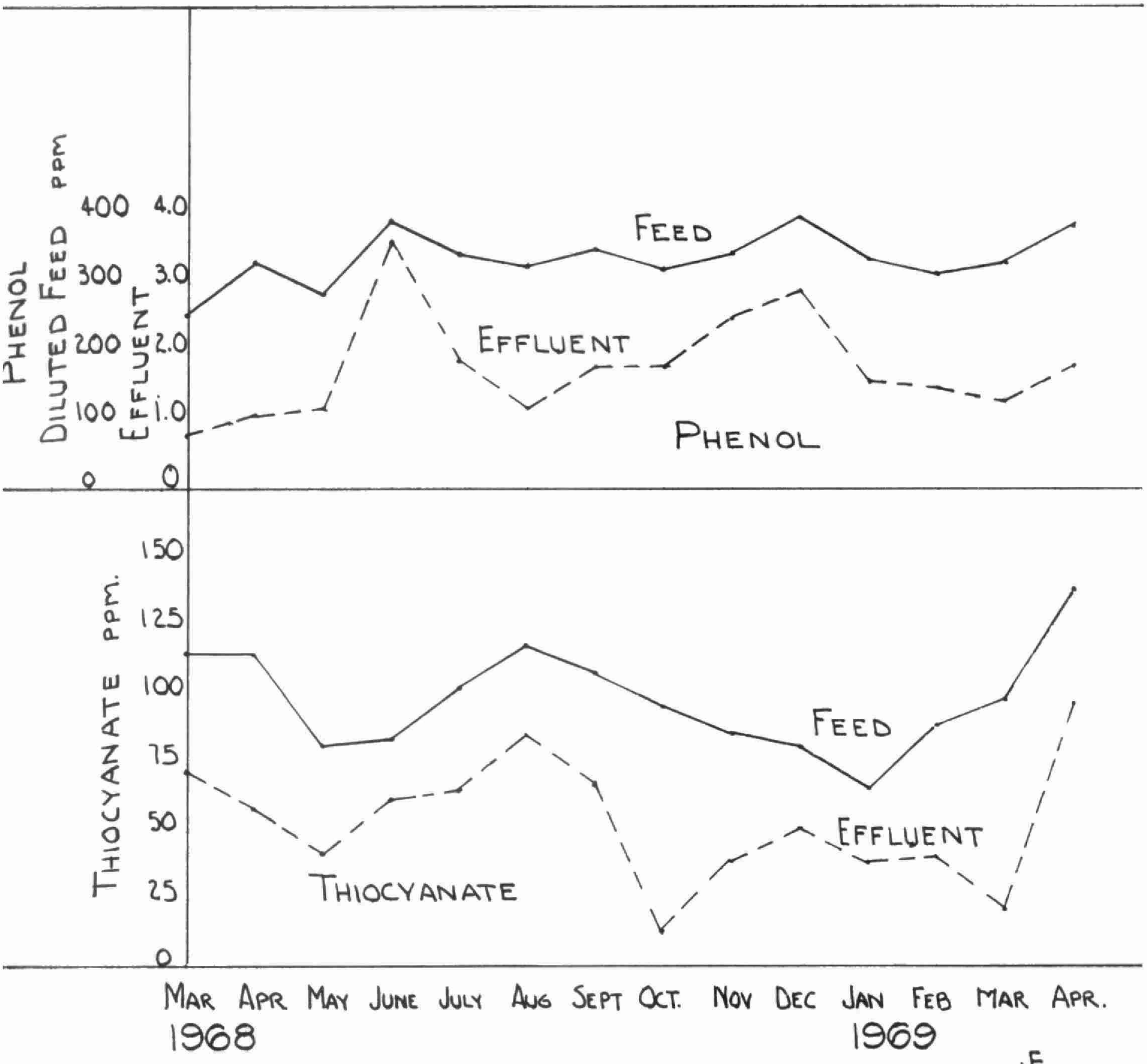


Fig 4

Graph of Concentration of Thiocyanate and Phenol in Diluted Feed and Discharged Effluent

Monthly Averages



EL

DR. G. E. SYMONS, PH.D.
EDITOR
WATER AND WASTES ENGINEERING
NEW YORK, N. Y.

"OXIDATIVE ASSIMILATION OF NITROGEN-DEFICIENT INDUSTRIAL WASTE"

A. F. GAUDY

BY

A. F. GAUDY, JR.
PROFESSOR AND DIRECTOR
BIOENGINEERING AND WATER RESOURCES
OKLAHOMA STATE UNIVERSITY
STILLWATER, OKLAHOMA

K. C. GOEL
LABORATORY DIRECTOR
DELAWARE WATER AND AIR RESOURCES COMMISSION
DOVER, DELAWARE

The term "oxidative assimilation" is one employed by microbiologists to denote microbial uptake of carbon source (under aerobic conditions) for the synthesis of non-nitrogenous cellular constituents. In order for cells to grow, i.e., multiply, a source of usable nitrogen is necessary, since important nitrogenous constituents such as proteins and nucleic acids (DNA and RNA) must be produced. However, in the absence of a source of nitrogen but in the presence of a sufficient number of living cells, all of the carbon source can be removed from solution (assimilated) and channelled into synthesis of such non-nitrogenous constituents as carbohydrate and lipid. During this process, oxygen is used as the terminal electron acceptor in the process of providing energy to accomplish the synthesis and, on a weight basis, the amount of cells (sludge) increases. In this sense the biomass has "grown" although the number of living cells has not changed. Thus it is possible to remove soluble organic molecules without adding nitrogen to the system during the substrate removal phase.

If this process could be used with a soluble organic industrial waste deficient or devoid of nitrogen, it would be possible to purify the waste without adding nitrogen to it. This would, of course, be a radical departure from conventional concepts. The problem arises in devising a way of perpetuating the process, since a given amount of biological solids cannot assimilate an unlimited amount of a carbon source, i.e., the capacity to take in the carbon compounds and convert them to carbohydrate and lipid components reaches a saturation level and the process slows down drastically. If, after permitting the biomass to synthesize the non-nitrogenous "stores," the sludge were separated from the mixed liquor and some of it were aerated in the absence of waste water (carbon source), i.e., if it were aerated under endogenous conditions, it might be expected that some of the non-nitrogenous compounds now stored in the sludge would be oxidized, thus regenerating the oxidative assimilating capacity of the sludge. Moreover, if some source of nitrogen (e.g., ammonium ion) were added to the "endogenating" sludge, some of the carbohydrate and lipid stored inside the cells could be used to produce new protein and nucleic acid thus increasing the viable cell population and enhancing the restoration of the assimilative capacity of the sludge. Such a process could be expected to save some of the cost of supplemental nitrogen, since not all of the sludge need be restored (or regenerated). Also, such a process could ensure that the treatment plant did not contribute to the stream enrichment problem due to leakage of nitrogen from the plant.

It is the purpose of this report to bring together various experimental findings which prove that this seemingly unorthodox mode of operation of an activated sludge process does indeed perform satisfactorily. This experimental evidence is taken from several reports published during the past four years (1)(2)(3)(4)(5)(6)(7). It is also our purpose to show how certain existing plants can be easily altered to make use of this mode of operation.

Komolrit, Goel, and Gaudy (1) conducted batch laboratory investigations in which a previously grown activated sludge was contacted with a synthetic waste (glucose as carbon source) in the absence of a source of nitrogen. The rate of purification as well as the rate of sludge accumulation was approximately the same as that observed for a control system to which nitrogen had been added. It was shown that carbohydrate was the major component of the sludge which was synthesized under nonproliferating conditions. After the carbon source was removed, a nitrogen source (NH_4^+) was added and a significant portion of the cellular carbohydrate was converted to protein under these endogenous conditions. Sludge which had undergone this interconversion of carbohydrate to protein was again capable of removing carbon source under nonproliferating conditions; however, the oxidative assimilation capacity of sludge which had undergone a similar endogenous period without addition of ammonium ion was greatly retarded.

These batch experiments led to the suggestion that the mode of operation for activated sludge treatment of nitrogen-deficient waste depicted in the upper flow diagram of Figure 1 might be feasible. It is seen that the nitrogen-deficient waste enters the aeration tank and is oxidatively assimilated, the sludge is settled, and purified effluent is channelled to the receiving stream without any contact whatsoever with the source of nitrogen. A portion of the settled sludge is channelled to the "endogenous aerator" where nitrogen is added and part of the non-nitrogenous compounds synthesized in the feeding aerator are converted to protein; the sludge is then recycled to the feeding aerator.

Comparison of this flow diagram with the one for a biosorption plant (lower part of Figure 1) shows that there is little difference in the flow diagrams. There is a significant difference in the mode of operation, since the nitrogen is added to the waste upon entering the contact aerator in the biosorption process. The detention time in this aerator is usually short (approximately 30 min.), and the biological solids concentration is maintained rather high (in the range 5000-8000 mg/l). While most researchers and engineers no longer believe that the soluble organic molecules are "adsorbed" on the sludge, the prevalent concept is that the soluble organics are taken up (assimilated) and stored in the sludge. The sludge is then settled and the stored materials are "burned off" (oxidized) in the sludge regeneration aerator. This concept has validity, but the addition of nitrogen to the waste before it enters the contact aerator militates against the success of the process. It has been shown that in the presence of a high concentration of biological solids the substrate is removed and channelled largely into non-nitrogenous cellular constituents even in the presence of a source of nitrogen (2)(3). Under such conditions (which are the ones obtaining in a biosorption plant), protein synthesis lags synthesis of non-nitrogenous components (mainly carbohydrates). Indeed, cellular protein which is needed for cell replication is usually made from the stored cellular carbohydrate; however, the short contact period in the aerator does not allow enough time for the interconversion, and a large portion of the nitrogen (usually added as ammonium ion) can be expected to pass out to the receiving stream with the effluent. Since a large portion of the supplemental nitrogen has been lost, there is a paucity of it in the sludge regeneration tank where it is really needed. To be sure, some of the storage products can be "burned off" (oxidized) but nitrogen source is needed here to "regenerate" the protein and DNA content of the sludge (rough indices of the degree of viability of the sludge).

In essence, it is the contention of the authors that a biosorption plant for the treatment of nitrogen-deficient waste tends to function like a continuous oxidative assimilation plant, but it is hindered from doing so efficiently because of the time-honored convention of adding the nitrogen to the waste before it enters the contact aerator rather than adding the nitrogen to the sludge after the assimilation stage. The conventional practice is based on the concept that, in order for microorganisms to multiply, a source of nitrogen is needed for synthesis of protein and nucleic acid. If one wished to remove the organic carbon from a waste by seeding it with a small microbial population, this concept would indeed govern because the rate of substrate removal in this case would be dependent upon microbial replication. This is true because the rate of exhaustion of the food supply is dependent upon the number of organisms. If, on the other hand, one employs a high concentration of organisms to begin with, the rate of exhaustion of the substrate is still dependent upon the number of organisms. However, in this case, large numbers are already present, and the carbon source can be taken up without much replication occurring, i.e., it can be taken up rapidly by the oxidative assimilation process and channelled into synthesis of non-nitrogenous cellular constituents. A source of nitrogen is not required for this process; the nitrogen source is therefore more effectively added to the sludge, not to the waste, in the case of high solids systems. These basic differences in the mechanism, as well as the kinetics, of substrate removal for high and low biological solids systems have been shown experimentally by Rao and Gaudy (2), and by Krishnan and Gaudy (3).

Thus far the work which led to proposing the oxidative assimilation flow diagram and the biological concepts on which it is based have been discussed. It is now appropriate to describe the experimentation which was accomplished to determine the mechanistic feasibility of the process with regard to carbon sources other than glucose, and the engineering feasibility with regard to the continuous operation of the process. First, it was essential to determine that the sequence of oxidative assimilation of carbon source, endogenous interconversion of storage products to protein, and consequent restoration of assimilation capacity was possible for compounds other than glucose. The compounds lactose and acetate were selected as carbon sources for batch experiments similar to those previously accomplished on glucose. Lactose was chosen because its metabolism is dependent upon the presence of inducible enzymes, e.g., β-galactosidase, and it seemed possible that during the endogenous phase dilution or degradation of the enzyme could occur; thus the cells might lose acclimation to the original carbon source. Acetate was chosen since it was important to determine the mechanistic feasibility of the process for carbon sources other than carbohydrates.

The results of experiments using these carbon sources were similar to those using glucose. Both compounds were removed rapidly in the absence of a nitrogen source. It was found that the storage compounds synthesized in the assimilation phase were converted to protein under endogenous conditions in the presence of an exogenous nitrogen source (NH_4^+), and when this "regenerated" sludge was again contacted with a fresh supply of carbon source, it had regained (or retained) its assimilating capacity (4). In the case of acetate, it was noted that the oxidative assimilation capacity of the sludge after the regeneration period was somewhat lower than that recorded in the first oxidative assimilation phase. The results left little doubt that the process worked for acetate but did provide cause for restraint in making recommendations as to its scope of applicability for various nitrogen-deficient waste waters. It was decided that the use of acetate as carbon source for experimentation in continuous flow pilot plants would provide a severe test of the operational feasibility of the process.

The bench scale pilot plant used in continuous flow studies employing various carbon sources is shown in Figure 2. Three separate long-term studies were made using the following carbon sources: glucose (5), acetate (6), and sugar refinery waste (7). In the basic engineering studies using either glucose or acetate, the amount of nitrogen supplied to the sludge in the endogenous aerator was varied. For all studies the volume of aeration liquor in the feeding phase reactor was 2400 ml. The waste (either acetate or glucose at 1000 mg/l) was fed at a rate of 400 ml/hr. The aeration liquor was channelled to the settling tank from which supernatant was continuously discharged. Twice daily (at 12-hour intervals) sludge was withdrawn from the bottom of the settling tank. A portion of it was wasted, and a second portion was diluted with the settling tank supernatant to a desired consistency and channelled to the endogenous aerator for conversion of cellular storage products to protein. Ammonium sulfate was added to this tank, and the sludge was aerated for twelve hours. Following this regeneration period, the sludge was channelled to the aerated holding tank and pumped to the feeding aerator at a rate of 200 ml/hr, and another batch of sludge was subjected to regeneration in the endogenous aerator. Thus regenerated sludge and nitrogen-deficient waste were continuously pumped into and contacted in the feeding aerator. It can be seen that maintenance of biological solids concentration and efficiency of COD removal would be, in this system, entirely dependent upon the phenomenon of continuous oxidative assimilation. The detention time in the feeding aerator was four hours, i.e., 2400 ml ÷ (400 ml/hr waste + 200 ml/hr recycle solids). All sludges were developed from an initial seed obtained from municipal sewage. In the case of the synthetic waste (glucose or acetate), the waste contained, in addition to the carbon source, various inorganic salts dissolved in a mixture of distilled and tap water (5)(6).

In these continuous flow experiments it was desirable to compare the nitrogen requirement with values usually considered ample in conventional practice. The BOD/N or COD/N ratio is usually employed as a design or operational parameter. In order to make such a comparison, the ammonium sulfate was added to the endogenous aerator, at any particular COD/N ratio, on the basis of the total COD supplied to the feeding aerator during each 12-hour period. For example, the COD of 1000 mg/l acetate is 1060 mg/l (6); therefore during any 12-hour period 5088 mg COD entered the feeding aerator (400 ml/hr x 12 hr x 1060 mg/l COD). For operation at a COD/N ratio of 10/1, 508.8 mg ammonia-N would be supplied to the endogenous aerator each 12-hour period. Since a volume of 2500 ml sludge was always used in the endogenous aerator, the concentration of exogenous nitrogen at the start of the endogenous period was 203.5 mg/l when the system was operated at COD/N of 10/1. Extended runs were made at COD/N ratios of 10/1 to 70/1. Analyses employed to assess the performance of the system included COD of the settling tank effluent and membrane filtrates (8), biological solids concentration in the reactors, protein and carbohydrate content of the sludge (9), and ammonia nitrogen carried over from the endogenous aerator and in the final effluent (10).

The results of previous batch studies had indicated that the use of acetate would provide a severe test of the process under continuous flow operations. The results shown in Figure 3 were obtained using acetic acid as the carbon source in the synthetic waste; the COD/N ratio was 70/1 in this experimental run. Thus, these results show that the process did successfully withstand a rather severe test of its applicability to a non-carbohydrate nitrogen-deficient waste. Based upon filtered effluent, the efficiency of COD removal was slightly over 90 per cent (feed COD of 1060 mg/l vs. average effluent COD of 98 mg/l). The COD of the unfiltered settling tank effluent is not shown in the figure. The average unfiltered supernatant COD was 140 mg/l, which yielded a value of 87 per cent for the efficiency of COD removal. The difference between filtrate and supernatant COD is attributable to COD of unsettled cells in the effluent. The rather close agreement of the average values for filtered and unfiltered effluent attests to the relatively good settling characteristics of the sludge. Indeed, throughout all of the experiments, the settling characteristics of the sludge were no different from those usually found with a conventional activated sludge.

In Figure 3 both the biological solids concentration in the feeding aerator and the biological solids concentration due to recycle sludge are shown (i.e., recycle sludge concentration x 200/600). The difference between these values represents the net sludge synthesis due to continuous oxidative assimilation (hatched area). The results leave no doubt that the process can work effectively under continuous flow conditions. At the high COD/N ratio employed (70/1), all NH_4^+ ion added to the endogenous aerator was used, i.e., there was no carryover to the feeding aerator; also, there was no ammonia-N in the plant effluent.

Pilot plant studies using a synthetic waste in which glucose served as carbon source were conducted using COD/N ratios of 10/1, 30/1, 40/1, 50/1, and 70/1. Again the process provided efficiencies of COD removal (based upon unfiltered settling tank supernatant) ranging from 94 to 90 per cent. At various times throughout the period of pilot plant operation, samples were taken from the endogenous aerator to assess the kinetic course and extent of conversion of cellular carbohydrate to protein. The results shown in Figure 4 are typical of many such runs. It is seen that the conversion takes place in less than twelve hours. It appears that the endogenous aerator detention time could be reduced to nine hours or less.

While all of the research thus far described yielded results indicating that the process was feasible from both a mechanistic (biochemical) and practical (operational) standpoint, no work had yet been accomplished on an actual nitrogen-deficient industrial waste. A decision was made to test the process on sugar refinery effluent. The waste was obtained from the Imperial Sugar Company refinery by personnel of the Visco Division of the Nalco Chemical Company, Sugarland, Texas. Samples were air-expressed weekly to the bioengineering laboratories in Stillwater, Oklahoma, and stored in the cold until fed to the aeration unit. The pilot plant was operated in a manner similar to that employed for the synthetic waste except that various detention times (eight hours and five hours) were employed as well as various nitrogen and phosphorus levels. No attempt was made to provide for a constant COD concentration in the feed, nor was the system run at a controlled temperature. This procedure was followed in order to test the process under the normal environmental changes which might be encountered in the field. Incoming shipments of sugar refinery waste were sometimes blended; however, there were at times severe fluctuations in the concentration of COD in the pilot plant feed. During these investigations, the temperature in the feeding aerator was 25 ± 4^{o}C. The most severe test conditions to which the system was subjected using the refinery waste were as follows: Feeding aerator detention time, five hours, COD/N = 60/1, COD/P = 140/1 (phosphorus, as phosphate, was added to the waste, i.e., not to the endogenous aerator). During operation under these conditions no attempt was made to adjust or to buffer the pH. The behavior of the system under these operational conditions is shown in Figure 5. It is seen that there were rather severe fluctuations in the concentration of feed COD and in the concentration of biological solids in the feeding aerator. However, the effluent COD (filtered or unfiltered) remained relatively steady. Daily analyses for ammonia-N were made and, except for one sample in which the NH_3-N concentration was 0.01 mg/l, none was detected in the effluent. BOD's were not run on the effluent but they were run on the raw waste and, using the BOD/COD ratio of the raw waste, the BOD/N ratio employed in this run was in excess of 40/1 (i.e., approximately double the conventionally employed ratio). Sludge samples taken from the endogenous aerator during the 12-hour period allowed for conversion of storage products to protein and nucleic acid indicated that a significant increase in protein content and decrease in carbohydrate content occurred in the endogenous aerator in nine hours or less, thus providing further indication that the detention time in the endogenous aerator can be reduced.

In summary, batch studies as well as continuous-flow, pilot plant investigations have shown the mechanistic and operational feasibility for engineering applications of the following sequential biochemical processes for nitrogen-deficient wastes: oxidative assimilation of the organic substrates in the waste water by acclimated sludge in the absence of a nitrogen source, followed by interconversion of the stored carbon to protein and other nitrogen-containing products during a period of endogenous metabolism in the presence of an exogenous source of nitrogen and, finally, recycling of this sludge with restored oxidative assimilation capacity for recontact with the nitrogen-deficient organic waste. This mode of operation has (in the laboratory) been shown to yield good treatment efficiency for carbohydrates and a noncarbohydrate substrate as well as a nitrogen-deficient industrial waste. The settling characteristics were comparable to those of a conventional activated sludge. Also in the studies on the sugar refinery waste there were some indications that the system could successfully withstand rather severe quantitative shock loadings. The process could be successfully operated without leakage of the supplemental nitrogen source in the plant effluent. Successful operation was maintained at a COD/N ratio as high as 70/1 in the studies using synthetic wastes. For these wastes the BOD/COD ratio was determined experimentally to be approximately 0.7. Therefore, the BOD/N ratio was approximately 49/1. For the sugar refinery waste, the highest BOD/N ratio at which the system was operated was in excess of 40/1. When these values are compared with the BOD/N ratio of 20/1 conventionally employed, the possibility for savings in the cost of supplemental nitrogen is readily apparent.

The results of experiments on this new mode of operation have permitted us to conclude that the continuous oxidative assimilation process is a useful one, and we therefore recommend its use to the field. There are naturally various aspects which should be investigated further; however, it seems to us that these could be more usefully investigated at the plant scale level. Experimentation at existing "biosorption" plants treating a nitrogen-deficient industrial waste could be rather easily facilitated at the plant scale level. Also, in view of the possible savings in nitrogen and alleviation of some of the eutrophication problems in receiving streams due to leakage of nitrogen in plant effluents, pilot plant work at any existing site at which nitrogen-deficient wastes are currently being treated biologically could prove to be a wise investment.

Further experimentation to determine optimum detention time in the feeding and endogenous aerators, optimum recycle solids levels, and the limiting BOD/N ratio seems warranted in larger scale work than we have employed in our studies. Also, it would be ideal to determine if the location of phosphorous supplementation (if the waste is deficient in phosphorous) could be split between the feeding and endogenous aerators.

In conclusion, it is felt that while the mode of operation herein recommended does represent a rather bold departure from the conventional mode of operation thus providing a possible deterrent for its acceptance by many designers in the sanitary engineering field, enough laboratory research has been accomplished to demonstrate its applicability to treatment of nitrogen-deficient wastes and its soundness from a mechanistic standpoint. It is hoped that industrial managers, engineers, and operational personnel interested in effecting savings in cost of operation and in obviating the need for concern over the possible contribution their treatment plant may make to the stream enrichment problem due to leakage of nitrogen will experiment with the process in the field.

ACKNOWLEDGEMENT

This work was made possible through financial support provided by the Federal Water Pollution Control Administration (USDI, Research Grant WP-00325). Studies to test the applicability of the process to sugar refinery waste were conducted with the financial support of the Nalco Chemical Company.

REFERENCES

1. Komolrit, K., Goel, K. C., and Gaudy, A. F., Jr., "Regulation of Exogenous Nitrogen Supply and Its Possible Applications to the Activated Sludge Process," Journal Water Pollution Control Federation, 39, 251-266 (1967).

2. Rao, B. S., and Gaudy, A. F., Jr., "Effect of Sludge Concentration on Various Aspects of Biological Activity in Activated Sludge," Journal Water Pollution Control Federation, 38, 794-816 (1966).

3. Krishnan, P., and Gaudy, A. F., Jr., "Substrate Utilization at High Biological Solids Concentrations," Journal Water Pollution Control Federation, Research Supplement, 40, R54-66 (1968).

4. Goel, K. C., and Gaudy, A. F., Jr., "Regeneration of Oxidative Assimilation Capacity by Intracellular Conversion of Storage Products to Protein," Applied Microbiology, 16, 1352-1357 (1968).

5. Gaudy, A. F., Jr., Goel, K. C., and Gaudy, Elizabeth T., "Application of Continuous Oxidative Assimilation and Endogenous Protein Synthesis to the Treatment of Carbohydrate Wastes Deficient in Nitrogen," Biotechnology and Bioengineering, XI, 53-65 (1969).

6. Gaudy, A. F. Jr., Goel, K. C., and Gaudy, Elizabeth T., "Studies on Continuous Oxidative Assimilation of Acetic Acid and Endogenous Protein Synthesis Applicable to Treatment of Nitrogen-deficient Waste Waters," Applied Microbiology, 16, 1358-1363 (1968).

7. Gaudy, A. F., Jr., Goel, K. C., and Freedman, A. J., "The Treatment of Sugar Refinery Wastes by a New Modification of the Activated Sludge Process." Paper prepared for Proceedings of the 4th International Conference on Water Pollution Control Research, Prague, Czechoslovakia, April (1969).

8. American Public Health Association, Standard Methods for the Examination of Water and Waste Water (12th Ed.), American Public Health Association, New York (1965).

9. Gaudy, A. F., Jr., "Colorimetric Determination of Protein and Carbohydrate," <u>Industrial Water and Wastes</u>, <u>7</u>, 17-22 (1962).

10. Ecker, R. E., and Lockart, W. R., "Specific Effect of Limiting Nutrient on Physiological Events During Culture Growth," J. Bacteriol., 82, 511-516 (1961).

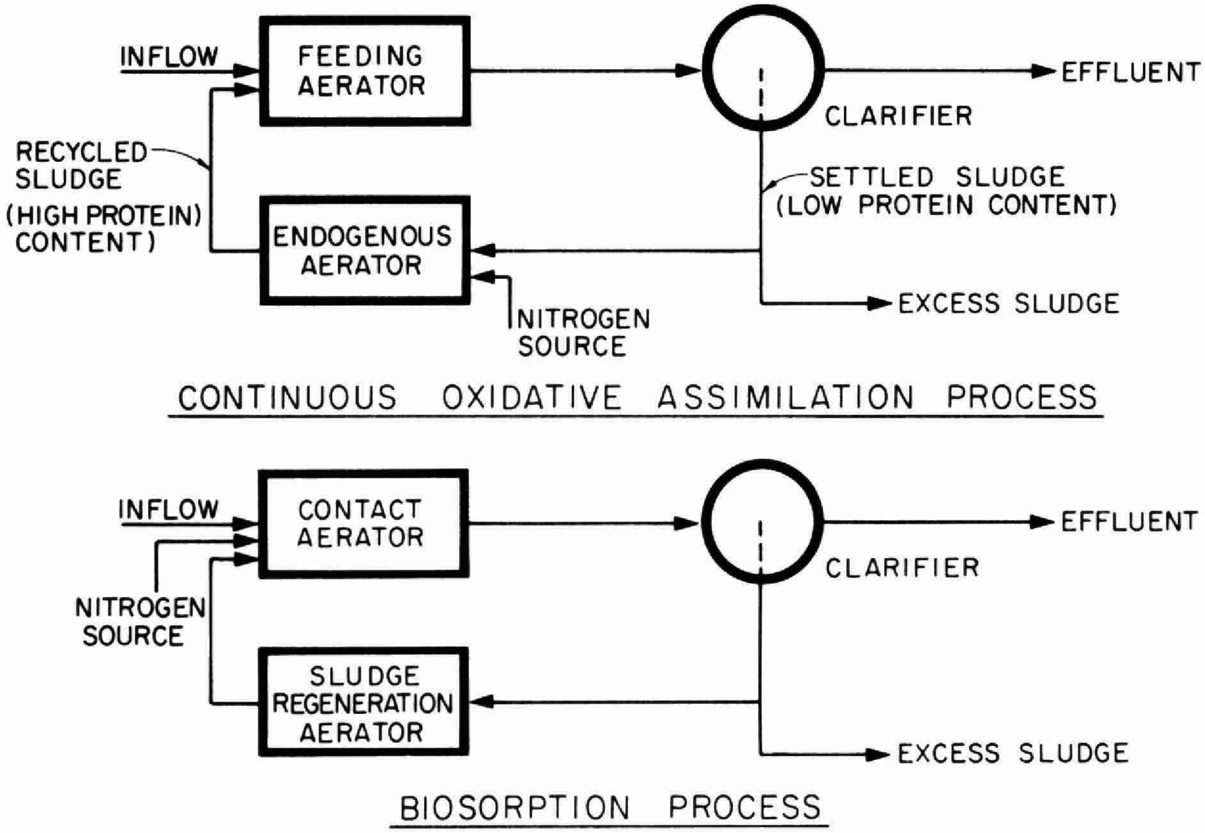


Figure 1 - Comparison of the continuous oxidative assimilation process and the biosorption process.

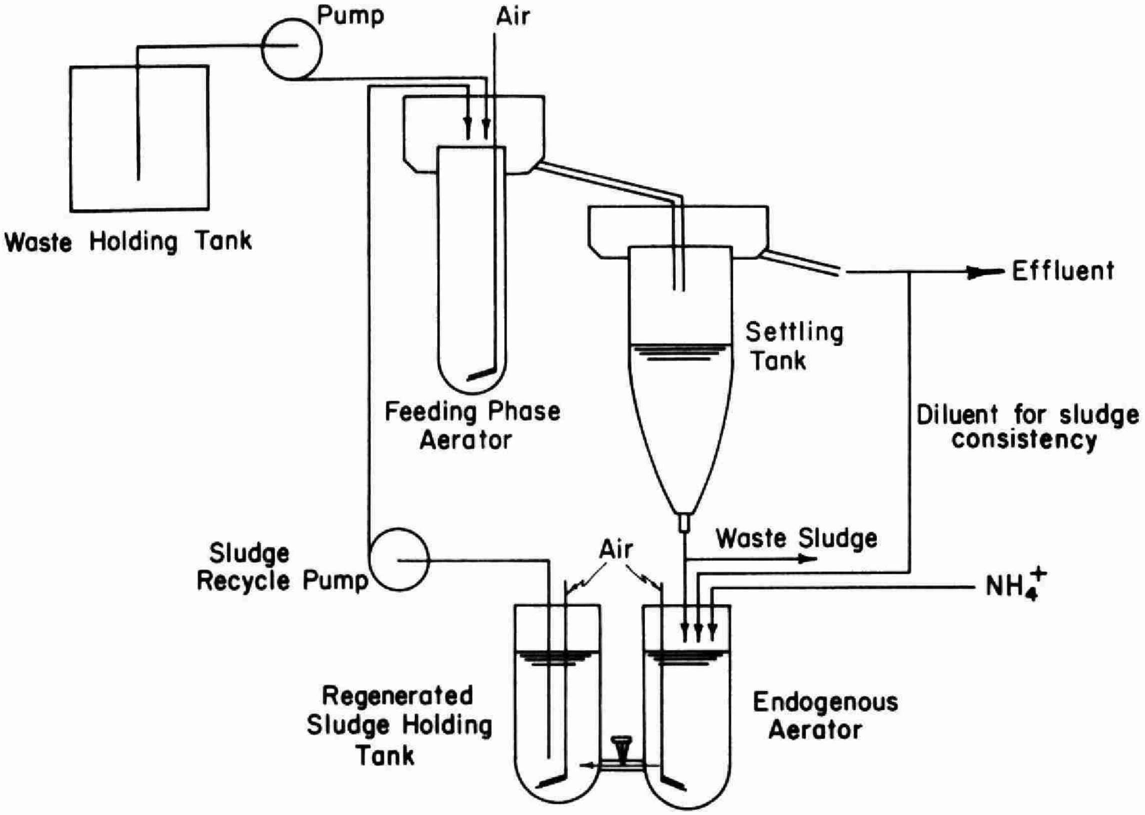


Figure 2 - Laboratory pilot plant for continuous oxidative assimilation process.

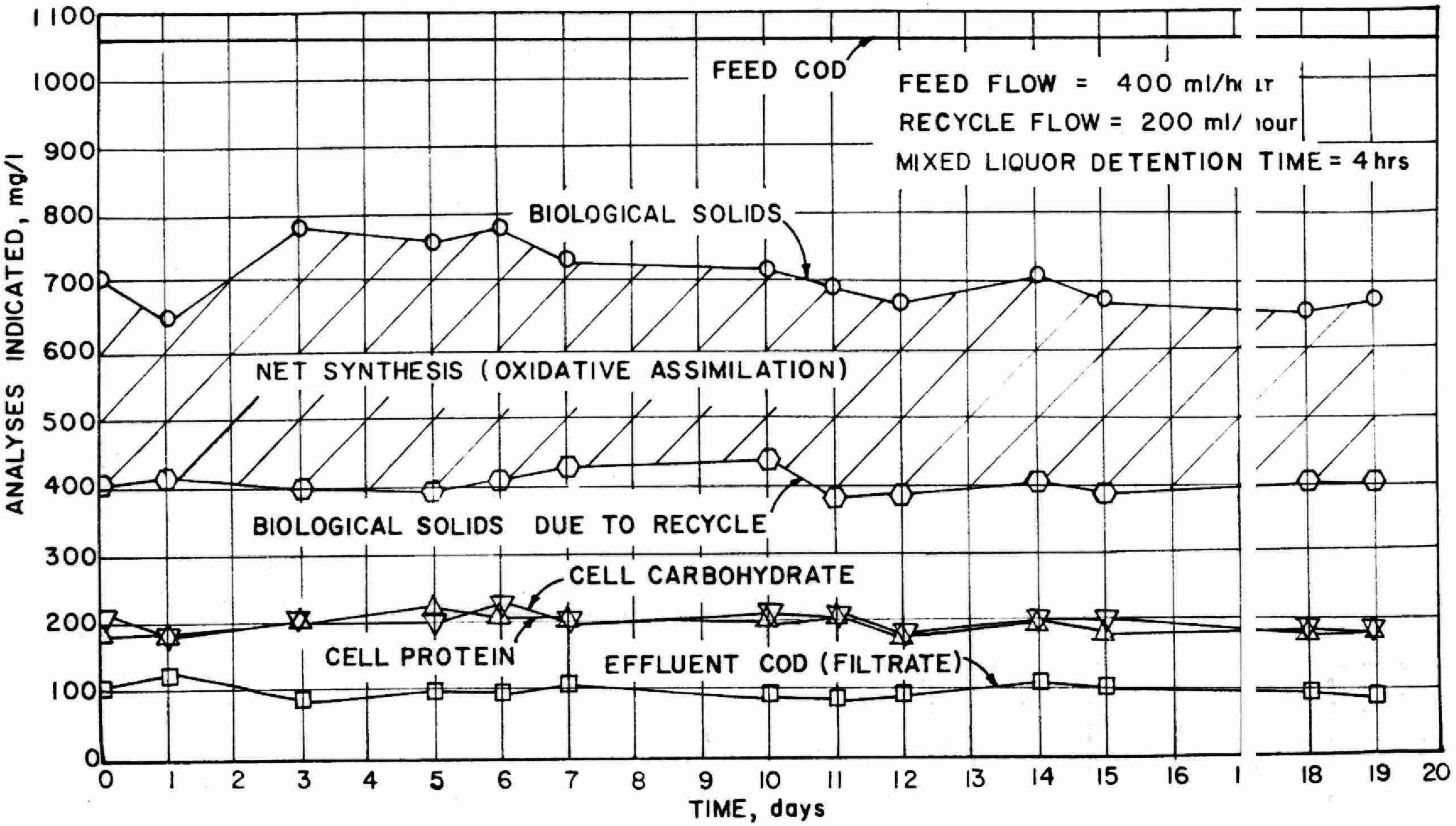


Figure 3 - Continuous oxidative assimilation of acetic acid in the feeding aerator. The biological solids had been previously subjected to endogenous respiration in the presence of ammonia nitrogen (COD to N = 70:1).

