SAMPLE – DO NOT REMOVE

Papers Presented
at
Sixth Ontario
INDUSTRIAL
WASTE
Conference

* * *

JUNE 14th, 15th, 16th, 17th
1959
AT
Delawana Inn, Honey Harbour, Ontario

* * *

SPONSORED BY
THE WATER AND POLLUTION ADVISORY COMMITTEE
OF THE
ONTARIO WATER RESOURCES COMMISSION

Papers Presented
at
Sixth Ontario
INDUSTRIAL
WASTE
Conference

◆

JUNE 14th, 15th, 16th, 17th
1 9 5 9
AT
Delawana Inn, Honey Harbour, Ontario

◆

SPONSORED BY
THE WATER AND POLLUTION ADVISORY COMMITTEE
OF THE
ONTARIO WATER RESOURCES COMMISSION

CONTENTS

PREFACE

The Sixth Ontario Industrial Waste Conference was sponsored by the Water and Pollution Advisory Committee of the Ontario Water Resources Commission. The meeting was held at Delawana Inn, Honey Harbour, Ontario, on June 14, 15, 16 and 17, 1959.

The proceedings of the conference are disseminated as a contribution towards the widespread aim of improving existing methods of industrial waste disposal. The papers are printed in this brochure in the order in which they were given. They are followed by a list of those persons who attended the conference, as well as an index for the proceedings of all such conferences held to date. The papers contain valuable information given by persons who are recognized leaders in their fields. A careful study of the papers is recommended for all who are concerned with the problem of industrial waste disposal.

Industrial wastes in the Province of Ontario constitute an important factor in stream sanitation. They must be considered in conjunction with domestic sewage and other wastes which may impair the quality of the receiving watercourses. The fact that Ontario is growing industrially at a rapid pace creates additional problems in this field. The objective of the Water Resources Commission is to make it possible for the operation of these various industrial plants in such a way that the quality of the streams may be maintained for the many uses which are normally required of watercourses. As the Province grows, this problem becomes more acute. It is necessary to plan in advance and to make certain that all wastes that are not reclaimable are adequately treated before they are discharged.

The industrial waste problem is one of great magnitude not only because of the complexity of the wastes themselves, but also through the cost involved in providing treatment. It thus becomes all important that effective measures be devised to produce satisfactory results, and at the same time, to utilize the most economical procedures. Measures to be adopted must be co-ordinated with the ever changing composition of industrial wastes. One of the best ways to meet this challenge is to hold annual conferences, such as this one, where there can be a free exchange of up-to-date information.

The Water and Pollution Advisory Committee has been responsible for the preparation of the programme of this Conference. The Committee members come from different departments of Government, and accordingly are interested in all types of pollution. By working together there is a co-ordination of efforts and interests, and a broader approach to this complex problem than would otherwise be achieved. Existing legislation in Ontario makes it possible to deal with all forms of wastes which may in any way impair the quality of the receiving stream. This is irrespective of the purpose which the stream may serve as its primary function.

The Water and Pollution Advisory Committee is grateful to all who have contributed in any way to this programme of papers and discussions. The interest manifest in these conferences is increasing, and this is reflected in the quality of the papers presented, as well as the general concern in this overall problem. The Ontario Water Resources Commission is glad to be of service in this way and will welcome any suggestions for attacking the problem more effectively.

For further information write to:

The Water and Pollution Advisory Committee,
Ontario Water Resources Commission,
East Block, Parliament Buildings,
TORONTO, Ontario.

SPRAY IRRIGATION FOR DISPOSAL OF TANNERY WASTES

R. R. Parker

Introduction

The title of this paper "The Disposal of Tannery Waste by Spray Irrigation" indicates a somewhat broader approach to the subject than the actual content of the paper will justify. When the question of preparing this paper was discussed for the first time, the author-to-be planned a paper based on personal experience and thus the paper was based on operations at our plant only. So if this morning's audience looks forward to a general review of spray irrigation practice as applied to tannery effluents, it is destined for disappointment.

Tannery Effluent Problem

The problem of the disposal of tannery effluent has received an increasing amount of attention over the period of the past twenty years, but the technology of treatment has not grown as rapidly as public interest. The problem has become greater for several fairly obvious reasons.

1. An increasing concern over stream and lake conditions.
2. The disappearance of many smaller plants and the consequent growth of large units.
3. Construction of small municipal sewage disposal plants, quite incapable of handling the volume and high B.O.D. load from sizeable tanning operations. The presence of these plants and the resultant feeling of the taxpaying and other public that a disposal plant should be a guarantee of unsullied streams, have combined to point a searching finger at all industrial undertakings in general, and in some cases, at tanneries in particular.
4. Many tanneries are located in what were formerly small communities. The increasing population and the resultant increase in the demand for recreational facilities accentuate the local situation.

Composition of Effluent

Tannery effluent varies considerably with the tanning process used but one is justified in stating that there are two general types of process and effluent - vegetable or sole leather tanning, and Chrome or upper leather tanning.

The term "vegetable" is used in its broadest sense and includes all tanning operations wherein one uses extracts of wood, bark, roots and other plant parts, including some by-products from the paper industry.

Chrome tanning is an operation whereby leather is tanned by treatment with a solution of an acid chromium sulphate.

The preparation of the cattle hide for either of these processes is essentially the same. The hide is washed to remove manure, blood and salt from the curing process and then immersed in a lime solution to remove or loosen the hair. The addition of sodium sulphate to the lime solution is frequently practised. The sodium sulphide accelerates the hair removal - in fact if added in sufficient quantity it will destroy the hair - and in any quantity it complicates the job of effluent treatment.

If all the effluents from the various stages of the process are mixed it is reasonable to expect a liquid of approximately the following composition:

Total solids	10000 p.p.m.
Suspended solids	4000 p.p.m.
Dissolved solids	6000 p.p.m.
B.O.D. 5 days	600 p.p.m.
pH	9 - 10.5

If the plant be a vegetable bark tannery, the effluent probably will be pinkish brown in colour, will produce a dark colour if mixed with waters containing iron compounds, and probably will have a somewhat higher B.O.D. value.

The effluent from a chrome process will be straw coloured or grey with little or no dissolved chrome salts. The excess lime precipitates the trivalent chromium compounds. In both cases the major part of the suspended solids is calcium hydroxide and some carbonate. Sodium chloride is the chief component of the dissolved solids.

In the Beardmore plant, both tanning processes are used and the effluents from all divisions of the tannery, except the vegetable tanning section, are mixed. Other additions are dye-drum wastes, pigment washings, and the domestic sewage from four hundred and fifty employees.

The discharge from the vegetable tanning process is segregated and handled separately for reasons that will be discussed later.

The combined wastes, which for purposes of simplicity henceforth will be referred to as effluent, amounts to approximately 500,000 Imperial gallons daily, on a five-day week basis. This effluent flows through a first and then a second primary sedimentation pond where the major portion of suspended solids is removed. The retention period is approximately four days and during that time the suspended solids content decreases to approximately 500 p.p.m. Storage in other ponds over a period of days or weeks reduces the suspended solids to approximately 200 p.p.m. This secondary sedimentation treatment completes the treatment of the effluent prior to spray application.

History of Treatment

As far as can be ascertained, and company records before the beginning of the century tell us nothing, the effluent was pumped to two abandoned gravel pits and from there it disappeared into the ground at a pleasantly satisfactory rate. Gradually the seepage rate diminished until other methods of disposal were forced upon the company.

The first remedy was the development of large storage ponds. Small dams with or without additional excavation provided these areas and a combination of evaporation and slow seepage rates sufficed to provide room each year for the volume produced. Later, one field, approximately five acres in extent, was cultivated and furrowed to provide additonal disposal area. This original tract is still in use, for ridge and furrow disposal, after some thirty years of operation. Over the years the capacity of the field has decreased and extensive cultivation several times a season is necessary if the field is to retain a reasonable portion of its usefulness. This deep cultivation, and by "deep" is meant a depth of 16 inches, followed by deep plowing, is expensive and also renders the area inactive for several periods of six to ten days each during the season. As the field operation is limited on the average to the May to November period, any interruption of operation is serious. In addition, the usefulness of the field is affected to an important degree by heavy rains, or continuous damp weather.

Searching for a better system, or an enlarged one, the decision was made in 1947 to apply the effluent in spray form. This change was prompted by the hope that spray application would utilize evaporation as well as seepage, and thus provide the required additional capacity. Preliminary tests indicated that it would be reasonable to expect an evaporation of 20 to 25% of the volume sprayed. The difficulties of evaluating or measuring evaporation and seepage, with due recognition of occasional unplanned run-off and allowance for variations of weather, combined to cast some doubts on the accuracy of this estimate. Continued operations showed these doubts to be justified.

Based on these early tests, a so-called "high" spray line was constructed. The line, approximately 750 feet long, was built of special welded pipe, varying in diameter from 10 inches to 6 inches, and supported on trestles 12 feet high. Spray nozzles were attached to 5-foot lengths of quarter-inch pipe. These feed pipes were screwed into welded fittings, attached to the main line at 9-foot intervals. The line was erected on a ridge with a furrowed field on one side, and extensive terraces on the other. Marley nozzles, chosen because of their relative freedom from clogging, were used and atomization at 25-lbs pressure was adequate.

While the anticipated evaporation rate was not realized, nevertheless there was considerable loss to the atmosphere under favourable weather conditions and to the writer there is some justification for high sprays over some terrain. On many occasions, in clear, windy weather, the writer has felt spray on his face when standing 300 to 400 yards from the spray line, when the only visible deposition on the land was in an area approximately 200 feet adjacent to the line.

Corrosion presented a problem. Despite large nozzle openings and pump screens, enough debris from the pond surface was drawn into the line to make plugged nozzles a major source of trouble. The line was expensive to build and maintain, and while it contributed a great deal there was no great regret over its demolition. It is interesting to observe that the principal factor limiting its use was the flooding of the terraces below the line, and during the later years of operation from 50 - 75% of the effluent sprayed was returned to the pump-house pond.

A floating spray-line with the nozzles approximately 12 feet above the pond surface was constructed, but the evaporation was not sufficient to justify continued operation. At that period the only parameter was gallonage. The problem of B.O.D. reduction had not been considered then. Now it is believed that continuous aeration would have effected a considerable reduction of the B.O.D. content but unfortunately there was no investigation of that phase at the time.

Some years of experience by this time indicated that the disposal problem had two separate and, in one sense, unrelated phases.

The first, of course, was the disposal of the accumulated wastes during the spring, summer and fall.

The second was the provision of adequate lagoon capacity to impound the winter effluent. It is obvious that weather was an ever-present threat. Late springs and early freeze-up shortened the period of application and put an added load on the lagoon system. Wet summers decreased the application rate, in addition to adding extra water to the lagoons.

Each year the spectre of enforced shut-down haunted the plant personnel, and obviously some other method of disposal must be tried.

In 1953 spray irrigation was described in several articles in the technical and lay press and these reports indicated a new approach. A visit to the Seabrook organization and a discussion of the remarkable results achieved there stimulated this interest. That year an attempt was made to use low-line spray irrigation in a major way.

At first, a spray head was set up in a wooded area. The orifices were 3/4" and 1/4" and the sprinkler had a rated capacity of 200 gallons per minute. Application rates at the outset were high, as much as 3 inches per day being applied.

Unfortunately, the first experiments were made with vegetable tan waste liquors having a pH value of 4.0 to 5.0. Either the low pH or some constituents of the liquor proved to be quite toxic to vegetation. Large hardwoods, maple and oak, were not damaged; at least, they are alive today. Very young trees, 1 to 3 feet high were killed, but new seedlings, in smaller numbers, appeared each spring. Most weeds succumbed but Jack-in-the-Pulpits grew and twitch grass flourished. Twitch seed is not available for test plantings but transplanted sod grew well. Wild cherry, cedar and sumach died in a short time. Despite the fact that the sprayed effluent fell on slopes with inclinations up to 30°, and covered in part with fallen leaves, there was little run-off. Where run-off occurred, it was chiefly at points where the sandy hillsides were undercut by impinging jets.

The wooded area was small, but not situated close to the large lagoons. Consequently attention was focussed on the other effluent and cleared land.

Results with the large nozzle on grass land were not very satisfactory, and as the experiment enlarged, smaller nozzles in larger numbers were tried. The final choice was a Rainbird No. 40 with 3/16" and 1/8" nozzles. This operation is rated at 10.4 U.S. g.p.m., and a spray diameter of 100 feet at 50 p.s.i. No. 35 sprinklers, a part circle type, were chosen for ridges and areas adjacent to roadways.

Lay-out

Discussions with other operators indicated there was an appreciable labour cost in most of the projects and it appeared that it would be considerably greater in this case because of the rolling terrain. The decision was made in the early stages of planning to utilize plastic pipe and a non-portable lay-out. Now one man devoting only part time to the job can take care of over twenty acres.

From a centrally located pump 100# plastic pipe conveyed the effluent to the disposal area and then through smaller lines which were laid out in more or less parallel lines at 80-foot intervals across the field.

To maintain nozzle position a tee was used as the principal connection. As these sprinklers had a 3/4" threaded connection, 3/4" galvanized tees were used. Into one through end was screwed a 3/4 inch plug to which had been welded a piece of 1/4" rod, 12 inches long and pointed. The sprinkler was screwed into the opposing end and a short nipple fitted in the side-opening. This nipple screwed into a tee, say 3-inches by 3-inches by 3/4 inches, completed the set-up. This is a remarkably simple arrangement and in our experience an extremely satisfactory one. The nozzle cannot move out of the desired location and position and yet the line can be moved with a minimum of effort. For example, when cutting the cover crop it is necessary only to move the line a few feet, and no laborious shifting of pipe lines is required. A valve at the end of each lateral may be installed if there should be any need to shut off individual rows of sprays.

Spray heads were spaced at eighty-foot intervals along each lateral to maintain the eighty-foot diameter pattern that seemed to be adequate. It is quite true that the recommended diameter is 100 feet but one should remember that these sprays were not subject to regular moves across a field and consequently some degree of overlap was permitted.

Our experience indicated that the gallonage specification would be exceeded to some extent and this arrangement would apply an acre foot in approximately 66 hours, or 0.2 inch per hour.

Early usage departed considerably from this pattern and with sprays at 100-foot intervals spraying for twenty-four hours and longer was done. This worked for a time but probably only because the fields had a well developed pasture crop and were in prime condition. This prolonged application either killed the grass or thinned it out to the point that local flooding occurred. The application was phenomenal for a period, in one case reaching a level of four inches per day for a three-week period but it is our belief that operation at this level is a mistake.

Currently, operations are on a six-hour cycle and this would appear to be a maximum under local conditions unless unusually dry weather is experienced. Continued rainfall, of course, will reduce the spray periods or, as sometimes has happened, compel the cessation of operations for one or more days.

Vegetation

Originally the grass was utilized as it was found. It was noted, however, that the growth was seriously affected in areas that bore an appreciable amount of alfalfa. These patches turned brown in a matter of a few weeks, and as there was little or no other growth in these areas, live vegetation was practically non-existent.

Some of these denuded areas were cultivated by hand and planted with a grass mixture that had been used by Mr. T. S. Toth and reported in the proceedings of the Fourth Ontario Industrial Waste Conference. Growth was satisfactory but an examination of sample strips after a season's use showed that original planting formula and a varietal census had little in common. This survey was carried out by Prof. Montgomery of the O.A.C. staff and in the course of a discussion of his findings he suggested that a simple choice of grasses might be as satisfactory as the more complex formulae.

The grasses found in the greatest abundance were Orchard Grass, Brome and Timothy and these three accounted for over 60% of the growth. The remainder consisted of Twitch, Bird Vetch and five others. Twitch and Bird Vetch are native grasses and commercial seed is not available. The amounts of the others were so small as to be negligible. Therefore it was decided to plant a mixture of Orchard Grass, Brome and Timothy.

After another season's exposure to sprayed effluent, a second survey was made by Mr. D. N. Huntley and Mr. G. E. Jones of O.A.C. and a new formula based on their findings was developed. This formula is still in use is as follows:-

Reed Canary	9#
Brome	8#
Timothy	3#
	20# per acre.

This mixture has given adequate coverage to date although the earliest seeding is only being sprayed for the second season. Growth has been heavy and there has been no appreciable kill, despite the fact that spraying was begun rather sooner than had been planned.

Additional acreage was planted this year and it is hoped that some spraying may be done on this area in the late autumn.

Some workers have reported that it is advisable, if not essential, to allow two full seasons to elapse between seeding and the first application of spray but it has been our experience that this period can be shortened, remembering always that the only hard and fast rule is to be certain that the top growth is able to withstand the rate of spray application. We even used light sprays during the period of early growth to offset the effect of an abnormally dry season.

The crop must be cut regularly and, in our opinion, should not be allowed to grow higher than 12 inches. It then should be cut to a height of four to five inches, raked, and the cut grass drawn away. On occasion, unfortunately, growth has sometimes outdistanced our workers and the grass has been higher than the optimum. Fall over, matting, and a prolonged period of drying after a rain are the penalties for this neglect.

In the spring the fields are fired to remove the matted grass resulting from late fall and early winter spraying. Hand raking before burning is recommended if there is an appreciable amount of matted dead grass on the area.

Soil

The soil in the areas now under spray have been classified as follows: A glacial till of the Dumfries type, over fine sand.

The under layer varies to some extent, but generally all sprayed areas are of the same type.

Unfortunately, there have been so many other variable factors in the operations over the past few years that it is not yet possible accurately to assess the influence of soil types alone. The experience of the next few years, it is hoped, will add to our knowledge.

The writer is the first to admit that this report lacks certain desirable basic data. Tests of soil permeability; sampling at various depths for determination of moisture content, salt retention, B.O.D. elimination; measurement of changes of the water table; development of optimum and maximum rates of application; all these would have been useful and interesting. However, this project has been, and is, primarily a practical one, and some of the more esoteric paths have been left unexplored. It is hoped that the future will provide both time and facilities for their investigation.

Seasonal Effect

Earlier in this report mention was made of the constant struggle with the seasons. The obvious solution to insufficient storage capacity and inclement summers is winter spraying. Reports have it that winter spraying has been done and is being done, but there also is proof that it has not been done by Beardmore & Co. Possibly the five day sojourn in the sedimentation ponds which results in a pump-house effluent temperature of 32°F explains the difference in results. Dairy wastes applied at a temperature of 70°F or higher will melt thin ice films and make feasible operation on most winter days. The writer's experience has been that spraying must not be carried on at or near freezing temperatures except during periods of bright sunlight, and then only in the early part of the winter. One attempt in mid-December resulted in a hillside covered with a treacherous and almost impassable coat of ice; the spray head springs would not function and once spray rotation ceased ice obstruction began. It was not uncommon to see cones of ice two to four feet high surrounding each spray head. Grease coatings, rubber sheeting over the moving parts, nothing improved the impossible conditions that forced a shut-down of spraying operations after the first few cold nights.

One could use warmer effluent by shortening the settling period, but the deposition of sediment on the fields would render them useless. It has been possible by an ultra cautious selection of spraying hours to extend the disposal season by a few days, but that has been the limit of our achievement. As an example, in 1957 spraying operations were discontinued on December 21st. In 1958 the same point was reached on November 20th.

There is another disadvantage resulting from cold weather operations. A heavy accumulation of ice in the fields melts slowly in the spring. Vegetation may be affected adversely and in addition, the opening of a new season may be postponed by as much as two weeks.

B.O.D. Reduction

Spray irrigation is used primarily as a means of disposal rather than treatment but one experience, while not conclusive, indicates the combined effect of aeration and filtration through soil. One spray area showed some rock outcrop, and it was assumed that a layer of rock under another shallow top layer of soil extended over a major portion of the area. While this was not proven, it was certain that wherever spraying was done in this area appreciable flow of water from the soil was observed along the lower margin of the field.

B.O.D. determinations produced the following results:-

Effluent before spraying	200 - 500 p.p.m. B.O.D.
Run off from field	6 - 9 p.p.m. B.O.D.

The marginal water was undoubtedly the result of the spray operation, as no water ever had been observed at this point before spraying was begun; moreover it ceased within a reasonable time after spraying was stopped. Judging by the few results obtained, it would be interesting to spray an under-drained area, but to date facilities for such an experiment have not been available.

Acreage Required

Heretofore various application rates have been cited but anyone planning an area for disposal of a specific amount of effluent recognizes that certain interruptions are inevitable.

During the season of 1958, the following overall results were achieved:

Total gallonage	60,000,000 Imp. gallons
Total acreage	23
Length of season	204 days
Application rate	2,600,000 gals. per acre 9.5 acre feet per season 0.56 in. per day

This result includes all interruptions for cutting and raking, breakdowns, wet weather, and all other reasons.

Costs

The following figures were taken from actual records of operations during 1958, and require only minor correction for labour costs, etc. In this example no estimate for soil preparation or seeding has been made as this varies greatly, depending upon the particular area involved.

An area of 6 acres was equipped for spray operation in 1958.

Piping and Spray Heads	$1,594.
Installation	122.
Total	$1,716.
Cost per acre	$286.

The pumping unit, with power-line and pump-house, cost in this instance approximately $2,000; but inasmuch as the pump feeds three other areas one cannot charge the entire amount against one plot. The cost of pumping equipment depends on many factors - the size of the whole installation, lay-out, pumping levels, proximity of power-lines, and therefore no specific allocation is made.

Complete operating costs for spray treatment only during the 1958 season were as follows:

Operating period May 5 to November 26.		
Number of days 204		
Power for 40 H.P. motor 204 x 20 hrs x 30 kw x 1.250		$1,530.
Labour - 5 hours per day		
204 x 5 x 1.20	$1,224.	
Fringes 10%	122.	
Supervision 5%	61.	1,407.
Installation $8,100. Interest charges @ 6%		488.
Maintenance & replacement $8100 @ 20%		1,620.
Mowing		527.
TOTAL		$5,572.

Gallonage 60,000,000
Cost per 1000 gal. 9.26¢

The allowance for maintenance may be considered somewhat high, but some corrosion is encountered and handling is far from gentle. Again because of local conditions, no allowance for the cost of land acquisition and taxes have been made.

The above figure is actual and is considerably less than rates quoted by many municipalities, or experienced in other methods of treatment. In comparison, disposal by ridge and furrow operation during 1958 resulted in a cost of 15.2¢ per 1000 gallons. This figure was developed from our records of tan liquor disposal, but as only gallonages were considered in each case the figures are comparable.

In reporting cost data on spray operations, only electricity was mentioned as the power used. Our experience with gasoline-powered pumps for this purpose has not been a happy one. In our disposal system, gasoline-powered pumps have been used in many applications and with great success, but not for spray line operation. To date we have not found a completely satisfactory unit. Low-head, large-volume pumps have given remarkable service over a period of years, but continuous operation of a relatively high-pressure (100 p.s.i.) unit requires an electric motor. Portability has been lost, of course, but the advantages of lower maintenance cost and satisfactory operation outweigh this feature.

Conclusion

The foregoing indicates the feasibility of the disposal of tannery effluent by spray irrigation. Ease of operation, low capital expenditure, low operational cost, flexibility - all these have been achieved.

Simplicity of operation and low operating costs have been dominant factors in the evolution of the present system. A minimum of supervision, a minimum of skilled labour, in fact, a minimum of any labour - these have been our targets.

The decision to use plastic pipe in this connection has been proven sound. As an example of the elimination of labour, the preparations for winter consist of unscrewing the spray heads and draining the pump.

The chief disadvantages are the restriction of operation due to climate, and the necessity for large lagoons, but given sufficient suitable terrain, these do not constitute insoluble problems.

Regarding its use in other industries, the presence of constituents toxic to vegetation is of prime importance, but in general the method, in our opinion, is worthy of serious consideration.

In closing, the writer's experience and consequent opinion justify the statement that the use of the spray irrigation method so far has been the only practical solution to our disposal problem, and without it we would not be operating today.

SPRAY IRRIGATION FOR DISPOSAL OF FOOD PROCESSING WASTES

G. Williamson

Introduction and General

This conference is just one indication of the attention and emphasis now being directed by our legislative agencies (Federal, Provincial and Local) towards the problem of the establishment and enforcement of satisfactory methods for the disposal of industrial wastes. It is also an indication of the help our own provincial Ontario Water Resources Commission is prepared to give to help each individual industry - indeed, each individual plant - to appreciate the size of its problem and indicate the most efficient means of tackling this.

Generally speaking, legislation to this end has been in effect in the U.S. for some considerable time and the enforcement of this is well established and accepted by industry; each State has its own legislation, all with considerable "teeth", with some States being more severe than others. Similar legislation and enforcement here in Canada has lagged somewhat, but it is now up to us, a rapidly developing country with increasing concentration in urban districts, to catch up in this matter in the interests of the population at large, for two basic reasons:

a. to reduce the "nuisance" caused by the indiscriminate dumping of untreated industrial liquid wastes.

b. to safeguard natural sources of water for use in the future. The overall demand for water is increasing by leaps and bounds and this could be a very scarce commodity in the not-too-distant future.

The food processing industries in general have a sizeable problem in this regard because of the volume of the liquid wastes involved.

In the canning industry it is estimated that an average of 50 gallons of water are used for each case of canned goods produced. (This figure can be very variable depending on the product and the methods of handling; in fact it can be doubled in some plants using water for conveying product, or where freezing is carried on also). Taking this figure of 50 gallons per case, and assuming an average seasonal cannery produces 500,000 cases, this means it has a total of around 25,000,000 gallons of liquid waste to dispose of. This typical cannery will operate over a maximum period of 20 weeks but the average operating period is probably between 11 - 15 weeks. On the basis of these figures we find that this cannery has for disposal between 180,000 and 350,000 gallons of liquid waste per day, 7 days per week, during its operating period.