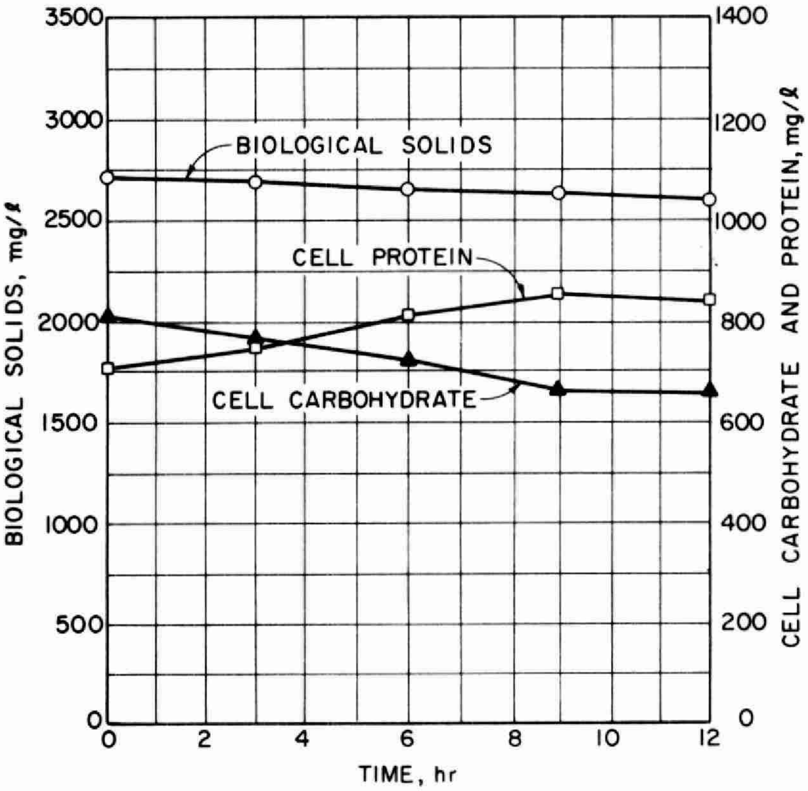


Figure 4 - Intracellular conversion of carbohydrate to protein in the endogenous aerator (COD to N = 50:1). The cells had previously assimilated the carbon source (glucose) in the feeding aerator.

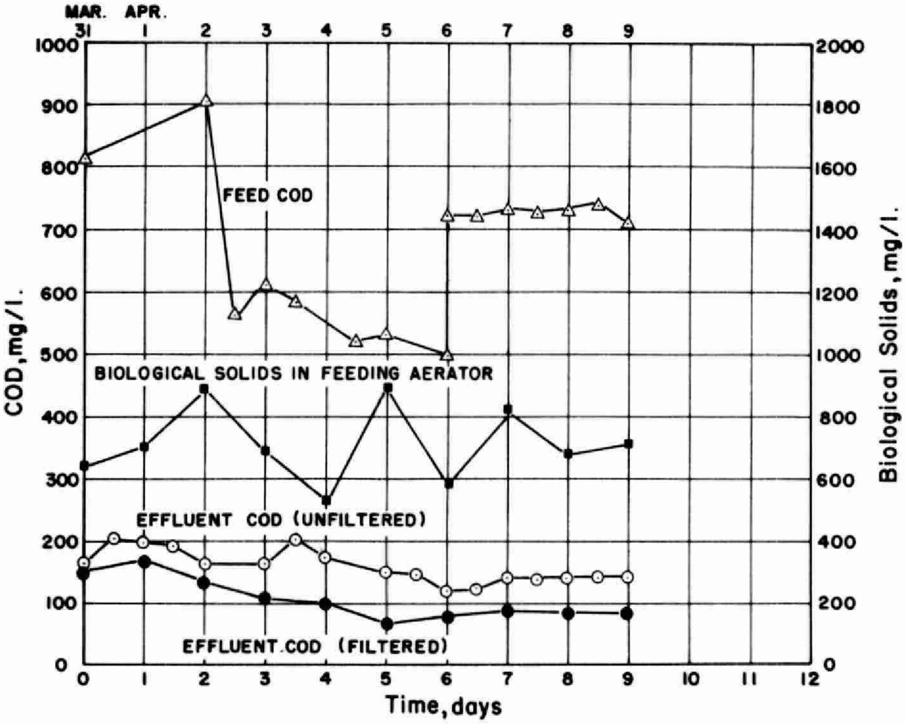


Figure 5 - Continuous oxidative assimilation of sugar refinery waste in the feeding aerator (detention time = 5 hours). The biological solids had been previously subjected to endogenous respiration in the presence of ammonia nitrogen (COD to N = 60:1).

R. W. **SLATER**

"TREATABILITY STUDIES FOR INDUSTRIAL WASTES"

BY

ROBERT W. SLATER
MANAGER

FRANK GUILLAUME
RESEARCH SUPERVISOR

PROSEARCH LIMITED
OAKVILLE, ONTARIO

INTRODUCTION

Industrial and domestic waste waters are highly variable, heterogeneous fluids and as a consequence they are difficult to characterise. However this has not prevented the very detailed description of "per capita equivalents": a term which has been applied with great diligence and enthusiasm to many industrial and domestic waste waters. It is the authors' opinion that the philosophy of describing waste water flows in terms of per capita equivalents is just about as meaningful as the philosophy of that same "per capita equivalent" as he walks down the street.

This inordinate desire for average characterization is well illustrated by the massive treatise written about the treatment of effluents from typical potato processing plants, typical pulp and paper mills, typical oil refineries etc. Whilst no detail may be spared on the cost of construction, tank sizes etc., very rarely is there any information on, for example, the variety of potato processed and its rate of conversion from starch to sugar at its particular storage temperature, the type of peeling process, the rate of entry into solution of recoverable starches. In the case of pulp and paper, management is already geared for capital expenditures of "X" dollars per ton of daily capacity and operating costs of "Y" dollars per ton of daily capacity. Yet these precisely reported figures are based upon typical or average plants with no mention of the specific nature of each individual waste.

A contributory factor in the development of this undesirable situation is the conventional parameters which are used to describe the quality of waste waters.

At the top of the list must come the five day biochemical oxygen demand. This was developed by a Royal Commission which was investigating the state of English waterways at the beginning of the century. The five day limit apparently arose because the typical British river takes approximately five days to reach the sea from its source. Consequently the term BOD_5 has questionable merit in describing not only the condition of Canadian rivers but also as an index of pollution in industrial waste waters. If the purpose of a particular waste treatment plant is to convert carbonaceous material from one form to another then it would appear logical to follow changes in carbon directly, rather than to use possibly misleading indirect determinations.

The other widely used descriptive parameter is suspended solids. This measures the amount of material retained on a particular grade of membrane filter. This would be useful if a treatment plant consisted of several acres of filter paper. However this is not the case and its use in predicting the performance of a clarifier has no basis whatsoever. Yet this is still the major design criteria for many engineers.

What is required is the development of parameters which are related to events occurring in treatment processes. This would lead to particle size characterization instead of suspended solids, to carbon balances instead of BOD_5 in and BOD_5 out. This would provide more insight into the fundamentals of the processes and through such understanding would come improvement.

All this can be of little comfort to the office-bound design engineer. He can apply the traditional solution to the problem. Such design criteria are readily available from many standard text books. Unfortunately the origin of a great deal of the design criteria is not obvious and its intelligent use is consequently made much more difficult.

A far higher degree of design control is apparently permitted if mathematical model design techniques are used. However the majority of these methods presuppose average or typical process characteristics for the waste water, which immediately limits their use. In many other instances the models were based upon the results of one particular system. Whilst the accuracy of the model in describing the results of one specific system is not questioned their suitability as universal solutions is unjustifiable.

In the following case histories are presented some examples of investigations into different "typical" wastes. Each total treatment process is regarded as the combination of different unit operations and the function of each operation is predicted by process simulation devices:

Case History No. 1:

One of the most widely used treatment processes is the separation of suspended solids from the waste flow using a clarifier. Various jar and settling tests have been borrowed from the metallurgical industries in an attempt to provide sufficient data on the settling characteristics of the particulate material so that the clarifier could be correctly designed. Unfortunately these simple tests do not reproduce the conditions present in a clarifier and consequently it is frequently difficult to interpret the results. For example, it is not possible to determine the effect of flow variation, or the effect of establishing a sludge blanket. This problem has been circumvented by the development of a primary clarifier simulator which does correctly reproduce process conditions.

The performance of this simulator on a "typical" domestic waste is shown in Fig. 1. Also shown is one of the more popular text book design graphs (1). The differences between the two are very marked and indicate that suspended solids removal would be a fraction of what would be anticipated from using the widely accepted design criteria.

Further data are presented in Fig. 2 and these show the removal of carbonaceous material which could be expected from the same clarifier. The percentage of total carbon removed varied between 1.0 and 2.5% and was independent of the hydraulic loading rate over the range investigated. The explanation for these unexpected findings comes from the organic carbon balance performed on the raw sewage. This shows that 48% of the organic carbon was in a form which could pass through a membrane filter with a mean pore size of 0.8 μ. Similarly 52% passed through a Whatman #1 filter paper.

If the purpose of the clarifier was to remove carbonaceous material then its performance was inadequate. The carbon balance performed upon the raw sewage indicates that about 50% of the organic carbon is completely in solution and consequently it should not be surprising that a gravity settlement process is not effective.

Case History No. 2:

A petro-chemical complex was discharging waste into a conventional lagoon. The quality of the effluent was unsatisfactory and did not meet the regulatory authority's standards in many respects.

The dissolved oxygen concentration in the lagoon was near zero and the obvious solution to the problem was felt to be through mechanical oxygenation. The theory was that the natural aeration capacity of the lagoon was limited and inadequate and that if only extra oxygen could be introduced then biological activity could continue unhindered. The results of the simulated, forced aeration lagoon are presented in Fig. 3. These show that even in the presence of excess dissolved oxygen the quality of the effluent was still inadequate. It was, in fact, still within the range of effluent qualities from the existing lagoon.

We also measured the oxygen uptake rate of the lagoon contents. The specification of oxygenation equipment could be based upon actual measurements in the real system: a vast improvement over the conversion of data obtained in deoxygenated water via ill-defined factors such as α, β, oxygen usage/lb. $B.O.D._5$, etc.

However, the aerated lagoon process was not successful, hence the next logical step - an activated sludge process - was investigated. A healthy culture of micro-organisms was fed with gradually increasing volumes of feed until the daily volume loading was 50% of the total sludge volume. This rate was held steady and the performance of the unit is shown in Fig. 4. The acclimatization period was followed by a rapid decline in the concentration of micro-organisms. Their flocculant characteristics degenerated until the "effluent" was almost identical with the "mixed liquor". The obvious conclusion was that, at this loading rate, the feed was severely interfering with the activity and performance of the micro-organisms.

This interference was investigated more definitively. The oxygen uptake rate (O.U.R.) of micro-organisms, injected with various concentrations of the feed, was used as an index of the relative inhibitory nature of the feed. The results are shown in Fig. 5. There was an almost linear increase in oxygen uptake rate with raw feed concentrations up to 20% by volume. Such a linear relationship indicates that the raw feed is a completely acceptable food source and is readily assimilated by the micro-organisms. The basic assumption is that the activity of the micro-organisms increases with the availability of food and its conversion to cell material will be directly related to the rate of usage of dissolved oxygen.

At raw feed concentrations greater than 20% there was a progressively more severe interference to the micro-organisms. These results confirm that difficulties would be anticipated in operating an activated sludge process at a feed rate equal to 50% by volume of the sludge.

The most obvious component in the raw feed was hydrogen sulphide; thus it was decided to investigate its effect on micro-organism activity. All detectable sulphides were removed after 24 hours of vigorous aeration. This stripped liquor was checked for interference in the same way as the raw feed, and exhibited an almost parallel effect - interference starting in the range of 15 - 20%. This was interpreted as showing that the sulphides were not the constituent causing the

the problem. Further, if an activated sludge plant were to operate at volumetric loading rates of 20% or less then the process should prove satisfactory.

This was tried and the results are presented in Fig. 6. This time there was a definite stabilization of the mixed liquor suspended solids and even indications of an upward trend towards the end of the study. The quality of the effluent was measured in terms of the total organic carbon. This showed a deterioration from start-up and some levelling off to a final concentration of 600 mg/l. Although this was half the concentration of the raw feed it also had a $B.O.D._5$ of 400 mg/l and would be totally unsatisfactory for direct discharge to a watercourse.

The different processes and parameters investigated in this study were self-corroborating. They jointly directed that the clients' money would be wasted by further intensive, biological studies. A programme of source investigation and reduction was suggested and is currently underway. This is to be co-ordinated by measuring parameters related to waste treatment processes.

Case History No. 3:

This next study was required to predict the treatment performed by an aerated lagoon process on a chicken packing house waste.

There are two types of aerated lagoons: one which keeps everything in suspension and prevents any material depositing, and the other which allows any biological sludge to settle and subsequently undergo anaerobic decomposition. These are basically different processes and the former may well be looked upon as a low rate activated sludge process. We have developed two types of aerated lagoon process simulators which reproduce the essential process characteristics of the two types. They have been designated Complete or Partial Mix.

The initial process characterization involved aeration of batches of the waste. The various parameters which describe the performance of the process are presented in Figs. 7 to 10. It should be pointed out here that the extensive use of the parameter BOD_5 was in deference to the wishes of the client. The trends exhibited are as anticipated. However, it is surprising to note that the decrease in filtered BOD_5 for both complete and partial mix processes were identical. The activated sludge similarities of the complete mix process might have been expected to influence the removal of soluble BOD_5 at a more rapid rate than the partial mix system. The considerable scatter in the BOD_5 data reported in Figs. 8 and 9 are indicative of the difficulties involved in the sampling of dispersed particulate materials - a further notice of the need to develop new, more meaningful parameters.

The common interpretation of Fig. 7 to 10 is that stabilized conditions have been created within about six days of start-up. In other words it is unlikely that any further purification would occur.

The laboratory simulation procedure was extended to investigate continuous operation and a hydraulic retention period of six days was used. The results for the complete mix process are presented in Fig. 11. Also shown are the actual results from the full scale installation over the same period of time. After about day 10 equilibrium conditions existed and there was good agreement between the performance of the laboratory process simulator and the full scale plant. The BOD_5's reported were identical whilst the suspended solids' values were within approximately 20%. This indicates that a high degree of confidence may be placed in the results of these laboratory studies.

In the actual plant the effluent from the complete mix cell passes into a stabilization lagoon where the settleable sludge accumulates. This also acts as an algae farm and whilst the BOD_5 of the final effluent is within the limits set by the regulatory authority, the C.O.D. was measured in excess of 100 mg/l. It is interesting to note that on occasion there was, in fact, an increase in C.O.D. across the final lagoon associated with algae production. The final data accumulated for this study was on the prediction of performance of a Partial Mix lagoon receiving the same feed and operating under the same retention period. One of the major differences would be that sludge would be allowed to accumulate in the forced aeration cell rather than be displaced to a second cell. The performance of the lagoon simulator is shown in Fig. 12. The effluent quality was good and as predicted by the batch degradation study.

It would appear that little merit is attached to a complete mix process followed by an algae lagoon and we would have recommended the adoption of a partial mix process.

During this study we collected some miscellaneous data on sludge production. In the aerated lagoon process this is fondly ignored as a problem for a future generation and rarely considered, and even more rarely documented. During the total test period, which was about one month, all sludge production was directly measured and reported as lbs sludge produced/lb BOD_5 applied. For the complete mix process this was 0.35 and for the partial mix 0.41. The difference may be ascribed to the greater degree of aerobic stabilization of the complete mix sludge. Final sludge production rates would necessarily take account of the long term anaerobic decomposition. This was not attempted in this study.

Case History No. 4:

The final study relates to the frequent problem of a plant designed and built for a projected hydraulic and pollutional load which will not be attained for several years. In these circumstances concern may be expressed because guide-line design limits such as retention periods, ratios of lb. BOD_5 applied : lb. micro-organisms present etc., will be missed. The fear would then be that the plant would not produce a satisfactory effluent until the feed conditions were in line with the process flexibility. This would involve engineering modifications to aeration equipment, tank volumes etc., and extra expense. We have recently investigated such a problem in our laboratory.

The plant is designed so that under ultimate design conditions it will operate as a conventional extended aeration activated sludge process. Three different volumetric loading conditions were checked under simulated plant start-up. In Fig. 13 a retention period of 24 hours was reproduced in a continuously fed activated sludge unit. A similar technique was followed for a retention period of 38 hours and the data obtained are reported in Fig. 14. The rate of increase of micro-organism concentrations is most rapid for the more highly loaded system. Also, even under start-up conditions the effluent is generally of a satisfactory quality.

The actual initial loading is reproduced in Fig. 15 - a retention period of 117 hours. The BOD_5 concentration in the raw feed was weak and variable, and gave values of 50 ± 30 mg/l. In contrast to the higher volumetric loadings this system exhibited a stabilized micro-organism concentration. The mixed liquor solids was largely within the limits of 225 ± 75 mg/l for a period in excess of three weeks. Presumably equilibrium conditions had been established between sludge production and its wastage into the effluent.

In this case it was shown that the plant could produce satisfactory effluents over a wide range of volumetric loading rates. It was therefore not necessary either to undertake modification of the plant or to maintain the process conditions at all times, similar to the text book dictums.

Conclusions:

We introduced this paper by pointing out inadequacies in some of the basic procedures involved in waste water treatment plant design. Some of the underlying reasons have been mentioned.

The importance of treatability studies effected through process simulation of the unit operations involved in a waste water treatment plant is emphasized. Such studies would permit the development of integrated flow sheets based on the actual operation of each component process.

In a manufacturing organization changes in the waste water through new product development or production techniques frequently occur. The effect on a waste treatment plant can safely and accurately be predicted in the laboratory, rather than discovering problems for the first time in the full-scale system.

In the final analysis, treatability studies can be used to predict the cost-effectiveness of different unit operations. In this way the choice of waste treatment processes is no longer shrouded in mystery, but based upon accepted financial criteria. The valuable product is clean water.

References:

(1) - Sewage Treatment Plant Design, FSIWA, Manual of Practice No.8, 1959: Page 93. Published by Water Pollution Control Federation, Washington D.C.

FIG.1 CLARIFIER PERFORMANCE COMPARISON

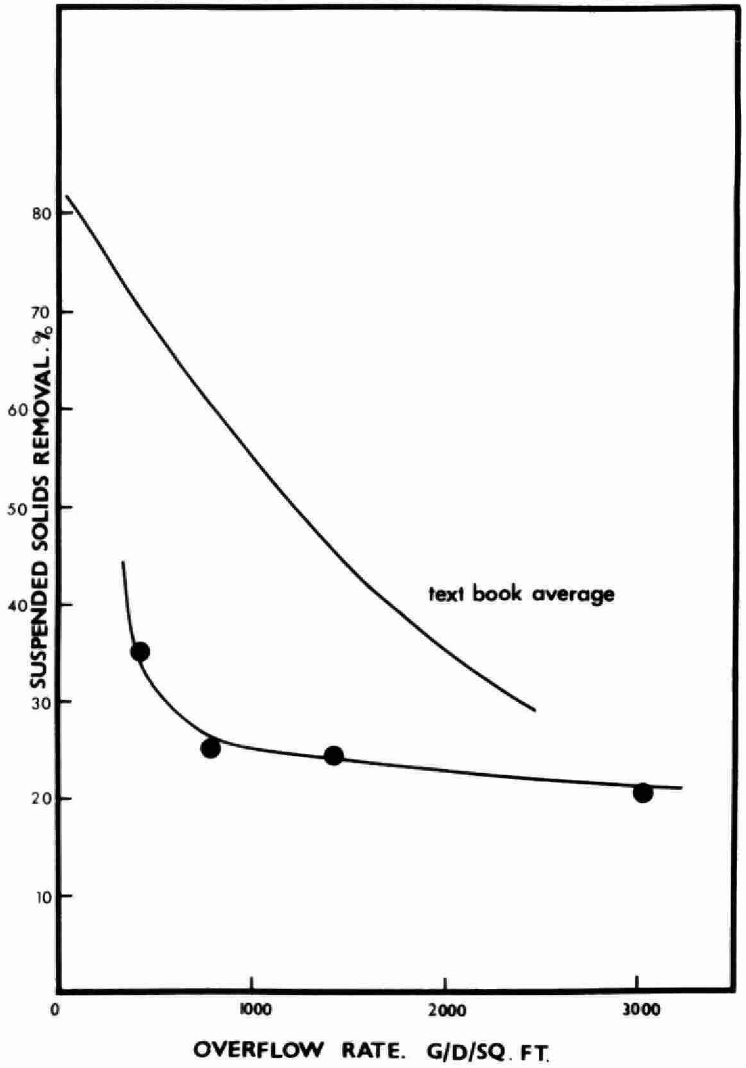


FIG.2 SIMULATED CLARIFIER PERFORMANCE

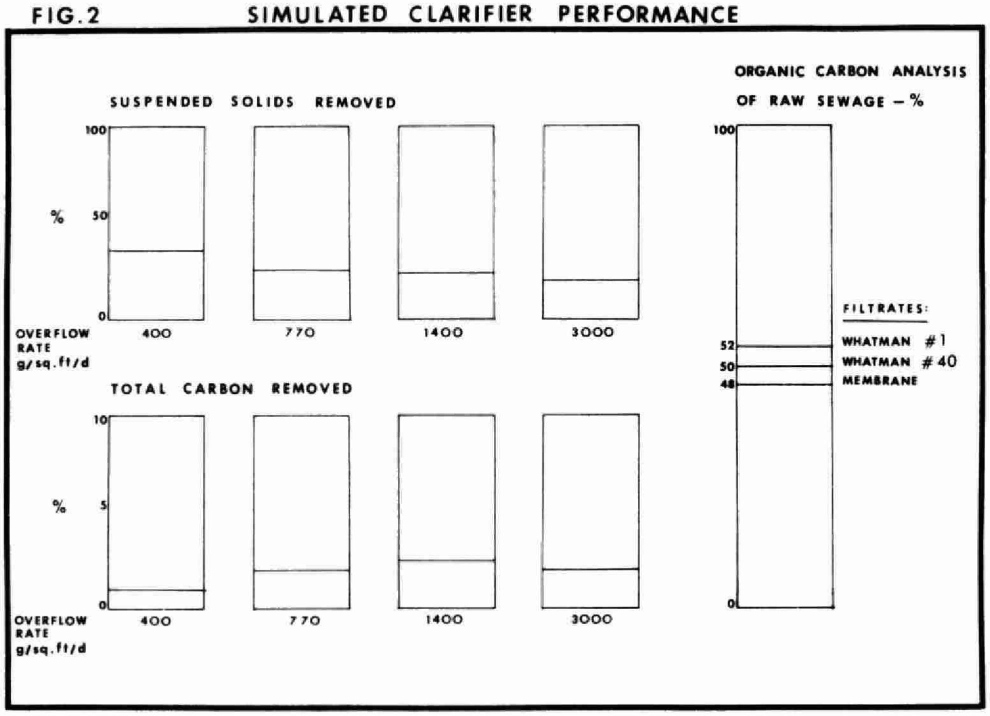


FIG.3 AERATED LAGOON SIMULATOR

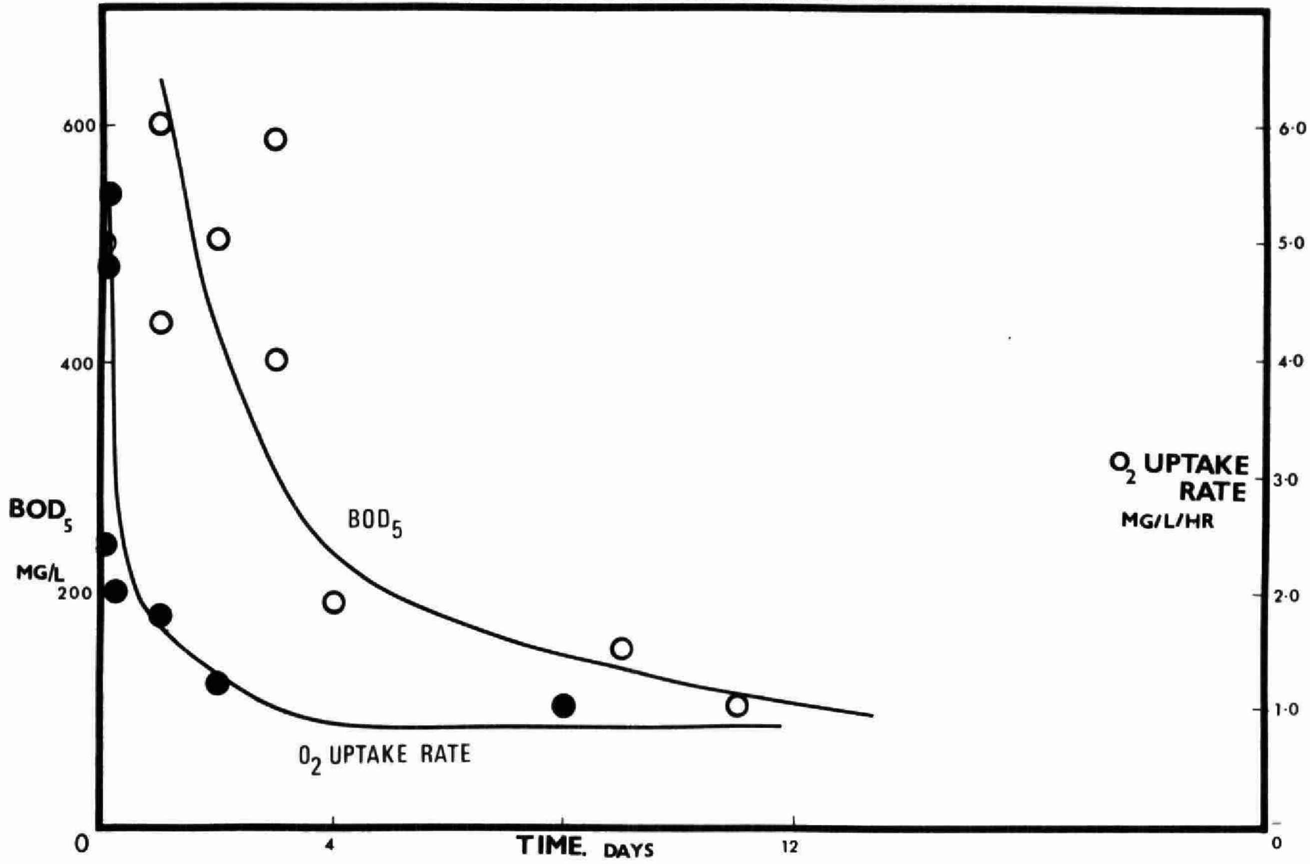


FIG.4 ACTIVATED SLUDGE 50% LOADING

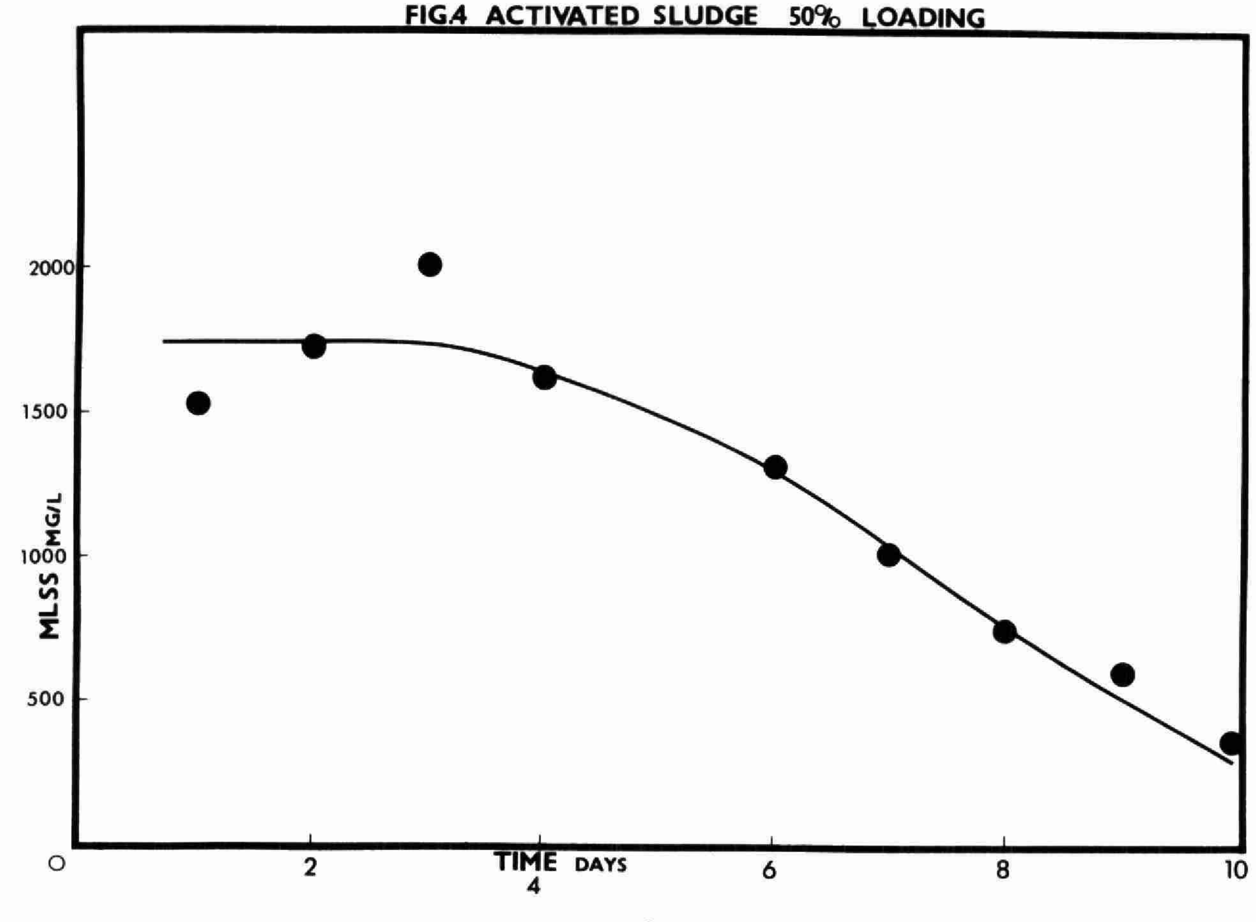


FIG.5 TOXICITY STUDY

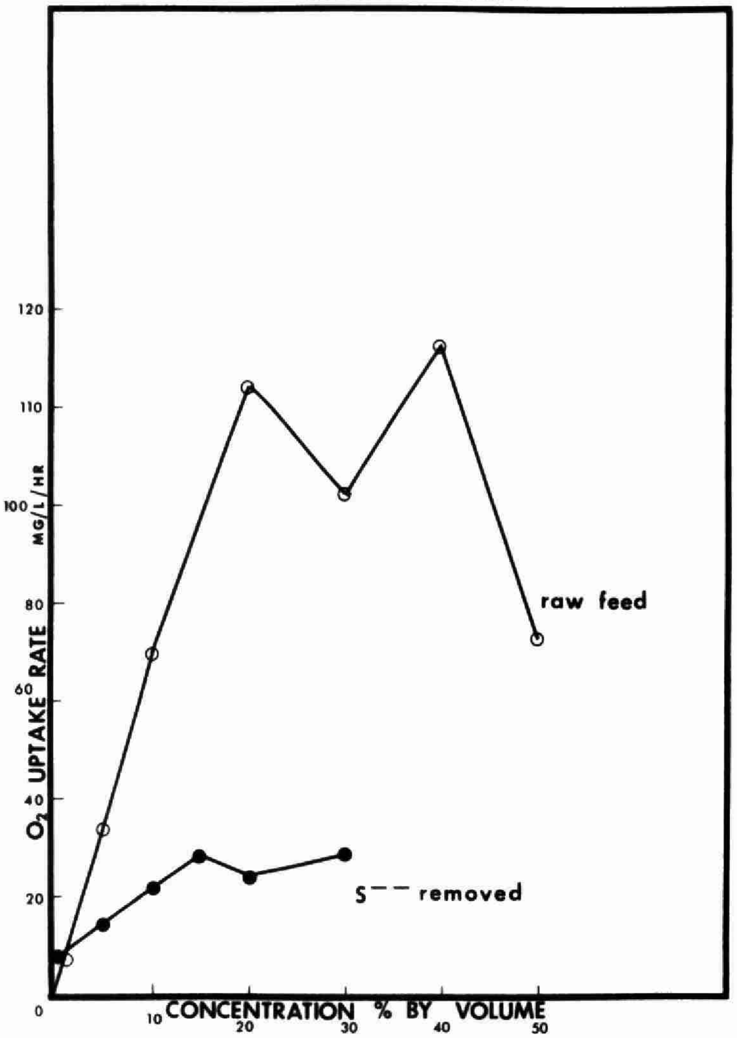


FIG.6 ACTIVATED SLUDGE 20% LOADING

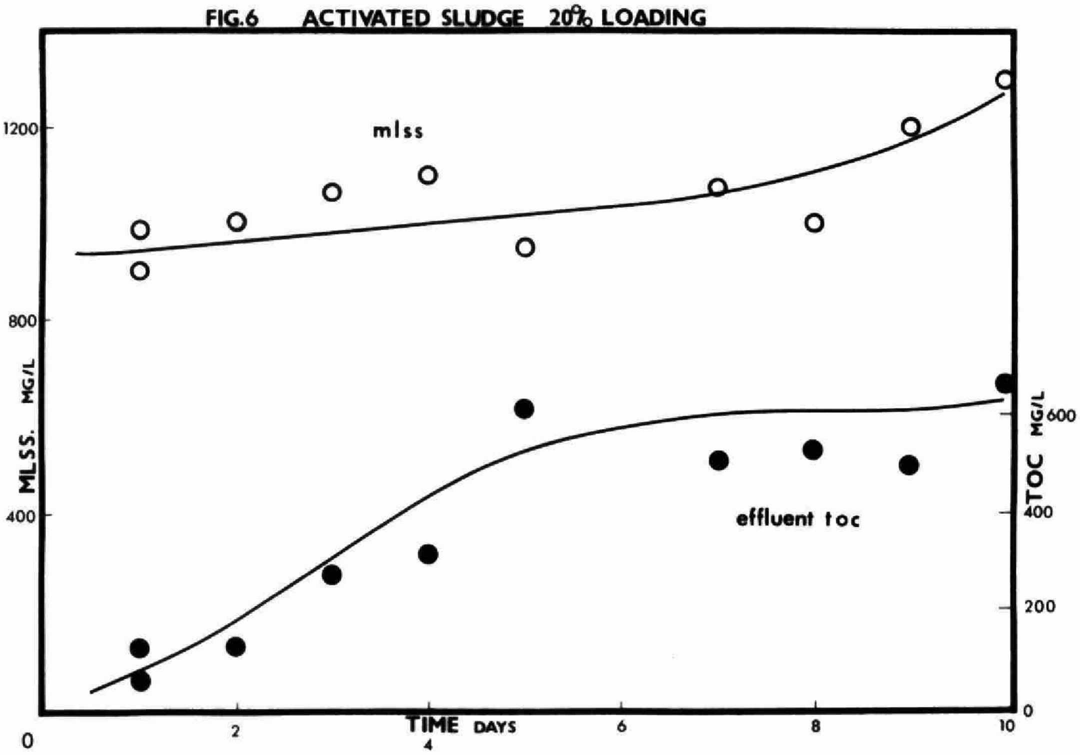


FIG. 7 AERATED LAGOON SIMULATOR

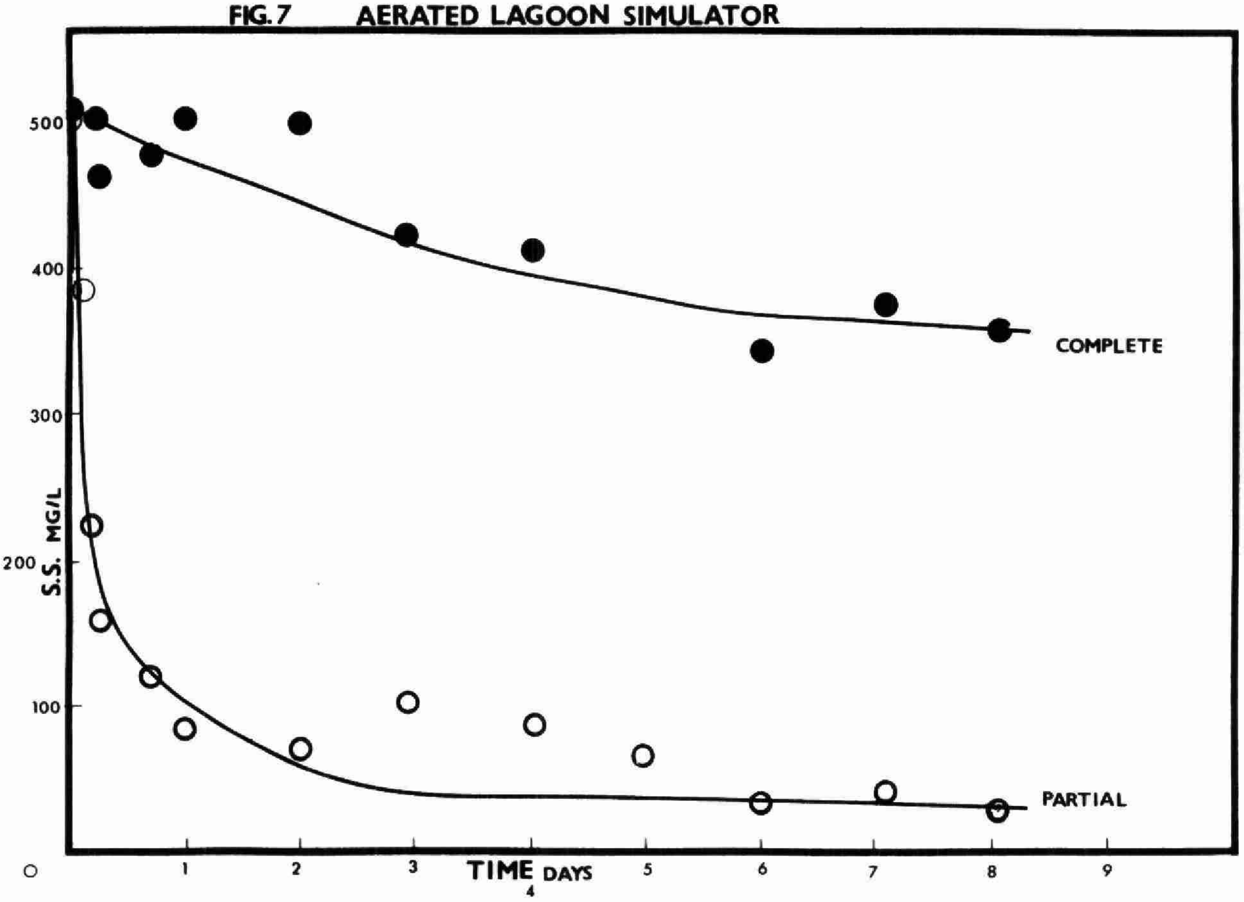


FIG. 8 AERATED LAGOON SIMULATOR

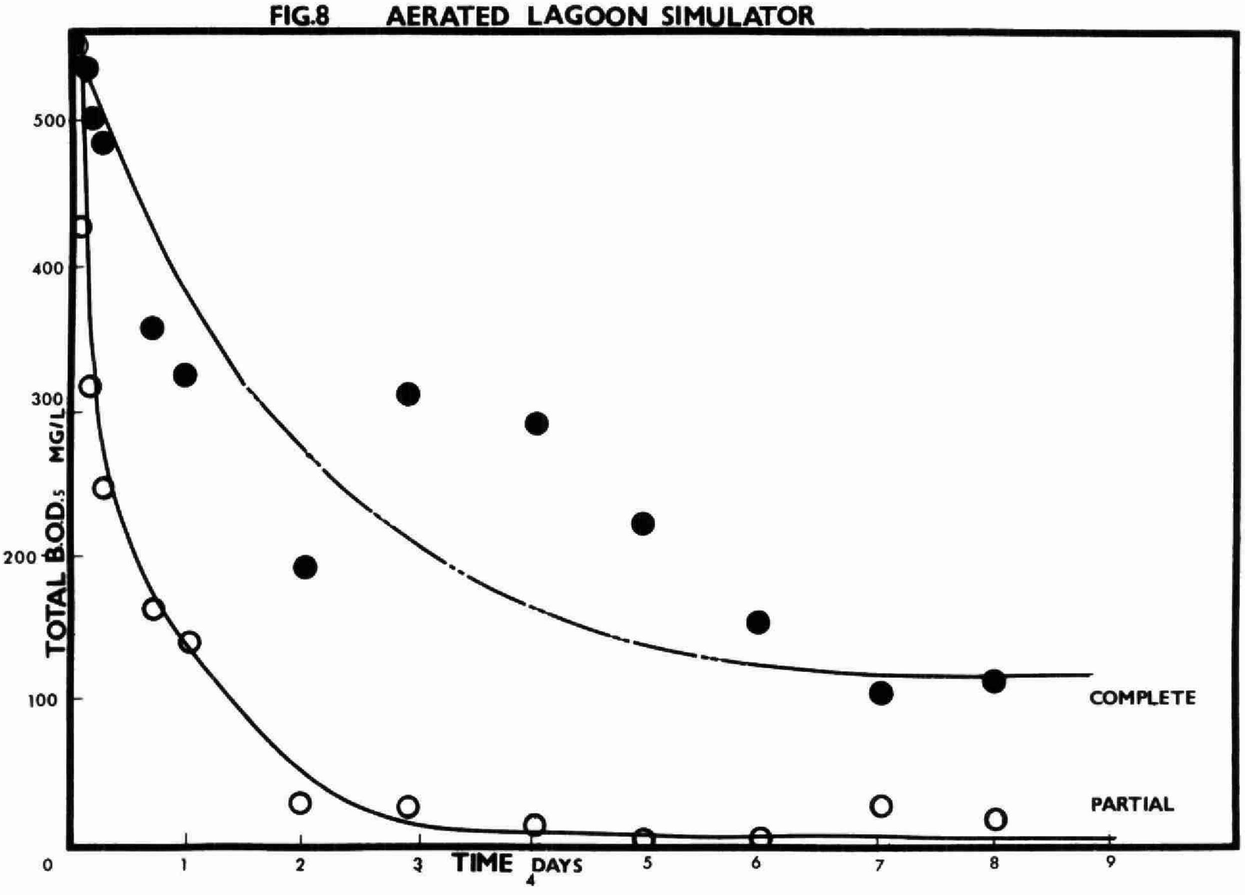


FIG.9 AERATED LAGOON SIMULATOR

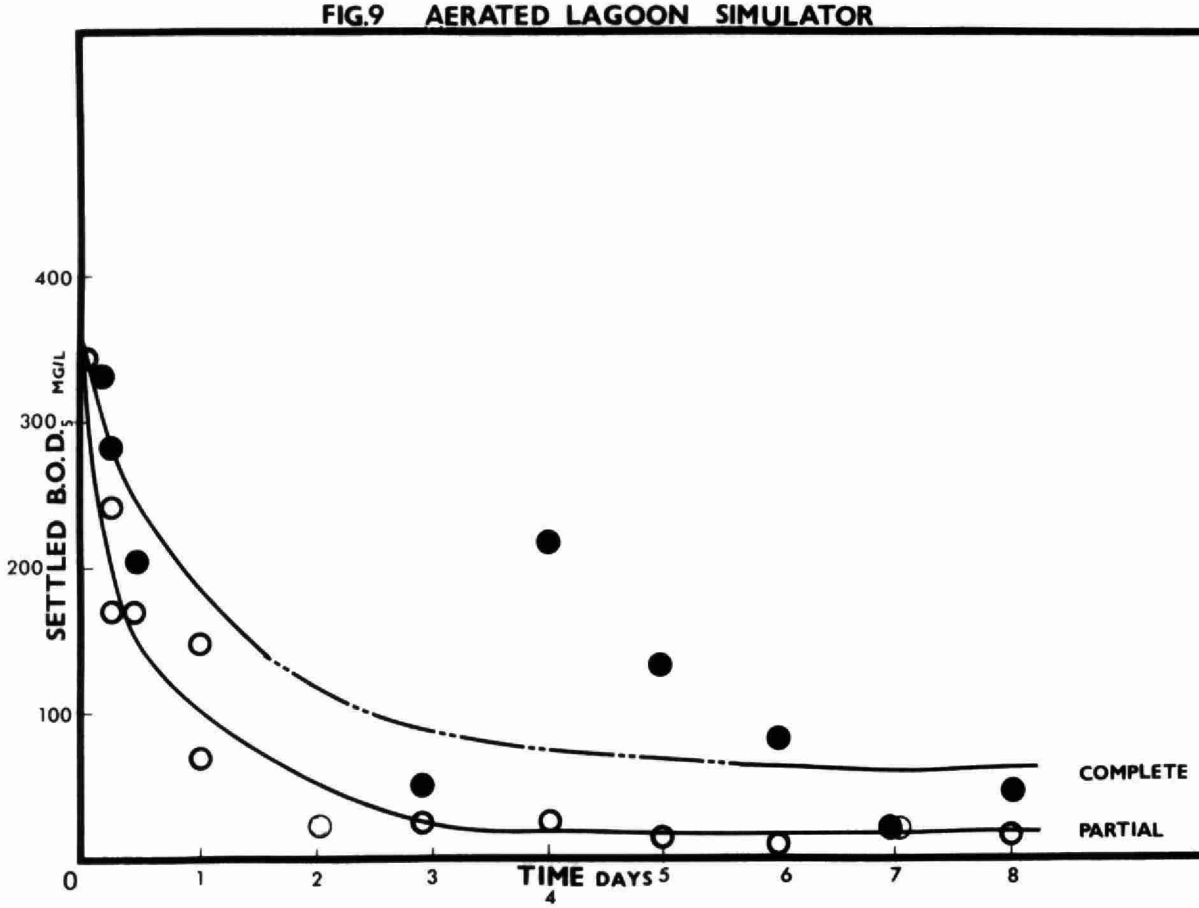


FIG.10 AERATED LAGOON SIMULATOR

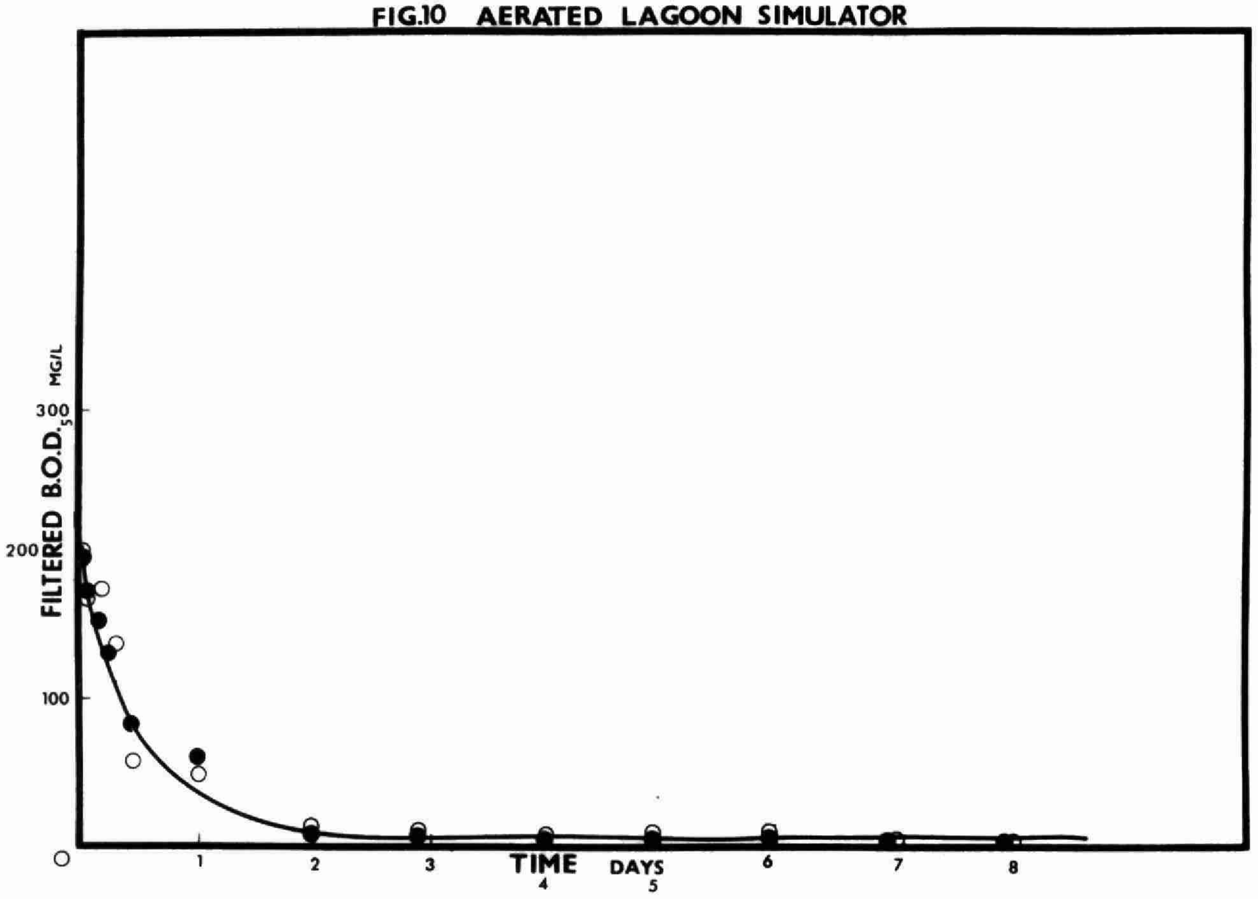


FIG.11 AERATED LAGOON SIMULATOR COMPLETE MIX

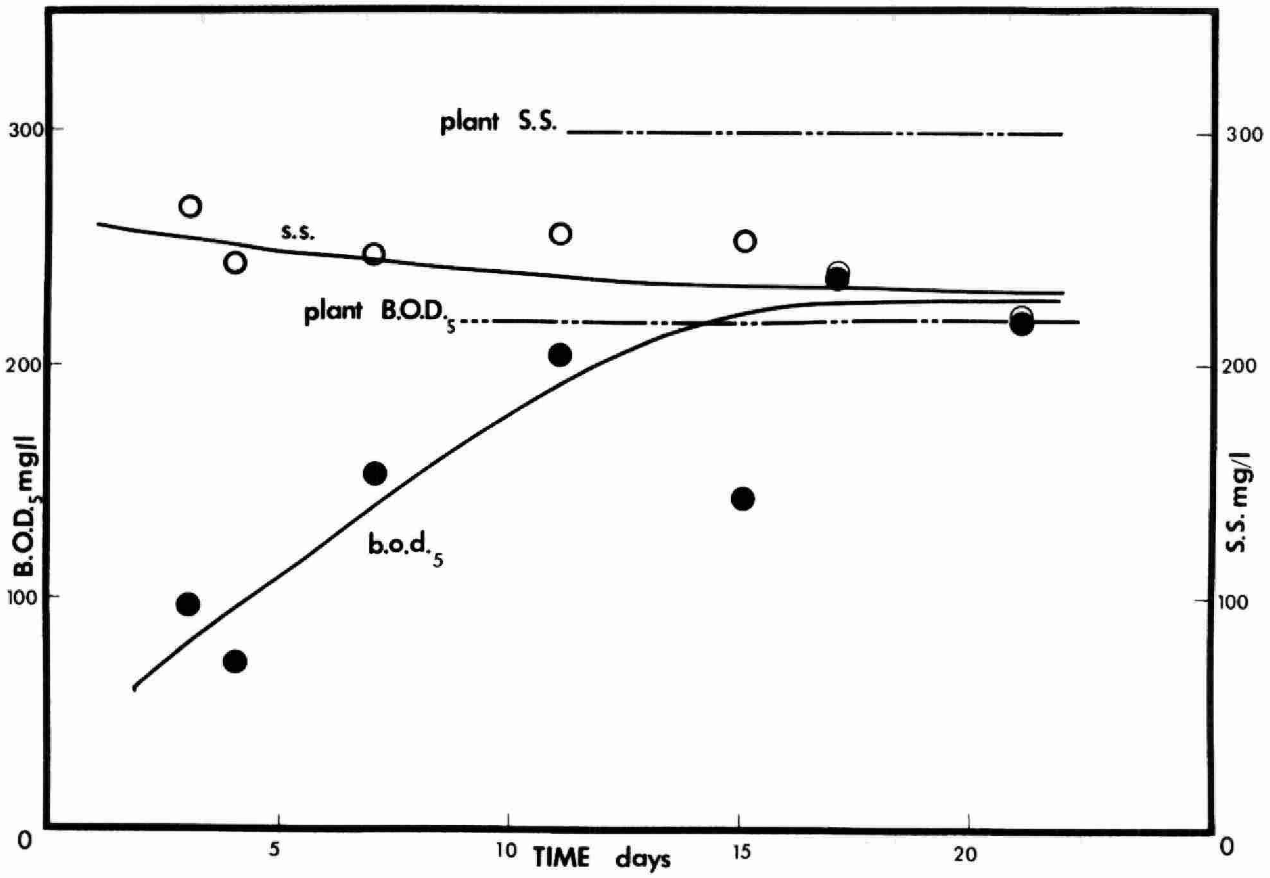


FIG. 12 AERATED LAGOON SIMULATOR PARTIAL MIX

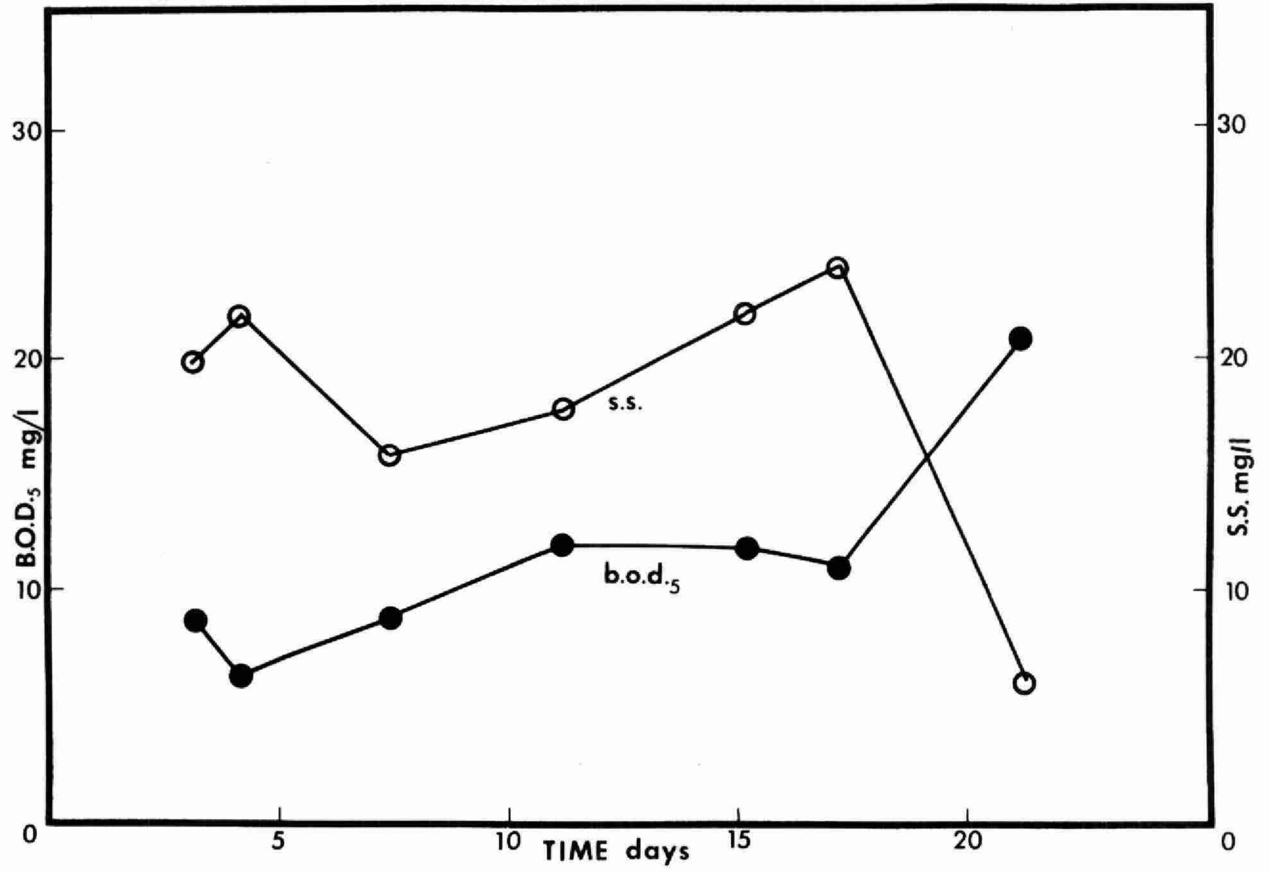


FIG.13 HIGH LOADING RATE

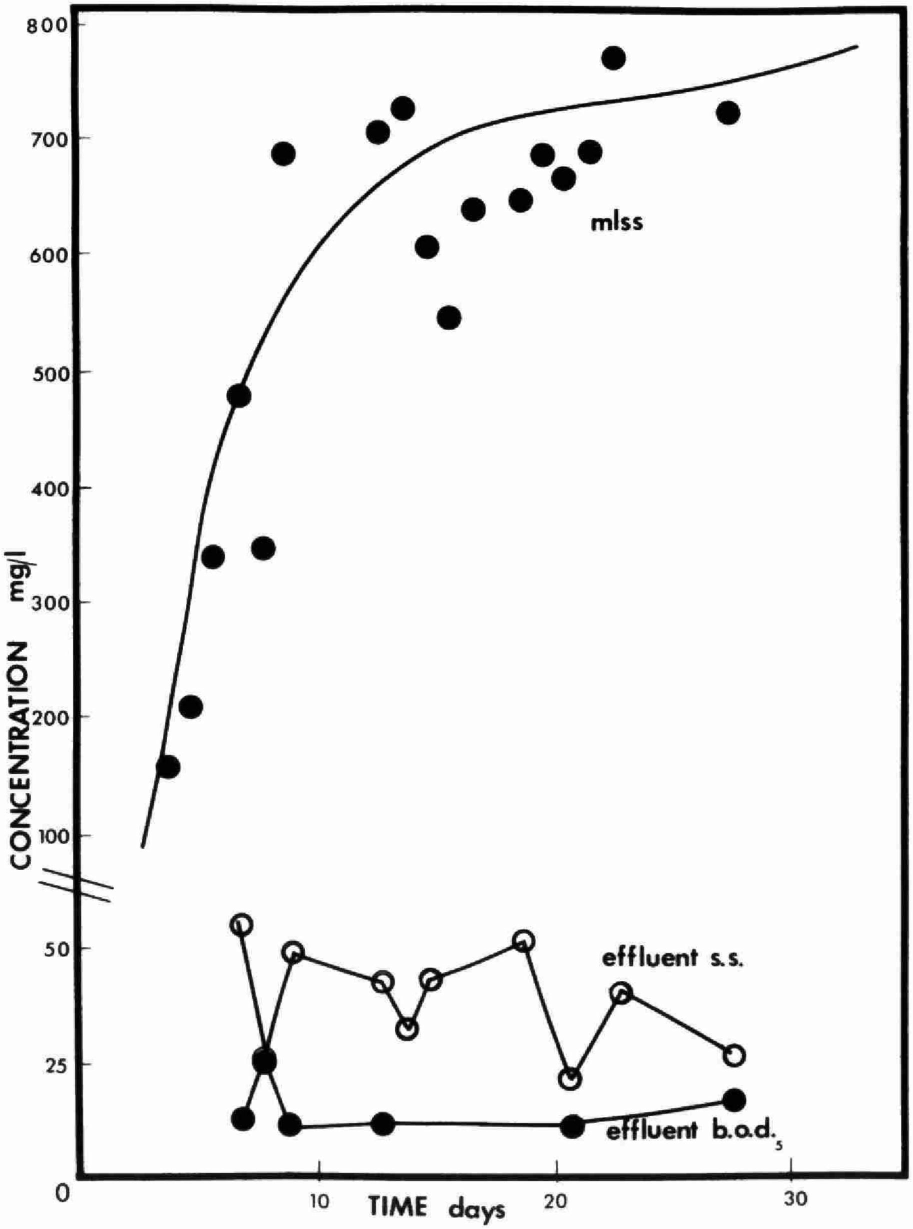


FIG.14 MEDIAN LOADING RATE

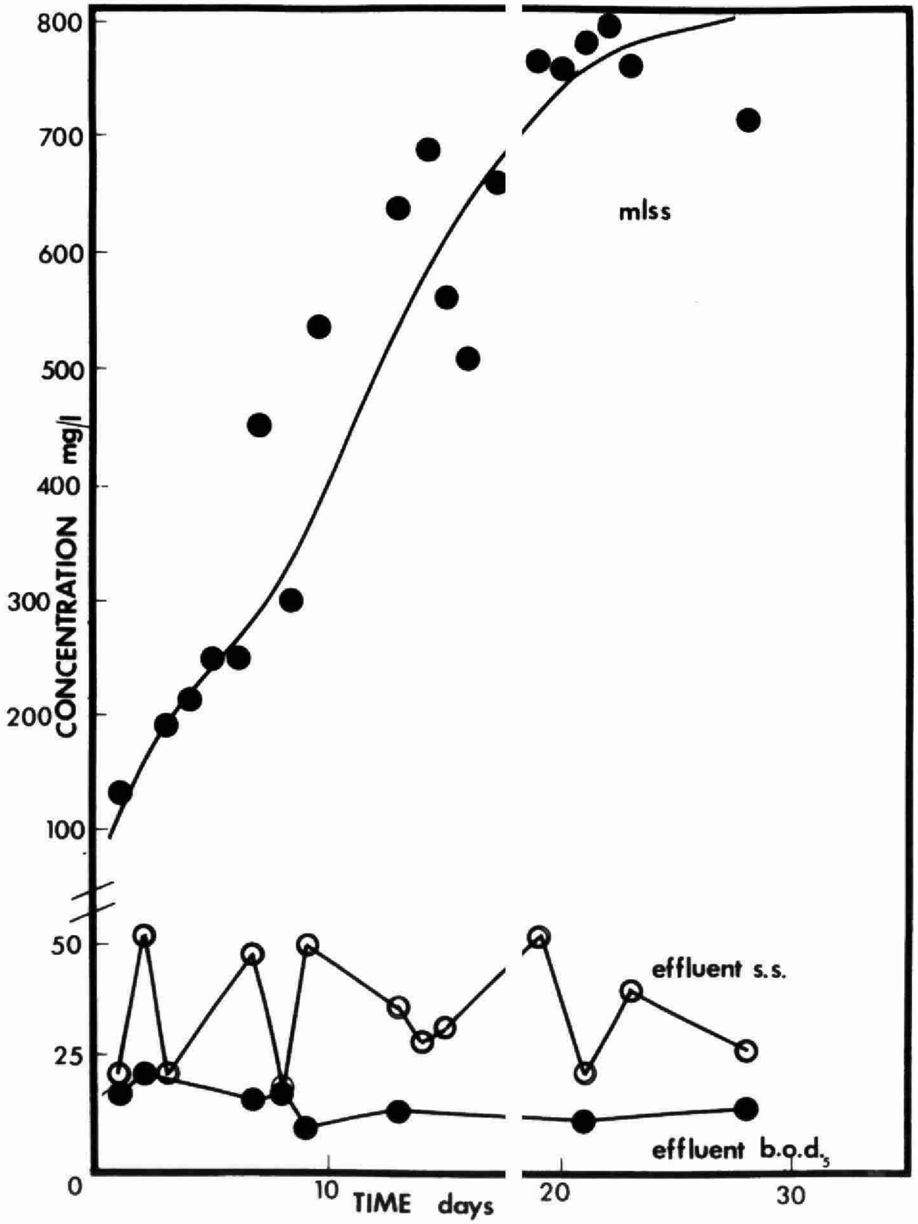
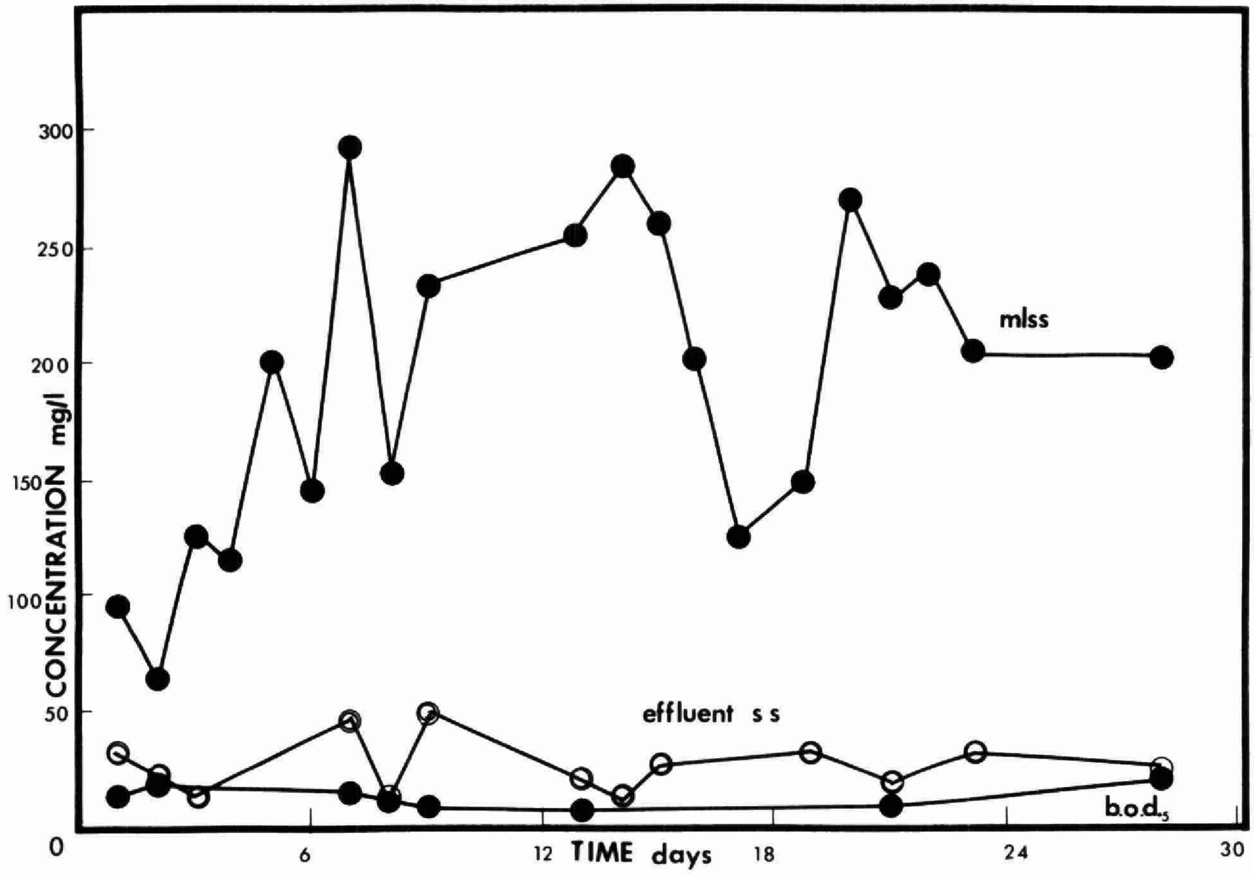


FIG.15 LOW LOADING RATE



"FARM ANIMAL WASTE DISPOSAL IN ONTARIO"

BY

S. A. BLACK
PROJECT ENGINEER
DIVISION OF RESEARCH
ONTARIO WATER RESOURCES COMMISSION
TORONTO, ONTARIO

INTRODUCTION

We are experiencing at present a dramatic change in the methods of producing farm animals for slaughter and for food products. The production of animals has emerged from the small, individual farm operation into a large-scale industrial enterprise involving hundreds of acres and thousands of animals. Small animals, such as pigs and chickens, are confined within buildings in which the humidity, temperature, sanitation and animal movement are controlled to produce the greatest weight gain in the shortest period of time. Such farms may now be regarded as industries so far as their mode of operation and wastewater problems are concerned. It is only a matter of time until the majority of animals produced for slaughter will be fed in similar environment controlled confinement areas.

Until recently, farms have not been thought of as serious sources of water pollution because of the diverse nature of their activities and the comparatively small scale of each unit. Where pollution matter entered a watercourse - often a ditch - that watercourse frequently was largely self-purified before receiving another discharge. Modern developments in farming, however, are tending to eliminate this safeguard.

The actual changes within the farming industry which have brought about a need for concern for farm animal waste management may be classified under the following headings:

(a) Specialization of farm operations has increased the concentrations of manure production.

(b) Confinement housing has led to further concentration of manure and significant changes in manure characteristics and, in particular, the trend towards liquid manure handling systems.

(c) Cheaper and more manageable commercial fertilizers have reduced the demand for manure as a fertilizer.

(d) Urban sprawl and farm area encroachment have brought more people into close contact with the environmental problems.

Confinement housing of livestock and poultry is perhaps the major factor in the creation of an immense waste disposal problem. In the confinement method, feed and water are brought to the animals and no longer do they drop their manure on pastures where it can be absorbed naturally. Instead, the wastes must be collected, stored and then disposed of. Where possible, these wastes are used as fertilizers for field crops and if the farmer grows his own feed, there is generally sufficient land available for this method of disposal.

The livestock or poultry farmer generally, however, is in the animal business, not in crop farming. He relies on commercially available food supplements for a considerable portion of his feeding requirements, and thus, he frequently does not have adequate land of his own for the disposal of all the animal wastes. The crop farmer, on the other hand, can usually buy and apply chemical fertilizers more cheaply than he can use free animal manure.

Organic materials were the first fertilizers ever used by farmers. Consisting mainly of plant and animal residues they were used primarily for their nitrogen supplying value and as soil supplements. With the advent of commercially available fertilizers, animal manures are being applied to the land primarily as a means of disposal of the waste with no regard to its value as a fertilizer.

In Ontario, we are fortunate to have adequate land for the effective disposal of farm animal wastes. The problem stems from the fact that the large operator may have to rely on his neighbours to provide this land area and that in Ontario there is an extensive winter period during which manures cannot be successfully applied to the land. This means that the manure must be stored for as long as a six month period. Conventional methods of manure storage cause the production of very foul odours, especially where pig manure is concerned, making spring application very unpopular with the neighbours. The large producer with inadequate land of his own for complete disposal of his manures should be able to give or sell the extra manure to surrounding farmers if the odour problem can be controlled.

Successful management of farm animal wastes in Ontario will largely depend upon two conditions:

1) that farmers, especially crop farmers, can be convinced of the fertilizing value of manures, and

2) that economical methods of managing manures and of controlling odours during storage and land spreading can be developed to allow for proper application of the wastes to farmland.

The latter condition is the basis of much of the research that is being carried out on farm animal waste disposal in Ontario.

POLLUTION POTENTIAL OF FARM ANIMAL WASTES

Farm animal wastes are only one of the several sources of agricultural wastes as shown in Figure 1. They do, however, present the greatest pollution potential of all sources. Farm animal wastes may contribute to air and soil pollution, to the spread of insect pests and vectors and to weed propogation and dispersion. Of primary concern today, however, is the water pollution aspect which occurs in the form of oxygen demanding materials, toxic substances, nutrient materials and pathogenic organisms.

The biochemical oxygen demand (BOD) of animal manures is extremely high and is also very high in feedlot runoff. Such high oxygen demanding wastes upon entering streams can cause oxygen depletion resulting in serious fish kills and profound long-term ecological changes. As a result the aesthetic as well as the practical value of the watershed will be affected.