The Dominion Bureau of Statistics shows that, in 1953 the production of <u>seasonal</u> canned vegetables, fruits and juices in Canada amounted to approximately ..... 27,000,000 cases. This would indicate that the seasonal canning industry alone has a total of ..... 1,350,000,000 gallons of liquid waste to dispose of during the summer period. It has been estimated by authorities in the U.S. that the water consumed by the canning industry represents only some 0.1% of the total industrial water usage, but that the organic content of the liquid waste makes the waste equivalent to about 10 times the actual comparative volume. Again, interpolating from research in the U.S. this would represent an annual organic load of around $19\frac{1}{2}$ million lbs. of biochemical oxygen demand.

Of course, the B.O.D. value of liquid waste from canneries varies enormously, not only between individual plants, but even at the same plant at different stages of the season because of:

a. The different products being handled throughout the season. (In this connection it is only necessary to point out that the B.O.D. value of waste from Asparagus may be as low as 16 p.p.m. whilst that from Pumpkin and Squash may be as high as 11,000 p.p.m.)

b. The degree of dilution of the waste. Those canners who rely on a municipal water supply, also those whose own water supply is limited, must always strive to out down the amount of water used in the process; this is accomplished by re-use through recirculation, also by cutting out water-conveyance of the raw material. Where this aim is accomplished it must be remembered that the B.O.D. value of the final waste will be higher than originally, and the disposal problem may be more acute even though the volume is less.

<u>Spray Irrigation</u>

With this introduction to the general problem of liquid waste disposal in the canning industry we will proceed to discuss the use of spray irrigation as a practical and efficient means of disposing of such wastes.

Spray irrigation for this purpose appears to have been first used in 1947 at a cannery in Hanover, Penn. Since that time the acceptance of the system has grown so rapidly, that in some States in the U.S. over 40% of the canners are using this method of disposal.

Why did this method take over so rapidly? The answer is relatively simple and can be summarised as follows:

1, it is cheaper to install and operate than other methods of treatment; this is always a major consideration.

2. when operated satisfactorily it meets the requirements of the authorities, as far as absence of odour and the elimination of pollution are concerned.

When approaching the installation and use of a spray irrigation system the following general principles must be considered:

Land

The availability and price or rental value of land within economical distance of the cannery may be the most critical factor when considering the possibility of spray irrigation. The amount of land necessary will depend largely on two things: the volume of waste to be disposed of, and the water absorptive capacity of the soil (with cover crop) concerned. Generally speaking the best soils for the purpose are gravel, sand or sand-loams. Clay soils can be and are used extensively but their capacity to absorb is less than the lighter soils and they have a tendency to "puddle" through an exchange of the Calcium ions with the Sodium ions usually present in the liquid waste, from brines etc. used in processing; where this set of conditions applies, a periodic application of agricultural lime is necessary to reverse this reaction.

Land used for the purpose should be relatively flat in order to minimize the possibility of surface run-off. Slopes of more than 6 or 8 per cent are not usually recommended unless soil type and rate of application permit this.

Land with soil drains will present additional considerations in that the rate and amount of application possible will be determined by the B.O.D. value of the run-off from the drains. The type of soil, the cover crop, and the depth of the drains will all affect this. In some instances the drain outlets have been plugged, but this can only be applied on a short-term basis.

A loose, well-aerated soil has more absorptive capacity; avoid compacting the land with heavy farm equipment or trucks. In order to encourage aeration it may be judged advisable to run over the land in spring with a light toothed harrow.

To sum up: no clear guide can be given on the amount of land necessary as this will depend entirely on local conditions. In order to arrive at some figure, the following may help:-

1. first estimate the amount of liquid waste to be disposed of per hour and hence per minute.
2. having decided the type of sprinklers to be used and knowing their capacity in terms of gallons per minute, it is easy to calculate the number of sprinklers required.
3. the "throw" of the sprinkler will determine the distance to be allowed between sprinklers. From (2) and (3) above it is possible to work out the area covered by each application.
4. it now remains to determine the absorption capacity of the land and this is the unknown variable. The rate of application of the most commonly used sprinklers fall within the range of 0.15 - 0.5 inches per hour. (Note: a useful figure to remember here is that one inch per acre is equivalent to approximately 23,000 gallons). Some soils will take an application of 3 - 4 inches provided this application is given over a period of 10 - 12 hours. In assessing the absorptive capacity of the land being used therefore, in addition to the physical characteristics of the soil itself and of the adequacy of the cover crop, the following factors must also be taken into consideration.

    a. the rate of application per hour

    b. whether the application is continuous throughout the 24 hours, or whether the plant is running only on a single shift basis.

    c. weather conditions at the time of application.

    In most cases it is arranged that the sprinklers are moved only once per day. In others it may be necessary to move twice per day. In the case of the installation with which I am most familiar it is necessary to move only every 3 to 6 days, but the absorptive capacity in this case could rarely be duplicated. It is usual to leave a 6-day interval between applications on the same land.

Cover Crop

An adequate cover crop is probably a more important factor even the soil type in determining the water-absorptive capacity of the land. Bare soil has relatively little capacity, the soil becomes "caked" and the water ponds or runs off if on a slope.

Vegetation increases the capacity in several ways:

a. It increases the surface area available both for evaporation and physical storage of water.

b. it introduces water into the soil through the roots.

c. it prevents soil erosion by binding the soil together.

d. by the natural process of transpiration, evaporation of the surplus water proceeds during rest periods during the 24-hour day, and also during the period between applications; this dries up the soil much more rapidly than would otherwise be the case. According to one authority the amount of water transferred from the soil system during the vegetative season by evaporation and transpiration is in the region of 8,000 gallons per acre per day; thus in a 6-day rest period between spray applications this would account for 48,000 gallons per acre, i.e. 2" of water, which could be the equivalent of the spray application.

Attempts to use Peas, Corn and grain crops as cover crops for this purpose largely failed. Alfalfa was originally popular but it has been established that the best covers are dense grasses of almost any species. This is not to say that the sod will retain the same species content under heavy spray applications; probably the more water-tolerant species will increase in proportion.

Avoid cutting the cover crop just prior to the spray application. One concern found it advisable to cut not less than 10 days before the application. Within reason the more luxuriant the growth the more efficient is the area for its purpose. It is possible to take a hay crop off the land particularly where it is possible to allow more than the usual 6 days between applications. It is common practise also to graze the land and in some cases grazing proceeds even whilst the irrigation is working. In both these matters care should be exercised on two counts:

a. To avoid compaction of the soil, when wet, with either farm implements or live stock.

b. There may be some constituents in the liquid waste which makes the grass undesirable for grazing too soon after the application. e.g. it is possible that a taint would be imparted to the milk of dairy cattle. The New Jersey State Board of Health, for instance, gave approval to the principle of grazing such land but required an interval of 10 days between the time spraying was discontinued and the milk cows were turned into the pasture.

Spray irrigation may interfere with the normal balance of plant food constituents and also with the pH of the soil. Cannery wastes are commonly high in organic matter and in nitrogen (both organic and ammonia nitrogen). It has already been mentioned that application of lime may be required on clay soils, but lime will also be required on almost all types of soil to assist with the decomposition of humus and to adjust the pH. The soil must be examined locally and adjusted as necessary. Nitrogen will not be required; periodic applications of lime will almost certainly be necessary; also it may be necessary to add Phosphates and Potash to restore the balance. The effect of leaching on the trace elements in the soil has not been assessed and no information can be given on this point.

It is reported that wooded areas are very good as "covers" for irrigation, and there is some published information on this. Instances of damage to some types of trees have been recorded. Those who have such areas available should investigate this possibility more fully.

Spraying Installation and Equipment

Having discussed the land and cover crop necessary and desirable, we will pass on to the equipment and lay-out required. In this connection I will draw reference to our own installation at Brantford, Ontario, as an example or comparison.

In the first place it is necessary to exclude all sanitary waste from the irrigation system; this must be treated in septic tanks in the normal way. Storm water from roofs and yards together with "clean" water from the plant (e.g. cooling canal drainage) can be disposed of through the established channels as it may cause embarrassment on the basis of volume if included in the irrigation system.

Screening

Factory wastes must first be screened to take out the solid matter. For this purpose either a vibrating (flat) screen or a squirrel cage revolving screen is used. The object must be to remove particles of the size which would tend to clog the nozzles, and the size of the screen necessary is, therefore, partly determined by the size of sprinkler opening to be used. 10-mesh screens are commonly used; in our case, we originally had a 20-mesh screen, but we have now increased this to a 14-mesh.

This primary screening is normally done at the plant, and from this point it remains to get the liquid to the irrigation site. Often the irrigation site is some distance from the plant (in one case, where the cannery is in the centre of a town, the distance is three and a half miles; often the distance is in excess of a mile), and pumping is necessary. In choosing the size and type of pipe to be used here the quantity and characteristics of the liquid must be borne in mind. In our own case, where the irrigation site is adjacent to the plant, we were able to discharge into a concrete storm sewer which conveys the liquid by gravity directly to the site; then in order to get our irrigation reservoir all we had to do was break into this storm sewer on the site.

Irrigation Reservoir

This should be kept as small as practicable; on the one hand it will be required to take care of normal fluctuations from the plant, but it must not be large enough that it allows any degree of stagnation with its consequent odour. Commonly a reservoir is designed to hold half to three quarter of an hour's supply. If there is any possibility of children or livestock being near to this reservoir then an adequate fence must be built around this; this is important as the dangers are apparent. In our case, working in sand, we found it necessary to shore up the sides of the reservoir with plank; we also soon found it was necessary to build a catwalk out to the centre of the reservoir with a rope block on the end so that the suction line and screen of the irrigation unit could be pulled up for cleaning.

Irrigation Pump

The capacity required here is of course determined by the amount of liquid to be disposed of, and the discharge pressure required will depend on the type of sprinklers decided upon. Pumps can be electric, gasoline or diesel depending on the economics of the situation. An electric pump will, of course, require less attention in the ordinary way, but when calculating the cost of this bear in mind that there are two factors involved; one, the annual service charge, and the other the actual hydro consumption. The choice will largely be determined by the length of the operating period each year and how permanent the installation will be.

The pump commonly draws water from the reservoir by suction; here the lift should be kept as low as practicable. In other cases, particularly where the installation is of a permanent nature, it is possible to build a pit alongside for the pump which can then be supplied by gravity. In cases where a suction lift is necessary check on the method of priming. In all cases a secondary means of screening at the inlet is necessary, either by constructing a screen box separately or as we did, by attaching an enlarged screen box directly onto the end of the suction pipe itself. The screen in this case can be of ¼" up to ½" wire mesh. Most commonly, particularly at plants operating only seasonally, a pump and piping system designed for agricultural purposes is used. We have such a system in use, using a 6" pump fitted to an industrial gasoline engine of 250 cubic in capacity (116 b.h.p.) This has a system of exhaust priming, is water cooled, and is fitted with automatic controls to stop the engine on (a) low oil pressure (b) high radiator temperature, and (c) low discharge pressure - indicating that the pump has lost its prime or that the reservoir is empty. Gas consumption is in the region of 2½ gallons per hour, on which tax is recoverable (for agricultural purposes). We have fitted a 200 gallon gas supply tank, feeding by gravity, and this tank is serviced on the site by the local Agricultural agent. The capacity of this pump, at the suggested maximum operating revs, is:-

500 U.S. gallons per minute at 150 lbs.

or

925 U.S. gallons per minute at 75 lbs.

Some plants consider it necessary to have a second pumping unit as a stand-by; this again depends on the local circumstances and on the length of the season.

Piping and Sprinklers

Piping consists of a main trunk line from the pump, from which the "laterals" branch. These laterals carry the spray nozzles spaced at the required distance. Piping throughout can be from a selection of materials, but the laterals, which have to be moved more or less frequently are usually of some light weight material such as aluminum with quick and simply operated couplings. Some installations, however, have permanent laterals, valve-controlled; in some cases these are even buried underground in situations where winter operation is required and there is danger of frost.

Sprinklers are usually of the self-actuating, revolving type. A selection is available, but it is not advisable to have nozzles of less than ¼" opening or these tend to clog. Sprinklers can either be "low" or "high"; my own individual preference is for the high type, as it is felt that the throw is increased, and that more direct evaporation to the air is accomplished.

In our case we use a 5" main trunk, which supplies 2 - 4" laterals. The spray nozzles are 9/32", on risers 42" high; the nozzles are designed to give an average discharge of 22½ gallons per minute at an operating pressure of 55 lbs. on the last nozzle in the line.

The risers were originally of aluminum, but these tended to snap off at the base through vibration, so we have replaced these as necessary with galvanized piping. Each of the laterals is fitted on the end with a flush plug which is opened once or twice on each shift to flush out the solid matter which tends to collect at the end of the lines. We do find it necessary to keep a piece of wire handy, and a raincoat and Sou'Wester so that it is possible to clear nozzles which do plug up occassionally.

Operational Details

We had a real disposal problem on our hands before we installed the spray irrigation system, which we did in 1956. Fortunately, conditions were ideal for this and could seldom be duplicated. We are able to rent 20 acres of land which is part of a wartime training aerodrome immediately adjacent to the factory - in fact we do not in practise use more than half of this. The land has a slope of approximately 2% and is pure sand for at least 80 feet deep - a rather coarse sand from the sub-soil down. The vegetation was originally mostly coarse high weeds, so fortunately we did not have to irrigate to the full extent the first year.

We found that the first effect was to kill off the weeds. Since that time the vegetation has completely changed and is now a well-developed sward of broad-leaved indigenous grasses; we did not seed at all. The capacity of this soil and cover to absorb water is terrific; and as I have already mentioned we find that we can irrigate for a period of 3 - 6 days without moving the sprinklers, and even so no odour is apparent. Even after a soaking of this magnitude one can walk on the land 12 hours after moving the sprinklers and not get one's shoes wet, and within 48 hours the surface is completely dry. One other point in our favour (just for the benefit of those who may be inclined to be envious) is the fact that this particular airfield is said to have the best air currents in the whole of Canada for gliding, and is used regularly for this purpose, including the National Championships; this air turbulence no doubt assists evaporation.

We have 500 gallons of liquid to dispose of per minute, and for this we have 24 sprinklers (of $22\frac{1}{2}$ gallons each). The pump is not, of course, working to capacity, since we only operate at a discharge pressure of 60 - 65 lbs., therefore the wear and tear on the motor is not severe.

We have three possible moves for the laterals, but sometimes if we are only operating a single shift it is only necessary to use two alternative positions. On the other hand, if operating around the clock we have a possible fourth position (or more exactly $3\frac{1}{2}$ -) for use if necessary.

One of the maintenance staff on each shift checks the oil and greasing. The shift engineer is in a position to observe if the motor cuts out during the period of operation, and will report this immediately; normally we try to adjust the revs so that the rate of withdrawal just keeps up with the supply.

In 1958 our cost for gasoline amounted to a figure equivalent to 0.18¢ per case. Capital investment in the equipment, new, would amount to approximately $4500.00, but with the amount of agricultural irrigation being practised at the moment it is possible to pick up some reliable used equipment at a better price than this; in fact we ourselves did just this.

References

1. <u>Canham, Robert A.</u>
   "Waste Handling Problems Common to the Canadian and U.S. Canning Industries".

2. <u>Ebbert, S. A.</u>
   "Spray Irrigation of Food Plant Waste Waters".

3. <u>Sanborn, N. H.</u>
   "Disposal of Food Processing Wastes By Spray Irrigation".

EVALUATING A SOIL FOR THE DISPOSAL OF WASTES BY SPRAY IRRIGATION

Dr. L. R. Webber

The objective of waste disposal by spray irrigation is to apply the maximum amount of water a given soil can absorb without causing surface run-off, contamination of the ground water, or injury to plant cover. To achieve the conservation of our soil and water resources it is essential that the disposal program not render a soil useless for plant growth through the addition of sterilants, excess soluble salts, undesirable microorganisms, or excess water causing anaerobic conditions.

Canham has described three methods for the surface disposal of wastes: (a) impounding lagoons; (b) absorption beds in gravel deposits; and (c) ridge and furrow. For these methods to work he set forth the following requirements: (a) no soil-clogging solids in the waste; (b) a soil with a rapid water-absorbing capacity; (c) level ground for even distribution; and (d) sufficient area to permit a drying-out period. (3)

Reports on the water-spreading programme in California describe the methods used to overcome a problem in the surface permeability of soils. The inability of such surface treatments as applications of slowly decomposing organic wastes and soil conditioners to provide satisfactory increases in the infiltration rate led to studies on the effect of deep subsurface soil treatments. Trenches or pits 10 feet wide, 10 feet deep and up to 1000 feet in length were generally successful when in contact with an aquifer along the sides and bottom. (8) A sand filter, grain size 0.5 to 1.6 mm., partially alleviated surface clogging. (9)

Numerous research reports dealing with subsoiling, chiselling, mole drainage, and pan breaking have been published. Generally none of these practices improved the moisture regime or aeration for a reasonable length of time in plastic clay soils. There is an exception in breaking up the tillage or traffic pans that occur just below the layer of normal cultivation. (1)

For spray irrigation of wastes the ideal soil is level, will absorb large quantities of water, support a luxuriant vegetation, and freely drain the excess water through the sub-horizons. Many soils will meet these limits; others require special management before they meet, in part, the ideal soil. The purpose of this paper is to outline: (a) a field system of classifying soils in terms of suitability for waste disposal; (b) the laboratory tests that are essential in characterizing the moisture absorption and moisture release by soils; and (c) a crop cover management programme.

Soil Survey

The soils have been mapped and classified, and reports prepared for 30 counties and districts in Ontario. In many instances these reports will adequately describe the suitability of a soil for spray irrigation purposes; in other cases it will be necessary to conduct a special soil survey of the proposed area and delineate the soil complexes. Knowing what soil type is in the area, we are able to place the soil in one of the following classes:

I. Suitable - - - where the waste may be applied at rates similar to those used in farm irrigation. Such soils are the well drained sandy loams, loams, silt loams, and some clay loams.

II. Limited Suitability - - - where several soil properties, like particle-size distribution, soil moisture properties, volume of voids, or drainage features require further characterization in the physics laboratory.

III. Not Suitable - - - because of rolling topography, shallow depth of soil over bedrock, particle-size distribution usually too fine as in days, or unsuitable soil moisture properties.

Of the many soil properties that lend themselves to measurement either in laboratory or under field conditions, the three principal ones are: (a) infiltration, or getting the water into the soil; (b) permeability, or moving the water through the soil; and (c) the storage capacity of a soil. These properties are direct functions of the volume relationships - the volume occupied by air and/or water at varying degrees of saturation. As all of the water will not drain away, we depend upon a vegetative cover to further reduce the moisture content of a soil.

Infiltration

Infiltration is defined as the maximum rate at which a soil will absorb water that is impounded at a shallow depth over the surface. The rapid reduction in the infiltration rate by cultivated soils is accompanied by the formation of a thin compact layer at the soil surface. The drop during the first hour in the infiltration rate of a plot planted to corn was nearly double the rate when the cover was grass, Fig. 1. The compacted layer was due in part to the beating effect of crops of water and a sorting of the soil particles to form a non-pervious soil. Even sandy soils may become impermeable because of a crust formation. The greater the vegetative canopy and the more extensive the root system the better will be the infiltration rate, Fig. 1.

Certain soils change appreciably in volume when subjected to a change in moisture. As a soil swells or increases in volume, it does so largely at the expense of the soil pores. Some of the large pores essential to proper drainage becomes capillary in size while smaller capillary pores are sealed to the movementof water. (2)

Some decline in the infiltration rate has been associated with microbial activity in the surface soil. It has been observed that the rate levelled off at a higher value when the microbial population was reduced by chlorination. (5)

Permeability

Permeability is defined qualitatively as the state of a porous medium relating to the readiness with which such a medium conducts or transmits fluids. The ease with which a soil transmits water under a gravitational force is determined largely by the volume occupied by large pores, often referred to as aeration porosity. A characterization of aeration porosity is made in the laboratory by saturating a soil core and then measure the volume of water removed as the tension is increased. de Vries has shown that as the bulk density of a soil was increased by compaction more water was held in the soil at a given tension, Fig. 2. Compression effected a decrease in the volume occupied by large pores and caused an increase in the tension necessary to drain the core. (4)

Some fine textured subsoils are so low in aeration porosity that the tile drains will not function and remove the surplus water. Subsoiling or mole drainage icreases the aeration porosity for only one or two growing seasons as the clay when saturated settles back to a consolidated state.

Storage Capacity

The maximum amount of water a soil can store is determined by the field capacity value, which is a function of the particle -size distribution. At some clay content a soil will reach its maximum storage value, Fig. 3. When a soil is wetted beyond the field capacity value, the additional water passes through the soil beyond the use of plants. It should be noted that the moisture content at the permanent wilting point also increases with an increase in the colloidal content but the shape of the two lines is quite different. Silty soils normally retain more water available for plants than clays and sands, Fig. 3.

For waste disposal purposes the well-drained soils of intermediate texture are preferred because of their storage capacity and adequate profile drainage.

Vegetative Cover

Experience has shown that a vegetative cover is an important feature of a programme as spraying onto bare soil will not achieve the degree of absorption often required. (3) While discussing infiltration, the merits of a grass cover were pointed out: increase the infiltration rate, prevent crusting, alleviate the clogging of soil pores, and improve the porosity relationships through a stable soil structure.

Evaporation from a bare and continuously moist soil will be equal to or better than from a vegetation-covered area. (6) However, the evaporation losses are confined to relatively shallow depths and are proportional to the rate at which water comes to the surface. A dry surface virtually prohibits further evaporation; the loss of water continues in minute amounts by diffusion through the soil pores. Capillary conductivity of water to an evaporating surface is very small once the soil has reached its field capacity value.

Transpiration is the key process in the utilization of water by plants and involves the evaporation of water in the air spaces in the leaf and its diffusion out into the surrounding atmosphere. The rate of transpiration follows a daily cycle that tends to parallel light intensity and increases with increasing length of day and daily mean temperature.

Several methods are available for estimating the evapotranspiration (evaporation plus transpiration) for crops. The Thornthwaite method, based on average monthly air temperatures and a correction factor for geographic latitude, will serve to indicate the volumes of water that may be involved. (7)

Mean Monthly Temperature, Rainfall and Estimated Evapotranspiration for Guelph, Ont.

Month	Mean Temp. °F.	Rainfall (inches)	Evapotranspiration (inches)
April	42	2.38	1.2
May	54	2.72	2.9
June	63	2.84	4.4
July	68	3.07	5.0
Aug.	66	2.86	4.4
Sept.	59	2.50	3.1
Oct.	48	2.39	1.7

The selection of a crop will depend on soil characteristids and the amount of water to be applied. Corn, spring grains, peas, many clovers, and some grasses are easily damaged by excess water. Reed canary grass will withstand flooding, is adaptable to a wide range of soil conditions, and with proper management continues growing all season.

Proper management implies adequate levels of soil fertility at all times during the growing season, correction of soil pH if feasible, and a clipping or mowing programme. A dense cover of grass will use more water when it is actively growing than when it is approaching maturity. Consequently, a grass cover must be mowed during the season and given one to two weeks, depending on soil moisture conditions, to recover and approach its maximum rate of water use before the irrigation starts. A well-designed disposal programme would include an off-and-on period of irrigation to permit the grass to recover, exdess water to drain away, and near-normal surface conditions to re-establish. The duration of the off-period would be something of the order of 5 to 8 days for a clay soil that had received 3 to 5 inches of water, spray plus rainfall. These limits depend on crop, soil, and especially the climatic conditions.

Summary

In the preceding discussion we were concerned with the disposal of water that had met certain standards of purity or safety. We recognize the highly technical aspects in filtering, purifying or decontaminating, and the importance of the biochemical oxygen demand. We have indicated the important soil properties that determine the amount of water a given soil can handle and stressed the importance of a cover crop.

Soil scientists are interested in the conservation and proper use of our soil and water resources so that soil shall not be made unproductive for the regionally adapted crops and water shall not be wasted nor made unfit for animal or plant consumption. Further soil research will provide the tolerances of soils and plants for what are now classed as foreign substances in the waste water. Research will assist in the design of disposal systems that use the water for the irrigation of marketable crops and will provide economic means of reclaiming the surplus water.

References

(1) Baver, L. D.:
"Soil Physics."
John Wiley and Sons, 1956.

(2) Browning, G. M.:
"Volume Change of Soils in Relation to Their Infiltration Rates."
Soil Sci. Soc. Amer. Proc., 4: 23-27. 1939.

(3) Canham, Robert A.:
"Current Trends in Handling Canning Waste."
Proceedings of the Fifth Annual Water Symposium on Water Pollution.
Louisiana State Univ., Baton Rouge, La., 1956.

(4) de Vries, Jan:
"The Effect of Artificial Compaction and Previous Cultural Ttreatment on Some Moisture Properties of Soils."
M.S.A. Thesis, Univ. of Toronto, 1959.

(5) Johnson, Curtis, E.:
"Effect of Chlorination on Some Physical and Biological Properties of a Submerged Soil."
Soil Sci. Soc. Amer. Proc. 22: 244-246. 1958.

(6) Penman, H. L.:
"Natural Evaporation From Open Water, Bare Soils and Grass."
Proc. Roy. Soc. A. 193: 120-145. 1958.

(7) Sanderson, Marie:
"Moisture Relationships in Southern Ontario."
Sci. Agr. 30: 235-255. 1950.

(8) Schiff, Leonard:
"The Status of Water Spreading for Ground Water Replenishment."
Trans. Amer. Geophys. Union. 36: 1009-1020. 1955.

(9) Schiff, Leonard and Johnson, Curtis E.:
"Some Methods of Alleviating Surface Clogging in Water Spreading With Emphasis on Filters."
Trans. Amer. Geophys. Union. 39: 292-297. 1958

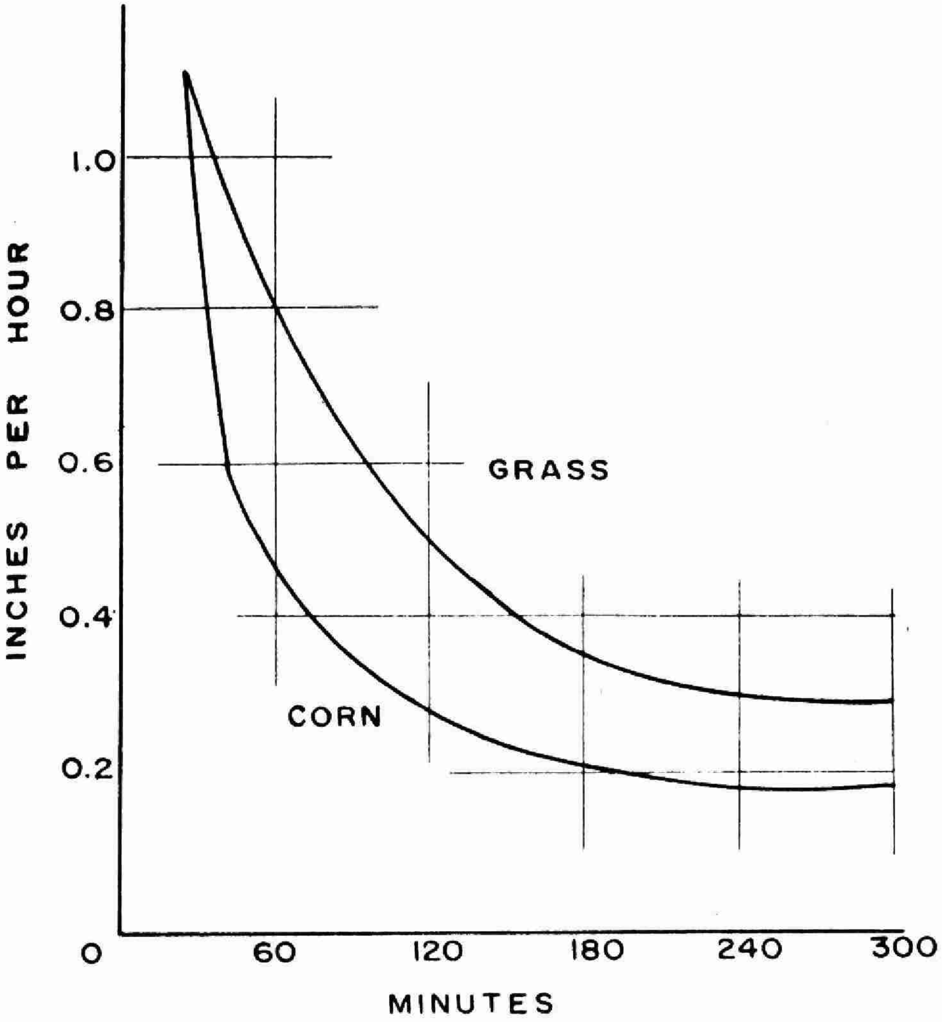


Fig. 1 - The change in infiltration with time under corn and grass covers.

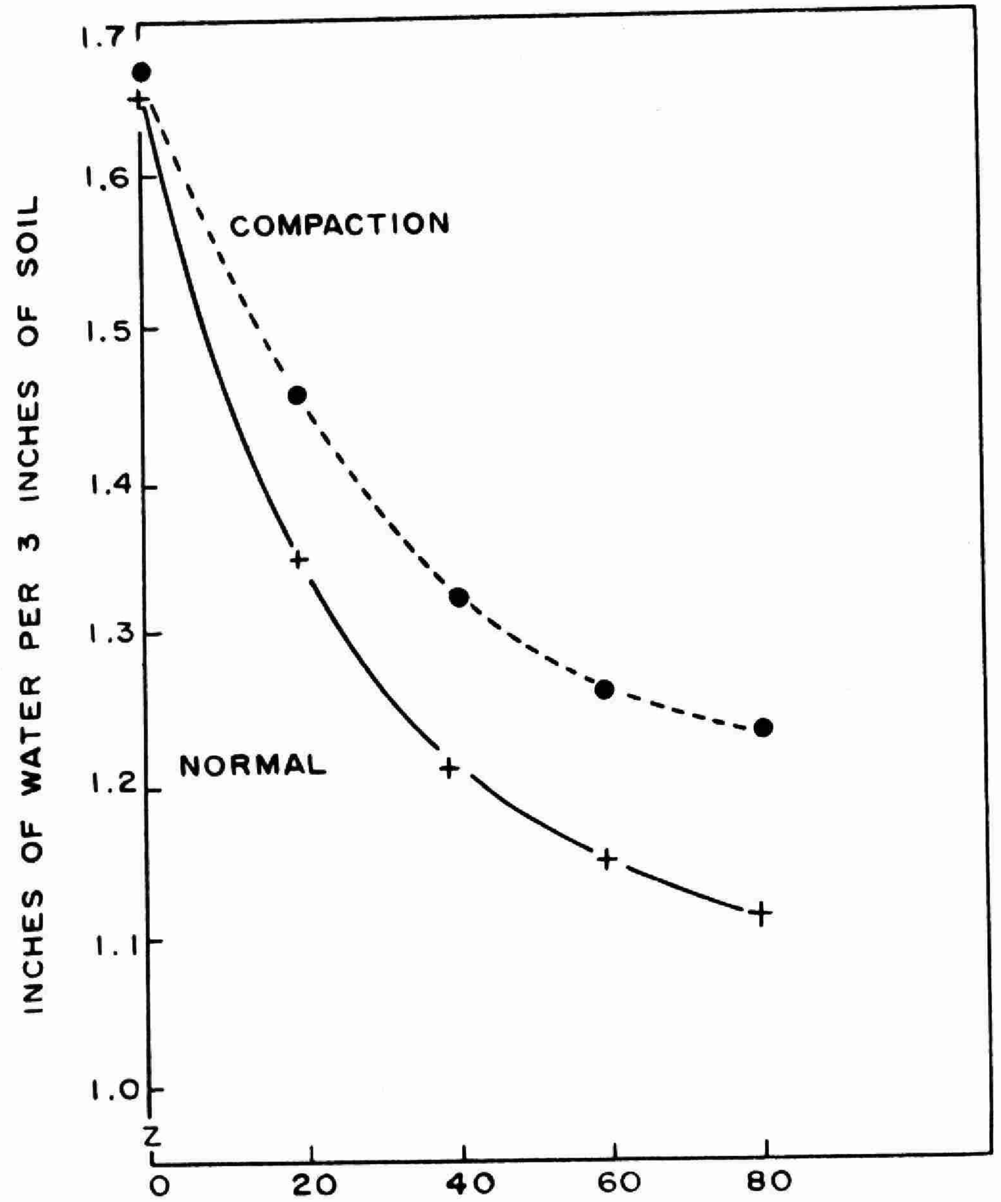


Fig. 2 - The water-holding characteristics of a soil as affected by compaction (after de Vries, 1959).

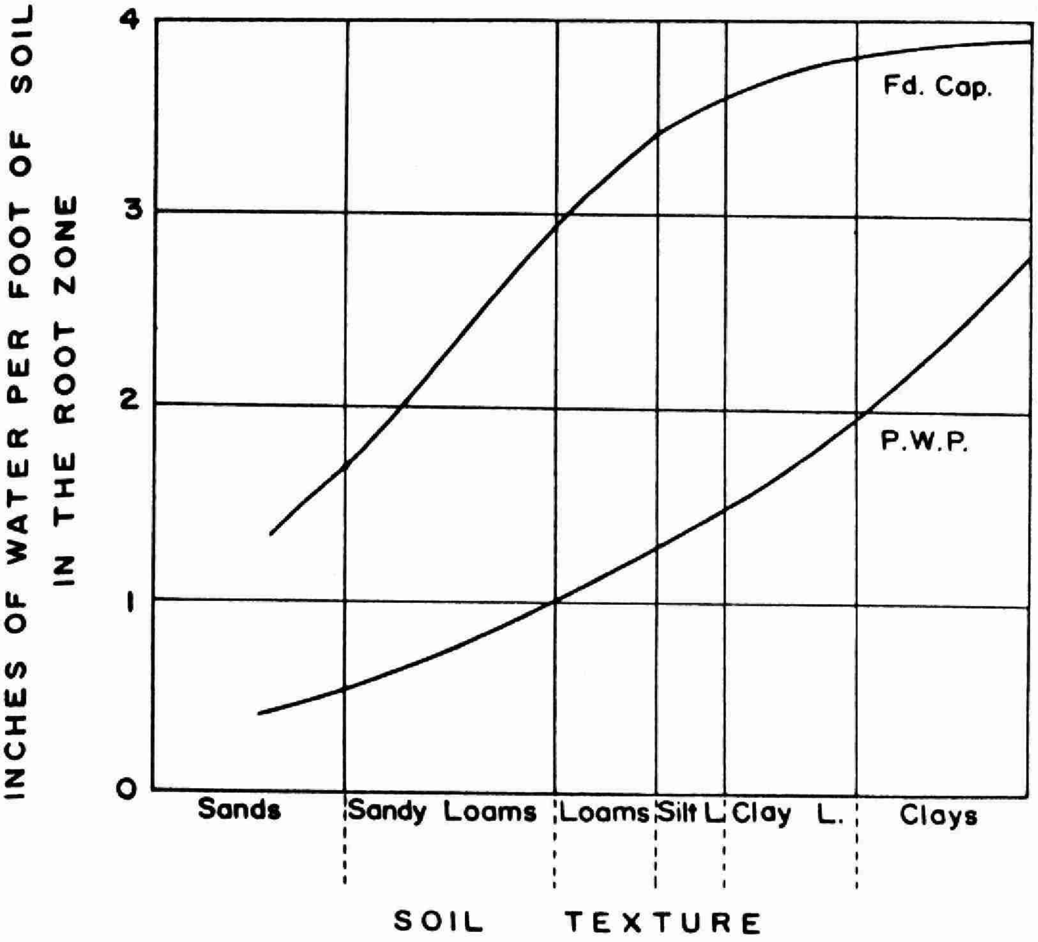


Fig. 3 - Water-holding characteristics of soils with different textures (after U.S.D.A. Yearbook, 1955).

TURBIDITY EFFECTS IN NATURAL WATERS IN RELATION TO ORGANISMS AND THE UPTAKE OF RADIO-ISOTOPES.*

Dr. J.B. Lackey
G.B. Morgan
O.H. Hert

Introduction

Silt in a natural water is almost universally objectionable to man. We want our drinking water and the water we use for our household and our cattle to be clear and sparkling. We want such water for swimming, to fish in, and upon which to boat. And yet man is generally the cause of muddy water as evidenced by soil conservation programs and by accounts of the first settlers upon the banks of natural waters. This is not entirely so--the Missouri has long been known as "Big Muddy" and the delta of the Mississippi ante-dates the coming of either Indian or white man.

It is not so obvious that silt is equally objectionable to organisms, which live in water. Yet a modicum of investigation indicates this frequently to be the case. Muddy streams generally have a quite limited fish population, both as to numbers and kinds. Spawning beds in sandy, gravelly or rocky stretches are abandoned when they become blanketed by silt. One of the reasons for the depletion of the shad run in the Schuylkill River of Pennsylvania was the large amount of coal dust from upstream mining. This spread far downstream and only recently has its dumping been stopped and the accumulated silt banks removed. While it is recognized that the sewage pollution of the lower river at Philadelphia was an effective barrier to the shad, the river clean up inaugurated by the city and state was deemed poor unless the coal mining dust problem be included.

Silt as a Pollutant

For many years our definition of stream pollution largely neglected physical factors such as silt. Attention was centered on toxic chemicals, and organic matter exerting a high oxygen demand. Turbidity might have been due to some of these factors, but it was recognized as often partially due to bacteria and oth-

---

*This research was sponsored in part by grants from the National Institutes of Health, Washington, D.C., and the Atomic Energy Commission, Washington, D.C.

er micro organisms. Thus a laundry waste has a turbidity due to colloids but also to enormous quantities of bacteria, colorless flagellates, ciliates and rotifers. Undue fertilization of a receiving water by largely inorganic substances frequently produces undesirable turbidity due to blue green algae and green flagellates. Turbidities or blankets of this type may be quite undesirable. Frequently they are transient, but sometimes they are long lived. As examples of such blanketing effects, complete coverage of natural waters by water hyacinth and various types of floating vegetation loosely termed duck weeds is cited. Objectional submerged blooms include minute green algae, small flagellates and diatoms such as plagued oyster production in Great South Bay on Long Island.

The above examples are undesirable because they operate to exclude a generalized flora and fauna which forms the first trophic level of productivity. It is postulated that excessive silt operates in the same manner. Perhaps it might be better to substitute physical factors, for the term silt has a rather limited connotation, whereas this discussion might involve such matters as coal dust, fibers as from asbestos production, clay, sand and loam.

Licking River Studies

Personal attention to effects of water borne turbidity dates back to studies of the Licking River of Kentucky in 1940. At that time it was noted the fork of the Licking which rose in the hills of Eastern Kentucky was subject to abrupt changes in turbidity. No measurements of the amounts of silt loading were undertaken but one week the stream would be clear, the next muddy. Coincident were abrupt quantitative and qualitative changes in the suspended microbiota of the stream. These occurred even when the water level rose but slightly. The habit of plowing and pasturing the steep hillsides left them very susceptible to erosion, so that a little rainfall produced a heavy silt load.

The West Fork of this river drained a Bluegrass area, and usually carried some colloidal clay, so that it almost never attained the clarity the other fork did at times. It was a well fertilized stream however, and its silt load was rarely heavy, whereas its plankton crop was usually quite dense. When both streams were clear, this plankton carried down as far as the steel mills near the junction of the Licking and Ohio. But when the East Fork was muddy, the plankton of the West Fork was obliterated almost at once after the junction. It was noted that the Chlorococcales, Euglenophyceae and Cryptophyceae, together with blue green and filamentous green algae disappeared first. Certain Volvocales, Chrysophyceae such as *Chrysococcus*, ciliates, and curiously, colorless flagellates were more resistant.

The data on which these statements are based have never been satistically treated, primarily because of a lack of data on attendant environmental factors. However, a study was made (1) of the White River of Indiana above Indianapolis and it was shown that at times of low flows, clarity, and high temperatures, an extremely rich plankton developed. Other factors taken into account excluded such matters as pH, the nutrient cycle, etc. A very extensive literature could be cited on the N-P ratio, sources of fertilization in a natural water, the cycle of organisms, blooms and other pertinent matters. The reader is referred to standard texts (2,3,4) for some such matters. Nevertheless, observations over a long period of time have substantiated the restrictive effects of silt, especially silt which settles out readily when the water is stilled.

General Effects of Silt

There has been a great amount of interest in silt of all sorts as a factor in reducing stream and lake productivity in the Pacific Northwest. Some of the interest has centered on light reduction as affecting algal plankton production. Some of it has centered on blanketing of fish spawning beds and the destruction of eggs. And some of it has centered on chemical changes produced in the waters affected. There has been far too little experimental work in the field and in the laboratory, for a really good story.

Since silting from natural erosion antedates man, a general summary regarding it is in order. At the base of the productivity pyramid is bacterial action. Most of this is independent of light, much of it independent of oxygen. Barring toxic substances in silt, bacterial activity is continuously tending towards mineralizing any organic part of the silt - leaves, dead organisms - and producing a stable bottom deposit. That silt is deposition often exceeds the rate of this bacterial function is self evident.

There are many protozoa, rotifers, worms and other organisms at the mud-water interface which feed on both bacteria and organic debris, and are likewise independent of light and oxygen. It seems this independence of oxygen is a characteristic not generally recognized, but it soon becomes apparent to a student of the mud-water interface. The activities of these higher organisms also tend toward stabilization.

With regard to chlorophyll containing forms - chlorophycean algae, diatoms, attached algae - the effects of silt are several, mostly bad. Light is diminished, and while many algae require very little light for photosynthesis, productivity is diminished. Many algae are carried to the bottom by adsorbed silt, and there buried. Attached algae are buried, or torn loose by mechanical action. But it requires an intensive "standing" by water borne silt to scour a rock free of a coating of diatoms; Coscinodiscus will readily attach to sand particles which are in suspension, while species of Melosira at times form a blanket over a bottom of mud.

Silt also sharply diminishes populations of attached but not emergent green higher plants. This is especially true of Charales, Utricularia, Potamogeton and like plants. Emergent plants are not too greatly affected. Krustaceans such as Daphnia or ostracods, small shellfish, snails, insect larvae and fish are quite adversely affected.

The White River Studies

With this background in mind, and with the picture of the White River situation above Indianapolis, analyses of the plankton content of White River stations below Indianapolis were begun in 1956. Monthly samples were collected by personnel of the State Board of Health, and a liter taken from the thread of the stream (which insured a well mixed sample) was fixed by adding 5% formalin. After standing until sedimented, the supernatant was decanted, and the organisms were identified and counted by the drop method.

The data is too extensive for more than summarization in this paper. Relevant factors included river stage, turbidity, temperature, pH, methyl orange alkalinity, total iron, chlorides, fluorides, sulfates, phosphates (ortho), coliform counts, and other information.

It was noted that increased turbidity meant a jump in the coliform count. Presumably the total count of bacteria also went up. But Sphaerotilus strands invariably diminished in the samples. Despite a usual large quantity of sulfates, sulfur bacteria were almost never found, especially in heavily silted samples. Recognizable bacteria in the samples, and as determined by the State Board of Health, seemed independent of temperature.

If the water was clear, there was always a fairly large species number, regardless of temperature. But larger populations were found at higher temperatures. Thus at Elliston, on October 4, 1956, the river had a turbidity of 33 p.p.m. and contained in excess of 50 species of identified microbiota distributed as follows:

Blue green algae	2 species	72,000	per	liter
Volvocales	3 + "	529,000	"	"

Other green algae	19+	species	52,516,250	per	liter
Diatoms	5+	"	12,462,000	"	"
Euglenophyceae	11+	"	1,424,000	"	"
Chrysophyceae	2	"	288,000	"	"
Cryptophyceae	1	"	160,000	"	"
Ciliates	2+	"	7,000	"	"
Rotifers	2+	"	750	"	"

The sediment in this sample was green and the turbidity was largely due to plankton. The picture might be termed typical for a low, clear water stage with relatively high temperature. A population of 67459 plankter per ml. is not unusual for well fertilized (eutrophic) rivers under such circumstances especially when the greater part is due to very small Chlorophyceae such as Chlorella, Selenastrum, Scenedesmus and allied genera, and to the usual summer bloom of the diatom Cyclotella. There is actually no indication of stream condition at this point other than its fertility. The large number of Euglenophyceae is due principally to E. pisciformis which probably indicates recent organic enrichment.

The above analysis could be repeated many times for the White River when clear. However, 1957 was a year when precipitation was up about 16 inches (16.01) above the normal of about 40 inches. In consequence, many of the samples were heavily silted, and analysis was difficult. When silt is heavy, many organisms cannot be found. Euglena is usually a round ball, often closely invested by silt, undoubtedly held by the mucoid secretion of the organism. A few species, Chrysococcus rufescens, and Cyclidium for examples seen unaffected, but their numbers are lower. As for example of the effects of silt produced by heavy rains the following data may be cited:

	Martinsville		Spencer	
Date:	4-11-53		3-7-57	
Turbidity:	115		110	
	Species	No. per ml.	Species	No. per ml.
Rotifers	0	0	1	1
Coperods	0	0	1	1
Blue green algae	0	0	0	0

	Species	No.per ml.	Species	No. per ml.
Volvocales	1	10	1	27
Chlorophyceae	2	68	3	519
Diatoms	4	89	5	1000
Chrysophyceae	2	21	2	272
Euglenophyceae	0	0	3	34
Dinoflagellates	0	0	1	1
Totals	9	188	17	1855

The Spencer sample, taken in March, has a much larger population despite its lower temperature. The Spencer sample for April had a turbidity of 550 p p m, and no organisms at all were found in the material. Similar high turbidity samples produced about the same result regardless of the time of year when taken. Of course dilution enters the picture; the river stage in March was 5.09 and in April was 16.08 at Spencer. That it is silt however, and not dilution, is indicated by the Licking River results.

Laboratory Experiments

Table I shows results obtained by using six silt types to carry organisms out of suspension. A dense bloom of *Golenkinia radiata*, *Euglena polymorpha* and *E. pisciformis* from a sewage lagoon was added to the top of a column of seven liters of dechlorinated tap water. They formed a layer about three inches deep, since the culture was about 25°C and the tap water 20°C. After the bloom had stabilized, about three minutes, the silting agent was poured in, gently. The bloom was immediately dispersed downward and usually the top three inches cleared up within 20 minutes.

TABLE I

EFFICIENCY OF SIX PHYSICAL AGENTS IN REMOVING *GOLENKINIA RADIATA, EUGLENA POLYMORPHA AND E. PISCIFORMIS FROM A 5 FOOT WATER COLUMN.

	Population, top 3 inches, per ml.				
Physical Agent Dosing rate, 1000 p p m	Initial at Time of Dosing	After 20 Minutes	After 24 Hours	Time For Suspensoid to Reach Bottom. Minutes	Time For Suspenoid to Clear. Minutes
Sand, 200-210 u	84000	1	3	5	120
Sand, 74-140 u	84000	6	8	8	180
Sand, <74u	84000	180	100	10	180
Muck	5800	22	32	3	24 hrs.
Clay, dried (settles fast)	14160	0	14	4	24 hrs.
Clay, not dried (settles very poorly)	107000	30		30	△

*Golenkinia not counted, only the two Euglena species.
△ Water did not clear up well.

At this time the population remaining at the top was counted. This varied from 0 to 180 *Euglenas* per ml. with usually about 2-3 times as many *Golenkinia*, although the latter were not counted. There were 7 liters in the tube ± 300 ml., and if the Euglena population had been evenly dispersed after adding the silt, each ml would have contained 1200, for three sizes of sand; 83 per ml. for the muck; 202 for the dried clay; and 1530 per ml. for the undried clay. Evidently all six classes of silting materials were highly efficient in carrying down the *Euglena* species. The muck was least efficient, removing about 3/4 of the population. The smallest sand size was next least efficient removing about 20 Euglenas to every three left suspended. It must be noted that these sand particles are little larger at maximum, and much smaller at minimum than the *Euglenas* and that they do not readily agglutinate about the *Englenas* as do the other materials. The wet clay, on the other hand does so agglutinate, and this clay left only one *Euglena* at the top for each 510 it carried down.

Euglena has a mechanism for hydrostatic adjustment in its flagellum. Also, it is positively phototropic, and there was a light above the tube in which these experiments were carried out. Nevertheless there was very little recovery of the top populations at the end of 24 hours. Evidently the silt removal mechanism is quite efficient. It is not inherently toxic, because bloom populations added gently above these materials show no decrease in 24 hours. Apparently it is burial in the silt which is ruinous. And yet there is enough plankton left for seed, so that after a suitable reproduction period, the organisms again thrive.

Silt, Microorganisms and Radioisotopes

Several workers (5,6,7,8) have investigated the absorption and adsorption of radioactive isotopes by microorganisms. Yet little has been done to determine what happens to these organisms and radioactive isotopes resulting from the action of non-living turbidity in rivers and streams. In general it is felt that the flora and fauna of a stream removes most of the trace elements, whether radioactive or not. It can also be shown that the turbidity removes an appreciable quantity of radioactivity both by adsorption and by physically removing the stream's micro-population.

To give support to the above ideas laboratory investigations were initiated. While these experiments do not duplicate stream conditions they do offer sound evidence regarding the removal of these dissolved radioactive compounds.

Five types of turbidity-causing material were used. These are as follows: 1. Muck, 2. Silt, 3. Clay, 4. Fuller's earth, and silt. Muck was collected from a rich deposit in a low boggy area. The muck was suspended in water and the sand removed by settling. The concentration of solids was determined and appropriate dilutions were made. Silt was collected from the bottom of a stream and the sand removed as for muck. Fuller's earth was the usual commercial grade reagent.

The silica sand used in these experiments contained very little foreign matter. This sand was ground and then screened to obtain the desired size.

Clay was obtained from one of the phosphate mines in the vicinity of Bartow, Florida. This clay was relatively iron free. The particle size was extremely small which was apparent from its slow settling rate.

Known concentrations of these 5 media were prepared by dilution. To each of the flasks was added a known amount of radioisotope. The flasks were shaken at given intervals to give maximum contact.

The uptake of the radioisotopes was determined by measuring the activity of the dissolved isotope before the experiment and measuring the activity remaining after removal of the suspension. This removal was accomplished by filtering the mixture through a fiber glass mat.

Results are presented in Tables II, III, IV and V.

The results in these 4 tables generally indicate that Cesium and Iron are most readily removed by adsorption. The two exceptions to this are muck and silt which more readily remove Uranium. It is generally accepted that Uranium is adsorbed on the surface of most yeasts and fungi causing death of the organisms. This phenomenom can be explained very easily since Uranium blocks the respiratory enzymes as most heavy metals do.

Silica sand is shown to have less ion exchange capacity than Fuller's earth. Even sand with a diameter of less than 47 microns has negligible ion exchange capacity.

Discussion

There seems little doubt the silt load of many of our rivers is increasing. In virgin territory natural erosion is subject to constant check from a natural and ever increasing cover of vegetation. Even in arid regions which are not increasingly so, natural checks to erosion tend to increase. But wherever man moves in,the tendency is to remove the cover of vegetation, and at times to add other means of silt and sediment production. Mining operations in a stream are a case in point. H.B. Ward in 1938 (9) published a paper on placer mining in the Rogue River of Oregon which was only slightly incriminatory of the practice. The experiments of Reed in the same paper were certainly inconclusive, and it seems quite logical to disagree with most of the conclusions in the whole paper. Certainly those pertaining to the microbiota are open to question. The whole weight of evidence from the works of Knight (10), Ellis (11), Kemp (12), Wallin (13), and various others, while mainly directed at the effects of physical agents on fishes, indicates that silt and physical agents are of a pollutional nature. There are some aspects of turbidity which indicate the picture is not altogether dark (no pun intended). These are that some organisms at the first trophic level live and thrive at the mud-water interface; that silt applied at a rate of 1000 p.p.m. still leaves a seeding of microorganisms in surface waters; and that there is an increase in mineral nutrients (14) from freshly brought in silt. There is also the work of Wallin (13) and Cole (15) to show that clay and wood fiber concentrations have to be very high to injure fishes. These studies led Bartsch (16) to conclude "it seems unlikely that natural turbidities will be directly lethal".