Excessive concentrations of nitrates in ground water used for drinking purposes may be biologically converted to nitrites in the digestive system and can cause methemoglobinemia (blue babies). They are also toxic to livestock. Animal manure can be a major source of nitrates in ground water, and the importance of its contribution must be considered.

With the present emphasis on eutrophication, the nutrient contribution of farm animal wastes to surface waters is now recognized. Nitrogen and phosphorus are the principal elements involved, but other plant nutrients are also important. Farm animal wastes contain virtually all of the macro-nutrients as well as the trace elements required to promote algae growth.

Organisms pathogenic to humans, animals and poultry may be present in the manures from domestic animals. These agents may be transported in our surface and ground waters. All waters receiving farm animal waste runoff must be considered as potentially dangerous to the health of humans and livestock.

Magnitude of the Problem

In 1967, there were over 5.5 million livestock with a value of $700 million and a total poultry population of some 31 million at a value of over $47 million within the Province of Ontario. The wastes produced by this number of animals has been estimated as being equivalent in strength to the sewage of some 30 million people or about 4 times the present population of Ontario.

Figure 2 shows the changes in population of chickens, pigs and cattle over the period 1941 to 1967. The numbers of each have fluctuated quite widely over the years but the actual increase in each case has been small. This in itself holds no real significance until one investigates the trends in farm sizes and numbers over the same period as shown in the next series of figures.

Figure 3 shows the trends in cattle populations on Ontario farms for the years 1951, 1956, 1961 and 1966. As can be seen the total number of farms decreased by about 30% from 1956 to 1966. The size of the farms as portrayed by the number of head has increased greatly.

Figures 4 and 5 indicate similar trends in pig and chicken farm concentrations.

As previously stated, this trend towards fewer numbers of farms but increasing concentrations of animals is the underlying cause of the manure disposal problem.

Properties of Farm Animal Wastes

An understanding of the properties of animal wastes is essential to any effective manure management program. These properties may be classified as physical, chemical and biological. When considering the field spreading of manures, the farmer is interested only in the quantity and fertilizer content of the wastes. In considering water pollution potential the biological quality of the wastes is also important.

The quantity and composition of animal wastes are affected by the particular characteristics of the animal, the feed ration and the environment. It is, therefore, impossible to specify exactly what the quantity and strength of the waste from a given animal will be. It is possible, however, to give estimates knowing the district the animals are raised in.

Figure 6 presents average daily manure production values of various livestock and gives some indication of the quantities to be handled.

As the chemical content of the waste determines its value as a fertilizer, Figure 7 gives some indication of the major nutrient content. Besides containing the major fertilizing elements, nitrogen, phosphorus and potassium, manure is also a good source of other nutrients such as calcium, magnesium, sulfur, iron, zinc, boron and copper.

Figure 8 presents the monetary value of liquid manures as fertilizers and can leave no doubt that field application of manures should be encouraged. Not only can manure provide necessary plant nutrients but land application also offers adequate treatment as well as final disposal of the waste if applied correctly.

In land disposal of farm manures, nitrogen is the nutrient which is most likely to cause adverse effects on crops when applied to the land in too high concentrations. Thus, the rates of manure application may be specified in terms of the amount of nitrogen in the manure. Figure 9 indicates land requirements for poultry and livestock manure utilization as determined by the Department of Soil Science, University of Guelph.

Figure 10 presents strengths and population equivalents of various livestock wastes. There is a wide range of data pertaining to the BOD of animal wastes, but this table does indicate the very high strengths of livestock wastes.

TREATMENT FOR ODOUR CONTROL

In order to be effectively applied to land, manure must be stored for periods extending to six months. Past storage methods have involved the use of manure pits, lagoons or other forms of holding tanks. These systems all end up as anaerobic digestion units and are characterized by foul odours during storage and especially at the time of emptying, particularly where swine and poultry manures are concerned. If field spreading of manure is to be made effective, these odours must be controlled at a minimum.

Processes used to control odours of farm manures during storage and at the time of field application may be divided into two main categories: (a) chemical and (b) aeration.

a) Chemical process

Hydrated lime, chlorine and deodorizing and masking compounds have been added to liquid manures to suppress or prevent the production of objectionable odours. None of these chemicals has proven to be entirely successful and all are very expensive.

b) Aeration process

Aeration processes, on the other hand, have been found to be very satisfactory. As the object of aeration, in this case, is to control odours, only that small amount of air needed to discourage anaerobic bacteria from predominating is required. Any method of mixing adequate air into the tank contents can effectively control odours, therefore, several diversified methods have been used in Ontario. One swine installation uses diffused air tubing running the length of a holding tank under slotted floors with a ½ HP compressor supplying the required air. This system is being compared to an anaerobic holding tank at the same location and is definitely effective while in operation.

Aspirators are being used in another installation to provide mixing and aeration of the contents. In this process the tank contents are re-circulated by pumping through aspirator jets which draw in air at the same time. Again operational problems have been experienced but the system does effectively control odours while in operation. This installation accommodates approximately 550 pigs.

Another system of providing oxygen to farm manures is the oxidation ditch. This system is being tested on a pilot scale on chicken wastes and there are now three full scale units in operation on swine wastes in Ontario. The system is similar to that used on domestic and industrial wastes but in these cases is being operated only to provide odour control. The brush is being run in each installation for a maximum of six hours per day, and in one case for only four hours per day. This system of aeration has also proven to be quite effective and economical. Fewer maintenance problems are being encountered here than with the above two processes.

SUMMARY AND CONCLUSIONS

Because of their high strengths, concentration of nutrients and bacterial content, farm animal wastes must be considered as a potential major source of water pollution in Ontario. The present trend towards industrialization in the scale and operation of farming operations magnifies the importance of sound waste management programs.

Water pollution by farm animal wastes occurs primarily in the form of runoff from poorly designed feedlots and leaching and runoff from fields where manures have been improperly or untimely applied.

Proper waste management practices can greatly reduce, if not eliminate, the farm animal waste source of water pollution. Proper design of feedlots including covers, concrete floors and retaining walls can prevent this source of pollution. The proper design and provision of adequate holding tanks to allow field application of manure, only at those times of the year when it can be immediately incorporated into the soil, will reduce greatly the amount of nutrients in field runoff. Simple methods of aerating the contents of holding tanks will reduce, if not eliminate, the emission of noxious odours making field application a much less unpopular task.

Admittedly, there is still much to be learned about the science and technology of controlling pollution from agricultural operations. As with all other forms of pollution, however, the problem can be contributed in large measure to the failure of making effective use of what is already known.

RECOMMENDATIONS

The following recommendations are presented as possible guidelines for reducing, to a large extent, the contribution of farm animal wastes to water pollution in Ontario.

1) That an educational program be put into effect to inform the farming industry of the immense pollution potential of their wastes and of the effects this pollution may have on our province's water resources.

2) That farmers, in particular, crop farmers be informed of the fertilizing value of manures.

3) That legislation be set up and enacted to enforce water pollution control in agricultural operations to the extent of present technical knowledge.

4) That research be continued to develop more effective, complete and economical waste management systems for farming operations.

5) That efforts be intensified to ensure compliance with existing zoning regulations and to introduce more stringent zoning requirements to provide buffer zones around urban areas. These actions must be designed to protect both the general public and the animal industry.

1. Human wastes from Ontario's 500,000 farm population.
2. Crop residues such as cornstalks, pea and tomato vines, etc.
3. Wastes from fruit, vegetable and milk processing plants and other rural industries.
4. Approximately 1,000,000 dead birds per year.
5. Residues from agricultural chemicals such as pesticides and other control agents.
6. More than 130 million lbs of livestock manure per day.

Figure 1 Sources of Agricultural Wastes

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June, 196		sab

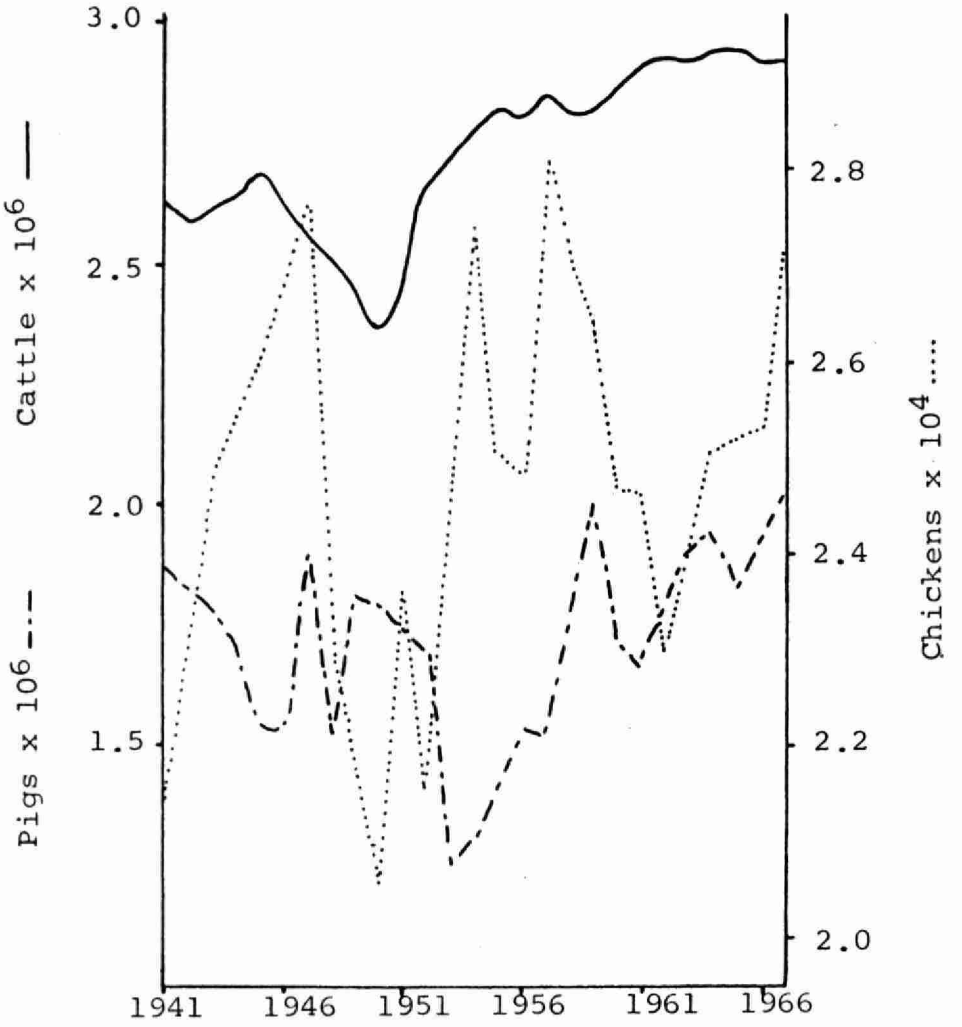


Figure 2 Numbers of Livestock on Ontario Farms

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June, 1969		sab

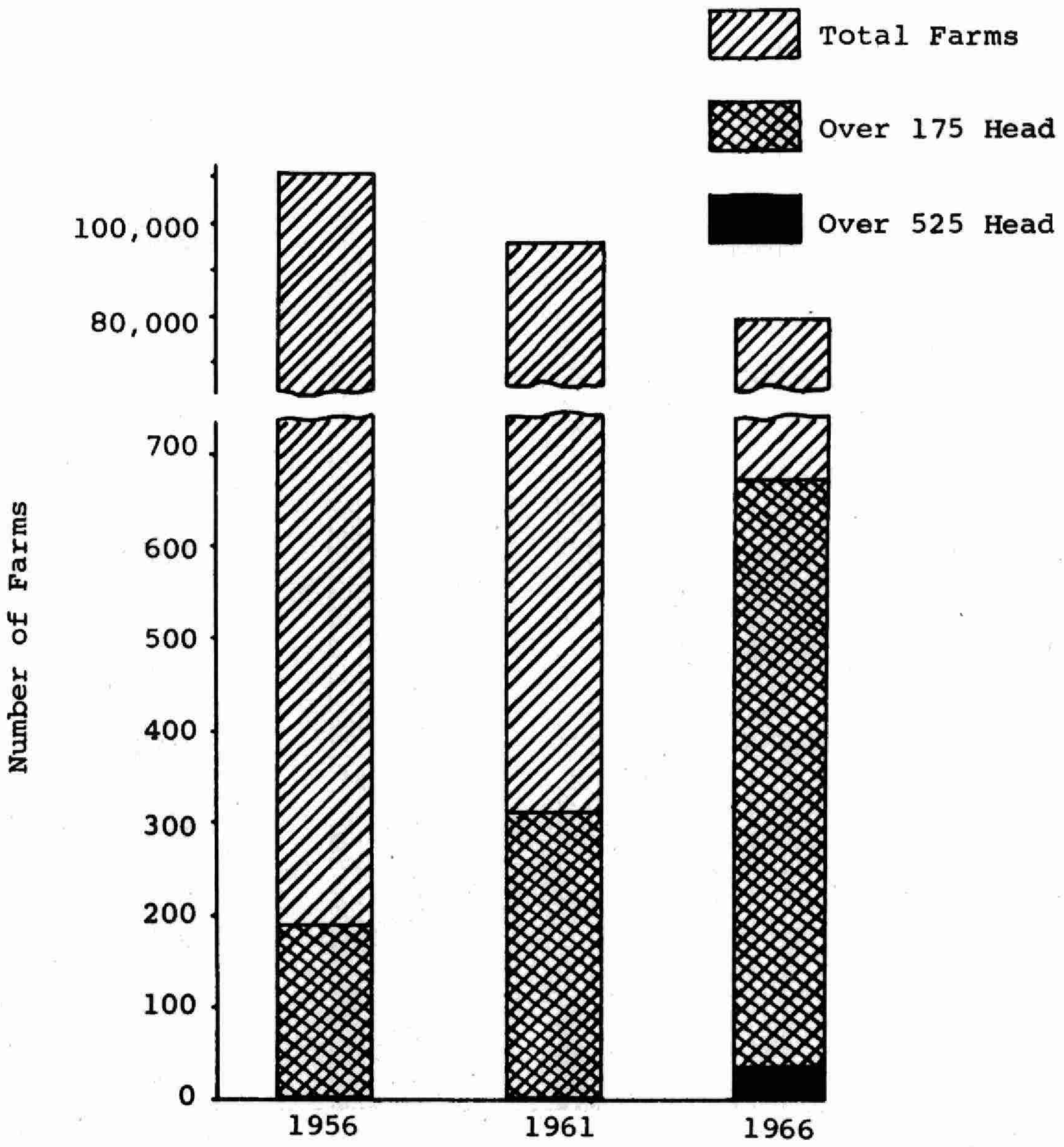


Figure 3 Trends in Cattle Concentrations on Ontario Farms

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June,1969		sab

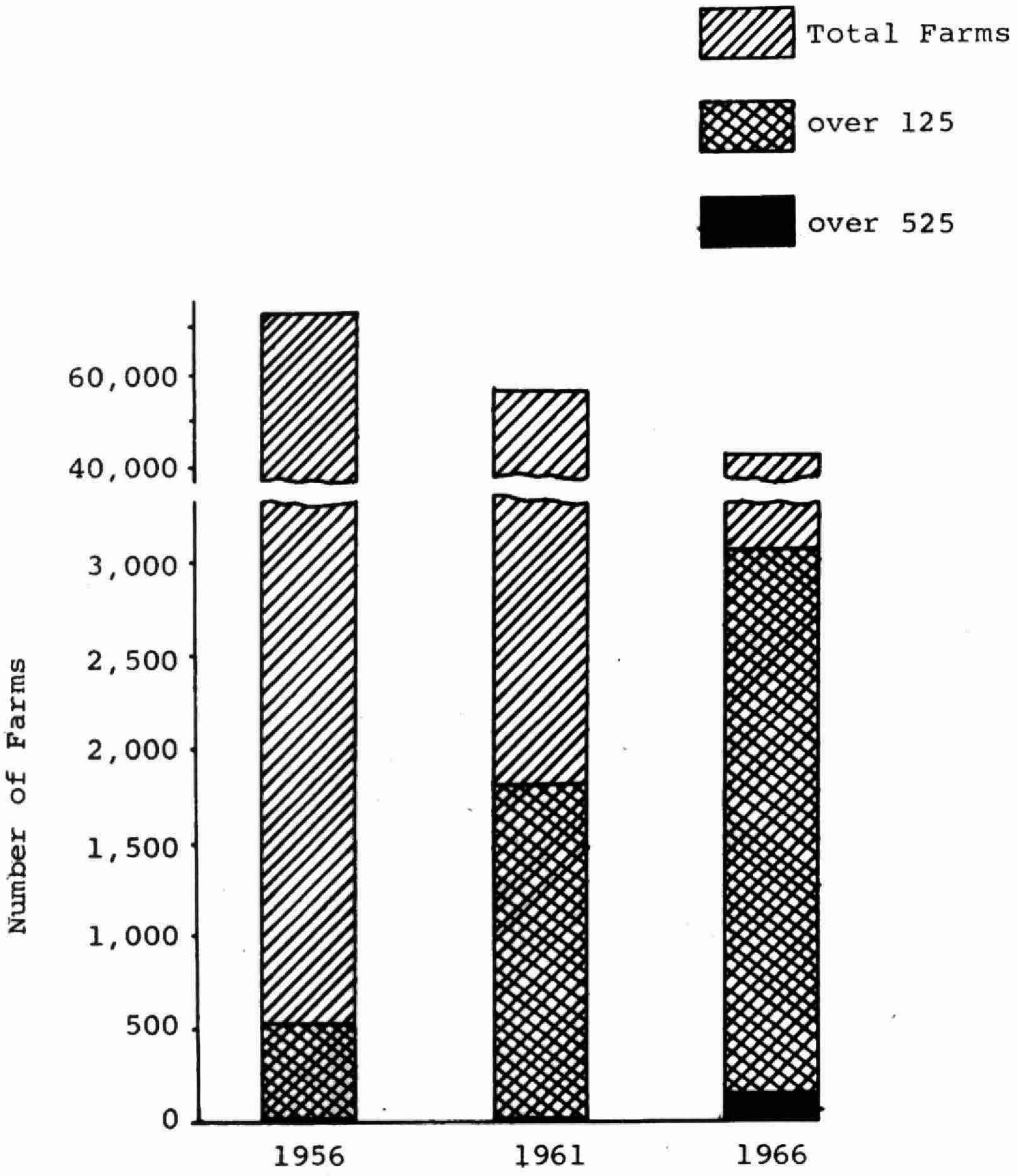


Figure 4 Trend in Swine Populations on Ontario Farms

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June, 1969		sab

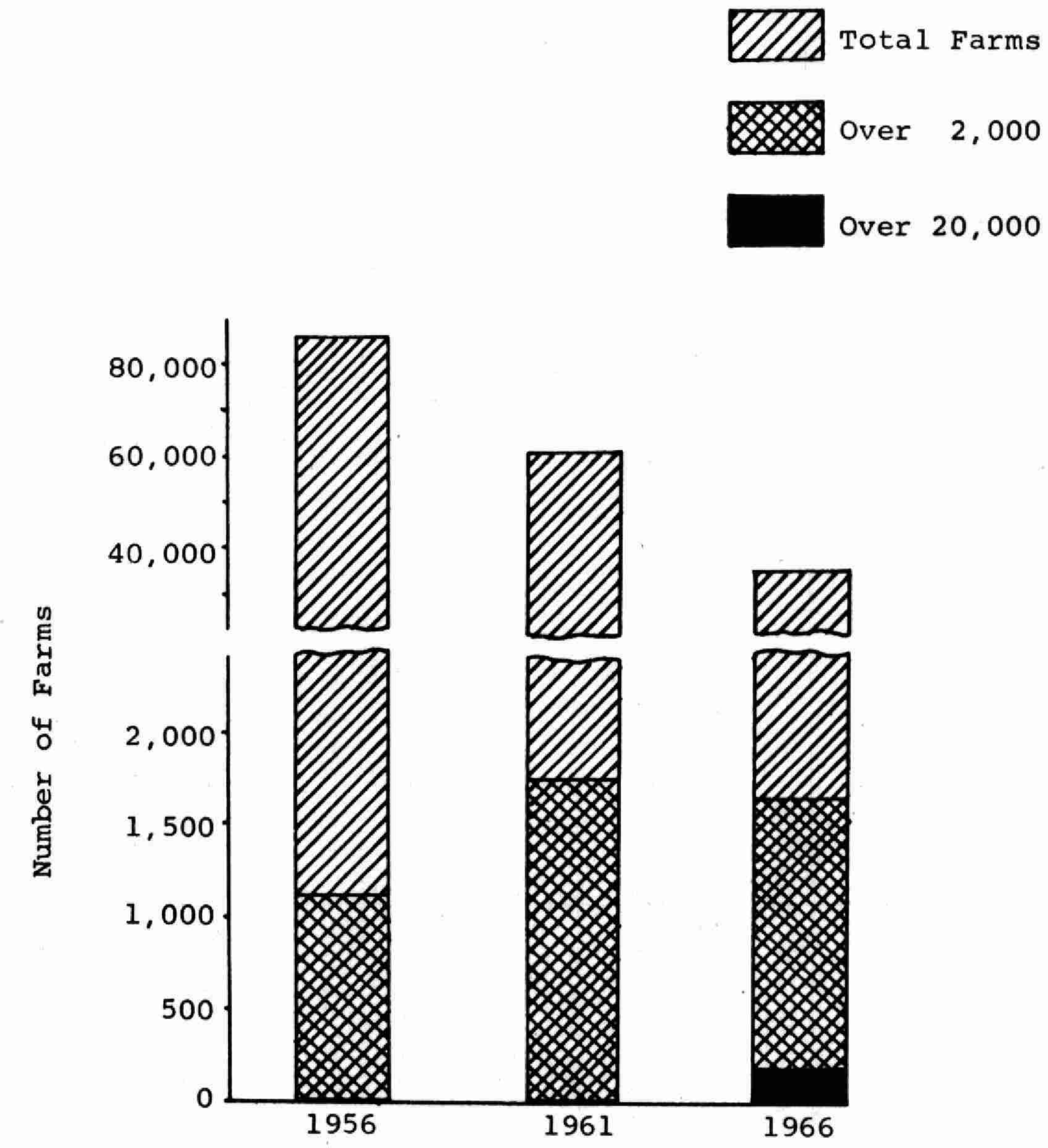


Figure 5 Trends in Chicken Concentrations on Ontario Farms

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June, 1969		sab

Operation	Manure*	
	lb/day	gal/day
1,000 broilers (0-4 lbs)	250	14.5
100 hens (5 lbs)	45	2.6
10 pigs (30-200 lbs)	70	8.6
2 beef cattle (400-1,100 lbs)	77	9.5
1 dairy cow (1,200 lbs)	72	9.5

* Assuming no dilution

Figure 6 Average Daily Production of Livestock Manures

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June, 1969		sab

Operation	Organic Matter	N	P
100 Milk Cows	145	7	0.45
300 Beef Cattle	220	11	0.70
300 Market Hogs	52	3	0.35
60,000 Broilers	670	44	7.35
10,000 People	65	9	5.0

Units of nutrient material are tons per year

Figure 7 Major Nutrient Material in Livestock Wastes

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June, 1969 sab

	Manure* (gal)	Total Value** ($)	Value/1,000 gal ($)
1,000 broilers - 10 weeks	1,000	25.50	25.00
100 hens (5 lb) - 365 days	940	25.25	25.00
10 hogs (30-200 lb) - 175 days	1,510	20.00	13.00
2 beef (400-1,100 lb) - 365 days	3,440	29.25	9.00
1 dairy cow (1,200 lb)	3,440	29.25	9.00

* no dilution of the manure

** valuing nitrogen at 10¢ lb, phosphate at 10¢ lb and potash at 5¢ lb

Figure 8 Fertilizer Values of Liquid Manures

Number of Animals	N-Excreted (pounds)	Required Acreage of Continuous Corn	
		Efficient Use*	Minimum**
1,000 broilers - 10 weeks	155	1.0	0.5
100 laying hens - 365 days	125	1.0	0.5
10 market hogs - 175 days	115	1.0	0.5
2 feeder beef - 365 days	140	1.0	0.5
1 dairy cow - 365 days	140	1.0	0.5

* Acreage required to use efficiently the nitrogen in the manure, that is, maximize the net returns above the cost of the nitrogen applied.

** The minimum acreage that could be treated annually without adversely affecting crop (yield or quality) or ground water

Figure 9 Land Requirements for Manure Utilization

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June, 1969 sab

Operation	BOD ppm	Population Equivalent
300 steers	8,000 - 16,000	1,120
50 milking cows	6,000 - 12,000	640
60 breeding sows	1,300 - 13,000	767
40,000 laying hens	8,500 - 40,000	5,333

Figure 10 Strengths and Population Equivalents of Livestock Wastes

ONTARIO WATER RESOURCES COMMISSION
DIVISION of RESEARCH

Farm Animal Waste Disposal

June, 1969 sab

SESSION CHAIRMAN
MR. J. M. COURTRIGHT
COORDINATOR-ENVIRONMENTAL CONTROL
SHELL CANADA LIMITED
TORONTO, ONTARIO

G. G. DUNN

"GRASS FILTRATION-POND STABILIZATION OF CANNING WASTE, A TWO-STEP PROCESS"

BY

T. G. STEVENS
CHEMISTRY SECTION SUPERVISOR

G. G. DUNN
MICROBIOLOGIST

CANADIAN CANNERS LIMITED
HAMILTON, ONTARIO

Introduction

Canadian Canners Ltd. is a food processing company which operates 12 canning plants across Canada. Of these, eight are situated in Ontario - two in the Niagara fruit growing area and six in the cash crop areas of south-western Ontario. The company processes, in season, a wide range of fruits and vegetables as well as fruit drinks and soups.

The factory which was the location of the work described here, is situated in the Niagara peninsula at St. Davids. The plant has been in operation continuously since 1896. Originally established as St. Davids Canning Co. Ltd. it was one of a group of canning companies which formed Canadian Canners Ltd. in 1903. The factory itself is situated on a small stream called Four Mile Creek which flows north to Lake Ontario - a distance of ten miles. The total amount of fresh fruit processed is about 8,000 tons per year. The season begins with strawberries in mid-June and runs through cherries, apricots, plums and peaches, finishing with pears at the end of November.

In the operation of this plant, water is used in many ways common to the canning industry - washing, conveying, peeling, cooking, cooling and factory cleaning and sanitation.

A very small amount of water enters the final product as sugar syrup, but most is discharged from the factory. The water used for cooking and cooling contacts sealed cans only and is not contaminated with organic matter. This water, unless reused in the plant, is discharged to the creek, slightly warmer than when received.

The remaining water, which carries in it the organic matter derived from the fruit during processing, is discharged as process waste effluent for treatment. Table I shows this effluent volume for a typical canning season.

This waste water is passed over 20-mesh vibrating screens to remove coarse solids such as pits, skin, cores, rejects and trimmings prior to any further treatment. Table II shows the average characteristics of the plant effluent after screening.

As in most canning wastes, the levels of nitrogen and phosphorus are low and there are no materials present which inhibit the biological degradation of the organic matter. The suspended solids which remain after screening constitute only 5 to 10% of the BOD_5 and their removal would be a minor part of any treatment process.

Prior to 1958, the factory used a "hold and dump" lagoon for waste disposal. Waste water from processing operations was held in a large lagoon over winter and discharged, partially stabilized, to the creek in the spring when creek flow was at its highest level. Factory expansion and more stringent effluent standards for waste discharges made this method no longer suitable. Therefore a programme of spray irrigation was begun in 1958 using aluminum sprinkler lines to distribute screened waste evenly over a forty acre field. By 1965 the system had grown to 140 acres with a maximum loading rate of 1/3" per day on the most heavily loaded sections. In spite of the large acreage involved, run-off to Four Mile Creek and adjoining property was a serious problem during the heavy packing season.

At that time a research project was started to determine how this waste could be treated economically and, at the same time, maintain the discharge quality standards as set out by the OWRC. The two experimental systems which will be described now are parts of this project.

Experimental Systems

A. Everfull Stabilization Ponds

The Everfull method uses a number of stabilization ponds connected in series. Flow takes place from pond to pond and eventually water discharges from the last pond to the receiving body of water. It was first used for canning wastes in the midwestern United States by the Del Monte Corporation (who gave a paper on their findings at this Conference in 1964).

Their work was concentrated on vegetable processing wastes in the midwest area of the U.S. Because of the generally higher BOD_5 and lower nutrient content of fruit wastes and because of the climatic differences between the Midwest and Ontario, we decided to carry out a pilot-scale study of this method before planning any installations.

Design

A 2.8 acre, 5-pond system was constructed for experimental work in 1965 on our irrigation property at St. Davids. Figure 1 shows the layout and size of each pond in the series. The first pond was the largest and shallowest. Succeeding ponds had smaller surfaces but were progressively deeper. When construction was finished, the ponds were filled with a blend of creek water and waste effluent to reach an arbitrary BOD_5 concentration in each pond. This blend was allowed to stabilize during the winter and spring of 1965-66 and the experimental study began in the summer of 1966.

Operating Method

Screened waste was pumped into the first pond beginning in early August. The waste water was supplied by way of a V-notch weir tank equipped with a recorder to determine volumes. The amount added each day was a small, but constant, proportion of the total waste volume from the factory. The final objective was to reach a total waste loading equal to one displacement of the contents of all ponds (i.e. 5.3 million gallons) using a suitable proportion of factory waste from each of the production operations.

Samples were taken at frequent intervals in each pond and analyzed to determine the progress of stabilization.

Observations & Results

The results of the first year's operations are given graphically in Figures 2 through 6. The objective of 5.3 million gallons of waste water (one complete displacement of the contents of the system) was not achieved. The total volume put through the system was only 68% of the objective. The total organic loading was nearly 47,000 lbs. of BOD_5.

The time in mid-October when the BOD_5 of the final effluent from Pond 5 began to exceed discharge quality standards coincided with a drop from 13°C to 9°C in the temperature in the Ponds (Fig. 2). A corresponding increase in the BOD_5 of the other ponds at this time was also noted. Loading of the system with waste water was discontinued shortly thereafter.

The BOD_5 progressions in the ponds are given in Figures 3 and 4. As loading proceeded, the BOD_5 in each pond rose in sequence; Pond 1 rising to the highest level (1,400 mg/l) and Pond 5 the lowest level above the initial conditions.

Figure 5 shows that the dissolved oxygen level in Pond 1 dropped rapidly to zero after loading began in early August and it remained anaerobic through the winter until the ice broke up in March. Ponds 2 and 3 became anaerobic in mid-September and Pond 4 (Fig. 6) in early October, becoming aerobic again in March. Pond 5 became anaerobic in mid-October and aerobic again in mid-November.

Pond 5 was ineffective except to dilute the effluent from Pond 4. By the time Pond 5 began to receive unstabilized effluent from Pond 4 ($>$ 15 mg/l BOD_5), the temperature had dropped and little further stabilization took place in Pond 5. The BOD_5 of the final effluent rose rapidly and soon exceeded the discharge quality standard for BOD_5.

From the time when Pond 5 received incompletely stabilized waste water from Pond 4 until it was necessary to stop loading, a volume of raw waste equal to 70% of the capacity of Pond 5 was put into the system. Better performance would have resulted if Pond 5 had been empty to begin with and had served as a hold and dump lagoon for unstabilized Pond 4 effluent. At that late point in the packing season, very little breakdown was taking place and we would have derived the full benefit of the space in Pond 5 to end up with a slightly better "volume treated" record.

When considering the performance of the Everfull system, the two closest alternatives should be included.

A hold and dump lagoon would contain the 5.3 million gallon objective, but the odour problem alone would make the system unsuitable, and there is a risk that stablization would be incomplete before the beginning of the next processing season. Odours were relatively well controlled in the Everfull system. The second alternative - an oxidation pond similar to those used to treat domestic wastes - would have to be very much larger than 5.3 million gallons in order to provide the detention time required to successfully treat this volume of raw canning waste, or even 3.6 million gallons.

All ponds in the Everfull system were completely stabilized by May, well in advance of the beginning of the 1967 pack. In 1967 and 1968, the system was operated with various modifications. The objective was to achieve one complete displacement of the volume of the system. However, the overall performance was not significantly improved.

The overall conclusion reached was that the system worked well at temperatures above 15°C (60°F). At lower temperatures, stabilization rates dropped too much to permit continued heavy loading, and a method of handling wastes produced under colder weather conditions would have to be provided.

B. Grass Filtration/Pond Stabilization

Development of this system began in 1967, based on observations made during 1966 on both the experimental Everfull ponds and on the factory spray irrigation systems.

As previously mentioned, the spray irrigation system had grown to 140 acres by 1965 and serious problems still resulted from runoff to Four Mile Creek. The soil in the St. Davids area is heavy clay, and when saturated, becomes almost impervious to infiltration from the surface. Therefore most of the waste water that is applied to the soil surface will run off except for losses through evapotranspiration.

During 1966 we carried out a careful study of the operation of the spray irrigation system, and when runoff became serious, steps were taken to discontinue spraying in certain parts of the system and/or store the waste temporarily in the old hold and dump lagoon at the plant.

A large number of analyses were carried out on runoff during 1966 and the results showed that although the spray irrigation system was far from being a satisfactory method of disposal, it still stabilized the applied waste to a large degree, the average BOD_5 of the runoff being about 200 mg/1. Therefore we already had the beginning of a good treatment system. The only requirement was a method of further treating the field runoff to complete the stabilization process and provide an acceptable effluent. The Everfull study has shown that fruit processing wastes at a BOD_5 of nearly 400 mg/l would stabilize without odour problems when held over winter in a pond.

Therefore it was decided to construct an experimental system composed of two parts: a spray irrigation system with provision for collection of the runoff and a stabilization pond large enough to complete the stabilization of the runoff from the irrigation system during the processing season. We called the spray irrigation section of this system the "grass filter" since this seemed to most closely describe its part in the process.

Design

1. Grass Filtration Section

To study the method of pretreatment by grass filtration on a practical scale, part of the factory's spray irrigation system was redesigned for this purpose. The total area of the section chosen was 63 acres and it had a slight natural slope toward one side (Figure 7).

To apply waste to the grass filter, the aluminum sprinkler system was laid out so the lateral runs were across the slope (instead of down-slope). Waste was sprayed onto the grass filter through 40 laterals running off a 5" main header. Each lateral was controlled by a valve at the main header. The laterals and sprinklers were on 60 foot centres, except where several long laterals were required on the low side of the field. These laterals had sprinklers at 90 foot intervals so that the correct pressure was maintained at the ends of the lines. The sprinklers had a spray radius of 60 feet and therefore full overlapping coverage was achieved over most of the grass filter.

Along the low edge of the experimental section, a ditch was constructed to collect the water flowing from the grass filter. (The earth removed from the ditch was used as a dike to protect adjacent property.)

The ditch was designed to convey the waste through a measuring weir into a small reservoir from which it was pumped to a large stabilization pond for final treatment. The pumping reservoir had a capacity of about 200,000 gallons which made it possible to collect the runoff over 24 hours or more and then pump it into the stabilization pond.

2. Stabilization Pond

The pond was of conventional design measuring 800' x 550' and had a maximum water depth of 5'. It contained 14 million gallons when full and was equipped with a valved drain to permit it to be emptied as desired.

Operating Method

1. Spraying on Grass Filter

The system was operated according to a schedule designed to distribute the bulk of the waste on the high or south side of the field, giving it a long run across the field before entering the runoff ditch. During the heavy packing season the schedule was followed for two 8-hour shifts on each operating day. Two or three laterals were used at once for half hour periods. A complete sequence was usually completed in 24 hours. Figure 8 is a copy of the check-off sheet used by the operator in carrying out the spray sequence.

2. Stabilization Pond

The collected field run-off was held in storage over the winter. When analyses in the spring of 1968 and again this year showed that the stored waste water was completely stabilized, it was released to Four Mile Creek. The lagoon is empty now and ready to receive runoff during the 1969 processing season.