The Proceedings of the Fifth-Symposium-Pacific Northwest on Siltation - Its Sources and Effects on the Aquatic Environment (14), and Bartsch's paper are particularly valuable as overall considerations of the sediment problem. What is especially needed now is direct experimental work on the long time effects of erosion silt on microbiota and on changing the nature of bottoms especially behind impounding dams. We also need long time studies on the effects of pulp and paper sediments on microbiota. It can hardly be argued that the increased numbers of oligochaetes in pulp deposits indicate a healthy condition. They rather represent a survival of the most adaptable. We also need studies on the pros and cons of large plankton populations since the adverse effects of many kinds of blooms are coming to be known.

In most streams light extinction is not a problem to the plankton, because current action keeps them moving, and at least part of the time they are exposed to light. Therefore a main difficulty of plankton organisms is being carried to the bottom and buried. Other difficulties are abrasive action, depletion of oxygen by silt, toxic chemical effects of the incoming sediment, and an upset of the nutrient ratio, as a sudden influx of PO_4- containing sediment so that instead of a possible 20 to 1 NO_3- PO_4 ratio, it becomes 1 to 1 or some such proportion.

Light extinction becomes of great importance to benthic photosynthetic organisms, and such extinction may result from silt or from a dense plankton bloom. This in turn affects the food crop of other bottom dwellers, so that even if the dangers cited above are not present, there may still be indirect adverse effects.

With regard to elimination of radioactive substances, it seems probable that here at least there are some advantages in turbidity, at least for silt or earthy sediments. This arises from an ability to settle out radioactive adsorbed substances; and the settling out effect on plankton which itself has taken up radioactivity. Once a radioactive substance has been incorporated into bottom mud, it is "out of circulation." It may decay there, be tightly bound, or sink deeper into the mud, possibly simply as a result of continued sedimentation. At any rate a highly turbid stream tends to be a decontaminative one, either by dispersal or by the above processes.

References

(1) Lackey, James B., and Eugene R. Hupp.
"Plankton Populations in Indiana's White River."
Jour. Am. Waterworks Assn. Vol. 48, No. 8, 1956.

(2) Welch, Paul S.
"Limnology"
The McGraw-Hill Book Co. New York. 1935.

(3) Whipple, George Chandler. Gordon Maskew Fair and Melville Conley Whipple.
"The Microscopy of Drinking Water."
John Wiley and Sons. New York. 1947.

(4) Gessner, Fritz.
"Hydrobotanik"
Veb Deutscher Verlag der Wissenchaften. Berlin. 1955

(5) Krumholz, Louis A.
"A Summary of the Findings of the Ecological Survey of White Oak Creek, Roane County, Tennessee, 1950-1953
USAEC, ORO-132 1954

(6) Ophel, I. L.
"Survey of Radioactivity in the Ottawa River, 1953."
CR-HP-572. Atomic Energy of Canada Ltd. Chalk River Project. 1954.

(7) Gloyna, E. F., E. R. Herman and W. R. Drynan.
"Oxidation Ponds - Waste Treatment Studies."
"Radioisotope Uptake and Algae Concentration."
AEC-3113, June 1, 1955. San. Eng. Labs., U. of Texas, Austin.

(8) Lackey, James B.
"The Suspended Microbiota of the Clinch River and Adjacent Waters in Relation to Radioactivity in the Summer of 1956."
ORNL-2410. Oak Ridge, Tenn. 1957.

(9) Ward, Henry Baldwin.
"Placer Mining on the Rogue River, Oregon, in Relation to the Fish and Fishing in that Stream."
State of Oregon, Dept. of Geol. and Mineral Industries Portland, Ore. 1938.

(10) Knight, A.P.
"Sawdust and Fish Life. 39th Annual Report."
Dept. of Mar. Fisheries, Fisheries Branch. 1907.

(11) Ellis, M. M.
"Erosion Silt as a Factor in Aquatic Environments."
Ecology, Vol. 17, No. 29. 1936.

(12) Kemp. H.A.
"Soils Pollution in the Potomac River Basin."
Interstate Commission on the Potomac River Basin. 1949.

(13) Wallin, I.E.
"The Direct Effect of Turbidity on Fishes."
Bull. Okla. A. & M. Coll., Biol. Series 2, Vol. 48. 1951.

(14) Kelley, Don W.
"Effects of Siltation on Production of Fish Food Organisms."
Proc. 5th Symposium Pacific N.W. on Siltation - Its Sources and Effects on the Aquatic Environment. 1959.

(15) Cole, Arch E.
"Water Pollution Studies in Wisconsin. Effects of Industrial (Pulp and Paper Mill) Wastes on Fish."
Sew. Wks. Jour. 7, No. 1935.

TABLE II

ADSORPTION OF RADIOACTIVE ISOTOPES BY MUCK

Isotope and Chemical Form	Conc. of Isotope uuc/l	Adsorbed Activity, uuc/mg		
		Contact Time		
		1 day	3 days	6 days
$U^{238}O_2(C_2H_3O_2)$	13,071	23	82	111
$Fe^{59}Cl_3$	114,942	292	571	108
$Cs^{137}Cl$	243,902	10	75	58
$Ce^{141}Cl_3$	250,000	16	54	46
$Ni^{63}Cl_2$	15,145	16	24	20

TABLE III

ADSORPTION OF RADIOACTIVE ISOTOPES BY FULLERS EARTH

Isotope and Chemical Form	Conc. of Isotope uuc/l	Adsorbed Activity, uuc/mg		
		Contact Time		
		1 day	3 days	6 days
$U^{238}O_2(C_2H_8O_2)$	13,071	81	122	79
$Fe^{59}Cl_3$	114,942	1,320	1,291	1,360
$Cs^{137}Cl$	243,904	146	158	142
$Ce^{141}Cl_3$	250,000	97	79	74
$Ni^{63}Cl_2$	15,145	13	25	18

TABLE IV

ADSORPTION OF RADIOACTIVE ISOTOPES BY CLAY

Isotope and Chemical Form	Conc. of Isotope uuc/1	Adsorbed Activity in uuc/mg		
		Contact Time		
		1 day	3 days	6 days
$U^{238}O_2(C_2H_3O_2)$	13,071	53	35	63
$Fe^{59}Cl_3$	114,942	268	281	435
$Cs^{137}Cl$	243,902	150	1560	1418
$Ce^{141}Cl_3$	250,000	59	647	695
$Ni^{63}Cl_2$	15,145	7.8	23.9	11.8

TABLE V

THE ADSORPTION OF $UO_2(C_2H_3O_2)$ BY SAND AND SILT

Adsorptive Medium	Particle Size Microns	Solid Concentration mg/ml	$UO_2(C_2H_3O_2)$ Concentration uuc/ml	Adsorbed* Activity uuc/mg
Sand 1	200-210	1	152	47
Sand 2	47-147	1	152	55
Sand 3	< 47	1	152	66
Silt	unknown	0.80	152	192

*Contact time of 6 hours.

EVALUATION OF SCALE-PIT PERFORMANCE

Dr. R. D. Hoak
Mr. H. C. Bramer

Inorganic suspended matter in waste water is considered by regulatory agencies to be a major stream pollutant. In consequence, many states have imposed limitations upon the discharge of such material. These regulations differ widely, primarily because there is no quantitative basis for evaluating the effects of suspended solids on water quality.

It has been claimed quite properly that suspended solids cause damage by clogging stream channels. But streams are obviously overloaded where such conditions occur, and it is improper to infer that it is therefore essential to remove suspended matter almost completely from waste water. Where limitations have been placed upon suspended solids in industrial wastes it has become customary to ignore the presence of natural silt. Thus effluent standards govern gross, rather than net, discharge; they take no account of suspended solids entering industrial plants in the raw water supply.

A recent statistical study (1) of data on suspended sediment showed a good correlation between loads and discharge rates for a number of rivers in the Middle Atlantic States. There was also a good correlation between mean load and drainage area, even though the physiography of the several drainage basins differed considerably. For example, the mean load at Sewickley, just below Pittsburgh on the Ohio river, was 4340 tons/day and at Mound City, Illinois, 950 miles downstream, the mean load was 128,600 tons/day. The relative proportions of these loads that were natural, industrial and municipal was not known, but the close dorrelation between loads and discharge rates suggests that most of the sediment had a natural source.

It is sometimes assumed that suspended solids, whether of natural or industrial origin, will eventually settle in streams. But this cannot really be true; if it were, stream channels would be choked with sediment. Among students of stream sediment it is customary to differentiate the bed-material load from the suspended load. Bed-material flows along stream bottoms, but more or less of it can become suspended sediment, depending upon channel configuration and water velocity. Suspended particles do settle in water at rates dependent upon their size and density, and upon the physical condition of the stream. But much of the settled material apparently does not stay where it drops to the stream bed; it flows at a rate governed by the stream itself and eventually reaches the ocean.

These considerations are important to the steel industry, which has to cohted with a large amount of waterborne suspended solids. The principal sources are blast furnace gas-washer water and rolling mill flume water. These settleable solids are in general recovered effectively in various kinds of sedimentation equipment.

Flue Dust Survey

Where questions arise about appropriate control of a specific stream pollutant, it is elementary that sound conclusions cannot be reached without fairly definite knowledge of the amount, characteristics, and effects of the material to be controlled. Mitigation of the effects of suspended solids has been a concern of the Ohio River Valley Water Sanitation Commission(ORSANCO) for a number of years. The Steel Industry Action Committee, which was formed to co-operate with the Commission in developing satisfactory waste-treatment methods, assigned the subject to a sub-committee for thorough study.

The settleable Solids Sub-committee decided to approach the problem on a factual basis by making an inventory of the sources and amounts of settleable material, and of the methods being used to keep it from flowing into streams. This inventory would provide a measure of the efficiency of current recovery practices and would guide the sub-committee in undertaking further investigations. A flue dust survey was made first, to be followed by one on mill scale.

A questionnaire, with detailed instructions on sampling and analysis, was sent to the 23 mills in the region under the jurisdiction of ORSANCO. The results (2) disclosed a wide variation in the amount of dust made and the efficiency of the kinds of equipment installed to recover it. This was not unexpected in view of the many factors that influence dust production and its capture. But the survey showed that the industry was doing a quite respectable job in spite of inherent difficulties. The average production of dust was 208 lb/ton of pig iron, but only 10 lb/ton was discharged to streams.

Relatively little information about effects on water quality is conveyed by the fact that the steel industry recovers an average of 95 per cent of the dust it produces. It is instructive, however, to examine what this means in relation to the natural silt load. At Bellaire, Ohio, which is immediately below the Pittsburgh-Youngstown district, the mean silt load is 7170 tons/day. (1) The median production of wet dust at capacity operation of the steel industry is 40 tons per day, and the median recovery of wet dust is 93.5 per cent. Thus all the mills above Bellaire discharge only about 2.6 tons of wet dust per day or only about 0.04 per cent of the mean silt load. It may be objected that the mean silt load is not a proper criterion and that the comparison ought to be made against the load at low stream flow. The silt load that may be expected at Bellaire five per cent of the time is 200 tons/day, and wet flue dust would then be 1.3 per cent of the total.

The performance of the steel industry in keeping wet flue dust out of streams would appear to be wholly satisfactory in terms of the natural silt load. But there are not yet any acceptable quantitative methods for evaluation of the actual effects on water quality of even a small discharge of flue dust. In order to define this influence it will be necessary to consider photosynthetic and physico-chemical effects, particle-size distribution, settleability under stream conditions, and esthetic values. Quantification of these factors will require extensive research in both laboratory and field, but a start has been made and it may be anticipated that most of the questions will eventually be resolved.

Mill Scale Recovery

Mill scale is equivalent to high-grade iron ore and it is recovered as completely as possible for reworking. Evaluation of mill-scale practice, however, presents a different and more difficult problem than was faced in the flue-dust survey.

Scale is flushed into a flume under a rolling mill and flows to a scale pit. These pits are of various shapes and sizes, and there is usually one for each roll stand. Thus there are many more scale pits than flue-dust clarifiers. Scale particles range in size from an inch or more in breadth to a micron or less. Roughly 90 per cent of the scale particles settle rapidly in water, and recovery of this portion of the total is not a problem. The 10 per cent that settles slowly is difficult to remove in typical scale pits, and opinion is divided over the necessity or desirability of removing some proportion of this finely divided material.

Scale is not uniformly distributed in flume water; the heavier particles flow along the bottom of the flume and only the finer particles are actually suspended. For this reason it is impossible to collect representative samples of the influent to a pit, and efficiency cannot be measured directly. Since heavy particles settle rapidly, an approach to evaluation of pit performance was made by measuring the efficiency of removal of particles that would normally be suspended in the flume water. Particle-size distribution analyses were made upon many influent and effluent samples from a number of scale pits, but the results were too erratic to provide a dependable criterion of pit efficiency.

Settling rates of suspended solids were measured during the study of flue-dust clarifiers as a guide to removals of solids to be expected in terms of equivalent quiescent settling times. Suspensions were allowed to settle in liter beakers for a series of time intervals, a 250-ml portion was withdrawn from the midpoint of the beaker, and solids remaining in suspension were determined according to Standard Methods. (3) This technique appeared to offer a means for evaluating scale-pit performance.

Ten different sedimentation units of various types and sizes were sampled as follows. Influent samplse (300 ml) were taken every 20 minutes over an eight-hour period and composited. Effluent samples (175 ml) were similarly composited. Settling rates were measured on influent composites at settling times of 5, 10, 15, 30 and 60 minutes. Total suspended solids were determined on effluent composites. A plot of the settling data yielded straight lines characteristic of the suspended particles. If a line were extended to its intercept with the ordinate representing the concentration of suspended solids in the pit effluent, a corresponding time could be read on the abscissa. This figure might be assumed to represent the settling time that would have resulted in the effluent concentration actually found, if the settling had been quiescent. These figures, obtained graphically, were at first called "equivalent quiescent settling times," but the extreme extrapolation of experimental data that was required did not justify the use of this term. Nevertheless, these derived figures were found to be characteristic of the performance of actual scale pits and they were therefore designated Sedimentation Index. Typical curves are shown in Figure 1; data are given in Tables 1 and 2.

Table 1

Quiescent Settling of Suspended Solids

	NSS in Influent, ppm				TSS, ppm	
Basin	5 min	15 min	30 min	60 min	Influent	Effluent
A	73	53	44	28	1120	155
B	-	67	38	22	873	191
C	147	108	73	50	3060	267
D	-	201	126	86	1615	105

Note: NSS = nonsettleable solids; TSS = total suspended solids.

Table 2

Effluent Concentrations vs.

Equivalent Quiescent Settling Times

Basin	Dimensions, ft L	 W	 D	Theoretical Retention, min	Sedimentation Index
A	50	8	10	7.2	0.06
B	35	9	18	8.5	0.10
C	69.75	12	17.5	12.6	0.19
D		90 diam		87.0	46.0

Designers of sedimentation basins take great pains to dissipate turbulence and thereby approximate quiescent settling. But the liquid in scale pits is quite turbulent, and this condition appeared to explain the extremely short quiescent settling times suggested by the data. If this were so, there should be a relationship between the energy of turbulence and settling rate.

A Laboratory Approach to the Problem

There is no dependable instrument for direct measurement of turbulence, but there is an obvious relationship between turbulence and the rate of mechanical agitation. A study of settling rate versus mixing rate was made as follows. A one-liter beaker was fitted with a glass stopcock 6 cm above the bottom. A liter of water filled the beaker to a depth of 12 cm. A flat-blade impeller, 19 x 25 mm, was centered in the beaker with the long dimension horizontal. A speed indicator was attached to the stirrer shaft. One-liter suspensions of -320 mesh carborundum powder in tap water were poured into the beaker with the stirrer running at a definite constant speed. At the end of a series of pre-determined retention times, 250-ml portions were withdrawn through the stopcock and analyzed for total suspended solids. The data are given in Table 3.

Table 3

Solids Remaining in Suspension, ppm

Retention Time, min	Stirrer Speed, rpm 0	 33	 67	 100	 134	 167
5	98	241	320	346	411	437
10	81	120	180	189	212	225
15	54	102	118	164	184	189
30	45	72	98	83	88	118
60	40	64	66	57	69	94

It will be noted that the concentration of suspended solids decreased with increased retention time, even when the suspension was quite turbulent. At 167 rpm, for example, the concentration fell 79 per cent in an hour. The time required for the concentration to fall to a specified value, with no stirring, was defined as the Sedimentation Index, SI. If the concentration of solids remaining in suspension is a function of the logarithm of the settling time, the relation can be expressed as

$$y = A + Bx$$

where

$y =$ Concentration of solids in suspension, ppm

x Log of settling time, min

The data for zero stirrer speed in Table 13 are plotted in Figure 2. By the method of least squares, the equation of the line is

$$y = 132.4 - 56.1x$$

Sedimentation indexes were computed from the data in Table 3, using Equation (1), with the results shown in Table 4.

Table 4

Sedimentation Index

Retention Time, min	0	33	67	100	134	167
5	5	1.16×10^{-2}	4.53×10^{-4}	1.56×10^{-4}	1.08×10^{-5}	3.72×10^{-6}
10	10	1.66	0.142	9.8×10^{-2}	3.81×10^{-2}	2.24×10^{-2}
15	15	3.48	1.81	0.274	0.120	9.8×10^{-2}
30	30	12.0	4.1	7.6	6.2	1.8
60	60	16.5	15.3	22.1	13.5	4.8

Reynold's number is a criterion of turbulence. In the above study, if the superficial linear velocity of the liquid is assumed to be the stirrer speed multiplied by the circumference of the circle describing the vertical center of gravity of the liquid, and the hydraulic radius is used instead of the beaker diameter, Reynold's number can be calculated from the expression

$$Re = 4\, mv\rho/\mu$$

where

Re = Reynold's number (dimensionless)

v = Superficial linear velocity, ft/sec

m = Hydraulic radius, ft

ρ = Fluid density, lb/cu ft

μ = Fluid viscosity, lb/ft sec

If the sedimentation index, SI, is a logarithmic function of Reynold's number, Re, and retention time, T, the relation can be expressed by

$$\log SI = \log Z + b \log T + c \log Re$$

This equation can be solved by means of the three-variable normal equations, which comprise a standard statistical technique. Using the data of Table 4, the equation becomes

$$\log SI = -0.0905 + 2.9226 \log T - 0.8542 \log Re$$

or

$$SI = 0.8119\, T^{2.92}/Re^{0.85} \quad \text{(Range of E: 0.01 to 100)} \qquad (2)$$

Observed values of SI versus values calculated with Equation (2) are plotted in Figure 3, and it may be seen that the correlation is fairly good.

The beaker experiments represent sedimentation on a batch basis, but scale pits are continuous-flow processes. Sedimentation was therefore studied in a horizontal flume to simulate a scale pit that would be long in proportion to its length and width. A suspension of 2000 ppm of -320 mesh carborundum powder in tap water was pumped to a 50-ft flume (5 in. wide x 4 in. deep) through a quarter-inch pipe suspended just above the water surface at the inlet end. A weir at the outlet end maintained a 4-inch water depth. Duplicate tests were made of the settling rate of the suspension pumped to the flume; the data are plotted in Figure 4.

Runs were made at two different flow rates; limitations of pumps prevented operation at a wider range of flows. Samples were taken at intervals along the flume by siphoning 500-ml portions from just below the water surface. The data are given in Table 5.

Table 5

Sedimentation in a Long Flume

Sample No.	Flow Rate, gpm	Distance from Inlet, ft	Suspended Solids, ppm
1	2.38	6	50
2	2.38	12	12
3	2.38	18	7
4	2.38	24	7
5	2.50	6	40
6	2.50	12	16
7	2.50	18	7
8	2.50	24	7
9	2.50	30	7
10	2.50	36	7
11	2.50	42	7

Reynold's numbers were calculated for the data of Table 5, using the superficial linear velocity and hydraulic radius of the flume. Retention times were computed by dividing volumes to sampling points by the volumetric flow rate, and sedimentation indexes were read from Figure 4. The data are given in Table 6.

Table 6

Equivalent Quiescent Settling vs. Retention

Sample No.	Velocity, ft/min	Retention, min	Re	E, min
1	2.29	2.6	1814	7.6
2	2.29	5.3	1814	30
3	2.29	7.9	1814	100
4	2.29	10.5	1814	8.8
5	2.40	2.5	1900	18.5
6	2.40	5.0	1900	100
7	2.40	7.5	1900	100
8	2.40	10.0	1900	100
9	2.40	12.5	1900	100
10	2.40	15.0	1900	100
11	2.40	17.5	1900	100

Development of an Empirical Equation to Predict Pit Performance

The laboratory beaker experiments indicated that SI is a function of the third power of T and the reciprocal of Re (rounding the exponents of Equation (2)). A plot of SI vs T^3/Re for the data from the flume is shown in Figure 5. It may be seen that there is a functional relationship between these parameters even though a range of values of T^3/Re corresponds to a single value of SI. The only variable not taken into account was the distance from the inlet to the sampling point, L. This variable may be included by postulating the function

$$\log SI = \log Z + \log (T^3/Re) + a \log L$$

or

$$\log (SI \cdot Re/T^3) = \log Z + a \log Z$$

Using the data of Table 5, a plot of log $(SI\ Re/T^3)$ vs. log L is shown in Figure 6. It may be seen that a direct, negative relationship is indicated. The line of best fit through the points yields the equation.

$$\log (SI \cdot Re/T^3) = 3.60 - 1.49 \log L$$

Thus log SI is seen to be a function of log $L^{-1.5}$ and

$$SI = 3980\ T^3/Re \cdot L^{1.5} \qquad (3)$$

Equation (3) is plotted on log-log co-ordinates in Figure 7, using the data of Table 5. The slopes of the curve is 1.30 and therefore

$$SI = f\ (T^3/Re \cdot L^{1.5})^{1.3} = f\ (T^{3.9}/Re^{1.3} \cdot L^{1.95}) \qquad (4)$$

The negative relationship of length to equivalent quiescent settling time seemed incongruous at first sight. The best explanation seemed to be that the effects measured in the flume were those of the areas available for particle flow-paths in vertical and horizontal planes, and not simply those of linear distance. Thus it might be postulated that depth, D, and width, W, should be included in Equation (4). Then

$$SI = f\ (T^4/Re^{1.5} \cdot LW \cdot LD) \qquad (5)$$

Data from four of ten sedimentation units were given in Tables 1 and 2. Data from all ten are given in Table 7 which includes retention times, basin geometry, and Reynold's numbers calculated for conditions at basin outlets.

Table 7

Sedimentation Indexes for Mill Installations

Basin	T, min	Re	L, ft	W, ft	D, ft	Effluent Concn., ppm	SI, min
A (1)	7.2	133000	50.0	10.0	8.0	155	0.06
B (1)	8.5	114800	35.0	18.0	9.0	191	0.10
C (1)	12.6	96000	43.5	17.5	12.0	267	0.19
D (2)	87.0	24600	45.0	70.7	15.5	105	46.0
E (1)	17.4	48300	34.0	15.0	8.5	743	0.11
F (1)	20.5	65800	40.0	24.0	10.0	147	0.07
G (3)	15.6	82400	84.0	15.0	7.5	439	2.8
H (2)	65.3	22900	37.5	58.9	9.5	208	51.9
I (3)	34.8	33600	110.5	12.5	3.75	435	5.7
J (3)	16.1	60400	110.5	12.5	3.13	366	5.2

Note: (1), scale pits; (2), flue dust clarifiers; (3) flue dust basins.

Equation (5) is plotted in Figure 8, using the data of Table 7, and it is calculated for the flume data in Table 8.

Table 8

Sedimentation Indexes from Equation (5)

Sample No.	SI Observed, min	SI Calculated, min
1	7.6	1.19×10^{-4}
2	30	5.11×10^{-4}
3	100	1.12×10^{-4}
4	100	1.97×10^{-4}
5	8.8	9.42×10^{-5}
6	18.5	3.77×10^{-4}
7	100	8.49×10^{-4}
8	100	1.51×10^{-3}
9	100	2.36×10^{-3}
10	100	3.40×10^{-3}
11	100	4.62×10^{-3}

The values for SI are several orders of magnitude smaller than would have been predicted by Figure 8. Depth is the factor that varied over the greatest range between laboratory and plant studies. Its effect was determined by plotting the function log $(SI \cdot Re^{1.5} \cdot LW \cdot LD/T^4)$ against log D for all plant and flume data in Figure 9. The slope of the line of best fit then became the exponent of D in the expression

$$ {}^{2.21}_{D} = {}_{SI} \cdot {}^{1.5}_{Re} \cdot {}^{4}_{LD/T} \qquad (6)$$

and thus SI may be represented as

$$SI = f\,(T^{4} \cdot D^{2}/Re^{1.5} \cdot {}_{LW} \cdot {}_{LD})$$

A plot of SI versus the new function is shown in Figure 10 on log-log co-ordinates. The equation of the regression line is

$$\log SI = 4.177 + \log\,(T^{4.}\ D^{2}/Re^{1.5} \cdot {}_{LW} \cdot {}_{LD})^{0.675}$$

or,

$$SI = 15021\ T^{2:67} \cdot D^{1.33}/Re \cdot \overline{LW}^{0.67} \cdot \overline{LD}^{0.67} \qquad (7)$$

The correlation coefficient for Equation (7) is 0.832 and the 99-per cent confidence limits of the coefficient are 0.537 and 0.948, indicating a significant degree of correlation. The standard error of estimate is 0.650.

Values of SI were calculated from Equation (7) and the corresponding concentrations of effluent suspended solids were read from the individual settling rate curves. Calculated values are compared with observed values in Table 9.