Observations and Results

Table III gives the hydraulic loading and discharge data by weeks for the 1968 operating period. The same information is presented graphically in Fig. 9. About 22.2 million imperial gallons of raw waste were sprayed on the grass filter during the season. The total volume in the stabilization pond reached 13,650,000 gallons, representing a net loss of 8,400,000 gal. or 39%. During the first two weeks, no runoff was pumped into the pond; the waste either soaked into the dry ground or evaporated. The volume of runoff relative to loading increased as the soil became saturated until the peak of the processing season passed in early October. On certain days, the volume of runoff exceeded loading because of heavy rain. Because of this, at least 1.5 million imp. gallons of rain were pumped into the stabilization pond.

The 1968 field runoff or grass filter effluent data are given in Table IV. The levels of BOD_5 and COD were less than 10% of values for the raw waste sprayed. Therefore organic loading of the stabilization pond was light and no problems were encountered in achieving complete stabilization by the spring of 1969.

Future Study

As mentioned earlier, a million gallons of rainwater was pumped to the stabilization pond along with grass filter effluent. Since pond volume could become the limiting factor on the capacity of such a system, we plan to be able to avoid pumping rainwater by providing a by-pass. This would allow us to pump raw waste directly to the stabilization pond during periods of heavy rainfall. Another project under consideration is to determine how much grass filter effluent the experimental Everfull pond system is capable of handling.

Summary

The combination of grass filtration/pond stabilization shows promise of being useful to the canning industry in Ontario. It is a relatively inexpensive method of treating waste water, particularly when used to augment an existing investment in land and spray irrigation equipment.

Everfull ponds operating on raw waste are limited by cold weather conditions, but this should not be a factor in a vegetable processing operation where the season starts and ends earlier in the year.

TABLE I

Waste effluent volume by product-1968

Product	Effluent millions of gallons	Dates
Strawberries*	0.5	June 29 - July 6
Apricots	1.5	June 27 - July 11
Cherries*	2.5	July 27 - Aug. 6
Peaches	7.1	Aug. 19 - Sept. 8
Peaches, plums and fruit cocktail	11.7	Sept. 9 - Oct. 5
Pears and fruit cocktail	5.2	Oct. 7 - Nov. 6
Pears	2.0	Nov. 7 - Dec. 2
Total	30.0	

*average of previous years - not processed in 1968

TABLE II

Average characteristics of screened fruit processing waste waters in mg/l.

Product	BOD_5	COD	Total Solids	Susp. Solids	Vol. Solids	lbs. BOD_5 per season
Strawberries	820	1,480	1,740		1,050	4,100
Apricots	1,800	3,090	3,100		2,380	27,000
Cherries	2,700	4,460	3,560		3,060	67,500
Peaches	1,340	2,330	3,120	330	2,340	95,000
Peaches, plums & fruit cocktail	1,750	2,450	2,590	370	2,440	205,000
Pears & fruit cocktail) Pears)	3,210	4,580	3,220	670	2,450	231,000
						629,600

TABLE III

Volume data (imperial gal.) for grass filter/ stabilization pond - 1968.

Date	Million gallons sprayed in week	Million gallons runoff in week	Runoff as % sprayed	Million gallons in stab. pond (cumulative)
Aug. 19-31	1.31	0	0	0
Sept. 1 - 7	3.13	0.99	31.6	0.99
Sept. 8-14	2.97	0.91	32.7	1.90
Sept. 15-21	2.83	0.92	30.6	2.82
Sept. 22-28	2.98	2.29	76.9	5.11
Sept. 29-Oct. 5	2.93	2.39	80.0	7.50
Oct. 6-12	1.43	2.49	174.3*	9.99
Oct. 13-19	1.22	0.83	67.7	10.82
Oct. 20-26	1.47	0.84	57.2	11.66
Oct. 27-Nov. 2	1.04	0.43	41.2	12.09
Nov. 3-9	0.54	0.55	101.5	12.64
Nov. 10-16	0.34	1.01	294.4*	13.65
	22.19	13.65	61.1	

* Heavy rain

TABLE IV

Grass filter effluent characteristics (mg/l)

Date	BOD_5	COD	Total Solids	Susp. Solids	Vol. Solids
Sept. 22-28*	80	233	966	266	392
Sept. 29-Oct. 5	82	201	1,540	160	980
Oct. 6-12	99	185	1,458	140	888
Oct. 13-19	52	212	2,472	140	1,392
Oct. 20-26	56	162	1,122	148	700
Oct. 27-Nov. 2	54	128	1,180	108	772
Nov. 3-9	52	127	894	96	554
Nov. 11-16	14	66	708	60	442

* weekly averages of daily grab samples

Pond	Surface Area	Depth	Capacity
1	.86 acre	57 inches	1.11 million gal.
2	.74 acre	83 inches	1.38 million gal.
3	.52 acre	101 inches	1.19 million gal.
4	.37 acre	104 inches	.87 million gal.
5	.34 acre	100 inches	.77 million gal.

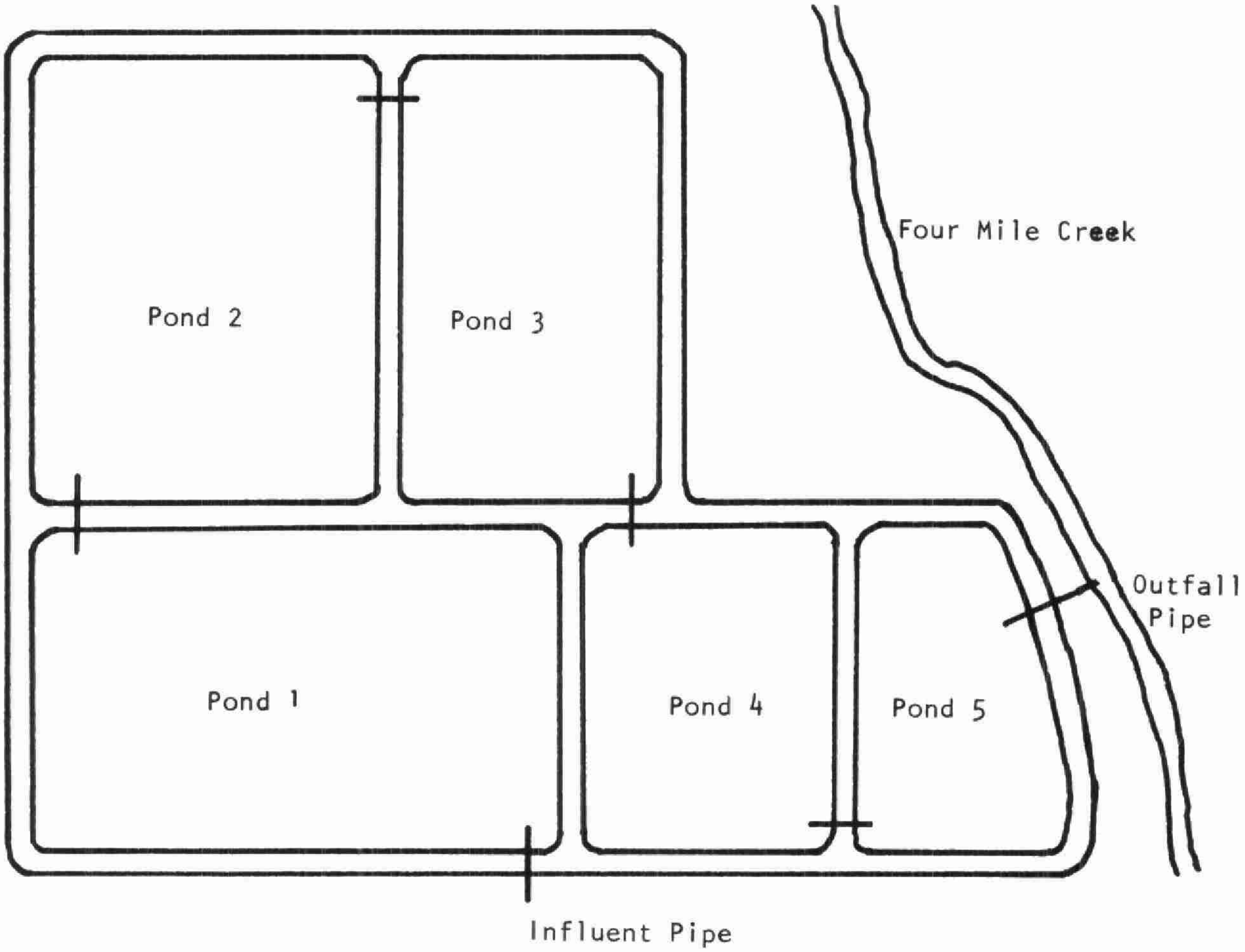


Figure 1. Experimental stabilization ponds

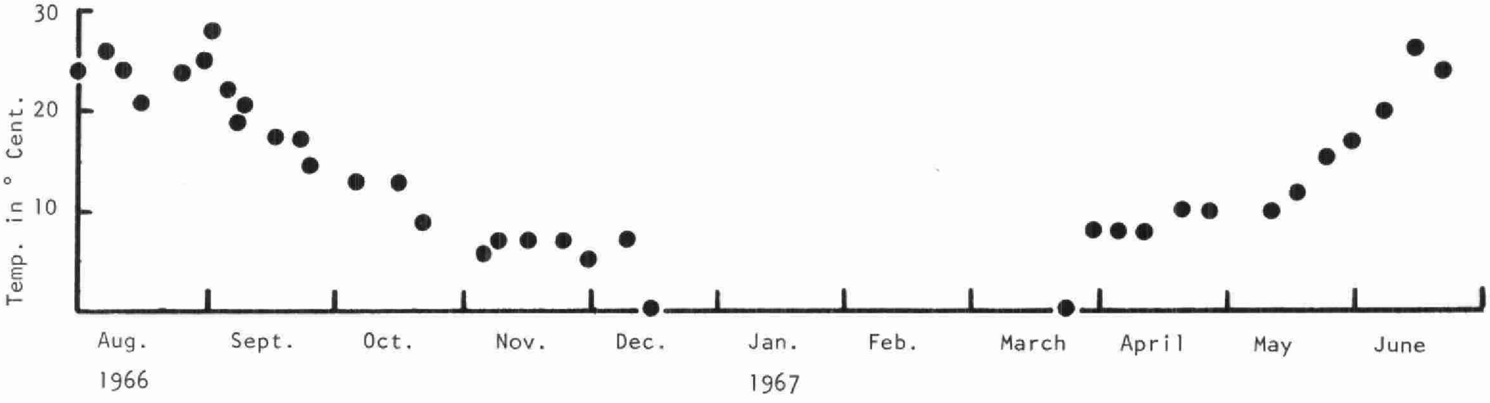


Fig. 2. Pond temperature (cent. degrees) 1966-67.

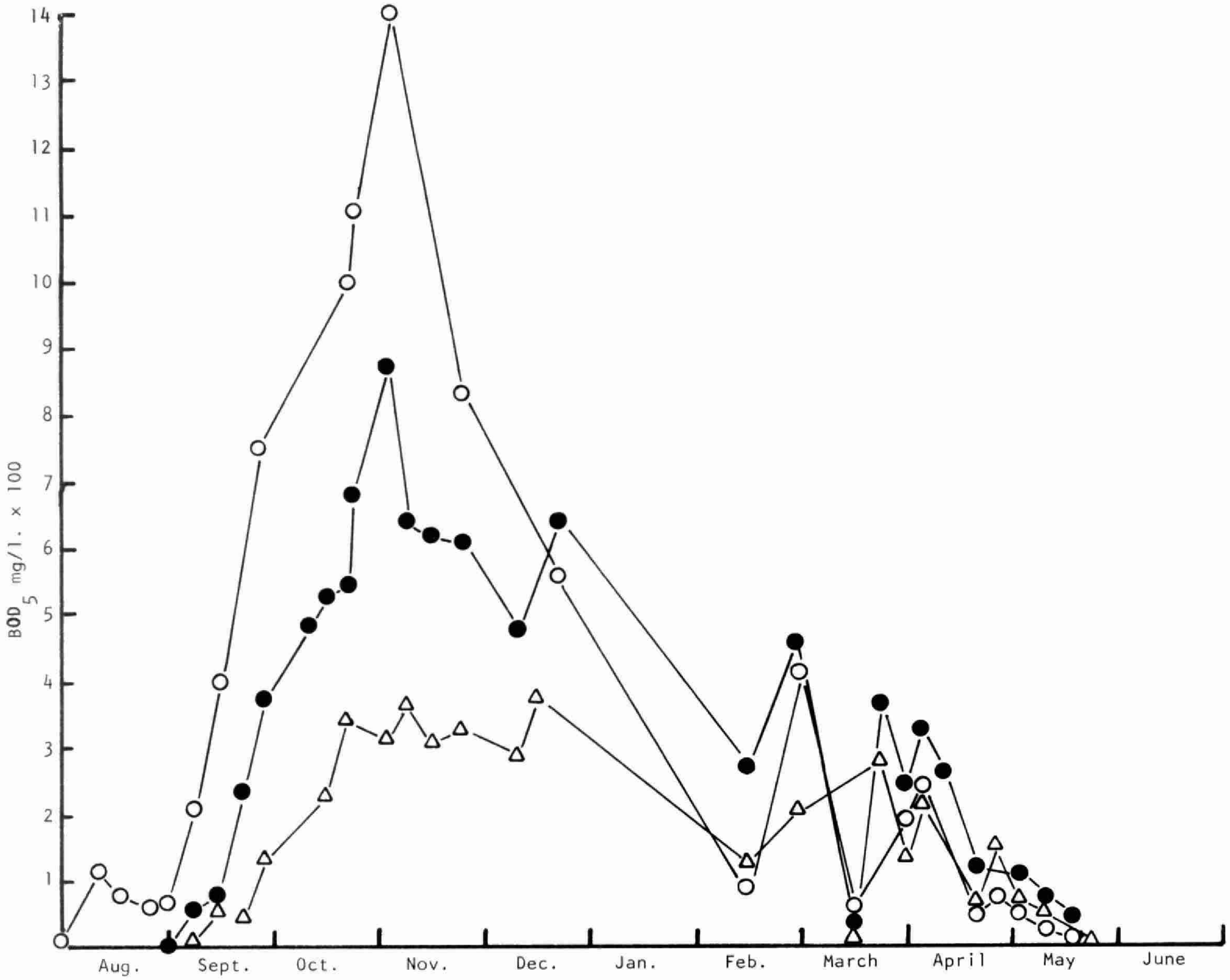


Figure 3. BOD_5 progression 1966-67; ○ Pond 1, ● Pond 2, △ Pond 3.

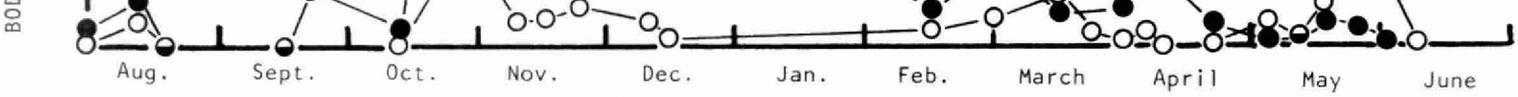


Figure 4. BOD_5 progression 1966-67; ● Pond 4; ○ Pond 5.

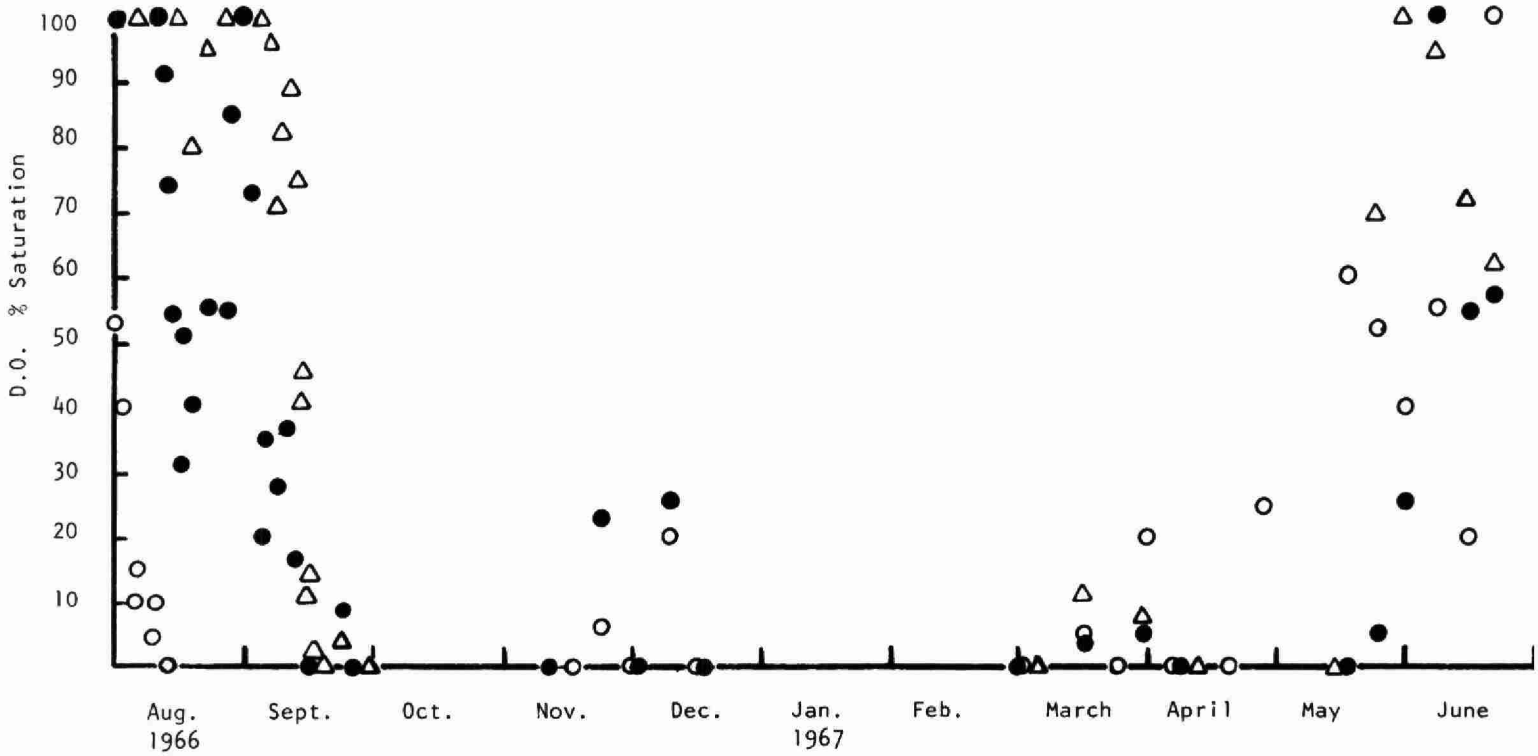


Fig. 5. Dissolved oxygen (% saturation): ○ Pond 1, ● Pond 2, △ Pond 3.

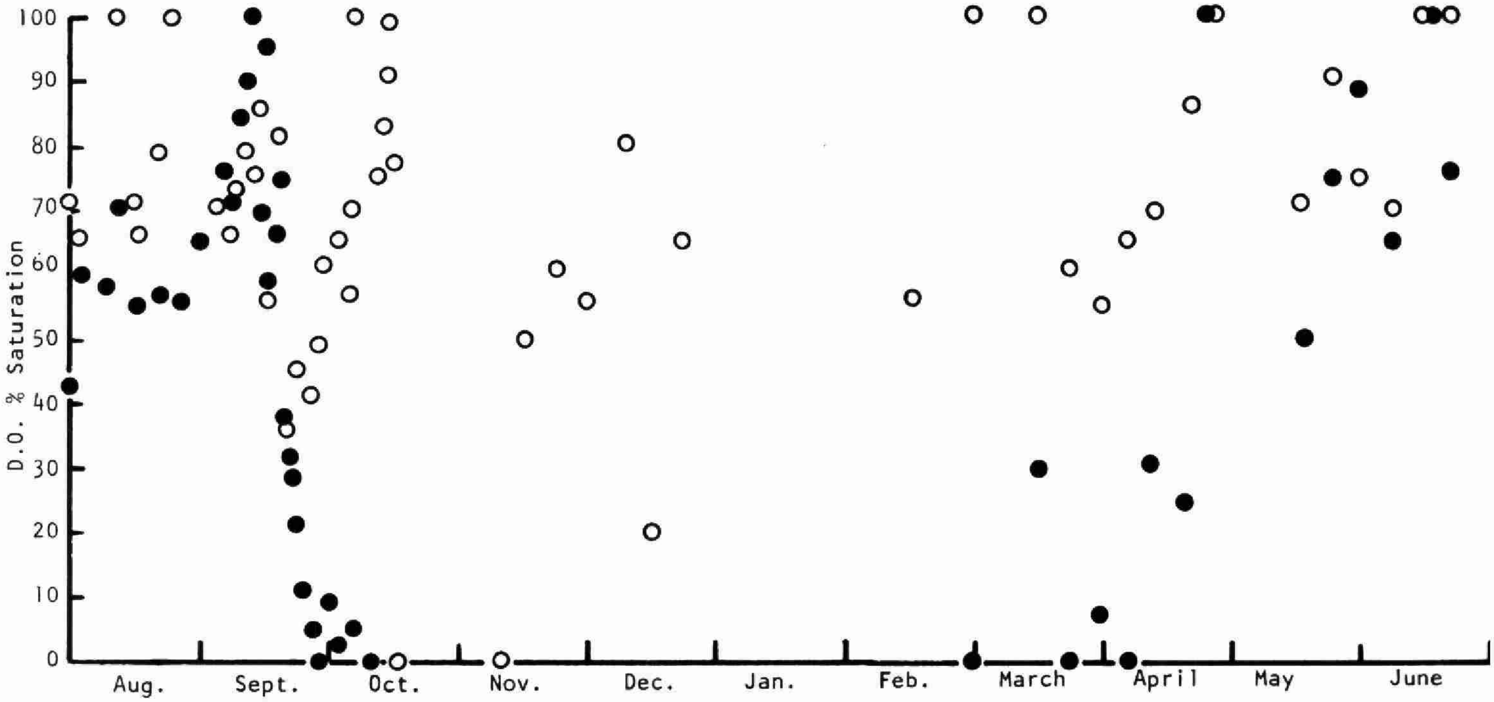
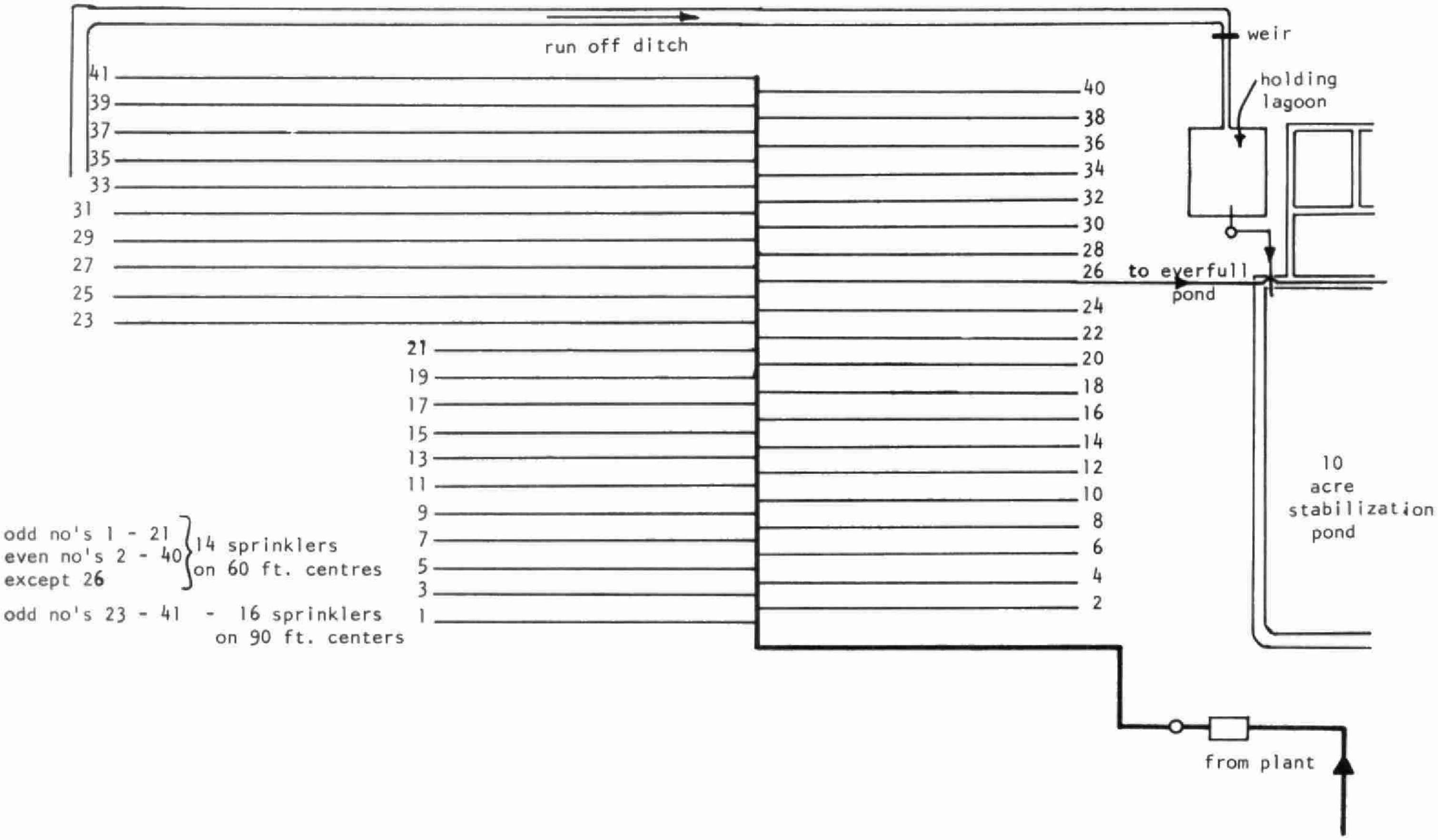


Figure 6. Dissolved oxygen (% solution), ● pond 4, ○ pond 5



Scale: 1 cm. = 120 ft.

Figure 7. Grass filtration system

LATERAL SPRAY SEQUENCE

A					B					C					D				
1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
6	7	8	9	10	6	7	8	9	10	6	7	8	9	10	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20	11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41

PLACE CHECK MARK BESIDE LATERAL NUMBERS AS THEY ARE USED.
WHEN ALL LATERALS UNDER A HAVE BEEN USED ONCE, THEN PROCEED TO B, C, D, A, ETC.

Figure 8. Lateral spray sequence form used by plant spray irrigator operator for grass filter.

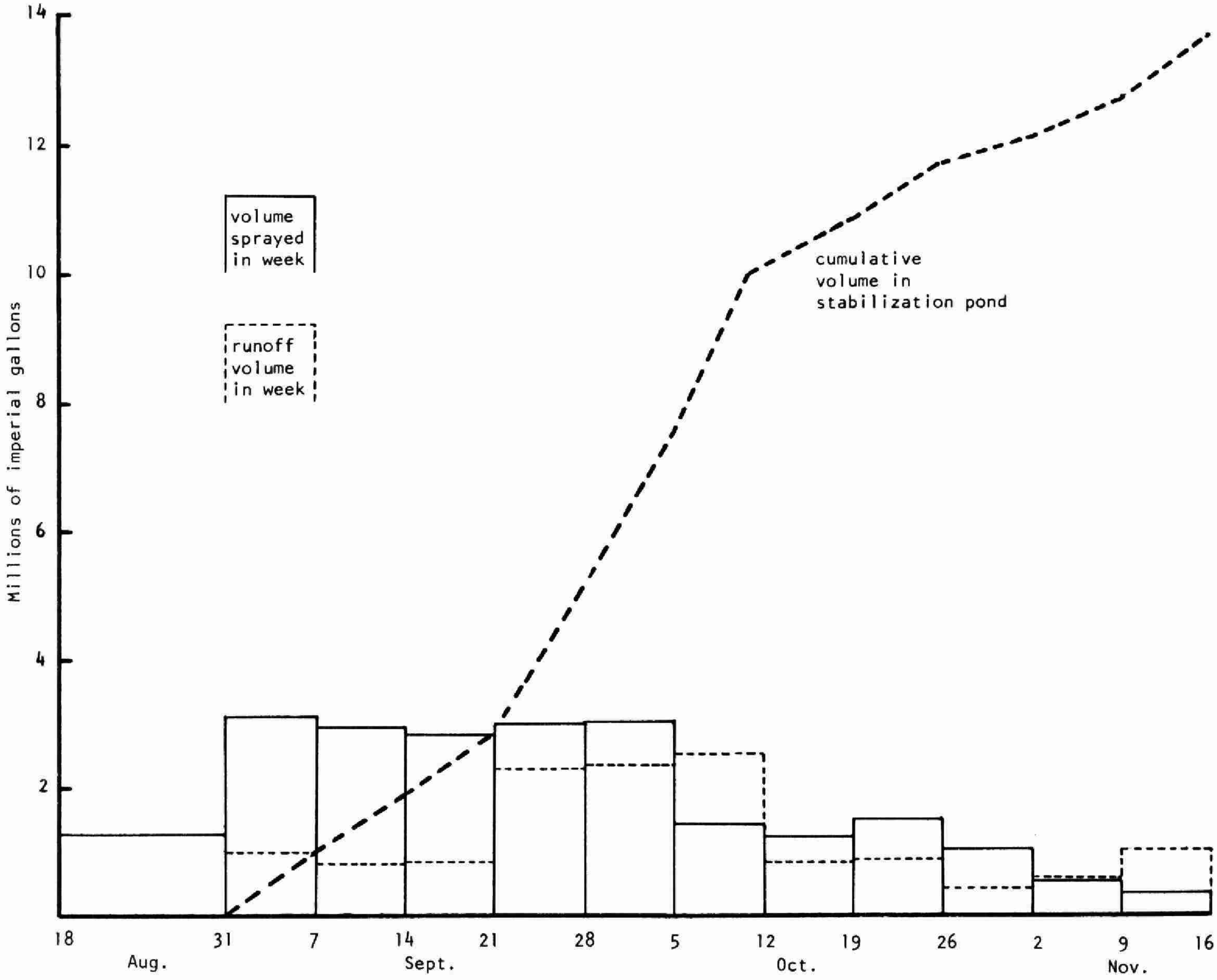


Fig. 9. Volumes of raw waste sprayed and grass filter effluent - 1968.

"PRE-TREATMENT OF WASTES AT BARRIE TANNING LIMITED BARRIE, ONTARIO"

BY

M. YATABE
ENGINEER
GORE & STORRIE LIMITED
TORONTO, ONTARIO

BACKGROUND

The City of Barrie with a population of 26,000 people cradles Kempenfeld Bay of Lake Simcoe. Tourism is important to the local economy and to ensure full recreational use of the Bay, good pollution control is necessary.

The City's pollution control facilities at the south tip of the Bay has evolved from a septic tank system, through primary treatment, to finally an activated sludge complete treatment plant of 3 M.G.D. design flow built in 1964.

There are many industries in Barrie discharging their wastes to the sewers. Consequently the sewage load for treatment is very high. The bulk of the load, however, comes from two industries - a meat packing plant and Barrie Tanning Limited.

From 1956 the City has been concerned about the high strength of the sewage. Reports on industrial wastes were made by the Department of Health in 1956, and by the O.W.R.C. in 1958, 1962, 1964 and 1967. In

1961 Gore and Storrie in a sewage report to the City referred to the unusually high strength of the sewage and specifically pointed out the need of treatment facilities at Barrie Tanning Ltd. for successful operation of the proposed activated sludge plant. The City requested Gore and Storrie to report further on required pre-treatment both at the tannery and at the packing plant. Following a survey in 1964 this was reported on in 1965.

In 1966 the City passed by-laws governing industrial wastes admission to municipal sewers and the imposing of sewer rates. Under this by-law the City in October 1966 ordered the Tannery to produce plans for waste pre-treatment within one year and to have the plant operational by the following year.

The pressing of these orders was due to continuing operational problems in the sewerage system and to increasing pressure by the O.W.R.C. to improve the sewage effluent to the Bay. Some of the problems encountered by the City were:

(1) Operational problems in treatment due to extremely high and variable B.O.D. loads.

(2) Handling of excessive amounts of sludge due to high suspended solids loads.

(3) Bad odour slugs at the sewage pumping station and at the Pollution Control Plant.

(4) Excessive maintenance of the sewer downstream of the tannery.

According to plant records from 1966 to 1968, the combined raw sewage B.O.D. to the Pollution Control Plant averaged 377 ppm and monthly averages ranged from 243 to 598 ppm. In an O.W.R.C. four day survey of December 1967 the average was 550 ppm and 8 hour composites ranged from 180 to 1050 ppm. Consequently it was difficult to maintain the O.W.R.C. objective of 15 ppm in the effluent.

The suspended solids of the raw sewage in the same period from plant records averaged 730 ppm with a range of 255 to 1296 ppm. In the O.W.R.C. December 1967 survey the average was 1450 ppm with a range of 895 to 1838 ppm. From a sewage flow of just over 2 M.G.D. the volume of raw sludge pumped was as much as 21,000 gallons daily. At such rates the anaerobic digesters accomplished very little work. An average of 15 truck loads per day of sludge had to be hauled away.

At the Toronto Street Pumping Station downstream of Barrie Tanning, the hydrogen sulphide created bad odours and corroded the copper piping and some of the electrical controls. At the Pollution Control Plant extremely bad odours were released at the aeration tanks every morning, leading to many complaints by the neighbours. It required the application of ferric sulphate at these times to remove the odour. Later on, it was found to be more effective to apply the chemical at the tannery. Until April of this year the City supplied Barrie Tanning with 100 lb. a day of the ferric sulphate, to be added at the time of the hairburn dumps.

The sewer downstream of the tannery had to dogleg backwards at a reverse slope when a new trunk sewer to the Toronto Street Pumping Station was constructed. For many years the City had to clean out the settled sludge and lime encrustations very frequently. Finally a new direct sewer with a steep grade had to be constructed, leading to less maintenance.

It was against this background that Barrie Tanning Limited requested Gore and Storrie Limited in January of 1967 to design and build a wastes treatment plant.

The attitude of the tannery was that, as citizens of a small community, this was something that had to be done. The Company in its many meetings with the City was in harmony with the City's objective. The City on its part, fully realized the financial burden this would impose on the Company. Thus, there was much rapport between the parties.

The Company has had strong roots in the community for a long time. It was founded in 1850 and moved to its present site in 1910. In 1958 to prevent the company from being sold to outside interests, the employees purchased the company and it has since been operated as an employee-owned cooperative. The financial position of the cooperative had improved only within the last few years, to a point where such an undertaking as the waste plant could now be considered.

The cost of a wastes plant was estimated in the 1961 Gore and Storrie Sewage Report as $70,000.00 with no attempt at a detailed analysis. When the final design was completed in 1968, estimated cost was $150,000.00. The actual contract price was $172,000.00. Total cost, including soil survey, engineering, supervision of construction and the mechanical screen came to $195,000.00.

The City of Barrie investigated all means of assisting the Company in the financing, and secured a ruling from Central Mortgage and Housing Corporation that, under Part 6B of the National Housing Act, the waste treatment plant could be eligible for a loan to the City under certain conditions. These were, that the municipality build, own and operate the plant on lands leased from the company; that necessary approvals from the O.W.R.C. and the Ontario Municipal Board be secured, and that the loan covers only those portions of new works separate completely from any existing structures or buildings. Consequently a loan for two-thirds of the contract price less 25% forgiveness was approved. The other one-third is to be debentured by the City. The Company leased the required land and a right of way to the City for $1.00 per annum for 20 years. Repayment of the loan over 20 years at 7½% interest by the tannery, to the City, as a special sewer charge, is to be made. The City is provided with security in the form of a mortgage on the Tannery buildings and property. A by-law covers the agreement between the City and Barrie Tanning Limited and stipulates that the City will supervise operation and maintain it, during the 20 year period with costs chargeable to the Tannery.

DESIGN

The tannery produces various grades of shoe leather from cowhides. Six packs a day of green hides and some pickled splits are processed.