Table 9

Calculated and Observed Values of SI

Basin or Flume Sample	SI, min	Effl. Concn., ppm	SI, min	Effl. Concn., ppm
A	0.06	155	0.11	145
B	0.10	191	0.23	170
C	0.19	267	0.74	215
D	46.0	105	217.	75
E	0.11	743	4.22	570
F	0.07	147	3.24	70
G	2.8	439	0.52	660
H	51.9	208	122	89
I	5.7	435	4.42	540
J	5.2	366	0.33	820
1	7.6	50	8.4	43
2	30	12	22.7	13
3	100	7	38.6	10
4	100	7	56.8	8
5	8.8	40	7.2	55
6	18.5	16	18.4	16
7	100	7	36.1	10
8	100	7	47.1	9
9	100	7	63.9	8
10	100	7	82.7	8
11	100	7	100.5	7

The calculated and observed values of effluent concentrations are plotted in Figure 11. It is apparent that the values from the flume agree better than those from mill installations. This probably results from the fact that it is easier to get representative samples from the flume, where volumes are small and feeds are constant.

Calculated and observed effluent concentrations for plant equipment are plotted in Figure 12. The 90-per cent confidence limits about mean effluent concentrations are shown for a sample size of 42 from extensive sampling work at three scale pits and three flue-dust clarifiers. It may be seen that only two of the calculated values fall substantially outside these limits. On the other hand, where 90-per cent confidence limits are calculated, it may be anticipated that at least one out of ten values will fall outside the limits. Thus it may be concluded that the empirical equation will yield results that are as reliable as an actual sampling survey.

Practical Use of Empirical Equation

Equation (7) would be rather awkward for practical use. It was therefore converted to a simpler form for a rectangular pit with inlet at one end and outlet at the other, and for water at normal temperature.

$$SI = 2.426\, L^{1.33} \cdot W^{2} \cdot D^{3.33} \cdot (2D + W)/Q^{3.67} \qquad (8)$$

where

SI = Sedimentation index, min

L = Effective pit length, ft.

W = Effective pit width, ft

D = Effective pit depth, ft

Q = Water rate, cfm

Using Basin A of Table 1 as a specific example, where $L = 50$, $W = 10$, $D = 8$, and $Q = 557$, Equation (8) gives $SI = 0.096$ min. A settling-rate curve for the influent to the pit during a sampling run is shown in Figure 13 as Curve 1. The sedimentation index from Equation (8) when projected to Curve 1 shows that the effluent concentration should be 147 ppm.

If the water rate through the pit were reduced, the concentration of scale particles would increase proportionately, but the lower flow rate should decrease turbulence in the pit and thereby improve the settling rate of the particles. If the water rate were reduced to 500 cfm the settling rate would approximate that of Curve 2 in Figure 13. From Equation (8), SI would be 0.153 min, equivalent to an effluent concentration of 153 ppm as read from Curve 2. If the water rate were halved the settling rate would correspond to Curve 3. For a flow rate of 279 cfm, Equation (8) gives an SI of 1.24 min, equivalent to an effluent concentration of 198 ppm.

At first glance it would appear that pit performance becomes poorer as the water rate is reduced. It is true that the concentration of solids in the effluent would increase, but the weight of solids discharged would decrease. At 147 ppm and 557 cfm the scale loss would be about 3.7 tons/day, but at 198 ppm and 279 cfm the loss would be 2.5 tons/day.

If the length of the pit were increased to 75 and 100 ft, with all other factors unchanged, SI would become 0.164 and 0.244, as read from curve 1, corresponding respectively to 137 and 130 ppm. Making the pit substantially longer would thus have only a slight effect in improving performance.

If the width were increased to 15 and 20 ft, with all other factors unchanged, SI would become 0.258, corresponding respectively to 129 and 115 ppm. Widening the pit would thus have a greater effect than lengthening it.

If the depth were increased to 12 ft, with other factors unchanged, SI would become 0.486, corresponding to 117 ppm. Of more practical interest is a reduction in depth, corresponding to the accumulation of scale. If the depth were reduced to 6 and 4 ft, SI would become 0.0315 and 0.0067, corresponding respectively to 168 and 198 ppm. This illustrates the effect on performance as scale builds up in a pit and indicates the importance of frequent cleaning.

Summary

An empirical equation has been developed from laboratory and field data for predicting the performance of scale pits in recovering finely divided material. The reliability of the equation is emphasized by the range it covers. It may be possible to refine the equation somewhat as more data become available, but it is not likely that it will ever be practical to evaluate scale-pit performance precisely.

The empirical equation has several advantages. Its use will greatly simplify surveys of scale-pit performance because it will be necessary only to collect settling rate data on influents and calculate sedimentation indexes from available physical data. It will allow an operator to schedule pit dredging on the basis of efficiency in terms of the depth of scale deposited. It will provide a basis for designing new pits from reasonably predictable figures for the settling rate of scale from new rolling mills. By the same token, it will serve as a guide to exclusion of design features that will be conducive to inefficient pit operation. If the equation proves out with additional mill and laboratory data it will represent a real advance in the technology of mill-scale recovery.

References

(1) Richard D. Hoak and Henry C. Bramer
"Natural Sediment as a Factor in Stream Pollution Control."
Sewage and Industrial Wastes, 28, 311 (March, 1954).

(2) Ohio River Valley Water Sanitation Commission
"Dust Recovery Practice at Blast Furnaces."
Cincinnati, 1958.

(3) American Public Health Assn.
"Standard Methods for the Examination of Water, Sewage and Industrial Wastes."
Tenth ed., New York, 1955.

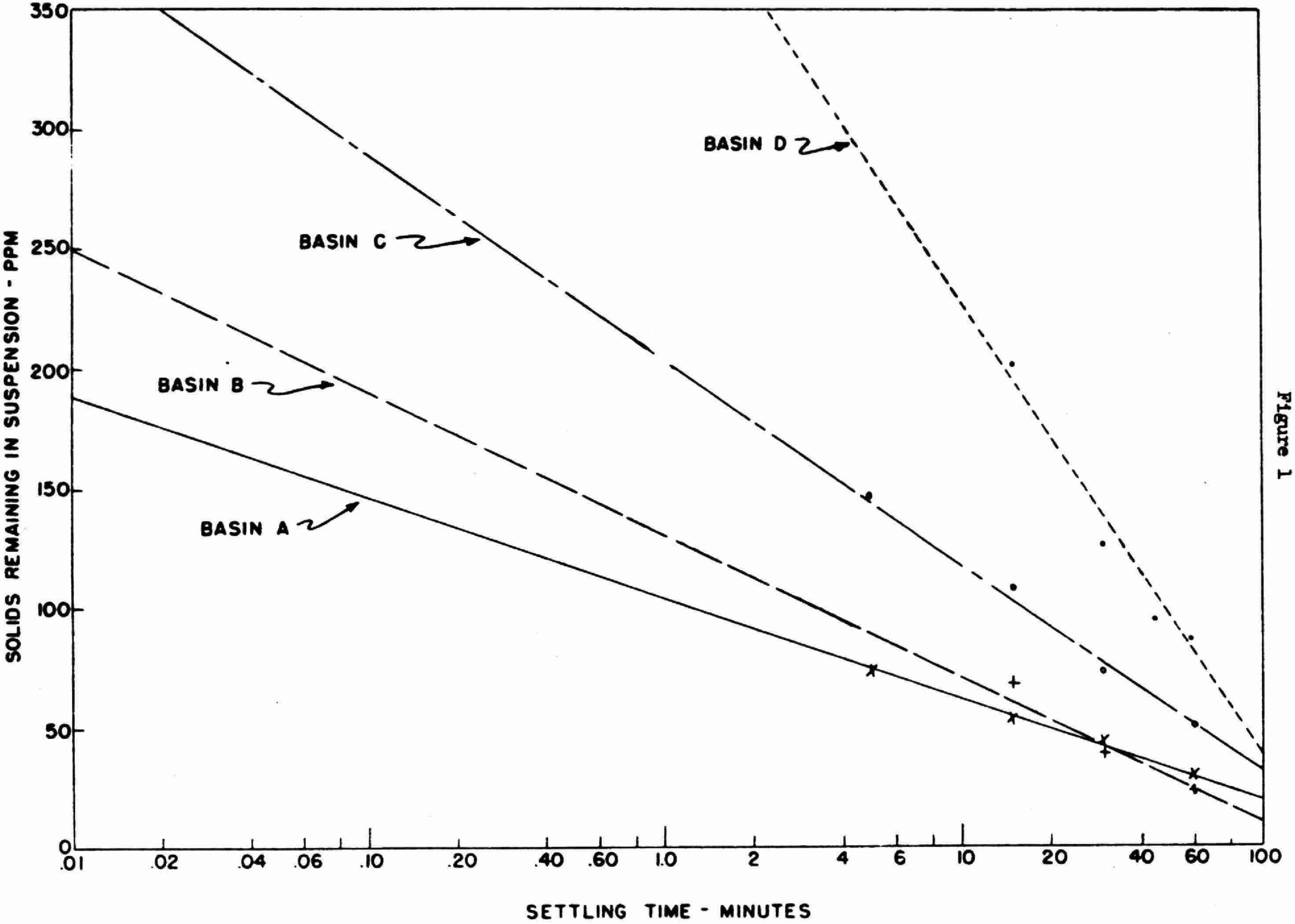
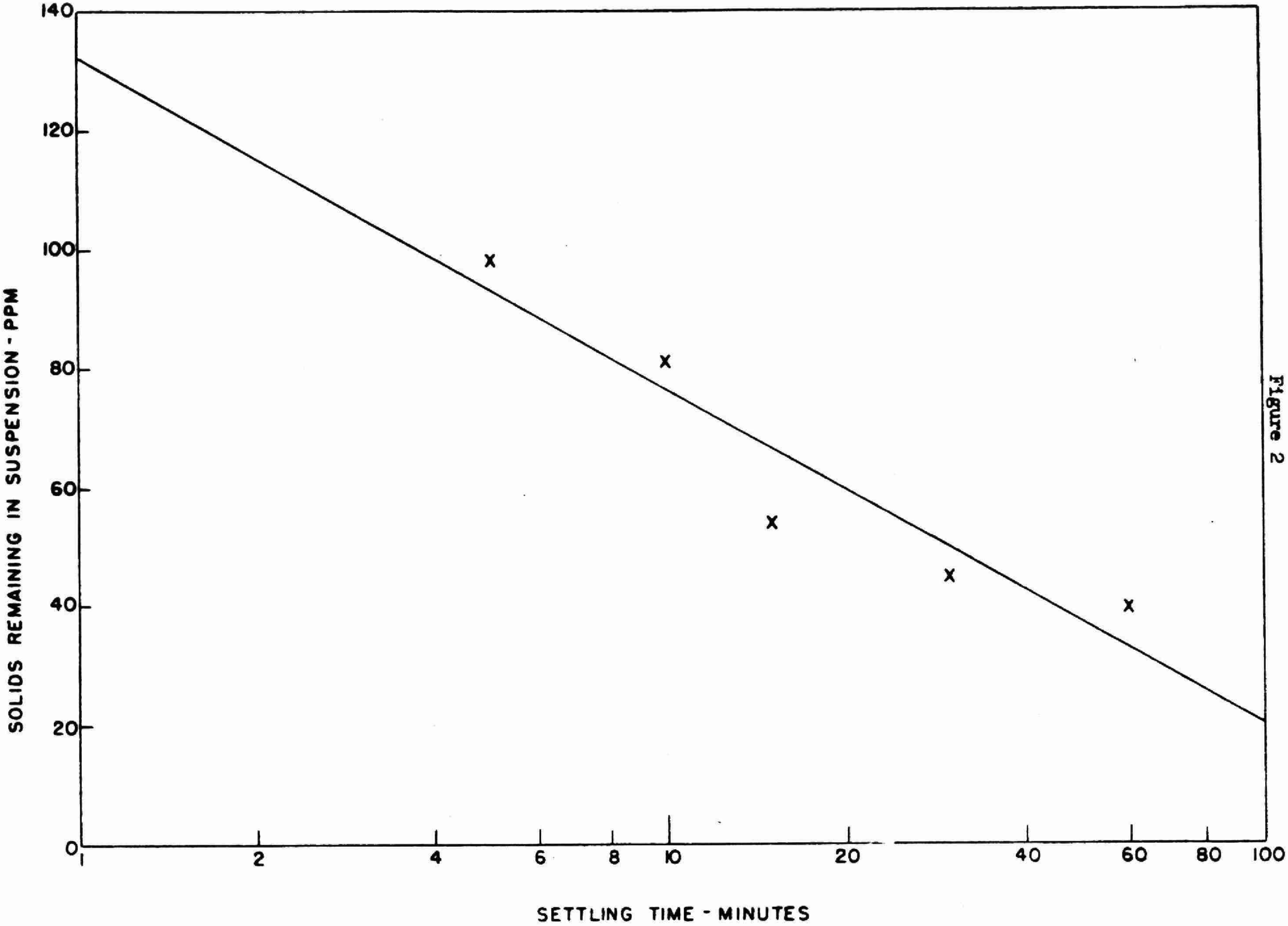

350
300
250
200
150
100
50
0
SOLIDS REMAINING IN SUSPENSION - PPM
.01
.02
.04
.06
.10
.20
.40
.60
1.0
2
4
6
10
20
40
60
100
SETTLING TIME - MINUTES
BASIN A
BASIN B
BASIN C
BASIN D

Figure 1



SOLIDS REMAINING IN SUSPENSION - PPM
140
120
100
80
60
40
20
0
1
2
4
6
8
10
20
40
60
80
100
SETTLING TIME - MINUTES

Figure 2

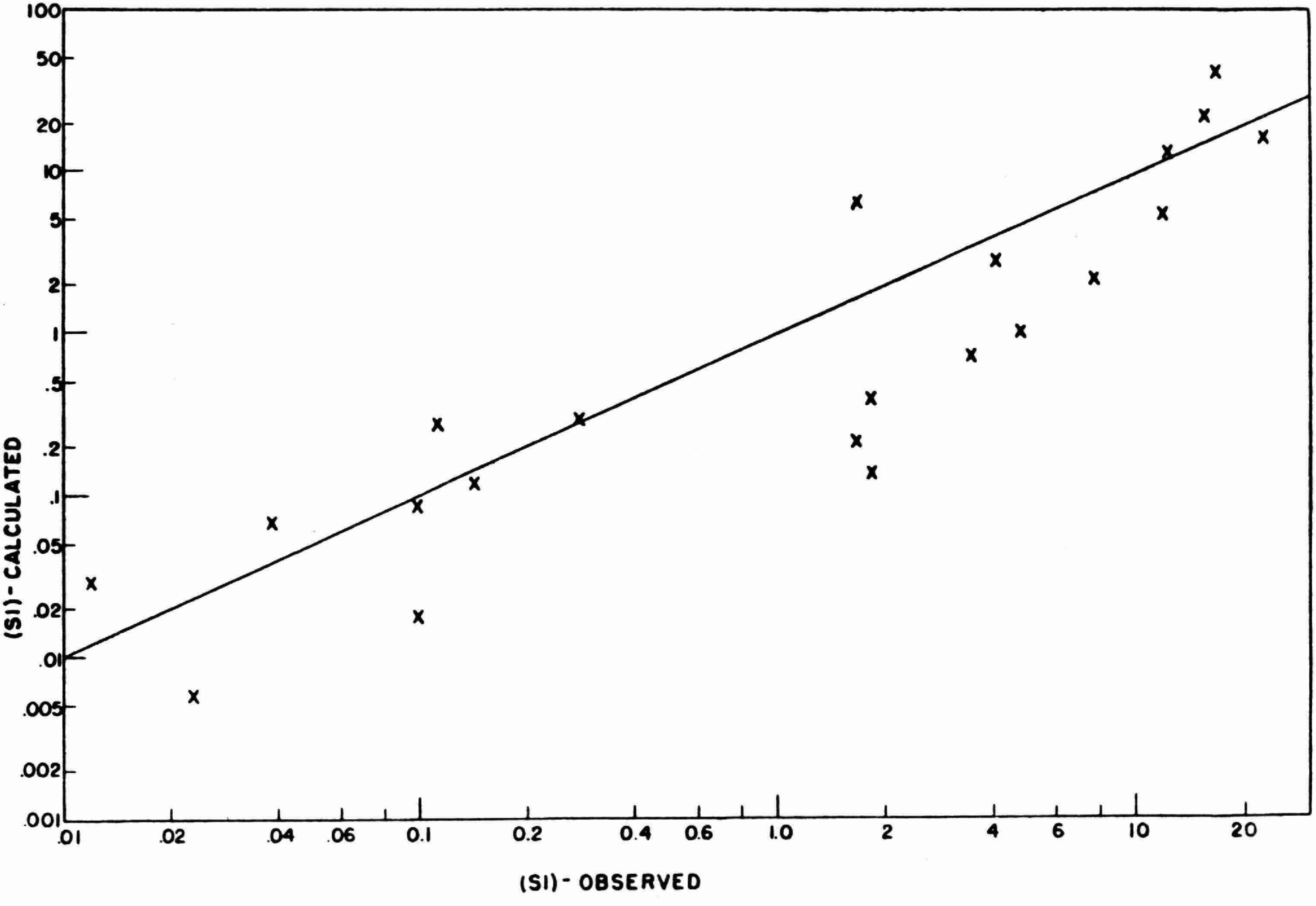

100
50
20
10
5
2
1
.5
.2
.1
.05
.02
.01
.005
.002
.001
(SI) - CALCULATED
.01
.02
.04
.06
0.1
0.2
0.4
0.6
1.0
2
4
6
10
20
(SI) - OBSERVED

Figure 3

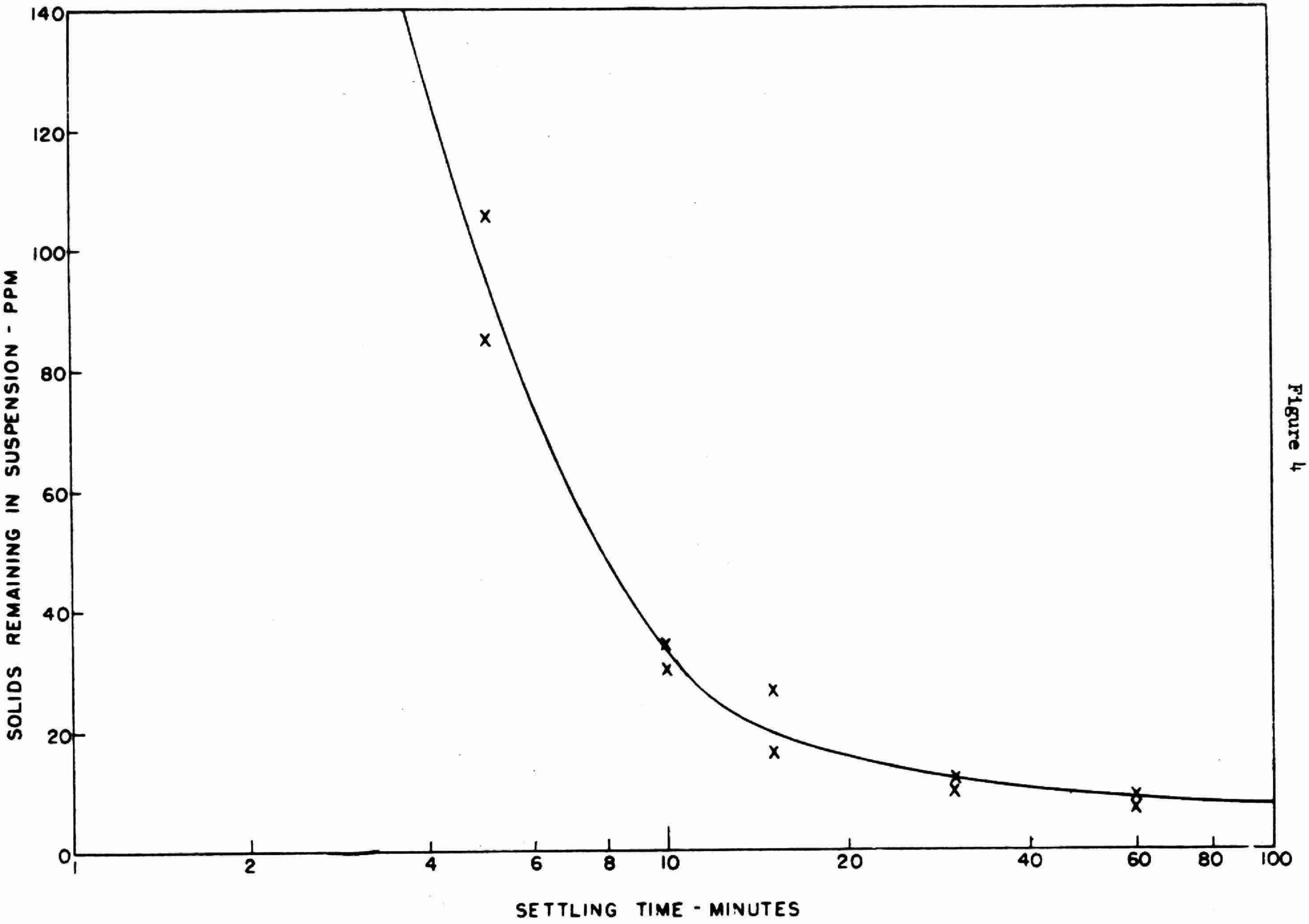
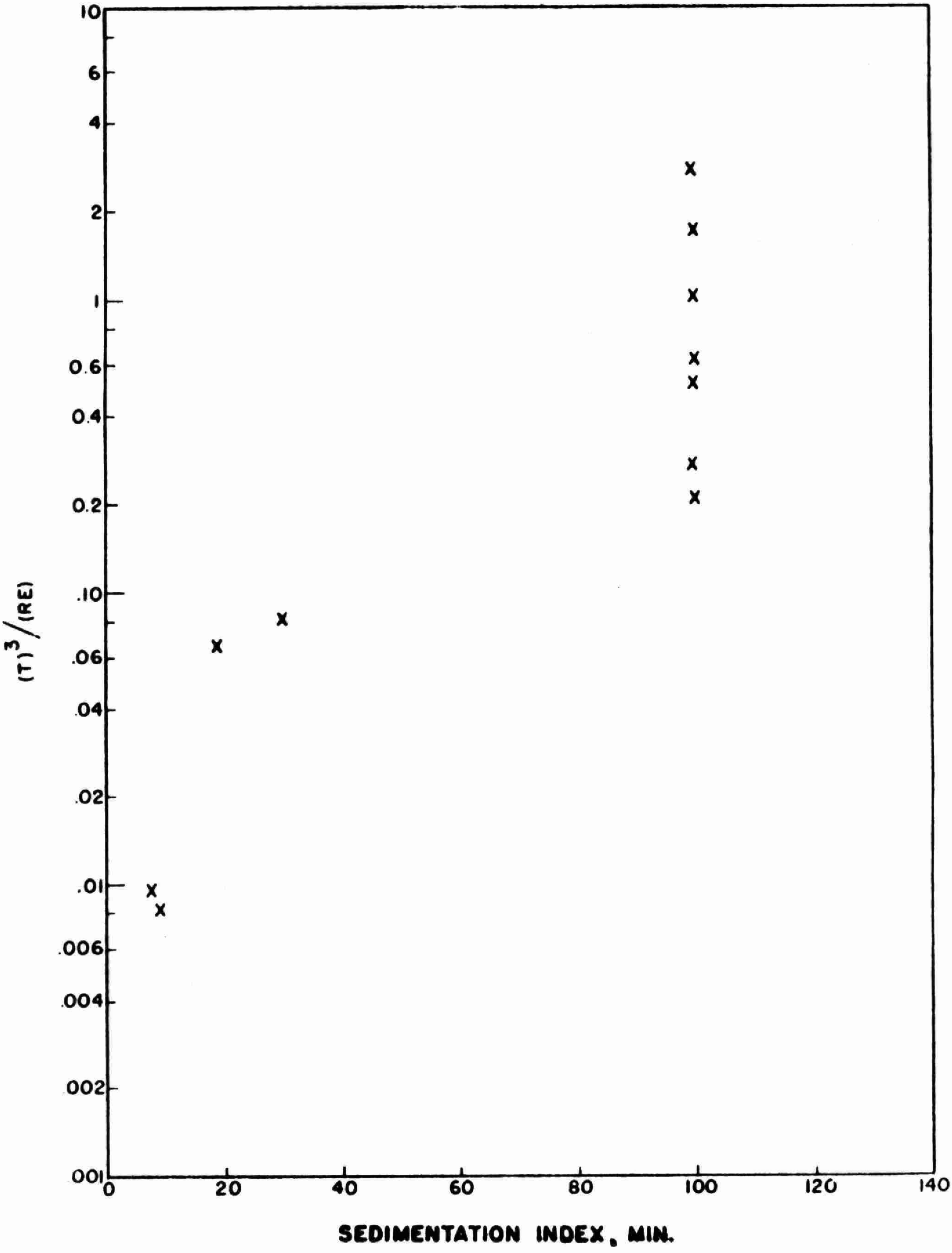

140
120
100
80
60
40
20
0
SOLIDS REMAINING IN SUSPENSION - PPM
1
2
4
6
8
10
20
40
60
80
100
SETTLING TIME - MINUTES

Figure 4

Figure 5


10
6
4
2
1
0.6
0.4
0.2
.10
.06
.04
.02
.01
.006
.004
.002
.001
$(T)^3/(RE)$
0
20
40
60
80
100
120
140
SEDIMENTATION INDEX, MIN.

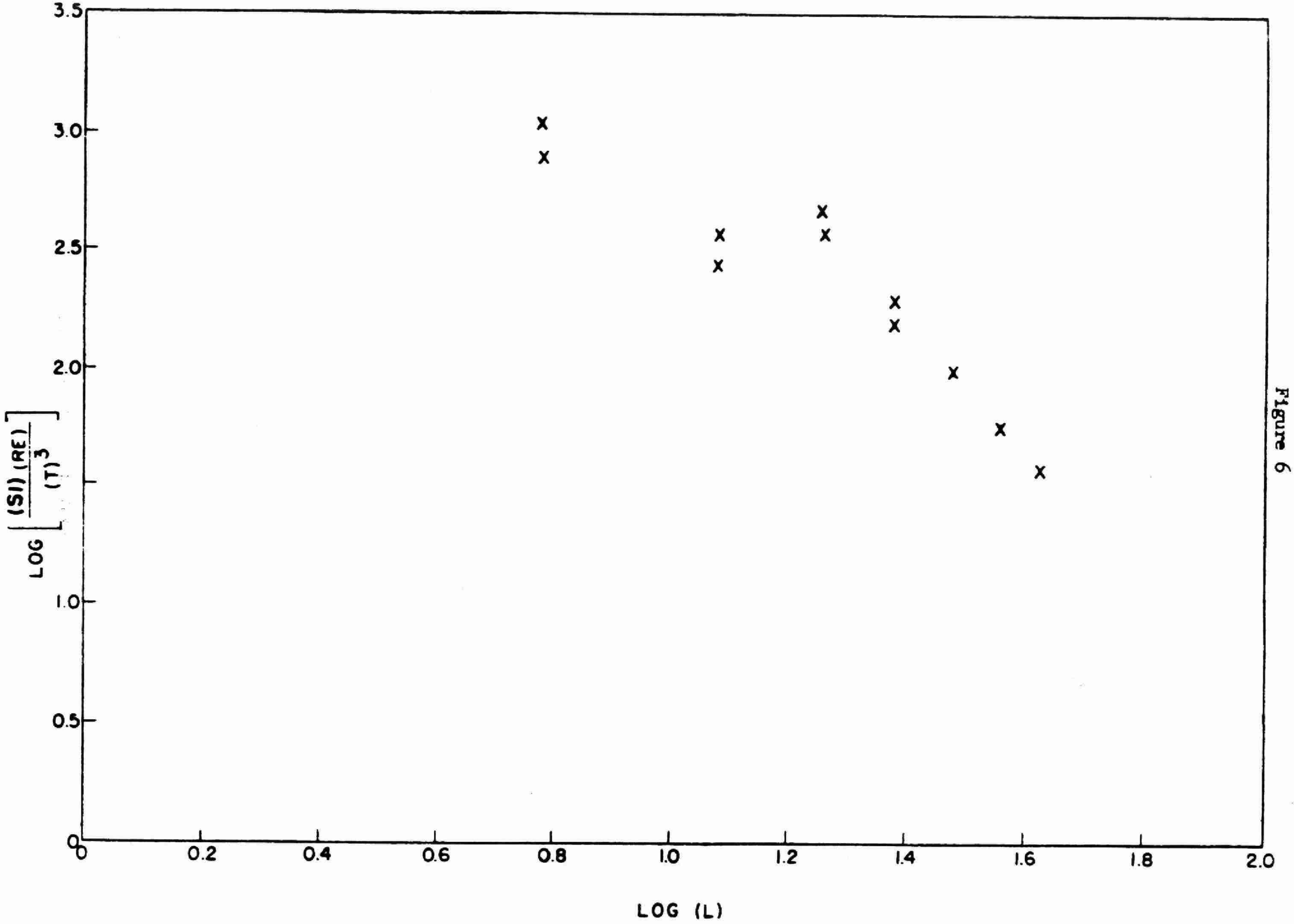


Figure 6

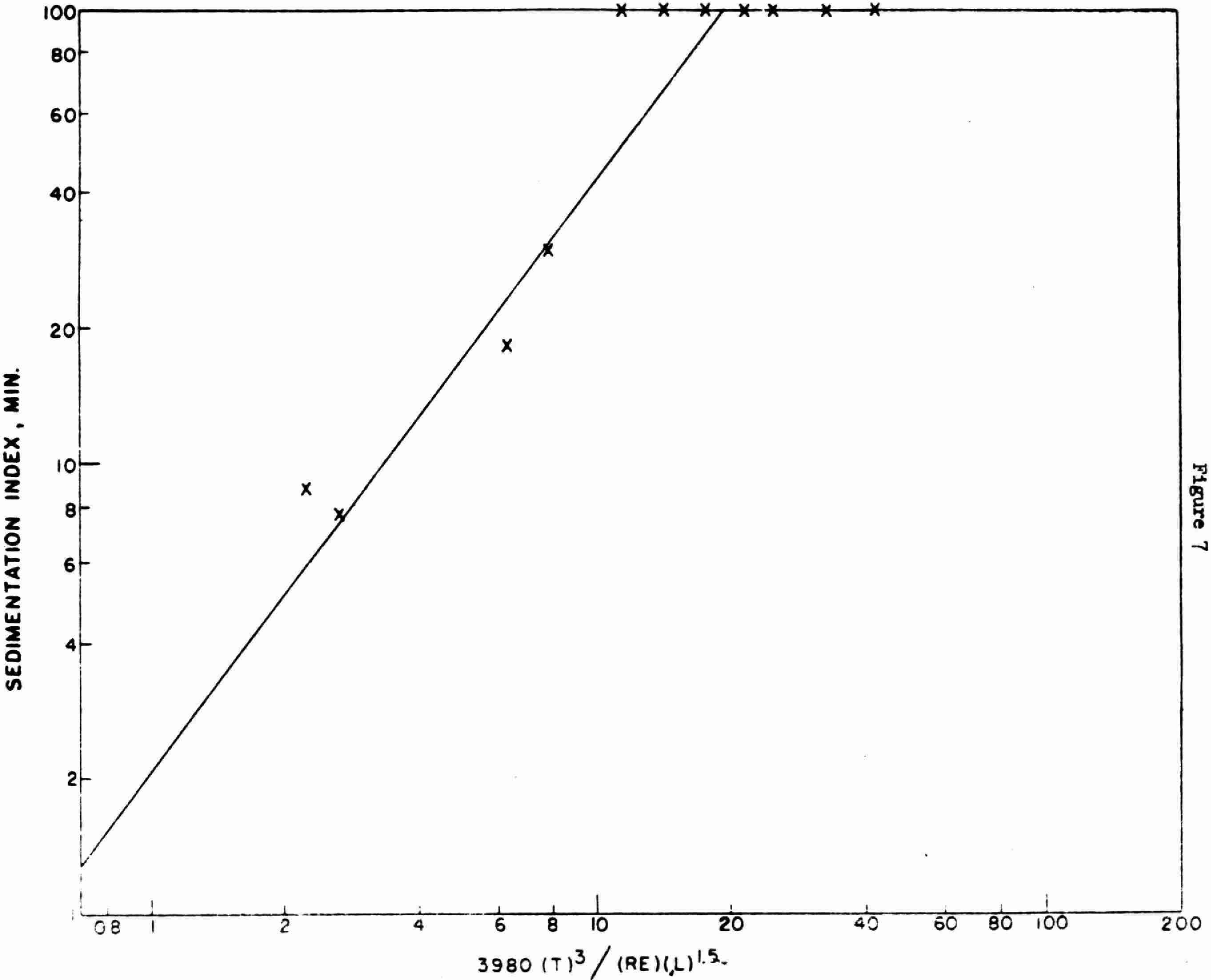

SEDIMENTATION INDEX, MIN.
100
80
60
40
20
10
8
6
4
2
0.8
1
2
4
6
8
10
20
40
60
80
100
200
3980 $(T)^3$ / $(RE)(L)^{1.5}$

Figure 7

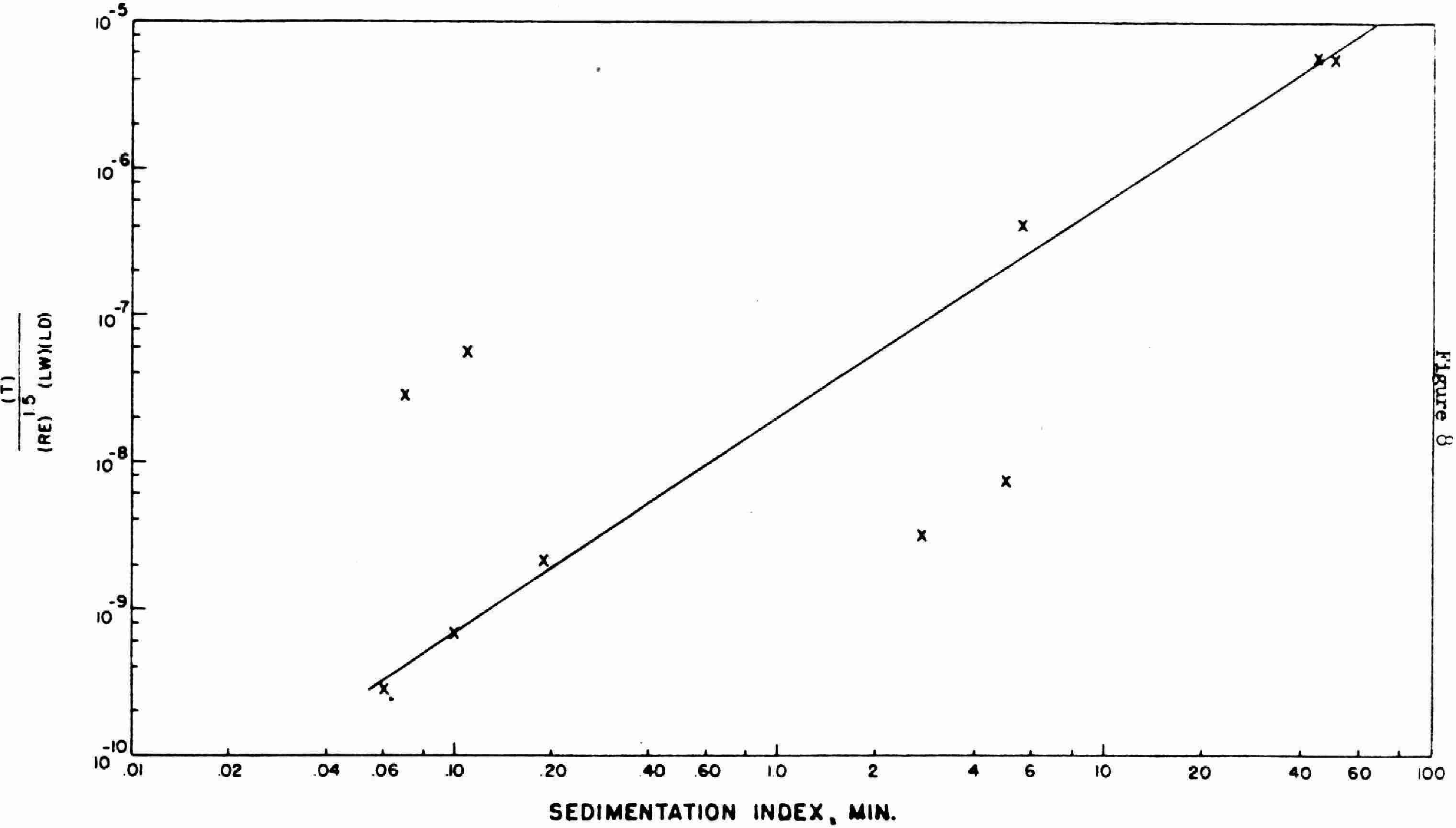

$\frac{(T)^4}{(RE)^{1.5}(LW)(LD)}$
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
.01
.02
.04
.06
.10
.20
.40
.60
1.0
2
4
6
10
20
40
60
100
SEDIMENTATION INDEX, MIN.

Figure 8

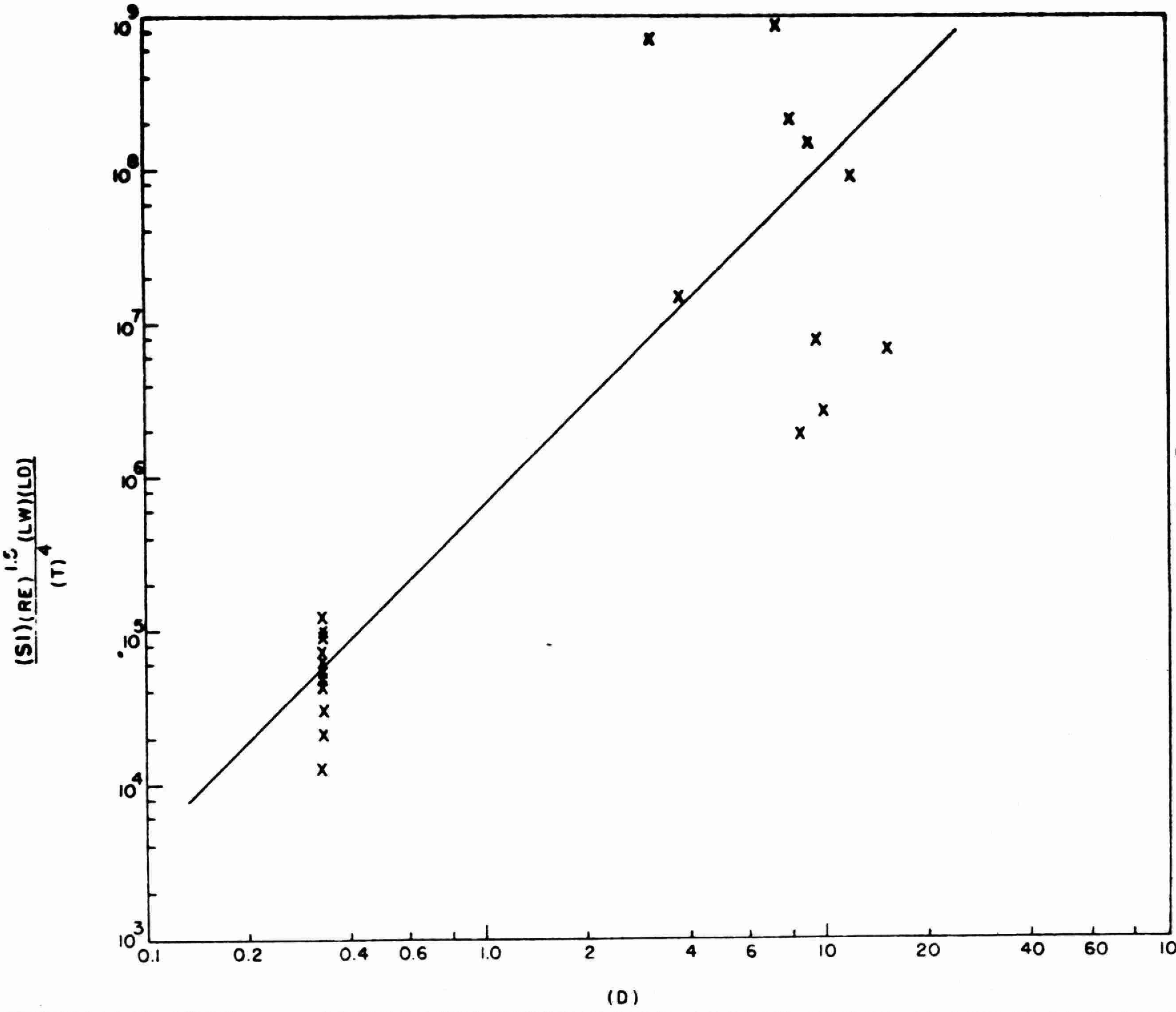

$\frac{(SI)(RE)^{1.5}(LW)(LD)}{(T)^4}$
10^9
10^8
10^7
10^6
10^5
10^4
10^3
0.1
0.2
0.4
0.6
1.0
2
4
6
10
20
40
60
100
(D)

Figure 9

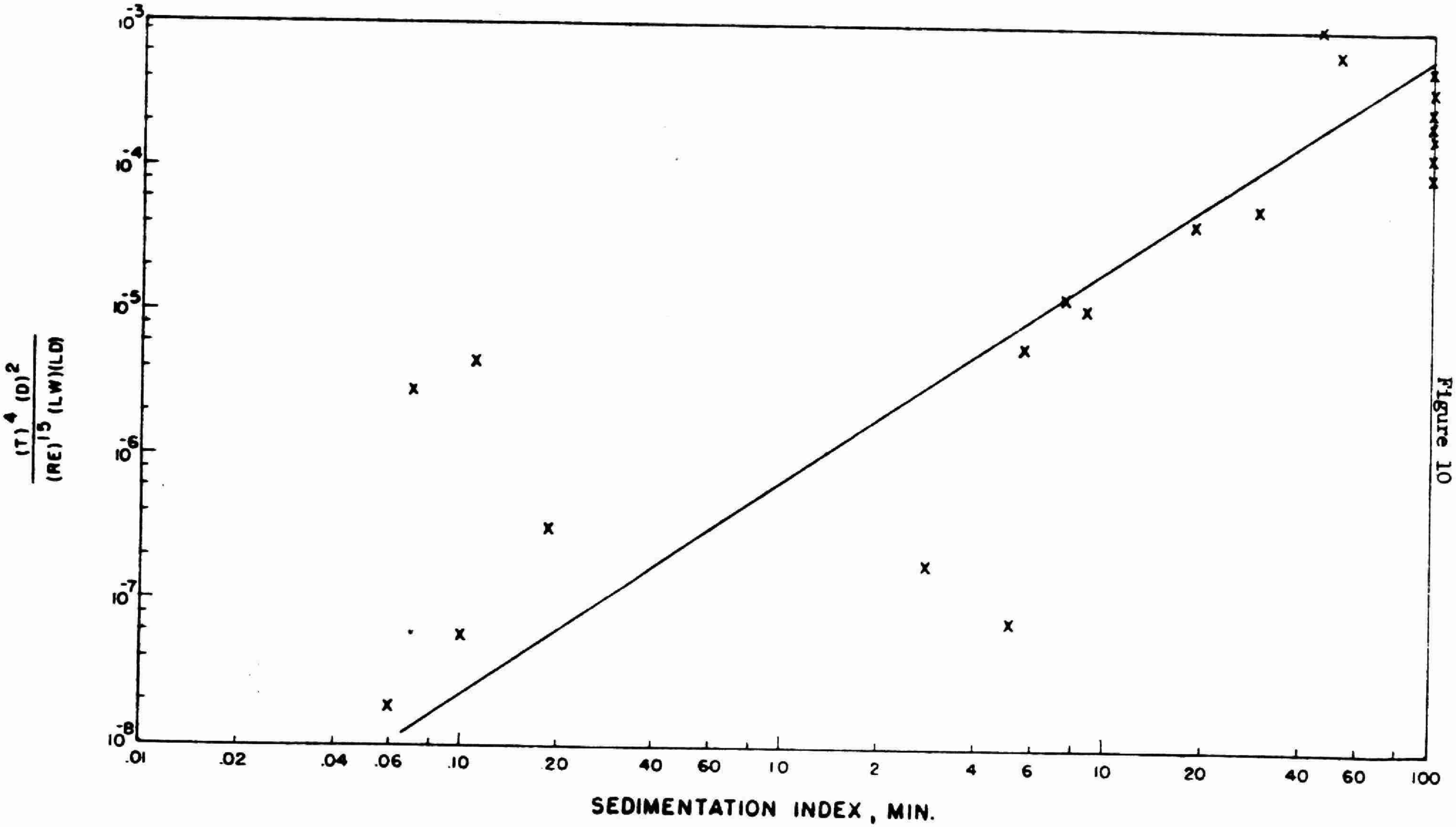
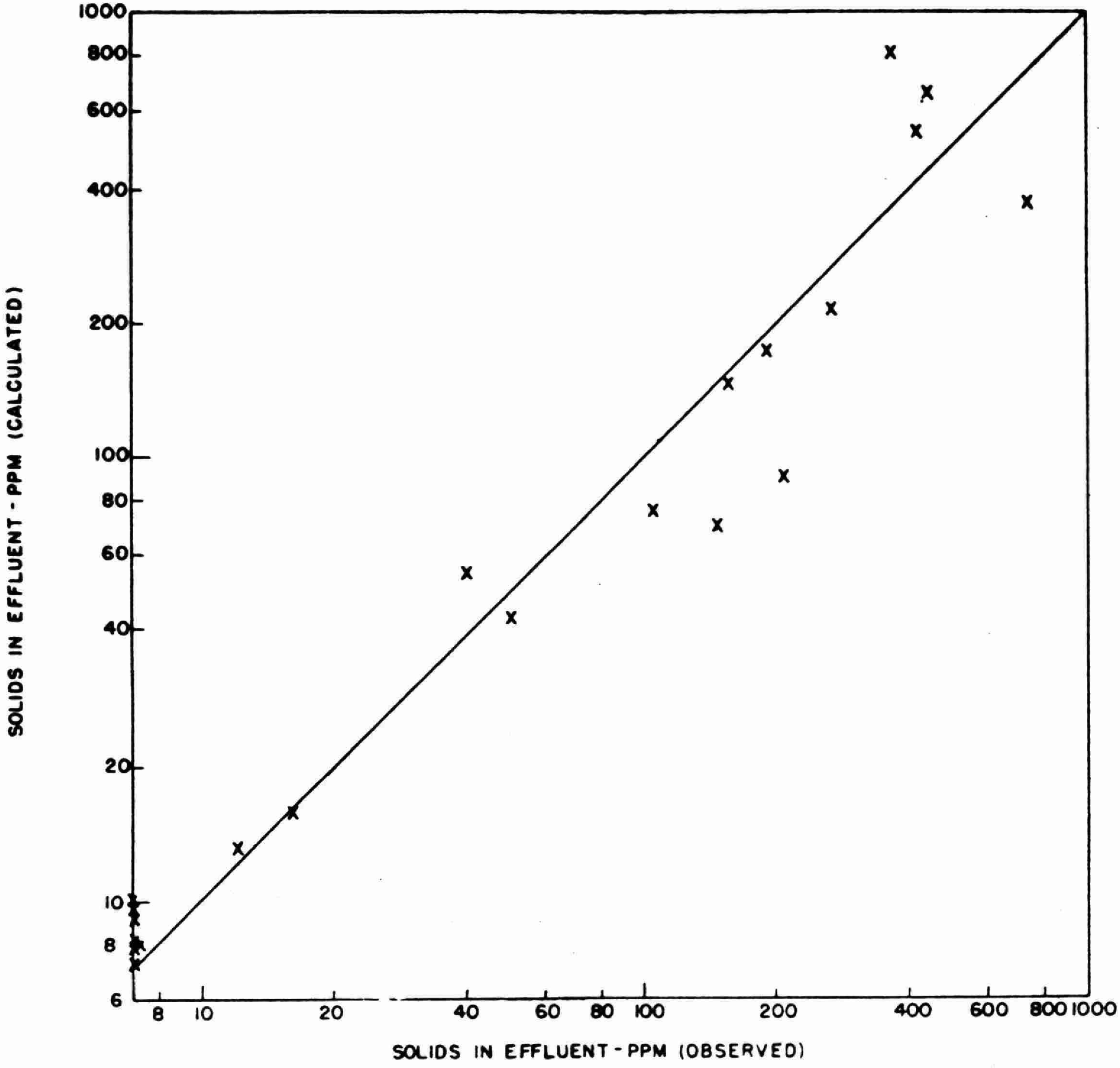

(T)4 (D)2
(RE)15 (LW)(LD)
10-3
10-4
10-5
10-6
10-7
10-8
.01
.02
.04
.06
.10
.20
40
60
10
2
4
6
10
20
40
60
100
SEDIMENTATION INDEX, MIN.

Figure 10



1000
800
600
400
200
100
80
60
40
20
10
8
6
8
10
20
40
60
80
100
200
400
600
800
1000
SOLIDS IN EFFLUENT - PPM (CALCULATED)
SOLIDS IN EFFLUENT - PPM (OBSERVED)

Figure 11

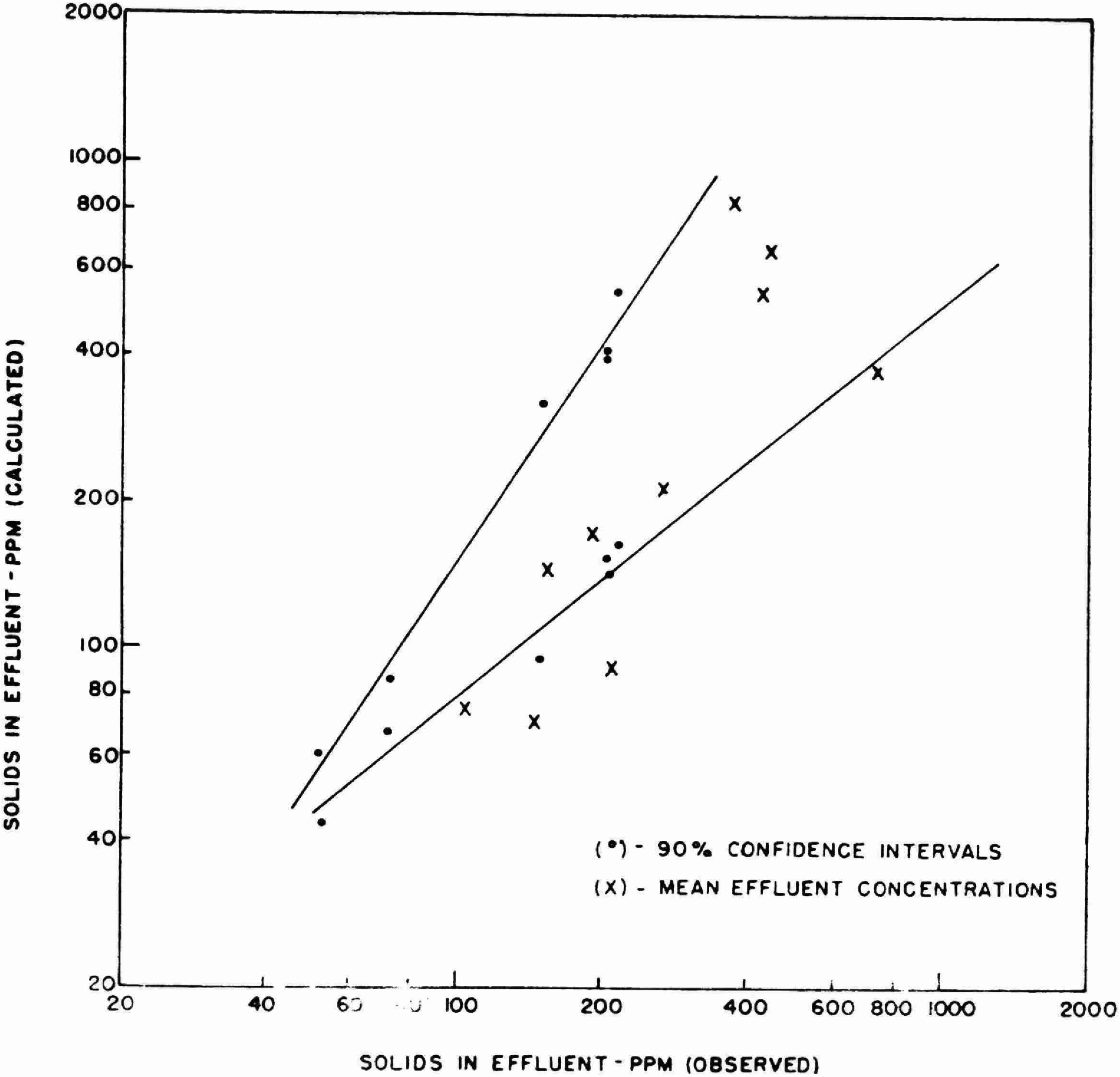

SOLIDS IN EFFLUENT - PPM (CALCULATED)
2000
1000
800
600
400
200
100
80
60
40
20
20
40
60
100
200
400
600
800
1000
2000
SOLIDS IN EFFLUENT - PPM (OBSERVED)
(•) - 90% CONFIDENCE INTERVALS
(X) - MEAN EFFLUENT CONCENTRATIONS

Figure 12

EFFECTS OF CARRIER-FREE P^{32} AND I^{131} ON THE ANAEROBIC FERMENTATION OF WASTE SLUDGE

Dr. W. H. Grune

C. Chueh

J. G. Lee

I Purpose and Scope

The purpose of this research contract was to study the processes of anaerobic digestion of sewage in the presence of radioactive wastes, to study their effects on sewage treatment plant operation, to establish the distribution of radioactivity in digested sludge, to safeguard personnel in sewage treatment plants from radiation hazards and to provide information of value in establishing tolerance limits for the final disposal of liquid radioactive wastes in accordance with the allowable concentrations of radioactive materials which may enter streams.