Liquid wastes are produced from the operations of the beamhouse, tanyard and the finishing department.

Beamhouse operations include washes, soaks, hairburning, liming, fleshing and bating. The waste waters contain manure, hair, fleshings, grease and spent chemicals such as lime, calcium chloride, sodium sulphide, sodium hydrosulphide, ammonium sulphate. They are characterized by very high B.O.D. and solids, high pH and sulphides.

Tanyard operations include pickling, chrome tanning, re-tanning, colouring and fat liquoring. The wastes contain wash waters and spent chemicals such as chrome sulphate, acid dyes, syntans, sulphuric acid, formic acid, phosphoric acid, sodium chloride, calcium formate, borax, detergents, sulphonated oils. They are characterized by low pH, trivalent chrome, warm temperature, high B.O.D. and solids.

Finishing wastes are highly coloured but low in strength and amount.

Tannery processes are batched and the same daily pattern of flow is usually followed. The strongest beamhouse wastes with lime and sulphides are discharged from 3:30 A.M. to 8:30 A.M. Tanyard operations start by 8 A.M. and spent chrome is discharged around 10 A.M.

Existing treatment facilities consisted of a large sump for the beamhouse and tanyard wastes, provided with a pump for lifting the wastes to a vibrating screen. Fleshings were conveyed separately to a wooden filter box. Screen and filter effluents flowed directly to the City sewers. Three hundred gallons of screening and 8000 lb. of fleshings were being removed daily.

Plant water is obtained from an underground reservoir fed by two wells on the property. With no meters at all, total waste water rates could be determined only approximately by going on the standby water supply from the City.

Data obtained in the July 1964 survey was as follows:

Average day waste flow 262,000 gallons.
Average B.O.D. 969 ppm.
Average suspended solids 2077 ppm.
Average Kjeldahl nitrogen 186 ppm.
Average chromium 71 ppm.
Average ether solubles 270 ppm.

Thus a B.O.D. population equivalent of the wastes was around 15,000 persons.

During this survey sedimentation tests indicated that four hour detentions gave the following average reductions: B.O.D. 49%, suspended solids 81%, Kjeldahl nitrogen 34%, chromium 70% and grease 72%.

Sludge studies at that time showed that approximately 7% by volume of the waste flow could be expected. Sixteen hours standing of the sludge reduced its original volume to 70% and after 24 hours to 60%. The limit of compaction on simple standing, without chemical or physical modification, appeared to be 50%. On further standing of two weeks the sludge became gelatinous.

Limited test work was carried out at that time to investigate the effect of some organic polyelectrolytes on B.O.D. and solids removals. Results with an anionic type appeared to show promise.

In 1967 for design purposes the following approach was taken:

(1) the tannery is to investigate first all possibilities of reducing the volume and strengths of the waste waters.

(2) after the above programme has been completed, confirmatory checks on the waste water characteristics to be carried out.

(3) soil surveys to be carried out when site location decided.

During the year the tannery managed to reduce the average waste water load from 262,000 g.p.d. to 185,000 g.p.d., a reduction of 30%. This was accomplished by:

(1) Transferring bating operations from the beamhouse paddles to the tanyard drums.

(2) Eliminating the green fleshing operations and using only lime fleshing.

(3) Eliminating the re-liming step following hair-burn. This also eliminated two-thirds of the lime consumption.

Tests were also conducted to see if any appreciable water saving could be made in re-tanning and fat liquoring operations by going to batch closed door operation compared to the continuous rinse method being used. No difference was found.

Checks were made of the water requirements in the fleshing operations. An average of 14,000 gallons was being used. It was determined that the bulk of this was being used solely for water transport in the gutters. The bulk of this could be eliminated by using mechanical transport means and this could lead to lower amounts of B.O.D. leached into the waste waters. This is to be a future project in the plant.

Following the reductions in the waste waters flows, the strength of B.O.D. increased but the solids showed a reduction. A one week survey by the O.W.R.C. in December 1967 showed average B.O.D. of 1200 ppm with a range of 374 to 2988 ppm. These values were confirmed by additional test work in February 1968. Bench tests indicated around 70% B.O.D. and 80% suspended solids could be removed from the strong beamhouse wastes by mixing with spent chrome solution and allowing two hours quiescent settling. Removals of 60% B.O.D. and 70% suspended solids were indicated when tanyard wastes were given four hours quiescent settling.

Soil testing of the available land behind the plant was carried out in December 1967. It showed that below approximately 8' of loose fill material there was 30' of fine running sand with firm clay at least 30' below that. The water table ranged between 3 to 6 feet below grade.

The overall concept of design of the plant was to provide primary treatment only, to try to meet by-law requirements of 300 ppm B.O.D., 350 ppm suspended solids, 100 ppm ether solubles, pH 5.5 to 9.5. It was fully realized that to meet these limits always, would be difficult, without secondary treatment, but it was contemplated that with some occasional help through chemical treatment, satisfactory results could be obtained most of the time.

The facilities of the pre-treatment plant provide screening, flow equalization, pre-aeration, settling, sludge removal and storage, scum removal, flow metering, tank truck removal of scum and sludge, and unwatering.

The existing wet well was altered to acommodate a mechanically cleaned bar screen (Figure 1). The vibrating screen was eliminated. The existing pump was removed and relocated to the new plant to serve as the unwatering pump. The screen with 5/8" openings collects 90 gallons daily of screenings.

Beside the wet well is a 3000 gallon plastic coated steel tank for holding the acidic spent chrome wastes diverted from the tanyard flow.

From the wet well the wastes flow through a manhole provided with an emergency by-pass valve to the plant proper (Figure 2). The plant consists of a pre-aeration tank, two rectangular settling tanks, control building and two sludge tanks, all constructed of concrete. Owing to the poor subsoil conditions and high water table, to overcome uplift conditions when the tanks are empty, the plant is designed as a monolithic structure on a floating raft foundation with wide footings. Well point dewatering had to be employed during construction.

The spiral-flow pre-aeration tank with air diffusers at the bottom provides 20 minutes detention for morning flows and 10 minutes for the afternoon flows.

Purpose of the tank is to strip off some of the hydrogen sulphide and other volatiles, to add some dissolved oxygen to the wastes and to assist the removal of grease and hair as scum in the settling tanks.

The settling tanks are each 16' wide, 43' long and 10½' deep for a total capacity of 93,000 gallons. Chain collectors protected by zinc anodes bring the sludge to the hoppers at the inlet end and the scum to the scum troughs at the surface. When operated continuously in parallel at the highest rate of 300 g.p.m. in the afternoons, the surface overflow rate is 300 g.p.d.s.f. The effluent flow is measured by a V-notch weir and transmitter with a recorder-totalizer located in the control building.

The control building ground floor houses two plunger type sludge pumps of 70 g.p.m. capacity each, the 70 c.f.m. blower and the electrical control panel. The basement contains the unwatering pump, the sludge transfer pump and sump pump.

The two sludge storage tanks each hold 18,000 gallons and are used on alternate days. The piping includes supernatant draw-off manifolds with clear plastic sight tubes.

OPERATIONS

The method of operation of the plant is a combination of batch settling, continuous settling and unwatering as follows:

(1) By 3:30 each morning settling tanks, aeration tank, wet well are all empty.

(2) Tank #1 is filled with beamhouse wastes and the spent chrome held from the previous day, between 3:30 to 8:30 A.M.

(3) Flow is diverted to #2 tank.

(4) Tank #1 is de-sludged between 10 A.M. to 11:15 A.M. and inlet gates opened.

(5) Both tanks start overflowing from around 1:00 P.M. and continue overflowing until 5 P.M.

(6) Both tanks are de-sludged between 6 P.M. to 9 P.M.

(7) Unwatering of both tanks takes place from 9P.M. to around 2 A.M.

(8) Supernatant from sludge tank is drawn off the following morning and compacted sludge is pumped to sludge truck.

The air blower, collectors, sludge pumps, and unwatering pump are all on automatic timer control with skip cycles for weekends.

Plant operations commenced in February 1969. A few mechanical problems were encountered in start-up including the necessity of changing the sludge transfer pump. A regular sampling and analysis routine has not yet been established. Consequently in the shortness of time only limited data has been obtained as follows:

(1) Average daily flow is 187,000 gallons, and ranges from 160,000 to 220,000 gallons.

(2) The temperature range of the incoming wastes is 38° F. The tanks evened this range to 18° F. in the effluent.

(3) pH of the influent ranged between 2.5 and 12.2 and of the effluent between 5.7 and 8.4.

(4) The amount of sludge pumped equalled 8% by volume of the waste water, reduced to 4% upon compaction. The average raw sludge solids were 2.3%.

(5) The limited B.O.D. and suspended solids analyses have shown a wide spread in values. B.O.D. of influent ranged from 705 to 2660 ppm and of effluent from 290 to 680 ppm. Suspended solids in the influent varied from 790 to 2516 ppm and in the effluent from 300 to 760 ppm.

Meanwhile at the Pollution Control Plant the effect of the pre-treatment plant operation has been marked. Odour problem has diminished. Effluent quality improved. Digester operations became more normal and improved supernatant quality enabled the plant to reduce sludge haulage from 15 to 5 loads daily.

PRESENT AND FUTURE STUDIES

Work is presently being conducted on odour abatement and on improving removals through chemical treatment.

The odour problem at the pre-treatment plant is, as expected, bad. The design of odour treatment facilities was purposely left in abeyance pending assessment of the problem under actual operating conditions. Ozonation of the air from the pre-aeration tank is the first approach. The tank was designed so that it could be covered and a baffled contact tank built over it for reaction of the air with ozone. A trial wooden box has been installed and testing has been commenced using three small ozonater units. Hydrogen sulphide concentrations in the untreated air varied over a day between 50 and 2000 ppm by volume in a quite inconsistent pattern. Beyond demonstrating that odour removals can be obtained by ozonation, no figures on removal rates have been obtained.

Bench studies have been started at the Pollution Control Plant on the effect of chemical flocculants such as alum and anionic polyelectrolytes. The waste pre-treatment plant has been designed to accomodate chemical feed equipment in the control building. The aeration tank and aerated inlet channel will also serve for flocculation purposes.

Future studies include further concentration of the sludge by mechanical means. The sludge tanks were designed to form the floor of any building extension required for housing such equipment. The current tank haulage costs are low and for the present at least, further capital expenditures for sludge treatment do not appear to be justified.

In summary, the City of Barrie has reduced considerably the waste water load to the Pollution Control Plant by building pre-treatment facilities for the wastes of Barrie Tanning Limited. This plant financed by the City through C.M.H.C. loan and debentures will revert to the tannery after repayment of the capital over 20 years. The plant provides primary treatment which can be augmented by chemical treatment.

Acknowledgement is given to the City of Barrie, to Barrie Tanning Limited and to the O.W.R.C. for making available much of the data used in this paper.

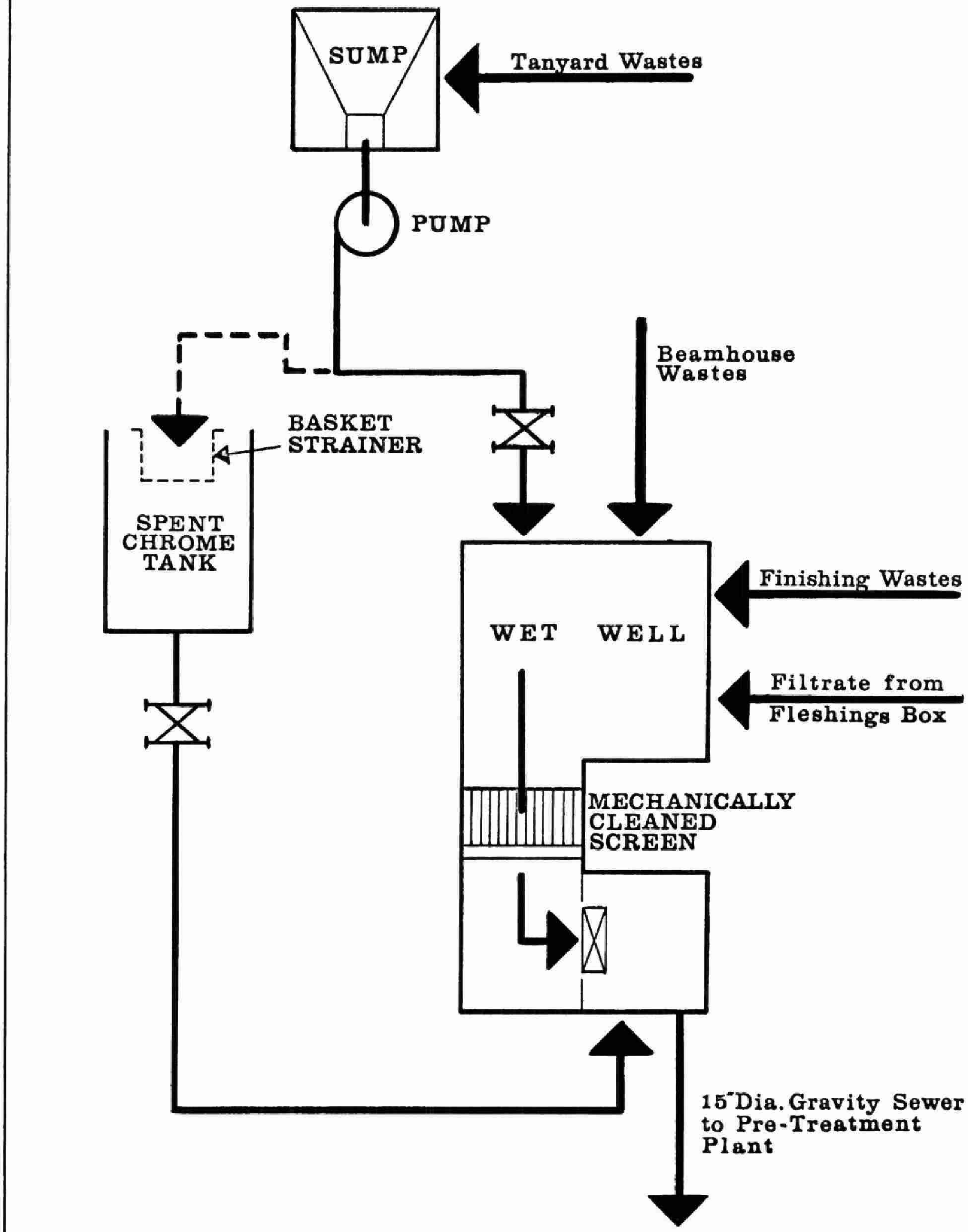

SUMP
Tanyard Wastes
PUMP
Beamhouse Wastes
BASKET STRAINER
SPENT CHROME TANK
Finishing Wastes
WET WELL
Filtrate from Fleshings Box
MECHANICALLY CLEANED SCREEN
15"Dia. Gravity Sewer to Pre-Treatment Plant

Fig. 1

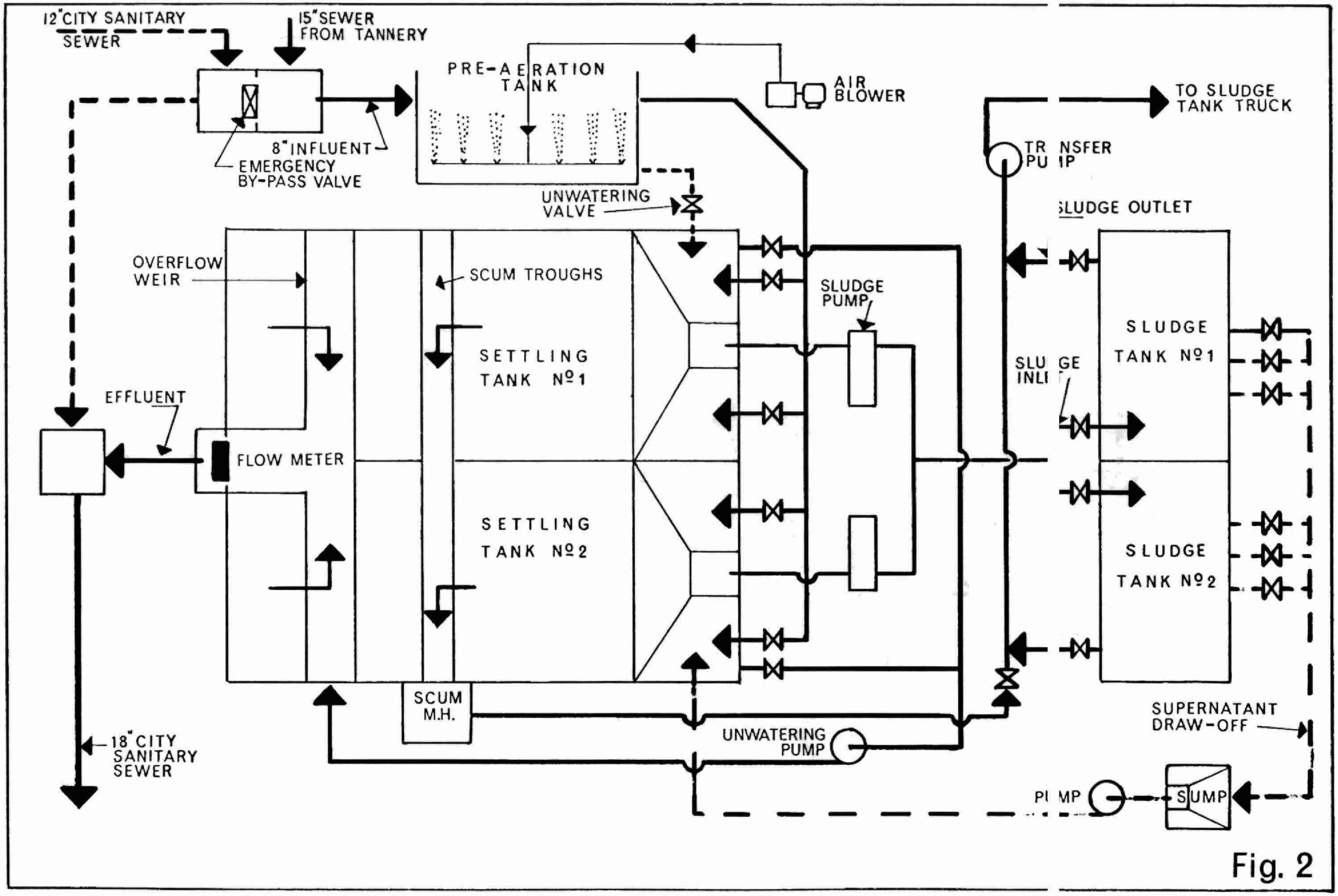

12" CITY SANITARY SEWER
15" SEWER FROM TANNERY
PRE-AERATION TANK
AIR BLOWER
TO SLUDGE TANK TRUCK
8" INFLUENT
EMERGENCY BY-PASS VALVE
TR NSFER PU IP
UNWATERING VALVE
LUDGE OUTLET
OVERFLOW WEIR
SCUM TROUGHS
SLUDGE PUMP
SLUDGE TANK Nº 1
SETTLING TANK Nº 1
SLU GE INL T
EFFLUENT
FLOW METER
SETTLING TANK Nº 2
SLUDGE TANK Nº 2
SCUM M.H.
SUPERNATANT DRAW-OFF
18" CITY SANITARY SEWER
UNWATERING PUMP
PI MP
SUMP

Fig. 2

T. D. ARMSTRONG

"TREATMENT OF POTATO PROCESSING WASTES AT SALADA FOODS LIMITED, ALLISTON"

BY

T. D. ARMSTRONG
DISTRICT ENGINEER
DIVISION OF INDUSTRIAL WASTES

B. I. BOYKO
SENIOR SEWAGE ENGINEER
DIVISION OF RESEARCH

ONTARIO WATER RESOURCES COMMISSION
TORONTO, ONTARIO

This story on Salada has been prepared by the authors, with the concurrence of the Company, to show not only the theoretical and practical aspects of treating a high strength organic waste, but also to point out the need for long range planning on the part of the Company, regulatory agency and municipality, prior to the establishing of a processing plant.

The area surrounding the Town of Alliston is ideal for growing potatoes and thus the desire of Salada to locate a processing plant in this municipality. Representatives of the Town of Alliston, the consulting engineer for the project, and Salada, met with Dr. A. E. Berry, the General Manager of the Ontario Water Resources Commission (OWRC), on March 13, 1959 to discuss the building of a processing plant. It may be pointed out that the OWRC was formed in 1956.

The site considered was in the south-eastern part of the town on a stream of intermittent flow. This stream, locally referred to as Spring Creek, winds close to a residential area and then through agricultural land for some 1-1/2 miles until it joins with the Boyne River. The Boyne River is of exceptionally high quality from a pollution point of view as it contains considerable quantities of various species of trout and other pollution sensitive forms of aquatic life. The flow in this river varies from an average of 75 cfs to approximately 350 cfs during the spring runoff.

As a result of the meeting on March 13, 1959, and subsequent negotiations, it was decided that the Company would locate in Alliston and that it would provide in-plant screening and primary settling of the waste flow and that the Town and company jointly, would construct biological treatment facilities.

HISTORY OF PRODUCTION

Initially, on commencement of operations on November 30, 1959, about 5000 lbs/hr of potatoes were processed into potato flakes on a 24 hr day. Production doubled the following year.

Additional equipment was installed in the summer of 1961, so that when operations started in September 1961, 3 new dehydrated products, "Slices, Au Gratin and Scallops", were processed, in addition to the production of flakes.

In January 1962, the first potato chip line was installed, and another one was added in the fall of 1963.

Processing on all lines is on a 5 day week, and with the exception of the chip line, extends from mid August to about the end of May. Raw potato consumption is currently about 100,000,000 lbs per year.

Water consumption has increased from about 200,000 gpd initially, to a range of from 680,000 to 750,000 gpd from 1965 to the present time.

Plant Processes (Figure I)

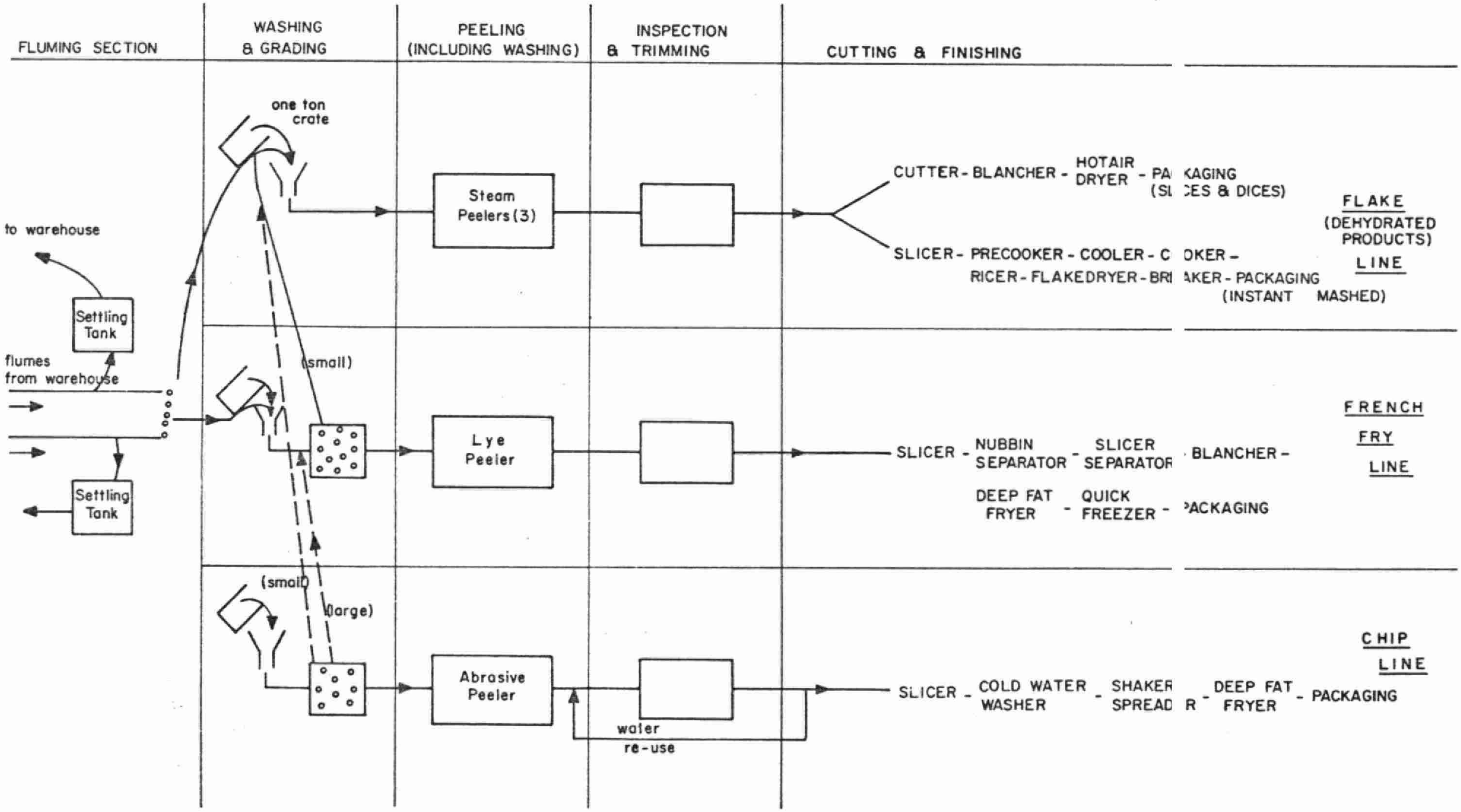
Storage

The Company constructed a 35 million lb warehouse in 1967, complete with fluming facilities to the processing plant. Potatoes from this flume are conveyed to the washing and grading area, while potatoes from other storage areas are transported in 2,000 lb crates.

FIGURE I.

POTATO PROCESSING OPERATIONS

SALADA FOODS LIMITED - ALLISTON



Processing Lines

(a) Chip Line - Potatoes are washed and graded to size with the small ones going to the flake line and the large ones to the french fry line. The medium sized potatoes that remain are used for chips. These are abrasive peeled, manually inspected and trimmed, and pumped to a metering tank. Water, which is used as the pumping medium, is recirculated back to the peeling section for re-use. The potatoes are sliced to chips, washed with cold water, and routed through a shaker-spreader to a deep fat fryer. From the fryer, the chips are flavoured and packaged.

(b) French Fry Line - The majority of the potatoes to this line are flumed from the main storage area. The potatoes are washed and graded with the small ones going to the flake line. The medium and large potatoes are then lye peeled, inspected, trimmed and conveyed to a metering tank. From this tank, they go to a slicer, a nubbin separator for removal according to length, a sliver separator for removal according to width, and a blancher. The french fry is then deep fat fryed, quick frozen and packaged.

(c) Flake (Dehydrated Products) Line - The grade-outs from the other lines and the slivers from the french fry line generally satisfy the demand on this line but if additional potatoes are required, they are obtained from the flume from the main warehouse. The whole potatoes are steam peeled, inspected and trimmed and routed one of two ways. They may be cut to slices and dices, blanched (leaching out of soluble solids), dryed with hot air and packaged. This portion of the line only operates about 4 months of the year. The potatoes may also be sliced, precooked, cooled, cooked, riced, dryed on a drum dryer, broken up and packaged as flakes or instant mashed potatoes.

WASTES FROM THE POTATO PROCESSING OPERATIONS

The breakdown of the operations in Figure I allows for a description of the wastes per section.

1. Flume Section - Water, the transport medium in the flumes, carries the sediment associated with the potatoes to one of two 8000 gallon settling basins where the majority of the suspended particles settle out. There is no means of continually cleaning these basins and the sediment is thus allowed to accumulate for periods of approximately one week

before the basin is dewatered and the bottom solids pumped to the treatment system. The supernatant in these basins is continually drawn off by a level controlled pumping system and pumped back to the warehouse for re-use.

The volume of waste from this area is not accurately measured as considerable quantities of water have to be added to render the solids pumpable, and for a similar reason, the concentration of contaminants cannot be accurately determined. The waste, however, would be characteristically of a high suspended solids, low BOD nature.

2. Washing and Grading Section - Partial washing is carried out in this section by spraying the effluent from the vibrating screen (french fry and chip wastes) on the potatoes. The waste flow from this section is, therefore, high in BOD, because of its primary use, and also contains appreciable quantities of suspended matter. There is no liquid waste associated with the grading operation.

The wastes from the remainder of the sections indicated in Figure I are described in Table I according to the processing line.

TABLE I

DESCRIPTION OF WASTES FROM THE PEELING, INSPECTION AND TRIMMING AND CUTTING AND FINISHING SECTIONS

	CHIP LINE (16 hrs)	FRENCH FRY LINE (24 hrs)	FLAKE LINE (24 hrs)
3. Peeling Section			
Volume (gpm)	50	40	100
BOD (mg/l)	400	1900	3000
SS (mg/l)	950	4500	3500
4. Inspection and Trimming Section		negligible flow solids only	
5. Cutting and Finishing Section			
Volume (gpm)	50	50	200
BOD (mg/l)	1600	1000	3000
SS (mg/l)	900	700	2000

All of the waste flows, with the exception of the effluent from the cutting and finishing sections of the chip and french fry lines, are directed through floor drains to a final sump wherein a travelling screen is located. This screen is equipped with a water spray for the removal of solids, however, the efficiency of solids removal from the waste flow is low and must be regarded as less than 10%. The effluent from the cutting and finishing sections of the chip and french fry lines is passed through a 30 mesh vibrating screen and routed to the washing and grading section for re-use. The percentage removal by the unit is estimated to be 30% SS and 10% BOD.

The average characteristics of the waste flow of approximately 700,000 gpd from the final sump to the clarifiers have been reasonably consistent over the years and current figures are shown in Table II.

TABLE II

RAW WASTE CHARACTERISTICS

5-DAY BOD (mg/l)	COD (mg/l)	pH	TOTAL SOLIDS (mg/l)	SUSPENDED SOLIDS (mg/l)	DISSOLVED SOLIDS (mg/l)	PHOSPHORUS as P (mg/l)	TOTAL KJELDAHL (mg/l)
2250	3150	6.1	2950	1300	1650	20	85

Factors that affect the quality of the raw waste are:

1. Maintenance within the plant

It has been found that if potato solids are allowed to lie in the drain lines from Monday to Friday, percentage increases in BOD of the flow from the line may easily reach 300%. This increase is attributable to the quick conversion of the potato solids to solubilized starch, proteins, amino acids and sugars and shows the importance of keeping the solids out of the drain lines.

2. Discharge from Lye Peeler

The weekly discharge of the contents of the lye peeler alters significantly the pH of the raw waste. The contents, in the amount of about 200 gallons, are now held in a storage tank and bled into the drain line rather than being dumped as a slug.

3. Cookout of Grease Tank

This highly alkaline flow may also alter the pH of the waste flow.

4. Cleaning of settling tanks

The weekly cleaning out of the settling tanks (fluming section) results in a considerable increase in the quantity of suspended materials being pumped to the clarifiers.

5. Quality of Potatoes

If unusually poor quality potatoes are being processed, there will be a noticeable decrease in effluent quality.

The Company is presently considering the installation of the following units as a means of improving the quality of effluent from the processing plant.

1. New travelling screen.
2. Vibrating screen for the total plant flow.
3. Continuous cleaning facility for the settling tanks (fluming section).

WASTE TREATMENT SYSTEM

History and Performance of Past Systems

The design of the original treatment system may be described as follows:

Design flow - 150,000 gallons per day

Industrial pre-treatment - screening (vibrating) and sedimentation in a 6,500 gallon tank with sludge cleanout facilities

Joint (Town and company) Biological Treatment -

Anaerobic lagoon - 5.42 acres and 67 days holding capacity at design flow - 600 lbs of BOD_5 per acre.

Aerobic ponds (2) - 5.42 acres each and 43 days holding capacity at design flow (each) - 60 lbs BOD_5 per acre.

The combined retention time for the design flow of 150,000 gpd would be 153 days if the aerobic lagoons were operated in series. The consulting engineer estimated that the strength of the raw waste would be 4,200 lbs BOD_5 and 5,544 lbs SS and that 38% BOD_5 and 70% SS would be removed by screening and settling. Thus the biological treatment system was designed with a capacity of 150,000 gpd and 2,600 lbs BOD_5 and 1,600 lbs SS per day.

The initial inspection was carried out by OWRC staff on May 12, 1960, after the plant had been in operation for about 5-1/2 months and there was still no overflow from the lagoon system.

No overflow occurred until plant start-up in the fall of 1960 and the first sample results (8 hour composite) are shown in Table III.

TABLE III

SAMPLE RESULTS, SEPTEMBER 28, 1960.

	5-DAY BOD (mg/l)	SOLIDS			FILTERED BOD_5 (mg/l)
		TOTAL (mg/l)	SUSP. (mg/l)	DISS. (mg/l)	
Raw Waste	1600	3084	1324	1760	-
Overflow from settling tank	1650	2714	1260	1454	-
Anaerobic effluent	620	1114	250	864	580
Aerobic #1 "	300	1028	174	854	190
Aerobic #2 "	280	1172	250	922	210

These results represent the best performance that was achieved by the original treatment system, as the sampling date followed closely the summer shutdown period during which the lagoons had had a chance to recover. The sampling date was also prior to a series of production increases. The associated loadings to the various units compared to design loadings are presented in Table IV.

TABLE IV

UNIT LOADINGS

Flow on September 28, 376,000 gallons	BOD$_5$ (lbs)		SS (lbs)	
	Actual	Design	Actual	Design
Raw Waste	6010	4200	4970	5544
Primary Effluent	6200	2600	4740	1660
Loading to Anaerobic Effluent	6200 lbs or 1140 lbs/ acre	600 lbs/ acre		
Loading to Aerobic Lagoon #1	2330 lbs or 430 lbs/ acre	60 lbs/ acre		
Loading to Aerobic Lagoon #2	1129 lbs or 208 lbs/ acre	"		
Final Effluent	1050	*25	940	*25
	* 15 mg/l for 150,000 gpd			

The undesirable nature of this effluent was pointed out to the Company and the Town by the OWRC, and in June of 1961, the consulting engineer for the project issued a report outlining the overloaded condition of the treatment facilities and suggesting means of improvement. It was also pointed out in the report that Salada once again planned on increasing production.

Two concrete clarifiers were installed in November 1962, as recommended in the consultant's report. These were each 26 ft. in diameter, with a continuous scraping and skimming mechanism. They had a sidewall depth of 8 ft. and thus an individual capacity of 26,500 gallons. With a flow of 400,000 gpd, the clarifiers in parallel and one foot of sludge in each, and with consistent plant flow throughout the day, the detention time was 2.75 hours and the overflow rate 380 gallons/day/ft^2.

The change of the anaerobic lagoon to an aerobic basin was considered in mid 1963, and it was implemented late in 1963.

A total of 127 aeration devices, known as bubble guns, were installed with an air supply of 1,560 cfm or 12 cfm per gun. Recent studies indicated that this corresponded to a maximum aeration capacity of approximately 4000 lb O_2/day.

An OWRC survey in the fall of 1964 indicated that the organic loading to the lagoon was 4,300 lb. BOD/day or 2.7 lb BOD/1,000 cu. ft./day. The associated hydraulic load was 475,000 gpd and the clarifier effluent BOD approximately 900 mg/l. Virtually no dissolved oxygen was found in the aerated lagoon at this time; oxygen utilization rates varied unaccountably from week to week although a field survey during the winter indicated a utilization rate of 1.2 mg O_2/l/hr possibly due to a temperature dependency. During this inspection only the first half of the lagoon was ice-free and little or no DO was found in the aerated lagoon.

A subsequent 1965 survey by the OWRC revealed a considerable increase in the organic and hydraulic load applied to the lagoon system. A 24-hr composite sampling survey indicated an organic loading of some 13,000 lb BOD/day; this corresponded to a flow of 680,000 gpd and an average BOD of 1,900 mg/l. The volumetric BOD loading to the aerated lagoon was then 8.1 lb BOD/1,000 cu. ft./day. While some of this increase in organic load was due to increases in production, inadequate operation of the primary clarifiers contributed substantially to the increased load.