It was necessary to establish the levels at which radioactive materials, such as radiophosphorus (P^{32}) and radioiodine (I^{131}) as discharged to sewerage systems, would exert injurious effects on the digestion process. It was also of interest to determine the degree to which the liquid and solid phases in a sludge digester would concentrate radioactivity and how much activity may escape into the atmosphere.

It was not to be expected that the anaerobic decomposition of sewage solids (sewage sludge) would lend itself to the high degree of treatment or decontamination required of radioactive wastes to meet the present standards. (1) It is known that a dose in excess of 1,000 roentgens is generally necessary to destroy bacteria (2), therefore sterilization of the biological systems in sludge at normal levels of activity was not expected. However, significant effects might result when high concentrations of radioactive isotopes become mixed with sewage sludge.

In a heterogeneous system such as anaerobic sewage sludge, it is difficult to predict the effects due to radioactivity because sludge composition and microbiological population are not yet fully understood. Since day to day variations in flow and character of sewage or wastes entering the disposal plant are a routine occurrence, but must nevertheless be treated to a reasonably uniform effluent quality, it was essential to establish the concentrations at which radioactive materials would interfere with the treatment plant operation. Anaerobic digestion and sludge disposal facilities may represent 50% of capital investment in the waste treatment plant. Operating and maintenance costs for digestion represent from 25 to 33 per cent of the annual budget (3). Because of this heavy investment in digestion and its importance in the treatment process, it was of particular value to investigate the digestion process under varying operating conditions.

A relatively greater concentration of the radioactivity in the liquid phase could result if the fermentation of sewage sludge were inhibited or the process otherwise upset. This effect would be reflected in a larger portion of the activity being discharged to a stream. With other chemical forms of the same radioisotope or other isotopes, a greater percentage of the activity could be absorbed in the sewage solids, which after drying are often used as fertilizer or as a soil conditioner. In either case, the potential hazards of relatively widespread environmental contamination are present day problems.

One of the most important aspects of this study was to determine the relative concentrations of radioactivity in the liquid and the solid components of the sludge after digestion. This was true in all cases, whether the radiation effects had inhibited digestion or whether insufficient activity had been added to destroy the microorganisms or otherwise alter the process. From a study of these results, the levels at which specific radioisotopes would interfere and actually inhibit the sludge digestion process could be ascertained. Futhermore, the degree of decontamination afforded by anaerobic decomposition could then be assessed at levels below significant radiation damage, as well as the decontamination factor attainable when the normal digestion process was destroyed due to radiochemical and/or radiobiological damage. In the latter case the process would be comparable to a slurrying operation and any uptake of radioactivity would be primarily by contact adsorption rather than by biological assimilation or uptake.

II Specific Objectives of this Study

This research program was divided into two parts which complemented each other. The first phase was to determine the effects from different radioactive materials at concentrations from 10 to 800 millicuries per liter. The goal of this phase was to assist in the establishment of maximum safe concentrations for disposal. The second phase of the program was directed towards concentration of the radioactivity in the solid, liquid or gaseous portions of the sludge. This part of the studies was undertaken to improve techniques for the ultimate disposal of these radioactive waste components in the atmosphere, soil and streams.

Specifically, these investigations evaluated the effects of radioisotope concentrations on the anaerobic digestion of sewage sludge and the action and fate of these radioisotopes after digestion by a number of qualitative and quantitative parameters, including:

(1) Quantitative measurement of gas production (in terms of liters of gas produced daily, corrected to standard temperature and pressure for cumulative values; total gas production based on mls/gram of volatile matter added; and total gas produced in terms of cu ft/lb of volatile matter destroyed.)

(2) Qualitative measurement of gas production (CO_2, CH_4, N_2, etc.) by means of chromatographic gas analysis.

(3) The rate of gas production, expressed in terms of k, the velocity parameter of a first-order type of reaction.

(4) The ultimate gas production, expressed in terms of L.

(5) Analysis of the autocatalytic nature of the anaerobic digestion reaction by means of the lag-phase, expressed in terms of τ,

(6) The rate of volatile matter reduction (for correlation with rate of gas production and results from electrical conductivity measurements).

(7) Analysis of the unit volumes of gas produced per unit weight of volatile matter destroyed (cu ft gas/lb of V.M.) as an additional parameter to measure the effect of radioactivity on digestion.

(8) Examination of the pH of the sludge, recorded continuously to measure the progress of digestion and to compare radioactive sludges with their corresponding controls.

(9) Maintenance of a constant incubation temperature and recording it continuously during the fermentation process to monitor any temperature changes.

(10) Measurement of oxidation reduction potential (to establish the reactivity of the anaerobic system with and without the presenne of radioactive contaminants and also to gain additional information on the processes underlying the fermentation),

(11) Determination of electrolytic conductivity, especially to follow the progress of total and dissolved solids in an effort to examine the effect of solids breakdown in the presence of radioactive material.

Additional determination of the characteristics of raw and digested sludge, gas and liquor, volatile acid production and radioassays of liquid, gaseous and solid fractions were included in the control work. The volatile acids produced in the sludge were measured both at the beginning and at the end of each laboratory run. If the volatile acids concentration value is allowed to rise much above 2,000 ppm, gas formation will drop off (4) (5). Therefore, the determination of volatile acids provides a good control test in plant operation. If digestion is inhibited because of too much organic matter or because a toxicant destroys the microorganisms, the formation of volatile acids (composed of formic, butyric, propionic and acetic acids) increases. During satisfactory digestion the concentration of volatile acids will normally not exceed several hundred ppm. Thus, significant differences of volatile acids concentration would be another indicator if the presence of radioactive contaminants inhibits the process.

III Experimental Method

A maximum of eighteen laboratory digesters in each run were employed in these studies. The exact number varied between runs depending on the requirements and information to be gathered. In the earlier runs, digesters with sludge samples ranging from 800 to 1,600 ml were used, depending on the concentration of radioactivity to be studied. In most of the later runs sludge samples of 450 to 1,500 ml were used. For each run observations from at least twelve digesters were necessary so that the data would lend itself to statistical analysis. These twelve digesters were operated on a batch basis to make this data homogeneous. In each of the other six digesters the sludge was recirculated through at least three electrode assemblies (ORP, pH and conductivity) and returned to the digester without any losses of CO_2 and CH_4 or the entrainment of any air. The details of the experimental method have previously been described in detail (6) (7) (8) (9) (10) (11).

The composite reactions involved in the anaerobic stabilization of the complex organic matter in well-seeded sludge may be characterized by a first-order reaction. The application of this type of equation is based on the assumption that the reaction velocity k is a function of the organic matter remaining to be decomposed:

$$\frac{dy}{dt} = k\,(G - y) \qquad (1)$$

where

y = the amount of gas produced in time t

G = total amount of gas generated during digestion

k = reaction velocity constant

t = time in days

Integrating the differential form between the limits of $t = 0$ and $t = t$, the equation becomes:

$$y = G\ (1 - 10^{-kt}) \qquad (2)$$

In general, this equation describes anaerobic digestion adequately. If the amount of seeding material is small compared to the raw solids concentration, an S-shaped or autocatalytic gas production curve is obtained. After an initial lag phase the rate of gas production increases until about one-half of the total amount of gas is generated. The rate of gas production then decreases.

To formulate the cumulative gas production where a seeding lag is present, Fair and Moore (12) used the autocatalytic equation which contains two reaction velocity constants as shown by the differential forms:

$$\frac{dy}{dt} = k_1\ (G-y) \quad k_2\ (G-y)\ y \qquad (3)$$

As an alternate approach, they separated the S-curve into two parts; the first to follow an exponential equation, and the second to follow a first-order equation. To formulate sludge digestion, autocatalytic reactions are often treated by neglecting the lower bend of the S-curve and fitting the upper part of the curve as a first-order reaction starting at some time later than $t = 0$. This is equivalent to extrapolating the origin of the curve to the end of the seeding lag at $t = 0$. The interval between the origin and the extrapolated point is called the lag or time-lag. Thomas (13) formulated the first-order reaction to include a time lag by the following expressions:

$$y = G\ (1 - 10^{-k(t-to)}) = G\ (1 - C\ 10^{-kt}) \qquad (4)$$

where τ = time-lag and $\tau = \frac{1}{k} \log C$.

IV Presentation and Discussion of Experimental Results

PART I

RADIOIODINE (I^{131}) STUDIES

A. Effect on Gas Production

The maximum level of carrier-free I^{131} activity investigated was 600 mc/l. Previously only results up to the 100 mc/l concentration were reported (6). Figure 1 shows a family of curves of cumulative gas production from Runs IX, X, XI, XII and XIII from digesters with plain sludge, those to which an equivalent concentration of salt(*) was added, and those containing carrier-free I^{131}.

To present the results of cumulative gas production in milliliters per gram of volatile solids added for all digesters from five experimental runs as separate curves would not be practical. Instead, the gas production data were adjusted from mls. of gas/gm V.M. added and expressed for each run as percentages of total gas production from the average plain sludge digester values at the end of 33 days. These composite curves(**) are presented in Figure 1.

There appear to be no significant differences in gas production due to the presence of I^{131}, or equivalent concentrations of salt, when compared with the plain sludge up to the 300 mc/l level of activity. At 600 mc/l a significant decrease in the gas production rate and reduction of total gas production are shown.

(*) "Salt" in the I^{131} studies refers to a solution of 6,220 ppm $NaHCO_3$ and 5,380 ppm Na_2SO_3 added to the controls to stimulate the solids in the carrier-free I^{131} solution, in accordance with the present Oak Ridge I^{131} process (14).

(**) The sludge varied from run to run, resulting in differences in 33 day cumulative gas values. Therefore, the gas values were calculated on a percentage of the plain digester values. These percentages then could be averaged between runs and plotted to produce a composite chart, showing all data on one graph.

The efficiency of gas production, expressed in terms of cu ft per lb of volatile matter destroyed, was not significantly affected in the presence of 1.0 to 600 mc/l of I^{131} when compared with the plain sludge. The quantitative values for Runs IX through XIII are presented in Table I.

1. Reaction Velocity Constant

Reaction velocity constants were computed for all digester runs with I^{131} and the results from statistical analyses using the t-test for significance are shown in Table II. It may be observed from this table that no significant differences were obtained with concentrations from 1.0 to 200 mc/l and only borderline significance ($P = 4.9\%$) when the highest concentration, 600 mc/l of I^{131} only, was compared with the plain sludge samples. Similarly, the control digesters, containing the equivalent concentrations of salt, exhibited no significant difference when compared with plain sludge. As a further test of the relationship of k on temperature, sludge mixture (based on the initial volatile matter concentration), salt concentration and concentration of I^{131}, a multiple correlation analysis from a total of 66 values yielded the following relationship:

$$k = 0.1287 - 0.0014T + 0.0568M + 0.00004S_c + 0.000016\,I_c \quad (5)$$

in which

T = temperature, °F

M = proportion of sludge mixture, basedoon fresh solids

S_c = concentration of salt solution ($NaHCO_3 + Na_2SO_3$), ppm; and

I_c = concentration of I^{131}, mc/l.

TABLE I

Experimental Conditions, Gas Production and Volatile Matter Reduction

Part I Radioiodine (I^{131}) Studies

Run Period (Days) Date	Dig. No.	EXPERIMENTAL CONDITIONS					Total Gas Production		Reduction Volatile Matter(%)
		Sludge Volume (mls)	Sludge Mixture	Inc. Temp. °F.	Conc. of Salts(b) (p.p.m.)	Conc. of I^{131} (mc/l)	Ml/gm V.M. Added	Cu.ft. per lb.V.M. destroyed	
IX	1	1800	1:1	85°	-	13.75	161.1	12.5	20.8
(26)	2	↓	↓	↓	-	13.75	21.4	0.6	54.7
	3				5.8	-	26.0	2.0	21.4
8/22/57	4				5.8	-	29.4	1.4	32.8
to	6				-	-	101.3	3.3	48.8
9/17/57	11				-	-	53.9	2.3	37.2
X	1	1400	1:1	85°	-	100	290.0	17.8	26.0
	2	↓	↓	↓	-	100	291.7	17.9	26.0
(54)	3				-	50	292.3	24.2	19.4
10/2/57	4				-	50	287.9	14.9	31.0
to	5				39.2	-	304.4	16.1	30.3
11/24/57	6				39.2	-	299.9	16.7	28.7
	7				-	-	309.3	16.9	29.4
	8				-	-	296.4	15.1	31.5
	9				19.6	-	298.4	16.2	29.4
	10				19.6	-	311.9	15.0	33.5
	11				-	-	293.4	13.2	35.5
	12				-	-	296.1	11.2	42.3
	13				-	-	240.5	21.7	17.8
	14				-	-	229.2	13.2	27.8
	15				19.6	-	263.6	15.1	23.0
	16				-	50	a	a	a

TABLE (cont'd)

Experimental Conditions, Gas Production and Volatile Matter Reduction

Part I Radioiodine (I^{131}) Studies

Run Period (Days) Date	Dig. No.	EXPERIMENTAL CONDITIONS					Total Gas Production		Reduction Volatile Matter (%)
		Sludge Volume (mls)	Sludge Mix-ture	Inc. Temp. °F.	Conc. of Salts (b) (p.p.m.)	Conc. of I^{131} (mc/l)	Ml/gm V.M. Added	Cu.ft. per lb. V.M. destroyed	
XI	1	800	1.1:1	91°	-	-	299.8	14.0	35.1
	2	↓	↓	↓	-	-	310.9	14.5	35.1
(39)	3	↓	↓	↓	6.76	-	297.6	13.2	36.8
1/3/58	4	↓	↓	↓	6.76	-	291.8	12.5	38.1
to	5	↓	↓	↓	67.6	-	302.8	14.1	35.1
2/11/58	6	↓	↓	↓	67.6	-	311.2	14.3	35.4
	7	↓	↓	↓	-	10	311.4	13.3	38.1
	8	↓	↓	↓	-	10	310.5	14.3	35.4
	9	↓	↓	↓	0.1(c)	10	303.5	13.4	37.0
	10	↓	↓	↓	0.1(c)	10	301.8	12.7	38.9
	11	↓	↓	↓	-	100	305.6	10.0	49.6
	12	↓	↓	↓	-	100	304.1	11.3	43.8
	13	1575	↓	↓	-	-	203.8	10.2	33.5
	14	1575	↓	↓	60	-	193.2	9.4	33.5
	15	1575	↓	↓	-	9	257.7	12.0	35.1
	16	1575	↓	↓	-	85	258.8	13.4	31.6
	17	800	↓	↓	10(c)	10	193.2	7.6	41.7
	18	800			10(c)	10	190.2	8.7	35.8
XII	1	500	1:1	91°	-	-	274.6	11.6	38.1
(34)	2	↓	↓	↓	-	-	274.0	8.5	51.9
3/28/58	3	↓	↓	↓	5.03	-	274.5	12.3	35.7
to	4	↓	↓	↓	0.461	-	280.2	10.6	42.4
5/1/58	5	↓	↓	↓	151.3	-	316.3	15.2	33.3
	6	↓	↓	↓	302.5	-	310.0	12.9	38.8
	7	↓	↓	↓	-	10	302.0	13.4	36.4
	8	↓	↓	↓	-	1	293.3	11.6	40.5
	9	↓	↓	↓	500(c)	10	284.2	13.3	34.3
	10	↓	↓	↓	1,000(c)	10	258.3	11.9	34.8

TABLE I (Cont'd)

Experimental Conditions, Gas Production and Volatile Matter Reduction

Part I Radioiodine (I^{131}) Studies

Run Period (Days) Date	Dig. No.	EXPERIMENTAL CONDITIONS: Sludge Volume (mls)	Sludge Mixture	Inc. Temp. °F.	Conc. of Salts (b) (p.p.m.	Conc of I^{131} (mc/l)	Total Gas Production: ml/gm V.M. Added	Cu.ft. per lb. V.M. Destroyed	Reduction Volatile Matter (%)
	11	↓	↓	↓	-	300	278.8	12.7	35.5
	12				-	600	232.1	9.5	38.6
	13	1500			- (e)	-	395.4(d)	12.6(d)	50.2(d)
	14				5.04	-	248.6	7.7	51.7
	15	↓			- (e)	10	353.4(d)	9.6(d)	58.7(d)
	16				-	100	286.0	7.5	61.2
XIII	1	450	0.5:1	92°	-	600	312.4	12.3	40.7
	2	↓	↓	↓	-	200	323.4	15.2	34.1
6/2/58	3				-	50	345.2	13.6	40.7
to	4				1,000(c)	10	321.5	14.4	35.8
7/22/58	5				1,000(c)	10	298.7	13.4	35.1
44 days	6				-	1	321.4	13.4	38.5
#1-12	7				0.34	-	338.2	13.7	39.5
	8				17.2	-	334.4	14.0	38.3
50 days	9				68.3	-	325.7	14.4	36.3
#13-16	10				206.2	-	336.2	12.8	42.1
	11				-	-	339.7	14.1	38.5
	12				-	-	334.0	12.9	41.6
	13	1000			38.6(e)	-	326.7(d)	8.4(d)	45.1(d)
	14	↓			-	1	313.6	12.3	40.7
	15				- (e)	1	312.9(d)	13.2(d)	38.1(d)
	16				-	100	215.0	9.5	36.1

(a) Pump line broke, spilling contents

(b) Composition of salts: 53.6% of $NaHCO_3$ and 46.4% of Na_2SO_3

(c) Represents concentration if I^{127} added in ppm for isotopic dilution study.

(d) These figures based on total volatile solids including that added during feeding.

(e) Digesters #13 and #15 were fed twice during the run, thus increasing the total content of volatile solids.

TABLE II

Average Differences and the Probability (P) of their Occurrences by Chance Alone for k, G and C Values at Various Concentrations of Carrier-free I^{131} and Salt (*) Added to Plain Sludge

(a) Comparing Plain Sludge vs. I^{131}

Plain Sludge vs I^{131} (mc/l)	No. of Digester Pairs	Values of k		Values of G		Values of τ	
		$\bar{d} = \frac{\Sigma(k_c - k_h)}{n}$	P (%)	$\bar{d} = \frac{\Sigma(G_c - G_h)}{n}$	P (%)	$\bar{d} = \frac{\Sigma(\tau_c - \tau_h)}{n}$	P (%)
1.1 to 600	20	-0.0018	50.06	+ 2.56	65.6	+ 0.61	37.3
1.0 to 200	17	-0.0024	41.44	- 2.11	72.4	+ 0.04	32.2
200 to 600	4	+0.0028	6.34	+22.90	18.7	+ 1.17	43.8
600	4	+0.0065	4.92	+28.40	26.2	+ 2.53	18.2

(b) Comparing Plain Sludge vs. Salt (*)

Plain Sludge vs. Salt (ppm)	No. of Digester Pairs	Values of k		Values of G		Values of τ	
		$\bar{d} = \frac{\Sigma(k_c - k_s)}{n}$	P (%)	$\bar{d} = \frac{\Sigma(G_c - G_s)}{n}$	P (%)	$\bar{d} = \frac{\Sigma(\tau_c - \tau_s)}{n}$	P (%)
.34 to 68.8	15	+0.0020	18.97	+ 9.31	65.5	- 0.03	28.1
206 to 30	4	-0.0005	87.93	-11.05	58.0	- 0.50	17.2

TABLE II (cont'd)

Average Differences and the Probability (P) of their Occurrences by Chance Alone for k, G and C Values at Various Concentrations of Carrier-free I^{131} and Salt (*) Added to Plain Sludge

(c) Comparing I^{131} vs. Salt (*)

I^{131} (mc/l) vs. Salt (ppm)	No. of Digester Pairs	Values of k		Values of G		Values of τ	
		$\bar{d} = \frac{\sum(k_h - k_s)}{n}$	P (%)	$\bar{d} = \frac{\sum(G_h - G_s)}{n}$	P (%)	$\bar{d} = \frac{\sum(\tau_h - \tau_s)}{n}$	P (%)
All	20	+0.0034	38.84	- 2.35	80.2	- 0.64	36.1
1 to 100	16	+0.0019	69.57	-12.06	19.4	- 0.02	65.8
200 to 600	4	0.0022	73.10	-36.47	18.9	- 1.21	42.8
600	2	-0.0070	28.75	- 4.95	32.3	- 2.59	33.0

(*) Salt refers to solution of $NaHCO_3$ $+Na_2SO_3$

The coefficient of multiple correlation, R, was found to be 0.56. This shows that there is a significant dependence of k-values on any or all of the factors measured, or a significant correlation of k-values with temperature, the type of mixture, concentration of salt and concentration of I^{131}. The value of $R = 0.56$ also shows that values of k may be predicted by substitution in the regression equation.

As a part of the multiple correlation analysis, the partial correlation coefficients, r, for the four variables with k were found to be:

$r_T = 0.13$ (partial correlation between temperature and k-values)

$r_M = 0.44$ (partial correlation between type of mixture and k-values)

$r_S = 0.03$ (partial correlation between salt concentrations and k-values)

$r_I = 0.08$ (partial correlation between concentrations of I^{131} and k-values.)

None of these variables exert a very significant influence on the reaction velocity constant. Certainly, the correlation between I^{131} concentration and k-values is highly nonsignificant. Only the type of mixture is shown to have a fair amount of correlation with k.

The results from t-tests of the regression coefficient with the standard error of the regression coefficient, $b_j/S_{b_j} = t_{N-n}$, with 61 degrees of freedom, show that only the regression coefficient for the mixture is significant ($t_M = 3.78$; $P < 1\%$). The strong influence of sludge mixture (seeding) is well established (15). Similar analyses of the other variables showed that $t_{temp.} = 1.05$, $t_S = 0.26$ and $t_I = 0.58$, none of which are significant t-values. It must therefore be concluded that I^{131} exerted no real effect on k-values, except at the 800 mc/l level as was shown in Table II.

2. Ultimate Gas Production and Lag Period

The ultimate gas volume G, was also not significantly affected by concentrations of I^{131} up to an activity of 600 mc/l of I^{131}, as shown in Table II. However, at activity concentrations of 600 mc/l a considerable reduction in total ultimate gas production is noted in Figure I.

The results from a multiple correlation analysis from a total of 66 ultimate gas production values, G, yielded the following relationship;

$$G = -276.5 + 8.123T - 161.63M - 0.0750\ S_c - 0.0810\ I_c \quad (6)$$

The coefficient of multiple correlation, R, was found to be 0.58, which is significant correlation and shows that with Equation (6) values of G can be predicted.

The coefficients of partial correlation, r, for temperature, type of mixture, salt concentration and I^{131} activity with G-values were found to be:

$$r_T = 0.24,\ r_M = -0.39,\ r_S = -0.02,\ r_I = -0.12$$

The minus sign (negative correlation) simply means that the value of G decreases as the seed ratio, salt and I^{131} concentrations increase. Since all of these partial correlation coefficients are small, it is evident that none of the four independent variables exert a significant influence on G-values.

From an analysis of t-tests of the regression coefficients, with D.F. = 61, the results show only a significant relation between temperature ($t_T = 1.98$; $P = 4\%$), type of mixture ($t_M = 3.33$; $P<1\%$) and ultimate gas produced. No significant correlations between concentrations of salt or I^{131} and G-values were found.

As may be seen from Figure 1 there appear to be no real differences in the lag, period, τ, in the presence of I^{131} concentrations up to 600 mc/l.

As shown in Table II, from an analysis of τ-values between plain digesters, those containing various levels of P^{32} and controls with equivalent salt concentrations, it was established that no significant differences exist.

The results from a multiple correlation analysis of the same basic data for the lag-period, C, yielded the following relationship:

$$C = -1.352 + 1.423M + 0.0014\ S_c + 0.00013\ I_c \quad (7)$$

in which the terms M, S_c and I_c are defined as previously.