This increase in organic loading (almost tripling from 1964 to 1965), coupled with an overestimation of the oxygen transfer capacity of the aeration devices, led to a complete failure of the treatment system. The conditions in Spring Creek and to a lesser extent, the Boyne River, deteriorated considerably and numerous complaints of water quality in these waters were received. Cognizant of the fact that more than minor modifications of the treatment system were required, the OWRC approached Salada and pointed out the need for action. The company responded by commissioning Simon-Carves of Canada Limited to investigate the pretreatment of the effluent from the potato processing plant.

A field study was carried out by the OWRC in an effort to assess the operating limitations of the primary clarifiers. The results indicated that the sludge could be concentrated to 6 - 8% solids. However, the higher solids concentration required a deeper sludge blanket, which in turn resulted in lower BOD removals. During 1965, the inadequate operation of the clarifiers resulted in excessive solids being discharged along with considerable leaching of potato solids into solution. At times the clarifier effluent BOD was greater than the raw waste BOD.

Table V indicates the chemical characteristics of the primary clarifier effluent. Note the high ratio of BOD/COD and also the high fraction of soluble BOD in the waste. Nutrient concentrations are marginal for biological treatment if the standard textbook requirements of 100:5:1: :BOD:N:P are used as a guide. The low pH values shown could be the results of excessive anaerobiosis in the clarifier although the raw waste pH itself is frequently below 7.0. There is also some indication that the time lapse between sampling and laboratory analysis results in a lowering of the pH.

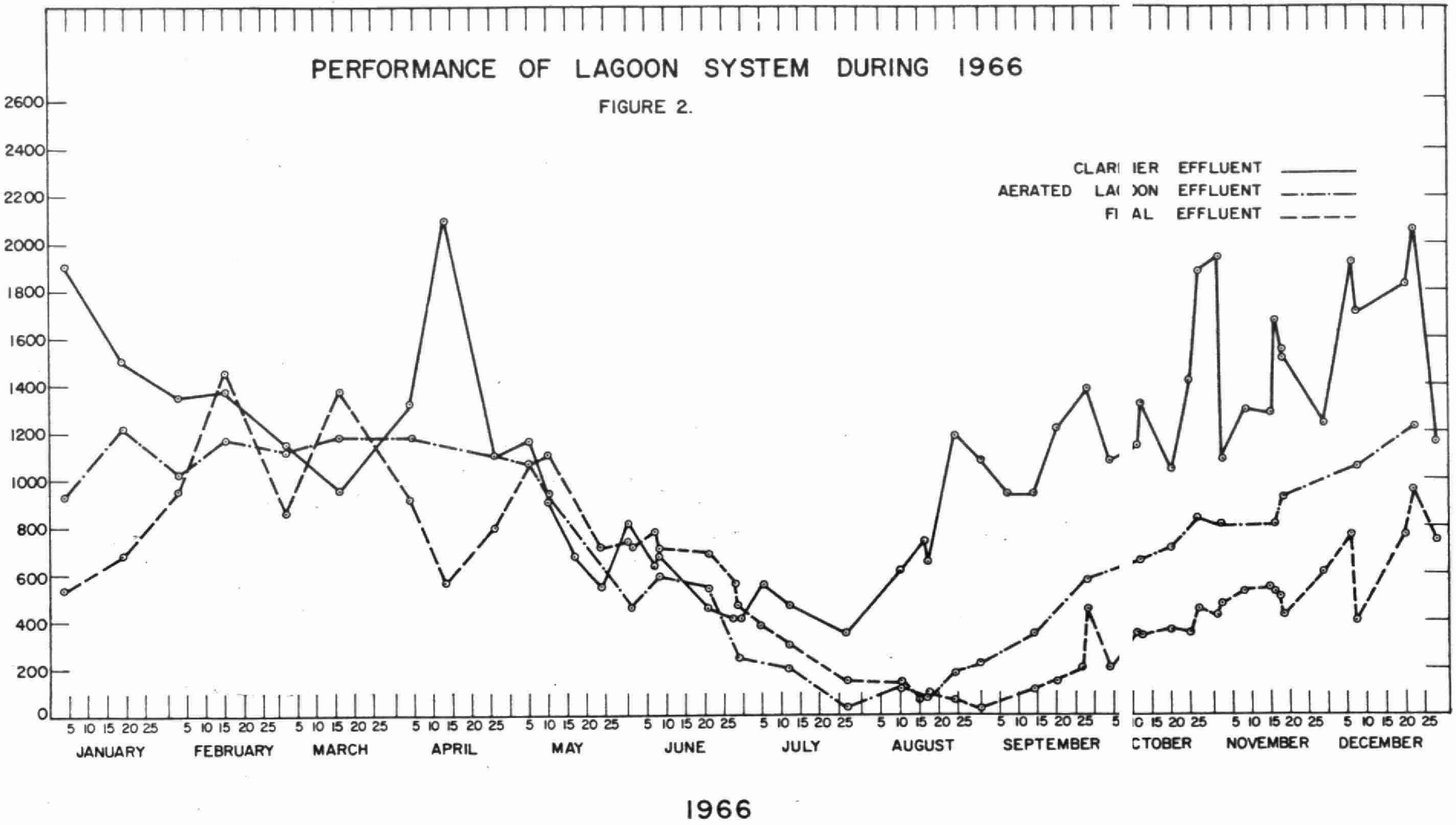
TABLE V

CHEMICAL CHARACTERISTICS OF PRIMARY CLARIFIER EFFLUENT

All results except pH in mg/l

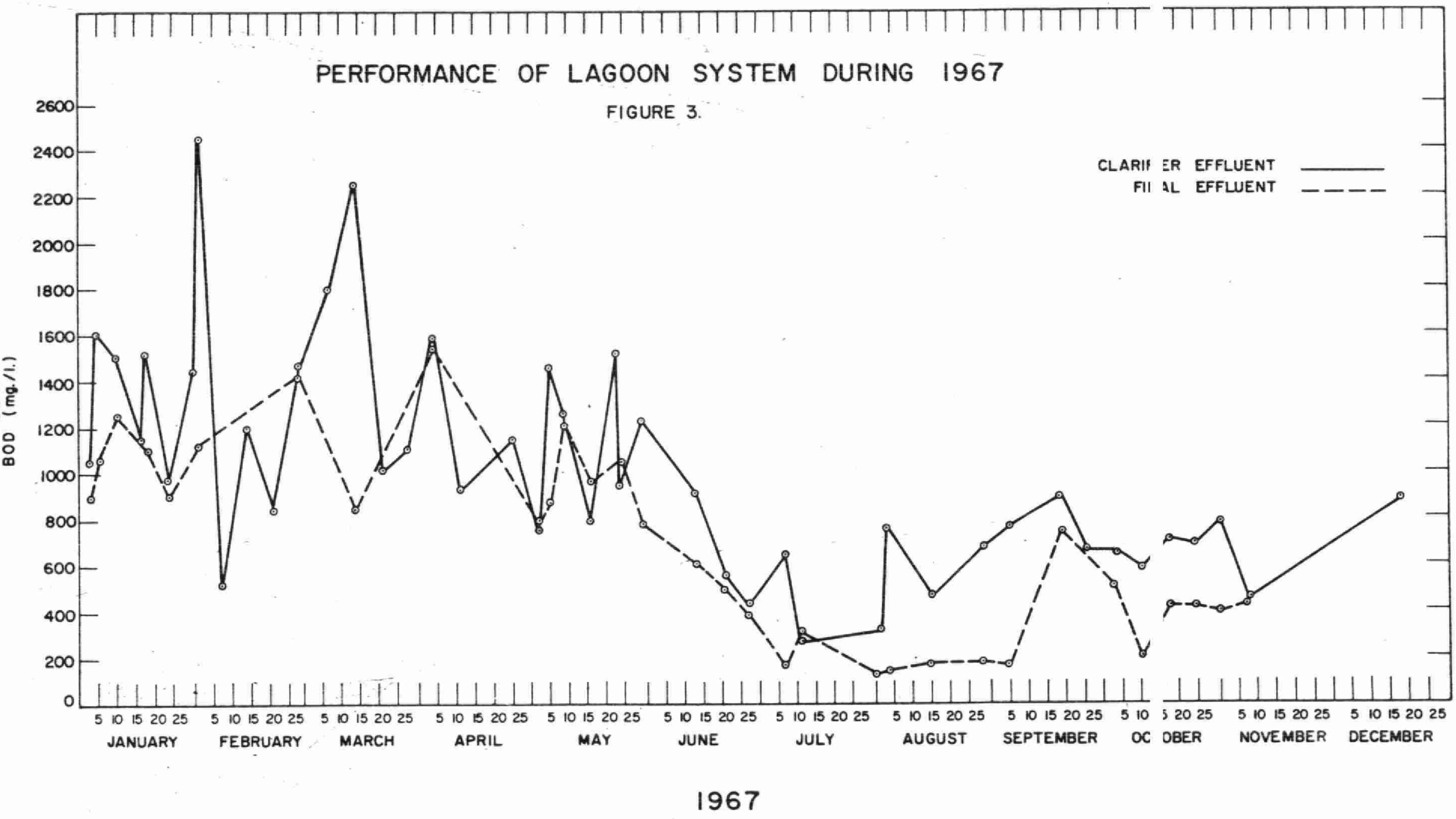
DATE	BOD	TS	DS	SS	pH	TOTAL KJEL.	P	COD
Aug. 26/64	980	1,422	906	516	5.9	58	11	1,520
Dec. 9/65	2,050	2,890	2,184	706	4.3	84	-	2,680
May 5/66	1,170 980F	2,322	2,042	280	10.9	51	23	1,400
June 29/66	1,420 330F	1,420	1,200	220	-	-	-	580
Aug. 10/66	400	1,726	1,472	254	-	-	-	800
Nov. 15/66	1,280	2,168	1,626	542	-	-	-	1,800
Feb. 2/67	4,360	5,136	7,218	1,918	5.5	-	-	5,160
May 5/67	1,460 940F	1,772	1,580	192	5.9	-	-	1,640
June 13/67	908 546F	1,710	1,566	144	7.8	-	-	1,500
Jan. 9/68	790	2,794	2,424	270	-	58	19	1,330
May 5/68	1,150	1,652	1,510	142	4.8	20	22	1,840
Nov. 19/68	1,060	1,830	1,520	310	5.9	84	12	1,680
Feb. 17/69	1,400	1,548	1,274	274	4.7	63	20	1,700
Apr. 30/69	1,000	1,294	1,094	200	6.0	64	5	1,300

Figure II and III illustrate the variations in lagoon effluent quality from 1966 through to 1967. These plots clearly indicate the delay effect due to retention (final effluent BOD greater than clarifier effluent BOD). At times, the effluent



PERFORMANCE OF LAGOON SYSTEM DURING 1966

FIGURE 2.



PERFORMANCE OF LAGOON SYSTEM DURING 1967

FIGURE 3.

discharging to the receiving stream was considerably in excess of 1000 mg/l BOD.

In mid-1967, Simon-Carves was given the go ahead to finalize a pretreatment proposal. From their laboratory studies carried out on primary effluent samples, they recommended design criteria for a pretreatment plant to reduce the BOD from approximately 1000 mg/l to about 300 mg/l, as on the basis of aeration capability, the lagoon system was considered to be capable of treating wastes of 300 mg/l BOD. A full scale activated sludge plant was designed and constructed on this basis. This plant consists of two 98,000 Imperial gallon aeration tanks, each equipped with a 50 HP "Simcar" aerator. At a flow of 750,000 gpd, the nominal aeration time is 6.2 hr. Clarification is effected by a 60 ft. diameter settling tank of 4.5 hr. detention, with an overflow rate of 250 gallon/day/sq. ft.

Upon completion of the activated sludge plant, the overall treatment facility became quite extensive. The capital cost of the works amounted to approximately $350,000. Figure IV outlines the complete treatment system serving the Company early in 1968. Field surveys were carried out in an attempt to assess the performance of the system throughout 1968. Figure V indicates the nature of the effluent quality monitored during this time and apparently, a high degreee of treatment was being achieved. However, in mid 1968, it was determined that primary clarifier wastes were by-passed directly to the receiving stream on frequent occasions. This by-passing was done to prevent upsetting the activated sludge plant. In September 1968, an agreement was made to block the by-pass and the Company was made fully aware of, and agreed to, the necessity of directing all wastes to the lagoon system, if the activated sludge section were by-passed.

PERFORMANCE OF ACTIVATED SLUDGE SYSTEM (1969)

The performance of the activated sludge system through 1969 is summarized in Table VI.

The data are based on average operating conditions and should only be interpreted as an indication of the nature of this particular activated sludge system. Primarily, the high applied organic volumetric loadings and the low final settling rates reflect the major differences between this and a conventional activated sludge plant.

Although not evident in this table, previous data indicate that the effluent BOD is a direct function of the effluent SS. At times, the filtered effluent BOD has been as low as 30 mg/l. These results confirm that the critical aspect of such a system is solids separation in the final clarifier. In this system, the lagoons were assessed to be capable of handling an activated sludge effluent of 300 mg/l BOD; consequently, complete solids removal was not considered essential. However, if the effluent from the activated sludge process were to be discharged directly to a receiving stream, then an additional solids removal or polishing device would be required.

TABLE VI

PERFORMANCE DATA FOR ACTIVATED SLUDGE SYSTEM - 1969

(All results in mg/l except pH
and those otherwise stated).

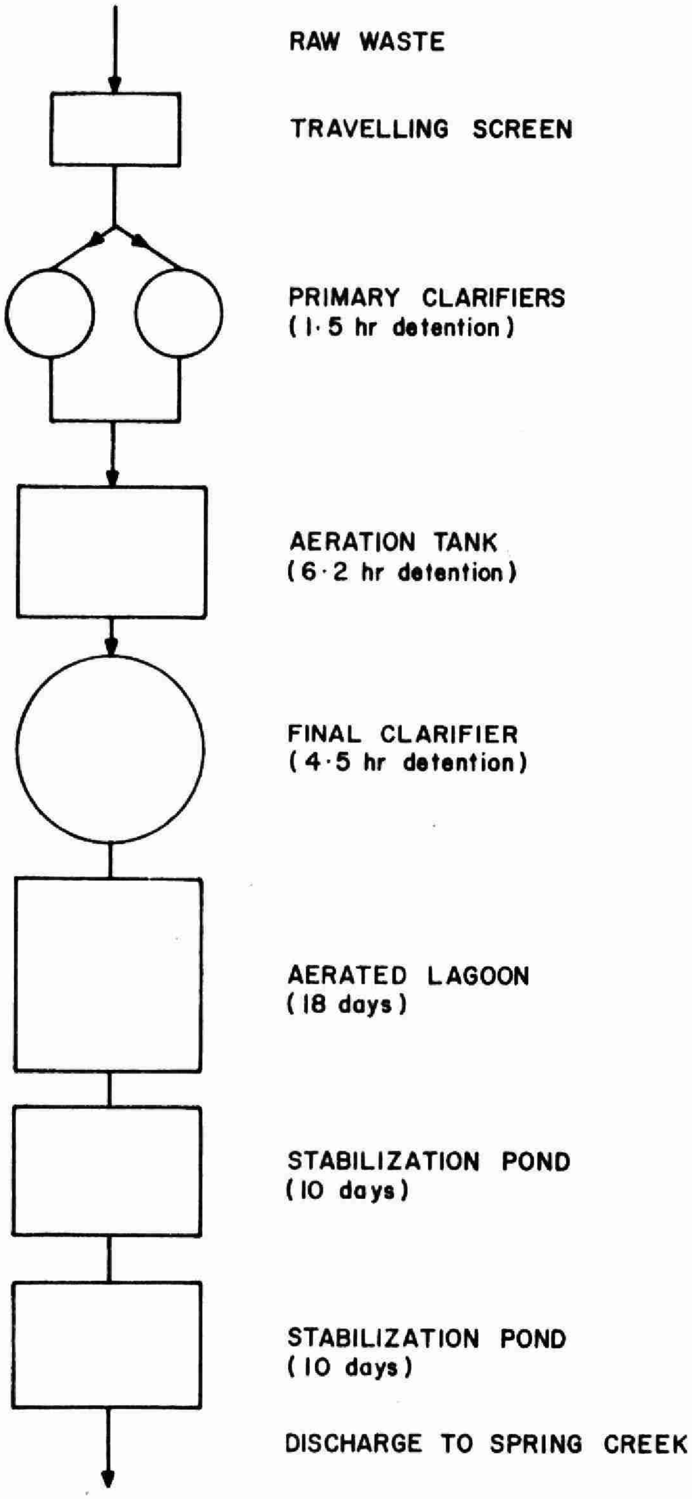
PRIMARY CLARIFIER EFFLUENT	Maximum	Minimum	Average
BOD	1600	640	1080
COD	1840	960	1470
SS	790	230	395
pH	10.6	5.2	6.6
P	70	15	44
NH_3 as N	21	9.8	15.9
Total Kjeldahl	95	57	70

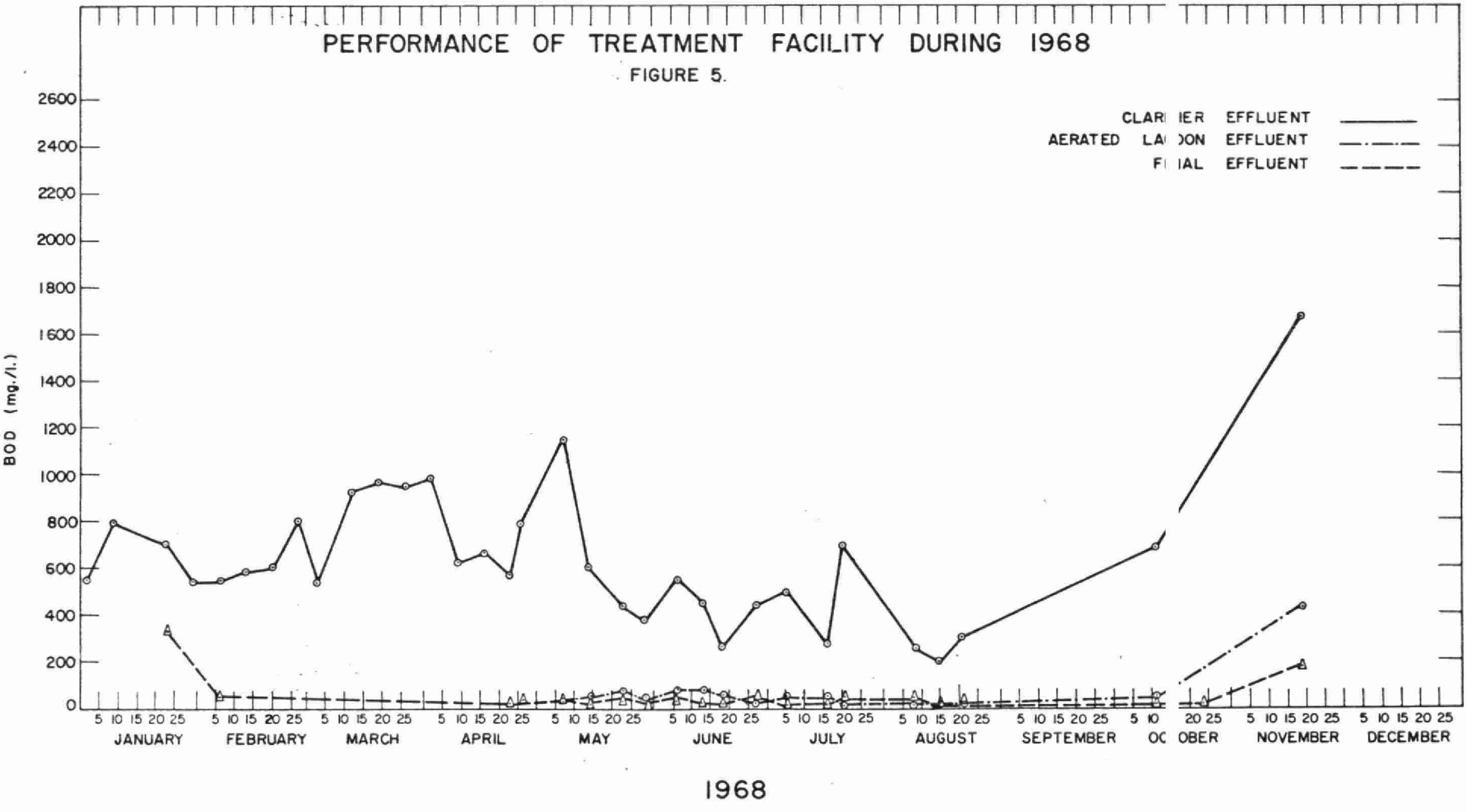
AERATION SECTION	
Detention Time in aeration section	6.4 hr
Volumetric BOD loading	250 lb BOD/1000 cu. ft./day
Clarifier Overflow Rate	260 gal/day/sq. ft.
BOD removal	75%
Return sludge rate (range)	50 - 100%

FINAL CLARIFIER EFFLUENT	Maximum	Minimum	Average
BOD	550	61	268
COD	630	140	424
SS	100	34	79
pH	7.8	7.3	7.6
P	36	6.2	21.7
Total Kjeldahl as N	43	18	31

FIGURE 4.

TREATMENT SYSTEM SERVING
SALADA FOODS LTD, ALLISTON
(1968)





PERFORMANCE OF TREATMENT FACILITY DURING 1968

FIGURE 5.

No data are shown on organic - solids loadings (food to microorganism ratios) as rigorous control of the mixed liquor suspended solids (MLSS) was not obtainable due to various plant upsets. These upsets usually resulted in low MLSS. A problem with excess sludge disposal during the spring resulted in high MLSS. It has been found, however, that by operating in a range of from 3 - 4000 mg/1 MLSS, optimum performance has been achieved.

The oxygen uptake rates of the mixed liquor were extremely high, at times in excess of 150mg O_2/1/hr. With such a system, the need for high intensity aeration devices becomes apparent.

PERFORMANCE OF LAGOON SYSTEM (1969)

Table VII summarizes the current lagoon effluent characteristics. These results are probably typical of any waste stabilization pond; it is disturbing to note the high SS content of the effluent.

TABLE VII

LAGOON EFFLUENT CHARACTERISTICS

(All results in mg/1 except for pH)

	Aerated Lagoon	Final Lagoon
BOD	70	50
Filtered BOD	40	30
COD	190	160
SS	80	90
pH	7.8	8.2
P	-	25
Total Kjeldahl	-	40

The overall effluent quality is a distinct function of the algal population in the final lagoon. Throughout the study, marked changes in the appearance of the contents of the lagoons have been observed. These changes consist mainly of a cycling between a clear, relatively colourless state to a turbid greenish condition. During the times of higher quality effluent, considerable zooplankton (rotifers and microcrustaceans) were observed. There was some predator interaction between the algae and zooplankton; however, the exact relationship between the two groups is not clear.

PERFORMANCE OF OVERALL SYSTEM (1969)

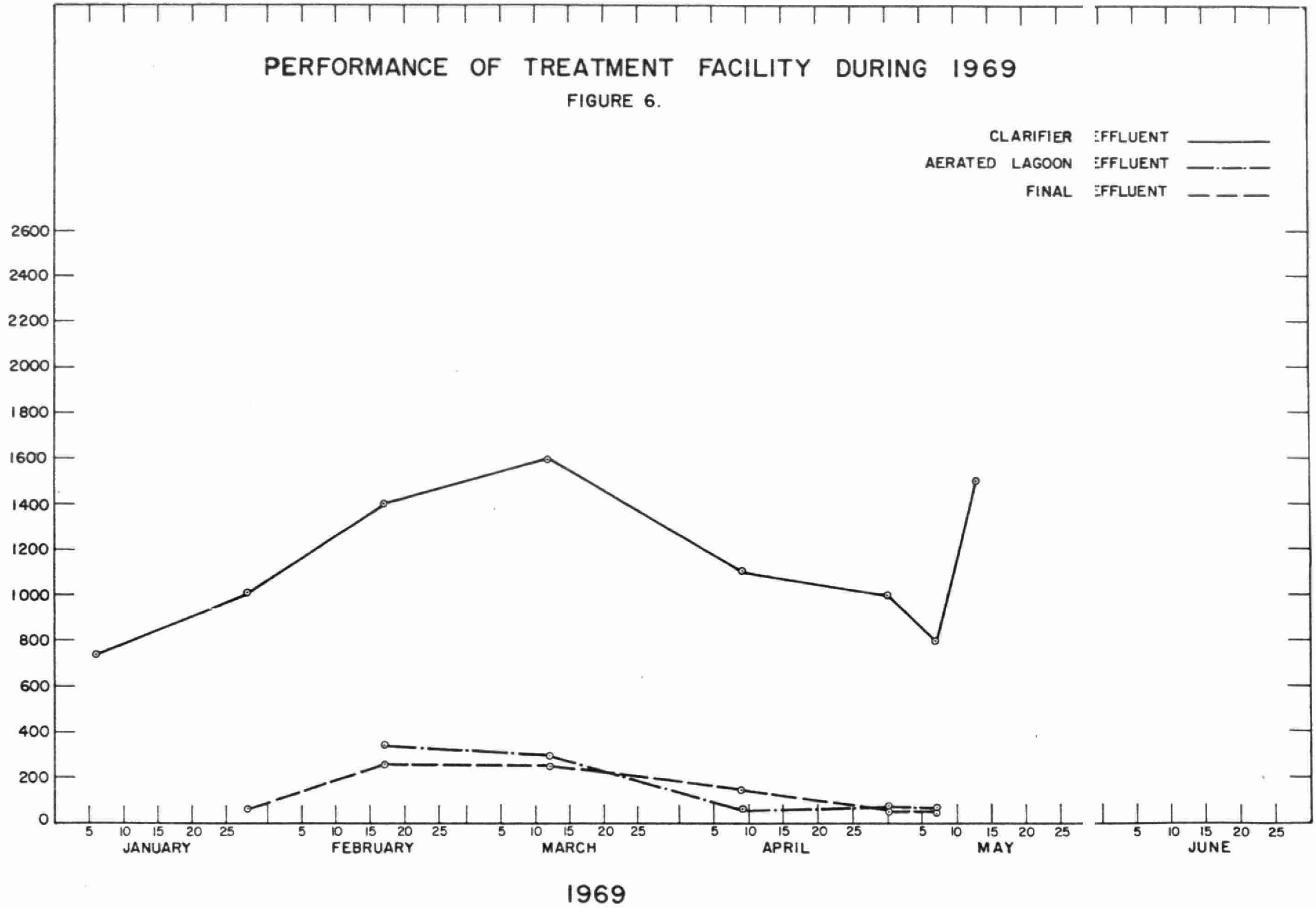
The overall performance of the entire system for 1969 is shown in Figure VI. The poor performance early in 1969 was considered attributable to the excessive quantities of activated sludge solids discharged during the process upsets due to sporadic caustic dumps.

PROBLEMS ASSOCIATED WITH THE ACTIVATED SLUDGE SYSTEM

As the essential part of the treatment system is the activated sludge process and since biological treatment of starch wastes usually yields a poor settling sludge, the necessity of having an experienced sewage plant operator was apparent. To circumvent this problem, an operator, experienced in the treatment of a combination of domestic and industrial wastes, was hired.

The two sources of problems causing severe operational upsets were the excessive quantities of grease and the caustic discharges. The grease dumps resulted in considerable sludge solids loss through the grease, air and solids mixture that formed and subsequently floated on the surface of the final clarifier. On occasion, lye discharges resulted in primary effluent pH values in excess of 10 for considerable periods of time. The plant upsets that usually occurred after these caustic spills were characterized by an extremely poor settling activated sludge along with a very turbid supernatant. At present, in-plant control has minimized the grease dumps and a holding tank for the caustic wastes has been provided. If necessary, pH adjustment is to be provided.

Throughout the study, the activated sludge was characterized by a bulky, poor settling floc. At times, a growth of filamentous organisms has dominated the system resulting in an extremely voluminous sludge. Chlorination of the return sludge and/or reseeding of the aeration tanks has been carried out to correct this situation.



PERFORMANCE OF TREATMENT FACILITY DURING 1969

FIGURE 6.

The major problem associated with this biological treatment system is excess sludge disposal. A considerable amount of sludge is removed in the primary clarifiers and this activated sludge system produces copious quantities of waste activated sludge. The weekly cleaning out of the settling tanks in the flume section also provides a severe solids loading. As previously stated, rapid removal of bottom sludge solids from the clarifiers is required to maintain optimum performance of these units. In this installation, land disposal is used for excess sludge. During the spring wet weather, the locating of a suitable area to dispose of the sludge, posed a problem. This resulted in very high MLSS being carried in the aeration section and consequently poor activated sludge plant performance was achieved.

SUMMARY

The Salada story points out the need for long range planning by the regulatory agency, the company and the municipality, prior to the building of a processing plant. Had the increases in production been accurately predicted, and an adequate treatment system capable of extension been provided, the undesirable situation which existed for a period of years could have been avoided.

Through the efforts of the OWRC and the co-operation of the company, however, this pollution problem has been eliminated, as with careful operation and conscientious in-plant control, the present treatment system appears capable of producing an acceptable effluent.

SIXTEENTH ONTARIO INDUSTRIAL WASTE CONFERENCE

REGISTRATION LIST

V.J. Agro, Alderman,	CITY OF HAMILTON,	167 Haddon Ave.W., Hamilton, Ontario.
T. Alkema, Lab.Technician,	L.S. LOVE & ASSOCS.,	160 Bay Street, Toronto, Ontario.
Wm. L. Andrews, Manager, Tech.Dept.,	THE BIRD-ARCHER CO. LTD.,	2nd Street, Cobourg, Ontario.
T. Armstrong, District Engineer,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
R.S. Aston, Chief Chemist,	COURTAULDS (CANADA) LIMITED,	Montreal Road, Cornwall, Ontario.
L. Atkinson,	MARSHALL MACKLIN MONAGHAN,	1480 Don Mills Rd., Don Mills, Ontario.
F.W. Bainborough, Sales Manager,	COMMERCIAL FILTERS, Waste Treatment Division,	1179 Caledonia Rd., Toronto, Ontario.
R.S. Baker, Chief Engineer,	THE PROCTER & GAMBLE CO. OF CANADA LTD.,	Burlington St. E., Hamilton, Ontario.
D.G. Barker, Principal,	CANADIAN-BRITISH ENGINEERING,	801 York Mills Rd., Don Mills, Ontario.
B.B. Barnes, Chief Industrial Waste Section,	NEW BRUNSWICK WATER AUTHORITY,	P.O. Box 1270, Fredericton, N.B.
M.G. Barrington, Vice President,	HISEY AND BARRINGTON LTD.,	7027 Yonge Street, Willowdale, Ontario.
N.A. Barron,	BP REFINERY CANADA LTD.,	P.O. Box 520, Oakville, Ontario.
T.J. Barry, Pollution Coordinator,	SHELL CANADA LTD.,	Sarnia Refinery, Corunna, Ontario.
E.J. Bartley, Manager,	FOUNDATION OF CANADA ENGINEERING CORP. LTD.,	P.O. Box 3245, Hamilton, Ontario.
T.W. Beak, President,	T.W. BEAK CONSULTANTS LTD.,	4999 St. Catherine W., Montreal, Quebec.
D.A. Bebbington, Works Manager,	DOMTAR CHEMICALS LIMITED, Tar & Chemical Division,	801 Lakeshore Blvd. W., Toronto, Ontario.

R.M. Bell, Assit.Operations Eng.,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave.W., Toronto, Ontario.
F.H. Bellstedt, Asst.Distillery Manager,	CORBY DISTILLERIES LTD.,	Corbyville, Ontario.
Dr. J. Benko, Sr. Research Officer,	LIGNOSOL, CHEMICALS LTD.,	P.O. Box 2025, Quebec 2, Quebec.
A. Bergs, Sr. Des.Eng.	FOUNDATION OF CANADA ENGINEERING CORP. LTD.	1200 Yonge St., Toronto, Ontario.
Dr. F. Besik, Ph.D.,	ONTARIO RESEARCH FOUNDATION,	Sheridan Park, Ontario.
Dr. J.K. Bewtra, Assoc.Professor,	UNIVERSITY OF WINDSOR, Civil Engineering,	Windsor, Ontario.
R.C. Reid-Bicknell,	EIMOC PROCESS OF CANADA LTD.,	165 Cartwright Ave., Toronto, Ontario.
J.E. Bindon, Sales Manager,	FLUIDTECH LTD.,	5220 Cherryhill Cres., Burlington, Ontario.
R.S. Binning, Sales-Engineer,	PERMUTIT CO.,	285 Raleigh Ave., Toronto, Ontario.
S.A. Black, Project Engineer,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave.W., Toronto, Ontario.
E.W. Blackmore, Works Manager,	DOMTAR CHEMICALS LTD., Tar & Chemical Division,	725 Stratherne Ave.N., Hamilton, Ontario.
P.J. Blundy, Pollution Control Eng.,	GULF OIL CANADA LIMITED,	385 Southdown Rd., Clarkson, Ontario.
B.M. Boyer, Regional Engineer,	DEPT. OF NATIONAL HEALTH & WELFARE,	382 King St. E., Kingston, Ontario.
T.D. Braunschweig, Chem. Engineer,	CONSULTANT,	P.O. Box 307, Mercersburg, Pa.17236.
W.A. Brechin, General Supt's.Office,	CANADA PACKERS LTD.,	95 St. Clair Ave.W., Toronto, Ontario.
F. Bremner, Engineer,	DOW CHEMICAL OF CANADA, LTD.,	Box 1012, Sarnia, Ontario.
K.M. Bright, Project Manager,	STANLEY CONSULTANTS, INC.,	Stanley Building, Muscatine, Iowa 52761.
T.M. Brock, Project Manager,	PROCTER & GAMBLE,	Burlington St. E., Hamilton, Ontario.

C.R. Browne, Project Development,	ONTARIO RESEARCH FOUNDATION,	Sheridan Park, Ontario.
H.A. Bryson, Sales Engineer,	GRAVER WATER & SMITH & LOVELESS	Oakville, Ontario.
D. Buratto, Engineer,	C.G. RUSSELL ARMSTRONG ASSOC. LTD.,	317 Bartlet Building, Windsor 12, Ontario.
G. Burch, V.P.-Engineering,	WOLVERINE WORLD WIDE,	9431 Courtland Rd., Rockford, Michigan.
H.R. Butler, Tech.Assistant to Manager,	INTERNATIONAL NICKEL CO. OF CANADA,	Copper Cliff, Ontario.
W.R. Cale, Manager,	ELECTRIC REDUCTION CO., Patents & Information,	155 Etobicoke Dr., Islington, Ontario.
H.A. Campbell, Waste Management,	ONTARIO DEPARTMENT OF HEALTH,	1 St. Clair Ave. W., Toronto, Ontario.
L.A. Campbell, Director,	ONTARIO RESEARCH FOUNDATION, Dept. Applied Microbiology,	Sheridan Park, Ontario.
D. Caplice, Director,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
A.J. Carlson, Assistant Dean,	UNIVERSITY OF MANITOBA,	Winnipeg, Manitoba.
R. Carrara, Chairman,	CITY OF CORNWALL, Anti Pollution,	1205 Third St. E., Cornwall, Ontario.
H. Carter, Sanitary Engineer,	SMITH & LOVELESS & GRAVER DIVS., PROCOR LTD.,	3rd Line, Oakville, Ontario.
W.P. Carter, Tech.Service Supv.,	C-I-L	130 Bloor St. W., Toronto, Ontario.
G.B. Caryll, Process Engineer,	MCNAMARA ENGINEERING LTD.,	797 Don Mills Rd., Don Mills, Ontario.
C.W. Case,	TODGHAM & CASE LTD.,	151 Thames St., Chatham, Ontario.
W.B. Cassidy, Manager,	NAPANEE INDUSTRIES LTD., Pollution Control,	51 Anne St., P.O.700, Napanee, Ontario.
M.J. Cathcart, Assistant to the General Manager,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.

D.S. Caverly, General Manager,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
M.F. Cheetham, Director,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
K.A. Childs,P.Eng., Waste Management Eng.,	ONTARIO DEPARTMENT OF HEALTH,	460 Main Street E., Hamilton, Ontario.
J.A. Choma, Assist.Engineer,	CORPORATION CITY OF LONDON, Sanitation & Industrial Wastes,	869 Kelly St., London, Ontario.
M. Chomyn, Sales Engineer,	EIMCO PROCESS OF CANADA,	165 Cartwright Ave., Toronto, Ontario.
J. Choquet, Industrial Planning Advisor,	GULF OIL CANADA LTD.,	3051 Broadway, Montreal, Quebec.
N.A. Chowdhry, Sr.Development Eng.,	ONTARIO DEPARTMENT OF HEALTH,	1 St. Clair Ave. W., Toronto, Ontario.
E.J. Cieplela, Manager,	FRANCIS HANKIN & CO. LTD.,	117 Crockford Blvd., Scarborough, Ontario.
H.A. Clarke, Asst. Director,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
D.J. Collins, Chairman,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
K. Conn, Chemist,	DEPT. OF ENERGY, MINES AND RESOURCES,	45 Spencer Street, Ottawa, Ontario.
T.A. Constantine, Engineer,	NISBET LETHAM LTD.,	206 Water Street, Sarnia, Ontario.
Dr.N.E. Cooke, Principal Chemical Engineer,	CANADIAN INDUSTRIES LTD.,	P.O. Box 10, Montreal, Quebec.
D.A.L. Coombs, Sales Engineer,	CHEMETICS LIMITED,	1827 West 5th, Vancouver, B.C.
G.G. Copeland, President,	COPELAND PROCESS (CANADA) LTD.,	1200 Harger Road, Oak Brook, Illinois.
R.E. Copeland, Consulting Engineer,	O'BRIEN & GERE,	1050 W.Genesee St., Syracuse, N.Y.
W.C. Cormode, Industrial Division,	DE LAVAL COMPANY LIMITED,	113 Park St. S., Peterborough, Ontario.

R.E.E. Costello, Sr.Vice President,	ABITIBI PAPER CO. LTD., Operations,	Toronto Dominion Centre, Toronto, Ontario.
J.M. Courtright, Coordinator,	SHELL CANADA LTD., Environmental Control,	Box 400, Terminal A, Toronto, Ontario.
W.G. Cousins, Engineer,	HYDRONICS CORPORATION,	Box 187, Metuchen,Illinois.
D.G. Cox, General Superintendent,	ELDORADO NUCLEAR LTD., Special Services,	Port Hope, Ontario.
G. Coxhead, Project Engineer,	SIMON CARVES OF CANADA,	1670 Bayview Ave., Toronto, Ontario.
F.L. Craig, Technologist,	ALGOMA STEEL CORPORATION,	Sault Ste. Marie, Ontario.
W.H. Craig, Regional Manager,	PENNWALT CORPORATION, Sharples Equipment Division,	111 Windsor Drive, Oak Brook, Illinois.
F.W. Crossland, Salesman,	FOXBORO,	3289 Lenworth Dr., Cooksville, Ontario.
G.F. Crossman,	FIELDING CROSSMAN & ASSOC. LTD.,	1570 Midland Ave., Toronto, Ontario.
D.H. Cullen, Asst.Regional Engineer,	DEPT. OF NATIONAL HEALTH AND WELFARE,	P.O. Box 86, Moncton, N.B.
N. Czornyj, Lab. Superintendent,	SUN OIL COMPANY LIMITED,	Box 307, Sarnia, Ontario.
J.H. Dales, Professor,	UNIVERSITY OF TORONTO, Political Economy,	St. George St., Toronto, Ontario.
J. Dalziel, Biologist,	DEPARTMENT OF FISHERIES,	P.O. Box 550, Halifax, N.S.
G. Das, Process Engineer,	VANLUVEN CONSULTANT LTD.,	5460 Patricia Ave., Montreal, Quebec.
H.M. Davis, Director, Research,	ST. LAWRENCE STARCH CO.,	Port Credit, Ontario.
J.H. Day, Development Engineer,	ABITIBI PAPER COMPANY LTD.,	Research Centre, Sheridan Park, Ont.
R.F. Day, Product Manager,	ALCHEM LIMITED,	Burlington, Ontario.
K.C. Dean, Project Coordinator,	U.S. BUREAU OF MINES, Salt Lake Metallurgy Resources,	1600 East 1st S., Salt Lake City, Utah.

P.B. Dean, Wildlife Biologist,	CANADIAN WILDLIFE SERVICE,	Box 878, Sackville, N.B.
J.R. DeCoe, Assistant Plant Eng.,	GENERAL MOTORS OF CANADA LTD.,	Oshawa, Ontario.
J. Delbridge,	TOWN OF EXETER,	Exeter, Ontario.
P.J. Denison, Research Executive,	H.G. ACRES & COMPANY LTD.,	1259 Dorchester Rd.N., Niagara Falls, Ontario.
G.J. Dicke, Sr. Research Scientist,	CRANE CANADA LTD.,	1355 Martin Grove Rd., Toronto, Ontario.
MacKenzie Dickson, Vice President,	SEPARATOR ENGINEERING LTD.,	2387A Eglinton Ave.E., Scarborough, Ontario.
M.D.H. Dickson,P.Eng., Vice President,	GIBB, ALBERY PULLERITS & DICKSON,	29 Gervais Dr., Don Mills, Ontario.
A.S. Doran, Vice President	AMES CROSTA MILLS (CANADA) LTD.,	90 Eglinton Ave. E., Toronto, Ontario.
J.G. Duncan, Technical Adviser,	SIMON CARVES,	208 Markham Rd., Scarborough, Ontario.
G.G. Dunn, Microbiology,	CANADIAN CANNERS LTD.,	19 Jackson Street E., Hamilton, Ontario.
D. Durant, District Manager,	WALLACE & TIERNAN,	925 Warden Ave., Scarborough, Ontario.
E.L. Duret, Teecher,	HUMBER COLLEGE,	#401, 220 Lake Promenade, Toronto, Ontario.
C.S. Dutton, Associate Partner,	PROCTOR & REDFERN,	75 Eglinton Ave. E., Toronto, Ontario.
C.H. Eidt, City Engineer,	CITY OF NIAGARA FALLS,	City Hall, 300 Queen St. Niagara Falls, Ontario.
H. Eijsenck, Publicity Photographer,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
D. Elcomb, Plant Engineer,	GENERAL MOTORS OF CANADA	1487 Walker Road, Windsor, Ontario.
A.C. Elliott, Supt.,Utilities Dept.,	THE STEEL COMPANY OF CANADA LTD.,	Wilcox St., Hamilton, Ontario.
E.E. Erling,	WHITE MOSSOP & ERLING LTD.,	13 Race St., St. Catharines, Ont.

R.R. Evans, Sr.Industrial Waste Engineer,	DORR OLIVER	Stamford, Conn.
W.V. Fairhall, Sales Engineer,	J.A. DEVINE & ASSOC.,	1195 Sheppard Ave., Willowdale, Ontario.
R. Farvolden, Associate Professor	UNIVERSITY OF WESTERN ONTARIO, Geology,	London, Ontario.
W.F. Fell, Staff Process Eng.,	ONTARIO PAPER CO.,	Thorold, Ontario.
W.C. Ferguson, Technical Assit.	THE INTERNATIONAL NICKEL CO. OF CANADA LTD.,	Copper Cliff, Ontario.
J. Fetchison, Waste Management Eng.,	ONTARIO DEPARTMENT OF HEALTH,	362 Dundas St., London, Ontario.
H.R. Fielding,	HUGH R. FIELDING LIMITED,	57 Toynbee Trail, Scarborough, Ontario.
J.H. Forster, Manager, Engineering Design,	ELECTRIC REDUCTION CO. OF CANADA, LTD.,	155 Etobicoke Drive, Toronto, Ontario.
G.W. Foster,	HOWARDS & SONS (CANADA) LTD.,	Wallrich Ave., Cornwall, Ontario.
D. Fowler, Superintendent,	CITY OF LONDON,	R.R. #8, London, Ontario.
Dr. J.D. Frame, Vice President,	A.P. FRAME, LIMITED,	200 University Ave., Toronto, Ontario.
G. Fraser, Staff Asst. to Works Manager,	ALCAN	P.O. Box 2000, Kingston, Ontario.
M. Frost,	CANADIAN PULP & PAPER ASSOC.,	2300 Sun Life Bldg., Montreal, Quebec.
S.E. Frost, Health Physicist,	ELDORADO NUCLEAR LTD.,	Port Hope, Ontario.
R.J. Gallant, Sr. Mechanical Eng.,	H.G. ACRES & CO. LTD.,	20 Victoria St., Toronto, Ontario.
I. Gardner, Quality Control Supv.,	CANADIAN JOHNS MANVILLE CO.LTD.	West Hill P.O., West Hill, Quebec.

L.A. Garklavs, P.Eng., Project Supv.,	ARTHUR G. McKEE OF CANADA LTD,	Terminal Building, Toronto, Ontario.
R.B. Gatley, Engineering Sales,	G.F. SEELEY & SON LIMITED,	108 Skyway Ave., Rexdale, Ontario.
E. Gatza, Waste Treatment Marketing,	DOW CHEMICAL OF CANADA,	Sarnia, Ontario.
O.R. Gaube,	H.G. ACRES & CO. LTD.,	Niagara Falls, Ontario.
A.F. Gaudy, Jr., Professor,	OKLAHOMA STATE UNIVERSITY, Civil Engineering,	Stillwater Oklahoma 74074.
J.P. Genge,	W.P. LONDON & ASSOC. LTD.,	56 Dorchester S. Niagara Falls, Ont.
A. Giroux, Councillor,	HAWKESBURY,	204 Main St. East, Hawkesbury, Ontario.
C.M. Glos, Chief Engineer,	TRACE & GLOS,	1170 Pelissier St., Windsor, Ontario.
S.P. Goodfellow, President,	GOODFELLOW ENTERPRISES (SARNIA) LTD.,	P.O. Box 280, Corunna, Ontario.
R.M. Gotts, District Engineer,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave.W., Toronto, Ontario.
W.J. Grant, Sr. Process Engineer,	GULF OIL CANADA,	800 Bay St., Toronto, Ontario.
M. Greenfield, Air & Water Quality Eng.,	DOFASCO,	Box 460, Hamilton, Ontario.
C. Greer, Marketing Manager,	NEPTUNE METERS LTD.,	3526 Lake Shore Blvd.W. Toronto, Ontario.
W.E. Grove, Jr., Plant Engineer,	L-O-F GLASS OF CANADA LTD.,	Collingwood, Ontario.
H. Grunwell, President,	THE GRUNWELL ASSOCIATES LTD.,	2209 Bostock Plaza, Clarkson, Ontario.
F. Guillaume, Research Supervisor,	PROSEARCH LIMITED,	5889 Airport Rd., Malton, Ontario.
C.G. Gurnham,	GURNHAM BRAMER, AND ASSOCIATES	223 W. Jackson Blvd., Chicago, Illinois.

F.A. Guy, Process Engineer,	KIMBERLY CLARK OF CANADA, LTD.,	Merritt St., St. Catharines, Ont.
A.S. Gwyn, Works Chemist,	UNION CARBIDE CANADA LIMITED,	P.O. Box 700, Point aux Trembles,Que.
F.M. Hager, Dev. Manager,	UNIROYAL,	Elmira, Ontario.
B.W. Hales, Sales,	CONTROL AND METERING LTD.,	305 Kipling Ave. S., Toronto, Ontario.
D. Halliwell, Engineer,	ABITIBI PROVINCIAL PAPER LTD.,	Thorold, Ontario.
T.J. Halwa, Chief Chemist,	TEXACO,	Port Credit, Ontario.
B.W. Hamer, Division Engineer	DEPARTMENT OF FISHERIES AND FORESTRY,	Sir Charples Tupper Bldg., Ottawa, Ont.
W.A. Hamilton, Commissioner of Works,	CORPORATION OF THE TOWN OF STREETSVILLE,	327 Queen St. S., Streetsville, Ontario.
H.J. Hamm, Prod. Manager,	COCHRANE - CRANE,	1355 Martin Grove Rd., Rexdale, Ontario.
W. Harris, Sales Industrial	CANRON LTD.,	169 Eastern Ave., Toronto, Ontario.
A.R. Hauck, Plant Chemical Eng.,	REGIONAL MUNICIPALITY OF OTTAWA-CARLETON,	111 Sussex Dr., Ottawa, Ontario.
F.A. Havlik, Asst. Manager,	INFILCO CANADA LTD.,	721 Progress Ave., Scarborough, Ontario.
J.D. Heaman, P.Eng., Officer-in-Charge,	PUBLIC HEALTH ENGINEERING SERVICE,	1 St, Clair Ave. W., Toronto, Ontario.
J.J. Heffernan,	M.M. DILLON LTD.,	50 Holly St., Toronto, Ontario.
G.W. Heinke, Assistant Professor,	UNIVERSITY OF TORONTO,	Toronto, Ontario.
D. Hickling, Asst. Manager,	GRAVER WATER/SMITH & LOVELESS,	Oakville, Ontario.
F.J. Higgins, Plant Engineer,	ARTEX WOOLLENS,	Sheffield St., Hespeler, Ontario.

C.W. Hills, Executive Engineer,	ACRES QUEBEC LIMITED,	1860 Sun Life Bldg., Montreal, Quebec.
A.J. Hiscock, Chairman,	PRINCE EDWARD ISLAND WATER AUTHORITY,	P.O. Box 2000, Charlottetown, P.E.I.
J.D. Hisey, President,	HISEY AND BARRINGTON LTD.,	7027 Yonge St., Willowdale, Ontario.
N. Hobbs, Works Engineer,	CITY OF NIAGARA FALLS,	300 Queen St., Niagara Falls, Ontario.
J. Hocking, Manager,	THE HARLAND ENGINEERING CO. OF CANADA LTD.,	9021 Salley Street, Lasalle, Quebec.
P.F. Hogan,	PROCTOR & REDFERN,	75 Eglinton Ave. E., Toronto, Ontario.
W.A. Holowacz, Plant Superintendent,	WELLAND WATER POLLUTION CONTROL,	Box 202, Welland, Ontario.
H.R. Holland, Sr. Eng. Assoc.,	IMPERIAL OIL ENTERPRISES LTD.,	Box 3015, Sarnia, Ontario.
R.C. Horne, Plant Engineer,	IBM CANADA LIMITED,	844 Don Mills Road, Don Mills, Ontario.
P. Hughes, Chemical Technologist,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
B. Hutchinson, Sales Engineer,	THE HARLAND ENGINEERING CO. OF CANADA LTD.,	9021 Salley Street, Lasalle, Quebec.
D.J. Hutchison,	FLUIDAIR PROCESS EQUIPMENT LTD.,	1409 Yonge St., Toronto,Ontario.
J.R. Jennings, Sales Manager,	SWECO CANADA,	22 Jutland Rd., Toronto, Ontario.
D.A.R. Jones, Sales Engineer,	GREEY MIXING EQUIPMENT LTD.,	100 Miranda Ave., Toronto, Ontario.
D. Jones, Manager,	CANADIAN PULP & PAPER ASSOC.,	2300 Sun Life Bldg., Montreal, Quebec.
L. Jones, Phthalic Anhydride Supt.,	DOMTAR CHEMICALS LIMITED,	801 Lake Shore Blvd.E., Toronto, Ontario.
P.H. Jones, Assoc. Professor,	UNIVERSITY OF TORONTO,	Toronto, Ontario.

L.J. Kamp, Project Engineer,	DEPARTMENT OF NATIONAL HEALTH AND WELFARE,	Tunney's Pasture, Ottawa, Ontario.
G. Kay, Supervisor,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
R.E. Kemp,	DOMTAR CHEMICALS LIMITED,	725 Strathearne Ave., Hamilton, Ontario.
D. Kerr, Chemical Engineer,	WELLAND CYANAMID,	Garner Road, Niagara Falls, Ontario.
W.R. Kiser, President,	SUB-SURFACE POLLUTION CONTROL CO.,	111 Victoria Ave., Chatham, Ontario.
P. Knox, Screening Specialist,	SWECO CANADA,	22 Jutland Rd., Toronto, Ontario.
P. Korol,	CALGON CORP. (CANADA) LTD.,	P.O. Box 69, Station D, Toronto, Ontario.
N.S. Kuhn,	HONEYWELL CONTROLS LTD.,	300 Yorkland Blvd., Willowdale, Ontario.
E.E. Kupchanko, Head Water Pollution Control Section,	ALBERTA DEPARTMENT OF HEALTH,	Administration Building, Edmonton, Alberta.
P. LaBelle, Plant Engineer,	MARBON DIVISION,	Box 10, Cobourg, Ontario.
A.J. Lafreniere, Utilities Engineer,	STEEL CO. OF CANADA,	Wilcox Street, Hamilton, Ontario.
E.A. Lancaster, Product Manager,	CANADIAN INDUSTRIES LTD.,	630 Dorchester Blvd.W., Montreal, Quebec.
P.J. Laughton, Engineer,	R.V. ANDERSON ASSOC. LTD.,	194 Wilson Ave., Toronto, Ontario.
D. Lennox, Research Chemist,	UNIROYAL	Elmira, Ontario.
H. Lightwood, Sewer Maint.Manager,	BOROUGH OF SCARBOROUGH,	2001 Eglinton Ave. E., Scarborough, Ontario.
W.C. Little, Salesman,	DOW CHEMICAL,	250 Bloor St. E., Toronto, Ontario.
W.K. Lombard, Vice President,	TRECAN LIMITED,	3289 Lenworth, Cooksville, Ontario.

R.H. Love,	DOW CHEMICAL OF CANADA LTD.,	250 Bloor St. E., Toronto, Ontario.
S. Love,	L.S. LOVE & ASSOC. LTD.,	160 Bay Street, Toronto, Ontario.
J.E. Ludberg, Coke Plant Supt.,	DOMINION FOUNDRIES & STEEL LTD.,	Box 460, Hamilton, Ontario.
R.W. Luhowy, Pollution Control Technologist,	CORPORATION CITY OF KITCHENER,	City Hall, Kitchener, Ontario.
D. Madill, Engineer,	C.G. RUSSELL ARMSTRONG ASSOCIATES LTD.,	317 Barlet Building, Windsor, Ontario.
J.A. Malcomson, District Manager,	PENNWALT CORPORATION - Sharples Division,	14700 Detroit Rd., Cleveland, Ohio.
S.W. Manson,	BP REFINERY CANADA LTD.,	P.O. Box 520, Oakville, Ontario.
L. Marshall,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
R.B. Marshall, P.Eng., Manager,	H.J. HEINZ CO. OF CANADA LTD., Consumer & Industry Services,	Leamington, Ontario.
L. Martini, Project Engineer,	JAMES F. MACLAREN LTD.,	321 Bloor St. E., Toronto, Ontario.
K.M. Mayall, Biologist,	ONTARIO DEPARTMENT OF ENERGY & RESOURCES MANAGEMENT,	880 Bay Street, Toronto, Ontario.
J.C. MacKellar, Engineering Supv.,	DUPONT OF CANADA,	Toronto Dominion Centre, Toronto, Ontario.
R. McClean, Sales Representative,	JOHNS-MANVILLE,	200 Tavistock, Downsview, Ontario.
J.J. McGrath, Metallurgical Manager,	ANACONDA AMERICAN BRASS LIMITED,	260 Eighth Street, Toronto, Ontario.
R.D. McKay, Director,	N.S. DEPARTMENT OF PUBLIC HEALTH,	P.O. Box 488, Halifax, N.S.
B. McKrittrick, Regional Engineer,	NEPTUNE MICROFLOC,	3526 Lake Shore Blvd.W., Toronto, Ontario.
P.W. McLaughlin, Tech. Sales Rep.,	CYANAMID OF CANADA,	1 City View Dr., Rexdale, Ontario.

K.A. McLennan, Chief Municipal Eng.,	MARSHALL MACKLIN MONAGHAN LTD.,	1480 Don Mills Rd., Don Mills, Ontario.
J.A. McNamara, Superintendent,	CITY OF NIAGARA FALLS,	City Hall, Niagara Falls, Ontario.
S.A. McWilliams, Sales Engineer,	CONTROL & METERING LIMITED,	305 Kipling Ave. S., Toronto, Ontario.
G.W. Mears, Laboratory Supv.,	ALCAN ALUMINUM CORPORATION,	P.O. Box 28, Lake Rd.N., Oswego, New York.
J.A. Meindl, Manager,	HYON CANADA LIMITED,	207 Queens Quay W., Toronto, Ontario.
R.H. Millest, Chief, Water Quality Div.,	DEPARTMENT OF ENERGY AND RESOURCES MANAGEMENT,	45 Spencer St., Ottawa, Ontario.
R.E. Mills,	DEPARTMENT OF ENERGY AND RESOURCES MANAGEMENT,	45 Spencer St., Ottawa, Ontario.
G. Mitrovich, Quality Control Supv.,	GREEN GIANT OF CANADA LTD.,	500 Ouellette Ave., Windsor, Ontario.
R.G. Mondoux, Manager,	EIMCO PROCESS OF CANADA, Water & Waste,	165 Cartwright Ave., Toronto, Ontario.
W. Moroz, Supv. Civil Eng.,	STELCO,	Wilcox St., Hamilton, Ontario.
V. Morris, Executive Eng.,	JAMES F. MACLAREN LTD.,	320 Adelaide St. S., London, Ontario.
M. Mukerjee, Plant Engineer,	CANADIAN JOHNS-MANVILLE CO. LTD.,	West Hill P.O., West Hill 784.
P. Mulligan, Plant Engineer,	AMALGAMATED ELECTRIC CORP.,	Bullock Drive, Markham, Ontario.
K.L. Murphy, Assoc. Professor,	MCMASTER UNIVERSITY, Chemical Engineering,	Hamilton, Ontario.
E. Myers, Filtration Plant Supt.,	CITY OF CORNWALL,	P.O. Box 877, Cornwall, Ontario.
G.D. Nicks, Blast Furnace Tech.,	DOMINION FOUNDRIES & STEEL CO.,	P.O. Box 460, Hamilton, Ontario.
T.J. Nolan, Sr. Project Engineer,	ATLAS STEELS COMPANY,	Welland, Ontario.
Dr. J.D. Norman, Assoc. Professor,	MCMASTER UNIVERSITY, Chemical Engineering,	Hamilton, Ontario.

J.P. Nunan, Hydrogeologist,	HYDROLOGY CONSULTANTS LIMITED,	1125 Dundas St. E., Cooksville, Ontario.
W.K. Oliver,	BP REFINERY CANADA LTD.,	P.O. Box 520, Oakville, Ontario.
D.H. Omstead, Vice President,	OMSTEAD FISHERIES 1961 LIMITED,	Wheatley, Ontario.
J.M. Owen, Production Manager,	ONTARIO MINNESOTA PULP & PAPER CO. LTD.,	Kenora, Ontario.
H.D. Paavila, Air & Stream Improvement Engineer,	C.P.P.A.,	2300 Sun Life Bldg., Montreal, Quebec.
J. Paisley,	TOWN OF EXETER,	Exeter, Ontario.
J.C. Paquin, Dept. Head,	UNION CARBIDE CANADA LTD.,	Box 5400, Belleville, Ontario.
M. Paraschak, Technical Supervisor,	ALLIED CHEMICAL CANADA LTD.,	Amherstburg, Ontario.
R.R. Parker, Consulting Engineer,	REID CROWTHER & PARTNERS LTD.,	797 Don Mills Rd., Don Mills, Ontario.
J.D. Paterson, Mill Chemist,	DOMTAR FINE PAPERS LTD.,	Cornwall, Ontario.
E.B.Pearson, Associate,	ATKINS HATCH & ASSOC. LTD.,	37 Bloor St. W., Toronto, Ontario.
L.E. Penner,	BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY,	3700 Willingdon Ave., Burnaby 2, B.C.
R. Penwill, Technical Rep.,	WORTHINGTON (CANADA) LTD.,	4180 Dundas St. W., Toronto, Ontario.
D.H. Perkins, General Manager,	SVERDRUP & PARCEL OF CANADA LTD.,	43 Eglinton Ave. E., Toronto, Ontario.
S.J. Peters, Sales Engineer,	WORTHINGTON (CANADA) LTD.,	4180 Dundas St. W., Toronto, Ontario.
W.M. Pinkerton, Sr. Sanitary Engineer,	MARSHALL MACKLIN MONAGHAN,	1480 Don Mills, Rd., Don Mills, Ontario.
Dr. L.A. Pogorski, Research Director,	CHEMICAL PROJECTS LTD.,	36 Greensboro Dr., Rexdale, Ontario.

R. Pollard, Chief Chemist,	EFFLUENT SYSTEMS LTD.,	203 Bentworth Ave., Toronto, Ontario.
D.A. Poole, Manager,	M.M. DILLON LTD., Water Resources Division,	Box 426 B, London, Ontario.
T. Posgate, Representative,	LEE CHEMICALS LTD.,	1119 Yonge St., Toronto, Ontario.
A. Price, Sr. Mechanical Engineer,	GENERAL MOTORS,	Plant 1, St. Catharines, Ont.
P.F. Pullen, Environmental Health Engineer,	RIO ALGOM MINES LTD.,	Elliot Lake, Ontario.
C. Quantz, Foreman,	TOWN OF AURORA, Pollution Control Centre,	27 Yonge St. S., Aurora, Ontario.
E. Raia, Associate Editor,	INDUSTRIAL WATER ENGINEERING MAGAZINE,	373 Fifth Ave., New York 10016.
I. Ramsay, District Engineer,	ONTARIO WATER RESOURCES COMMISSION,	411 Donald St. E., Fort William, Ontario.
J.R. Ranford, Special Representative,	CANRON LTD.,	169 Eastern Ave., Toronto, Ontario.
T.E. Rattray, Scientific Officer,	CANADIAN ENERGY, MINES AND RESOURCES,	45 Spencer St., Ottawa, Ontario.
W.J. Reed, Assistant Supt.,	CITY OF NIAGARA FALLS, Plants,	300 Queen St., Niagara Falls, Ont.
C.B. Reid, Sr. Tech. Manager,	B.F. GOODRICH CHEMICAL CANADA,	Box 548, Welland, Ontario.
A. Reimer, Industrial Waste Control Supervisor,	THE METROPOLITAN CORPORATION OF GREATER WINNIPEG,	455 Ellice Ave., Winnipeg, Manitoba.
W. Rodman, Design Engineer,	CITY OF NIAGARA FALLS,	300 Queen St., Niagara Falls, Ont.
J.R. Root, MPP Vice Chairman,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
C.J. Ross, Manager,	CANADIAN CANNERS LIMITED,	19 Jackson St. East, Hamilton, Ontario.
D.W. Roughley, Sewerage Works Design Eng.,	CORPORATION CITY OF HAMILTON,	Hamilton, Ontario.

E.L.L. Rowe, Chairman,	NOVA SCOTIA WATER RESOURCES COMMISSION,	P.O. Box 2107, Halifax, Nova Scotia.
A. Rude, Chemist,	ONTARIO MINNESOTA PULP AND PAPER,	1121 Scott, Fort Frances, Ont.
W.B. Russell, Vice President,	LYCO SYSTEMS INC.,	P.O. Box 569, Williamsport, Pa.
C.C. Rutherford, Project Manager,	AKINS ASSOCIATES,	30 Court Street, Canton, N.Y. 13617.
S.A. Rybb, President,	EFFLUENT SYSTEMS LTD.,	1262 Don Mills Rd., Don Mills, Ontario.
J.A. Sanvido, Water Pollution Control Plant Supt.,	CORPORATION OF THE CITY OF GUELPH,	City Hall, Guelph, Ontario.
K. Schaumburg, Field Sales Manager,	RITTER PFAUDLER CANADA LTD.,	285 Raleigh Ave., Toronto, Ontario.
C. Schroeder,	STELCO,	Hilton Works, Hamilton, Ontario.
M. Schwartz, Sanitary Engineering Department Head,	M.M. DILLON LIMITED,	141 Maple St., London, Ontario.
F.C. Schwenger,	TRG CONTRACTORS LTD.,	Burlington, Ont.
G.T.G. Scott, President,	CANADIAN BRITISH ENGINEERING CONSULTANTS LIMITED,	801 York Mills Rd., Don Mills, Ontario.
E. Sexton, Staff Process Eng.,	ONTARIO PAPER CO. LTD.,	Thorold, Ontario.
J. Shantora, Engineer,	DEPARTMENT OF HEALTH,	1 St. Clair Ave. W., Toronto, Ontario.
K.H. Sharpe, Assistant General Manager,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
D. Sheppard, Reporter,	TORONTO TELEGRAM,	440 Front St. W., Toronto, Ontario.
J.M. Simpson, P.Eng. (C.E.),	W.N. HORNER & ASSOCIATES,	89 Queen Street, Truro, Nova Scotia.
J.R. Sinclair, Control Superintendent,	ABITIBI PROVINCIAL PAPER,	Thorold, Ontario.

Dr. R.W. Slater, Manager,	PROSEARCH LIMITED,	5889 Airport Rd., Malton, Ontario.
S.E. Smith, Sr. Sanitary Engineer,	NEW YORK STATE DEPARTMENT OF HEALTH,	84 Holland Ave., Albany, New York.
M. Sobolov, Supt. Lab. Services,	HIRAM WALKER & SONS LIMITED,	P.O. Box 518, Walkerville, Windsor.
D.E. Spade, Research Engineer,	PLANT INDUSTRIES, INC.,	17411 Irvine Blvd., Tustin, California.
M.E. Spear, Contracting Engineer,	HORTON STEEL WORKS LTD.,	401 Bay Street, Toronto, Ontario.
A.R. Steedman, Project Dev.Engineer,	THE CORPORATION OF THE TOWN OF BRAMPTON,	24 Queen Street E., Brampton, Ontario.
H.R. Stewart, Pilot Plant Engineer,	UNIROYAL LTD.,	Elmira, Ontario.
F.H. Stratman, General Manager,	CHICAGO BRIDGE & IRON CO.,	1200 Harger Road, Oak Brook, Illinois.
J.B. Sutherland, Manager,	DORR-OLIVER-LONG LIMITED, Sanitary & Centrifugal Sales,	174 West Street S., Orillia, Ontario.
F.J. Sweeney, Sr. Process Chemist,	SHELL CANADA LTD.,	Oakville Refinery, Box 308, Oakville, Ont.
G.E. Symons, Editor,	WATER AND WASTES ENGINEERING,	466 Lexington Ave., New York, N.Y.10017.
J. Tattersall,	H.G. ACRES,	20 Victoria St., Toronto, Ontario.
C.N. Taylor,	POWER PLANT SUPPLY CO.,	Oakville, Ontario.
J.R. Taylor, Supv. Design Engineer,	ONTARIO HYDRO,	620 University Ave., Toronto, Ontario.
J.K. Theil, Chief Engineer,	KILBORN ENGINEERING LTD.,	36 Park Lawn Rd., Toronto, Ontario.
C.H. Thompson, Environmental Eng.,	CORPORATION CITY OF KITCHENER,	City Hall, Kitchener, Ontario.
G. Thompson, Refinery Engineer,	CANADA PACKERS LTD.,	2200 St. Clair Ave. W., Toronto, Ontario.
S.W. Thomson, Alderman,	NIAGARA DISTRICT HEALTH UNIT,	2556 Sherwood Rd., Niagara Falls, Ont.

L.M. Tobias, Director,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
J.A. Turner, Plant Engineer,	LIBBY MCNEILL & LIBBY CANADA LTD.,	330 Richmond St., Chatham, Ontario.
J.R. Turner, Tech. Assistant,	ALLIED CHEMICAL CANADA LTD.,	100 N. Queen St., Toronto, Ontario.
M.A. Tyler, Chief Engineer,	T.W. BEAK CONSULTANTS LIMITED,	4999 St. Catherine St.W Montreal, Quebec.
Dr. J.A. Vance,		Box 83, Woodstock, Ontario.
J.C. Van Esterik, President,	NEW CANADIAN PROCESSES LTD.,	6 Bayshill Dr., Toronto, Ontario.
R. Van Lammers, Sales Engineer,	PROCOR LTD.,	3rd Line, Oakville, Ontario.
A.L. Van Luven, President,	VAN LUVEN CONSULTANTS LTD.,	5460 Connaught Ave., Montreal, Quebec.
J. Villamere, Engineer,	CANADA DEPARTMENT OF FISHERIES,	P.O. Box 5667, St. John's, Newfoundland
C. Viscount, President,	FLOW CONTROLS LTD.,	291 Progress Ave., Scarborough, Ontario.
F.A. Voege, Assistant General Manager,	ONTARIO WATER RESOURCES COMMISSION,	135 St. Clair Ave. W., Toronto, Ontario.
W.K. Voss, Vice President,	ONTARIO PAPER CO. LTD., Manufacturing,	Thorold, Ontario.
W. Wachsmuth,	GRAVER SMITH & LOVELESS,	Oakville, Ontario.
W.M. Walkinshaw, Chief	ONTARIO DEPARTMENT OF HEALTH, Public Health Engineering,	1 St. Clair Ave.W., Toronto, Ontario.
A.R. Wallace, Special Project Eng.,	PUMPS & SOFTENERS LTD.,	680 Waterloo St., London, Ontario.
E.C. Walton, Director of Operations,	BOROUGH OF SCARBOROUGH,	2001 Eglinton Ave. E., Toronto, Ontario.
H.G. Walton, Tech. Representative,	CANADIAN JOHNS-MANVILLE CO. LTD.,	565 Lakeshore Rd. E., Port Credit, Ontario.

R. Warriner, Assistant Professor,	QUEEN'S UNIVERSITY,	Kingston, Ontario.
Dr. O. Washburn,	UNIROYAL RESEARCH LTD.,	120 Huron St., Guelph, Ontario.
J.A. Watson, General Supt.,	GENERAL MOTORS OF CANADA Plant Engineering,	St. Catharines, Ontario.
Dr. P. Watts, Manager,	CRANE CANADA LTD., Research & Development,	1355 Martin Grove Rd., Rexdale, Ontario.
L.R. Webber, Professor,	UNIVERSITY OF GUELPH,	Guelph, Ontario.
R.F. Weidner, Lab. Manager,	DEARBORN CHEMICAL CO.,	3451 Erindale Station Rd., Mississauga, Ontario.
W.R. Weir, Vice President,	DOMINION FOUNDRIES AND STEEL, LIMITED,	P.O. Box 460, Hamilton, Ontario.
T.E. White, Pollution Control Supt.,	CORPORATION OF CITY OF OSHAWA,	50 Center Street, Oshawa, Ontario.
J.C. Williams, Director,	CANADIAN PACIFIC Transportation Systems Dev.,	Room 369, Windsor Stn., Montreal, Quebec.
P. Williams, Pipe Manager,	CANADIAN JOHNS MANVILLE	565 Lakeshore Rd. E., Port Credit, Ontario.
W. Williamson, Sr. Waste Management Eng.,	ONTARIO DEPARTMENT OF HEALTH,	1 St. Clair Ave. W., Toronto, Ontario.
H.S. Wilson, Environmental Control Coordinator,	IMPERIAL OIL LTD.,	Sarnia, Ontario.
J.A. Wilson, Supervisor,	REX CHAINBELT (CANADA) LTD., Process Equipment,	1181 Sheppard Ave. E., Willowdale, Ontario.
N.D. Woollings, Technical Manager,	ALCHEM LTD., Consulting Services,	P.O. Box 5002, Burlington, Ontario.
M. Yatabe, Engineer,	GORE & STORRIE LTD.,	980 Yonge Street, Toronto, Ontario.
C.A. Young, Agriculturist,	INTERNATIONAL NICKEL,	Copper Cliff, Ontario.
D.C. Young, Engineer,	METRO TORONTO WORKS DEPARTMENT,	11th East, City Hall, Toronto, Ontario.
Dr. J.E. Zajic, Professor	UNIVERSITY OF WESTERN ONTARIO,	London, Ontario.