The value of R, the coefficient of multiple correlation, for the initial lag-period was found to be 0.73. This shows a highly significant correlation between -values and any or all of the other three variables. The partial correlation coefficient shows a good correlation with the type of mixture ($r_M = 0.87$). The partial correlations of τ with the concentration of I^{131} ($r_I = 0.12$) and salt concentration ($r_S = 0.1$) are poor.

Similarly, the results from t-tests of the regression coefficients point to the mixture type ($t_M = 8.87$, $P < 1\%$) as highly significant but the concentration of I^{131} ($t_I = 0.57$) does not appear to have any real effect. Aside from the fact that the significance of the mixture (sludge seed) is established, the insignificant correlation between τ-values and I^{131} was to be expected from the previous discussions of t-tests of τ-values from Table II.

3. Reduction of Volatile Matter, Volatile Acids and pH

The results of I^{131} studies show that the reduction of volatile matter was not affected by the addition of I^{131} at the activity levels studied. Generally, the volatile matter reduction ranged between 33 and 52 per cent as may be seen from Table I.

The volatile acids concentrations did not exceed 1,000 ppm in any of the digesters during the I^{131} studies, and usually remained below 800 ppm at the end of the digestion period. Up to 600 mc/liter of I^{131} exerted no noticeable effect on the concentration of volatile acids in sludge.

Figures 2, 3 and 4 (digesters 14, 15 and 16, Run XII) show typical plots of cumulative gas production, temperature, ORP, conductivity, and pH against time in days. Comparing the results of continuous pH measurements from digesters 14, 15 and 16 containing up to 100 mc/liter of I^{131}, the variation of pH was normal. The initial acid fermentation phase reached its maximum on about the third day and was followed by a normal rise to a buffered pH at about 7.2 to 7.4 This behavior was almost identical for the three digesters.

B. Effect on Redox Potential and Liquid Conductivity

Previously described procedures (6) were used to continuously record redox potentials and conductivity measurements. No significant differences were found between the redox potentials obtained from the various digesters, regardless of whether they contained plain sludge, I^{131} activity or equivalent salt solution.

As may be seen from Figures 2, 3 and 4, the E_h value of the redox potential at the end of the digestion period was -165 mv for digester 14 (control), -145 mv for digester 15 (10 mc/liter) and -225 mv for digester 16 (100 mc/liter). However, the gradual trend of ORP is more significant than absolute values of the potential. Thus, there appears to be no real effect exerted on redox potentials from I^{131} in concentrations up to 100 mc/liter. Because of the possible development of leaks in flow lines and contamination of the laboratory with radioactive sludge the maximum activity added to any recirculating digester was 100 mc/liter.

During Run XII the conductivity started at approximately 2,500 umhos and reached a value of about 6,500 umhos for digesters 14 and 15, as compared to a final value of over 10,000 umhos for digester 16, containing 100 mc/l of I^{131}. However, the data are too meager to generalize any effects.

C. Effect on Gas Quality

Chromatographic analyses of gases produced during digestion were carried out for all studies with I^{131}. Samples from each of the digesters were analyzed during each run on a daily basis to follow changes in gas composition with digestion progress. The chromatograms for eight representative digesters from two daily runs are reproduced in Figure 5.

The anlysis of chromatographic curves, representing digesters 1 through 12 (except 6 through 9) on the eighth day of Run XIII, shows that for most batch digesters methane production was approximately 74% and carbon dioxide concentration about 26%. The only significant difference was exhibited by digesters 4 and 5, to each of which 1,000 ppm NaI as I^{127} had been added. The CO_2 content for digesters 4 and 5 was 33.5% as compared to 26% for the plain, control and radioactive sludges. The purpose for these two digesters was to examine to what extent higher concentrations of stable iodine might affect anaerobic digestion.

The lower half of Figure 5 shows that on the fourteenth day of Run XIII there was little difference between the quality of the gas in any of the digesters. Even digesters 4 and 5 had established a composition almost identical to the digesters containing I^{131} or plain sludge. By this time the sludge appears to have assimilated the stable iodine I^{127} and the inhibitory effects disappeared.

The t-test analysis between CO_2 values for Run XII shows a significant effect ($\bar{d}_{CO_2} = 3.4\%$; $P \ll 1\%$) at the 600 mc/l concen-

Table III

Percent of Carbon Dioxide in Sludge Gas From Chromatographic Analysis

Run XII - I Studies

Dig. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Type	Plain	Plain	Control (10)	Control (1)	Control (300)	Control (600)	10 mc/l	1 mc/l	10 mc/l +I127	10 mc/l +I127	300 mc/l	600 mc/l	Plain	Control (100)	10 mc/l	100 mc/l
Day 1	59.4	57.2	59.9	59.6	60.2	59.6	59.7	59.7	60.3	61.4	59.4	58.2	61.3	59.5	56.2	44.6
2	52.2	52.7	51.7	51.7	50.7	50.1	50.6	51.3	53.1	55.9	50.4	59.4	52.1	48.4	48.5	42.1
3	45.1	46.8	45.4	45.2	44.2	43.5	44.7	45.3	47.3	51.4	44.7	44.5	46.3	42.5	43.9	36.6
4	40.1	40.8	44.0	41.5	40.3	40.5	40.8	41.7	43.2	47.6	41.9	42.1	43.5	38.7	38.1	31.5
5	36.8	37.9	37.0	36.9	36.2	36.2	36.9	36.9	40.3	43.1	38.5	38.8	35.2	31.4	30.2	30.1
6	36.5	34.5	34.5	35.1	32.9	31.4	34.0	35.1	38.5	39.6	37.0	38.7	30.7	26.5	27.5	28.1
7	31.9	31.8	31.2	31.9	30.5	31.3	32.1	32.4	34.1	39.2	35.3	36.3	27.1	26.7	27.0	27.7
8	30.5	29.8	30.4	30.0	29.5	31.0	30.2	30.3	31.5	37.1	33.4	35.4	30.7	26.2	29.9	26.5
10	28.0	28.9	29.2	29.1	29.1	29.3	29.2	29.3	29.9	31.5	30.5	32.4	30.7	25.1	29.0	26.2
11	29.6	29.3	29.1	29.9	29.7	29.8	29.6	29.7	30.9	30.8	31.5	32.2	27.7	24.4	28.2	24.5
12	30.2	29.6	29.4	29.7	29.6	29.6	30.0	29.9	29.5	30.2	29.9	31.5	25.8	24.9	27.3	24.4
13	31.7	30.9	30.9	31.6	30.5	30.7	30.5	30.4	29.8	29.5	29.5	30.5	24.3	22.9	26.0	23.0
14	29.7	29.5	28.8	28.1	29.5	30.0	28.7	28.9	28.7	30.6	29.0	28.9	20.3	23.5	21.5	22.6
17	30.2	29.9	29.1	30.3	29.5	30.3	30.0	30.7	30.0	30.6	30.0	29.8	31.2	24.3	32.2	24.1
31	29.4	30.0	30.2	30.8	29.8	30.4	30.8	30.3	31.4	29.6	30.0	29.8	25.7	20.0	31.4	21.0

Table III

Percent of Carbon Dioxide in Sludge Gas From Chromatographic Analysis

Run XIII - I^{131} Studies

Dig. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Type	600 mc/l	200 mc/l	50 mc/l	10 mc/l $+I^{127}$	10 mc/l $+I^{127}$	1 mc/l	Control (1)	Control (50)	Control (200)	Control (600)	Plain	Plain	Control (100)	1 mc/l	1 mc/l	100 mc/l
Day 1	57.5	56.8	57.3	57.6	59.2	52.6	57.6	57.6	57.5	57.1	60.4	56.9	57.3	57.0	57.5	51.2
2	46.1	44.9	49.4	50.9	50.9	52.4	46.4	46.1	49.7	48.4	51.0	49.2	49.5	48.9	53.3	51.5
4	37.1	33.4	40.7	45.1	45.5	42.0	41.3	40.9	39.4	36.5	40.6	39.7	40.1	40.9	43.3	43.0
6	25.3	24.9	24.6	38.1	37.9	28.8	27.7	27.6	27.3	35.5	27.4	26.5	31.8	30.0	32.6	32.9
7	26.9	24.6	25.9	34.5	34.8	25.8	24.6	25.7	25.1	26.0	25.0	23.9	26.3	27.4	28.2	32.1
8	27.3	26.1	25.8	33.4	33.7	25.9	26.4	25.6	26.1	26.3	26.1	25.7	52.6	27.0	43.4	31.3
9	26.9	26.1	25.9	30.8	30.3	25.3	26.6	25.6	27.9	25.7	26.1	26.1	47.6	25.2	44.3	30.2
10	26.9	26.3	25.6	29.0	28.5	25.3	26.3	26.7	26.7	26.0	28.2	26.8	41.5	24.4	41.4	30.8
11	27.0	26.7	25.2	26.1	26.3	26.1	26.5	26.8	25.2	26.0	25.8	25.5	34.7	23.7	35.3	30.0
14	28.1	26.2	25.9	25.0	25.0	25.9	25.5	25.7	25.6	25.9	25.1	25.9	23.9	23.4	27.4	24.0
15	30.4	29.0	28.1	28.5	23.7	26.5	29.4	28.5	29.2	29.0	28.6	30.9	51.2	24.2	45.7	25.5
16	29.3	27.3	26.3	28.8	28.7	27.3	28.7	28.5	28.9	29.1	28.3	28.8	47.3	25.4	43.1	25.4
17	25.7	26.0	25.6	27.2	27.6	27.1	27.3	27.1	27.8	28.0	26.6	27.2	42.7	24.6	41.5	25.7
30	23.1	24.9	23.3	24.9	23.6	27.4	25.5	23.9	24.8	24.3	25.7	25.4	41.6	23.1	23.9	17.6
42	22.4	21.4	21.0	23.0	25.3	23.9	22.5	22.3	23.2	22.5	23.3	23.7	19.4	21.2	25.2	19.2

tration of I^{131} on gas composition as can be seen from the data presented in Table III. Up to the twelfth day of Run XII the digester with 600 mc/l of I^{131} shows that the CO_2 concentration is consistently greater than its corresponding control. A similar but smaller effect appears to exist in the presence of 300 mc/l of I^{131}. There was little or no difference in gas quality for digesters with activities below 300 mc/l when compared to the controls.

Before drawing any definite conclusion, it must be pointed out that the same effect of I^{131} on gas quality was not exhibited by the data obtained during Run XIII. In the latter case, even with the maximum level of activity (600 mc/l) only a small difference in gas quality between radioactive and control digesters was observed ($\bar{d}_{CO_2} = 0.5\% = 12\%$)

D. Distribution of Activity between Liquid and Solid Phases

Figures 6, 7, 8 and 9 present the data from Runs X, XI, XII and XIII. Data from the four runs with I^{131} are plotted in Figures 6 and 8. Data from only Runs XII and XIII are presented in Figures 7 and 9. The individual curves and results from many laboratory determinations are discussed below.

Figure 6 represents the per cent uptake of solid to liquid activity (A_S/A_L based on μc/gm) for initial I^{131} activities ranging from 10 to 600 mc/l. It appears from Figure 6 that the activity lodged in the solid increases slightly in relation to that in the liquid from 10 to 600 mc/l, which was the highest concentration used. The opposite trend from a limited number of 10 to 100 mc/l data was previously reported (6). It can be expected that the activity in the solid increases as the initial activity increases since the solids may absorb activity or because some of the activity in the liquid is adsorbed on the solid and concentrated on its surfaces during sample preparation by evaporation. Furthermore, the activities of solids and liquids were determined on a per gram basis. Since some of the organic solids disappeared to produce gas, this tended to increase the activity per gram, assuming that no activity went into the gas. These samples were counted with a gamma-ray spectrometer in the Georgia Tech Power Plant Laboratory where the background was relatively high. The instrument when used on the low range (XI) with a high background is inherently inaccurate, considering that $k(\frac{cpm}{cpm})$ was equal to 105. This was the justification to eliminate the 1.0 mc/l level data.

Figure 7 shows that the decontamination factor does not increase significantly with an increase in initial activity. The decontamination factor is the ratio of the initial over the final activity. Generally speaking, decontamination by the liquid is slightly greater than by the solid phase. However, the entire range of decontamination factors is only from 0.5 to about 1.1 and therefore no significant trend in either direction is shown. In figure 7 only values from Runs XII and XIII could be shown because previously the initial activities in liquid and solid portions of the sludge could not be ascertained.

Figure 8 represents the proportion of I^{131} activity removed by the liquid phase or the sludge supernatant, as a percentage of initial activities from 1.0 to 600 mc/l. This really is the efficiency of removal by the liquid since A_o is the initial activity, A_t is the final activity remaining, and A_o-A_t represents the activity removed. It is noted that the activity removed by the liquid decreased as the initial activity was increased. Whereas around 12 per cent of the activity is taken up by the liquid at the 1.0 mc/l level, only about 7.5 per cent of the activity remains lodged in the liquid supernatant at the 600 mc/l level. Again, there is no real difference, however, the same trend of somewhat increased uptake by the solid portion of the sludge at the higher initial concentrations may be of interest. A similar trend was previously reported for Runs X and XI only (6).

To further examine the degree of uptake between liquid and solid portions of sludge, all initial and final activities of the liquid as well as all initial and final activities of the solid were plotted against initial activity in mc/l as shown in Figure 9. For Run XII, there is little difference between the initial liquid and final liquid activities and there is little difference between the initial and the final activities of the solid phase in the sludge up to 100 mc/l. However, there appears to be some increase in the activity of the final over the initial activity in the case of the solid between 10 and 100 mc/l. Between 100 and 600 mc/l this difference becomes much greater. In this range the final activity in the solid phase of the sludge is consistently higher than the initial activity that was present. Conversely, the final activity in the liquid is consistently lower than the activity initially in the liquid phase of the sludge system. Figure 9 shows that for Run XII at the concentration of 600 mc/l of I^{131}, the final solid activity is 658 μc/gm compared to 455 μc/gm initially present in the solids when digestion began. Since all data was corrected to a common reference (date of O.R.N.L. assay) this difference cannot be attributed to decay (which would yield results in the opposite direction if not taken into account). Some concentration of activity by the solid was therefore noted, although the mechanism is not determined.

For Run XIII there appear some real differences of activity between the initial and final samples of the sludge solids beyond the 10.0 mc/l initial activity level (A_o in mc/l). Differences in the liquid phase do not appear until a concentration of 50 mc/l is reached. The distribution of activity in the liquid is the reverse of that noted for Run XII, the samples of liquid phase at the end of the digestion period showing greater activity than at the beginning of the experiment. However, the trend of increased uptake by the solids is shown again. The final activity in sewage solids (at $A_0 = 600$ mc/l) was 473 μc/gm, while the initial activity was only 432 μc/gm, with decay accounted for. Thus, from a carefully conducted gravimetric basis (μc/gm), it is shown that 143 per cent and 100 per cent, respectively, of the initial I^{131} activities were in the sludge solids at the end of digestion in Runs XII and XIII.

PART II

RADIOPHOSPHORUS (P^{32}) STUDIES

A. Effect on Gas Production

The maximum concentration of high specific activity P^{32}(*) investigated was 800 mc/l. Figures 10 and 11 show families of curves of cumulative gas production from Runs XIV and XV respectively, from digesters containing plain sludge, those to which an equivalent concentration of salt (**) was added, and those containing carrier-free P^{32} from 1 mc/l to 800 mc/l of activity levels.

(*) High specific activity P^{32} will be referred to hereafter as "carrier-free" P^{32}. Carrier-free P^{32} has a specific activity of approximately 300,000 curies/gm (290,000 c/gm). The high-specific activity of P^{32} used in these experiments was from 10^{-4} to 10^{-3} times this specific activity as shown by O.R.N.L. assays, or 300 c/gm (50 to 300 c/gm). In earlier work at this laboratory, P^{32} with specific activities from 100 to 300 mc/31gms KH_2PO_4 were added to the sludge (6). This activity was only about 0.3 c/gm (0.1 to 0.3 c/gm). Therefore, the P^{32} applied in the present studies represents a much higher specific activity than previously, greater by a factor of 10^4 compared to the earlier work.

(**) "Salt" in these carrier-free P^{32} studies refers to a slightly acid solution of PO_4 in weak HCl (approx. 0.4 N HCl). The carrier-free solution of P^{32} (designation P-32-P-1) was received in this chemical form from Oak Ridge National Laboratory. To the controls an equivalent concentration of NaCl was added to compensate for the milliequivalents of chlorides added with P^{32}-acid solution. The maximum PO_4 concentration added to any digester (800 mc/l) amounted to only 5.85 mg/liter which represents such a small increase in phosphates already present that no adjustment in the phosphates was made.

Figures 10 and 11 show the effect of increasing P^{32} concentrations from 1 mc/l to 800 mc/l on cumulative gas production. The two runs are comparable because the same concentrations of P^{32} were added to the sludge, the same temperature (91 °F) was maintained and close to the same substrate composition was used (ratio of raw to digester 0.92:1 and 1.15:1, respectively).

It is apparent from Figures 10 and 11 that no deleterious effect on gas production due to P^{32} is exerted at the 1.0 and 10 mc/l activity levels. It may be noted that beginning with the 100 mc/l of carrier-free P^{32} some reduction of gas production appeared, when compared with the results from plain digesters. Rapidly increasing differences and greater reductions in gas production were clearly demonstrated as the concentrations of P^{32} were increased to 200 mc/l, 400 mc/l and 800 mc/l. The gas production is reduced to approximately 90 per cent in the presence of 200 mc/l, to approximately 75 per cent in the presence of 400 mc/l and to about only 50 to 65 per cent at the 800 mc/l radiophosphorus (P^{32}) activity in the sludge. Table IV below summarizes these reductions in total gas production at the end of 30 days of digestion and at the end of each run from the laboratory data. Figures 10 and 11 clearly show the effect of P^{32} concentrations.

TABLE IV. Gas Production in Presence of Carrier-free P^{32}

Lab. Run	Time of Digestion (Days)	Concentration of Carrier-Free P^{32} 200 mc/l	 400 mc/l	 800 mc/l
XIV	30	89.9%	_____(a)	49.6%
	41	90.8%	_____(a)	47.6%
XV	30	87.5%	72.5%	67.5%
	32	87.2%	77.2%	67.3%

(a) It was not possible to include a digester with a concentration of 400 mc/l in Run XIV. However, this level of P^{32} was studied during Run XV.

Figure 12 shows the results of cumulative gas production for digesters 9 through 12, Run XV. To these digesters, acting as the controls, the equivalent concentrations of chlorides were added, equivalent to concentrations of 100, 200, 400 and 800 mc/l of P^{32}. The gas curves show that there is no difference between the controls and the plain sludge and that there is extremely little difference between the individual digesters. This demonstrates that the experiment was under careful control and the experimental error a minimum. Therefore, the results from the controls as shown in Figure 12 lend additional emphasis that the reduction in gas production is significant for the 800 mc/l concentrations of P^{32}, probably due to the radiation intensities produced by radiophosphorus.

In contrast to the reduced gas production phenomena in the presence of P^{32} activities up to 800 mc/l, added as KH_2PO_4 with a maximum concentration of 22.9 per cent, previously described (6), in these studies the gas production rate did not drop to zero after the first few days when the same concentrations of carrier-free P^{32} were added, except on about the tenth day in the presence of 800 mc/l in Run XIV, see Figure 10. Because a solution with 22.9% of KH_2PO_4 has a pH value of approximately 5.1 which is detrimental to the microbiological organisms responsible for anaerobic digestion, the breakdown of the fermentation process was principally ascribed to chemical effects due to KH_2PO_4 rather than to radiological effects from P^{32}.

The digesters containing carrier-free P^{32} in excess of 100 mc/l during Runs XIV and XV exhibited an increased inhibition of the digestion process as shown in Figures 9 and 10, but instead of the daily gas production rate dropping off to zero as previously reported (6), the daily gas production rate decreases more gradually and uniformly. Since the addition of carrier-free P^{32} did not cause detrimental conditions of pH to the microorganisms responsible for digestion, the uniform decrease of the gas production rate would indicate that the microbiological system was gradually exposed to, or above, its lethal tolerance or toxicological limit.

Since bacterial kill phenomena are governed by time-concentration effects, it is quite possible that the gradual destruction of digestion was due to ionizing radiation. The conclusion that these deleterious effects on gas production at concentrations in excess of 100 mc/l of carrier-free P^{32} are due to radiological effects is further supported because the controls exhibited no differences from the plain sludge, as already discussed.

As may be seen from Table V, the efficiency of gas production, expressed as ml/gm of volatile matter added, and cu ft/lb of volatile matter destroyed, was similarly reduced, especially for digester 1, Run XIV (300 mc/l) and digesters 1 and 2, Run XV (400 and 800 mc/l). At concentrations of 100 mc/l and less of carrier-free P^{32}, there was no difference in the efficiency of gas production compared to the digesters without any activity. Gas Production in both Runs XIV and XV was quite similar to that experienced during plant operation. According to Van

Kleeck (16), under favorable conditions of digestion, gas production should be from 11 to 15 cu ft/lb of volatile matter destroyed.

In the foregoing discussion only the batch digesters, Nos. 1 through 12, have been included. The recirculated digesters, Nos. 13 through 16, were not included because the data obtained is too variable to be useful to draw definite conclusions. This is largely caused by the fact that at various intervals throughout these runs some of the flow lines broke and additional sludge was added to make up for the loss. Obviously this procedure makes this data nonhomogeneous and precludes it from a combined analysis with the batch digestion experiments.

1. Reaction Velocity Constant

The reaction velocity constants were computed from all the cumulative gas production curves for 16 digesters in Run XIV and 17 digesters in Run XV. The reaction velocity constant was obtained by fitting the data to a first order type of curve with a lag phase in accordance with the discussed theory on pages 5 through 7 and Equation (4).

It was decided that a k-value, based on 30 days of data, was satisfactory for a comparison of all digesters, although these runs continued for 32 and 41 days, respectively. The results of statistically evaluating the significance of effect due to the presence of radioactivity in concentrations from 1 to 800 mc/l of carrier-free P^{32} are shown in Table VI. A comparison was made in each case between k-values for plain digesters versus k-values for digesters with P^{32} at each level of activity. Students' t-distribution and the "t-test" for significance were used to obtain the probabilities.

As in many cases where biological reactions are involved, the test for significance was based on the 95 per cent confidence limits. Therefore, with the use of the t-distribution, an average of the differences between plain and radioactive sludge parameters is considered significant only when such stated difference can be expected to occur due to chance factors alone less than 5 per cent of the time.

Table VI shows no significant difference in the reaction rate of anaerobic digestion up to 100 mc/l. However, when the k-values from those digesters containing only 800 mc/l were compared with the plain sludge, a probability of only 0.9 per cent was found. Therefore, there is a significant effect on the reaction rate due to the presence of carrier-free P^{32} ac-

TABLE V

Experimental Conditions, Gas Production and Volatile Matter Reduction

Part II Radiophosphorus (P^{32}) Studies

Run Period (Days) Date	Dig. No.	EXPERIMENTAL CONDITIONS					TOTAL GAS PRODUCTION		Reduction Volatile Matter (%)
		Sludge Volume (mls)	Sludge Mixture	Inc. Temp. °F.	Conc. of Salts (a) (p.p.m.)	Conc. of P^{32} (mc/l	Ml/gm V.M. Added	Cu.ft. per lb. V.M. Destroyed	
XIV (41) 8/7/58 to 9/17/58	1	450	0.9:1	91^b	-	800	125.9	6.4	30.8
	2				-	200	239.1	11.1	33.4
	3				-	100	253.5	10.9	36.1
	4				-	10	265.6	11.4	36.0
	5				-	1	262.3	11.2	36.5
	6				-	-	262.0	11.9	33.9
	7				-	-	266.4	11.2	37.0
	8				0.7	-	265.4	11.2	36.9
	9				7.3	-	264.7	11.2	36.6
	10				73	-	262.5	10.3	39.9
	11				146	-	261.2	11.2	36.2
	12	↓			584	-	264.7	10.6	39.1
	13	1000			-	-	260.5	23.7(b)	17.6(b)
	14				-	10	282.3	17.0	26.6
	15				-	100	255.4	15.1	27.1
	16	↓	↓	↓	-	10	275.8	14.7	30.1

TABLE V (cont'd)

Experimental Conditions, Gas Production and Volatile Matter Reduction

Part II Radiophosphorus (P^{32}) Studies

Run Period (Days) Date	Dig. No.	EXPERIMENTAL CONDITIONS					TOTAL GAS PRODUCTION		Reduction Volatile Matter (%)
		Sludge Volume (mls)	Sludge Mixture	Inc. Temp. °F.	Conc. of Salts (a) (p.p.m.)	Conc. of P^{32} (mc/l)	Ml/gm V.M. Added	Cu.ft. per lb. V.M. Destroyed	
XV (32) 10/30/58 to 12/1/58	1	450	1.1:1	91°	-	800	155.7	7.7	32.4
	2				-	400	179.1	7.9	36.4
	3				-	200	202.7	8.0	40.7
	4				-	100	223.6	8.9	40.3
	5				-	1	228.5	8.6	42.8
	6				-	-	232.1	10.1	36.9
	7				-	-	230.5	9.9	37.5
	8				0.223	-	236.4	10.8	35.2
	9				22.77	-	238.9	10.3	37.1
	10				45.54	-	238.9	10.1	38.1
	11				91.08	-	237.6	10.4	36.7
	12	↓			182.16	-	239.1	9.9	38.6
	13	1000			-	-	243.2(c)	8.2(b)	47.3(b)
	14				-	10	228.6	24.3(b)	15.1(b)
	15				-	10	372.6(c)	22.4(b)	26.3(b)
	16				-	1	228.1	88.3(b)	4.1(b)
	17	↓	↓	↓	-	-	274.1(c)	13.1	33.5

(a) P^{32} received as H_3PO_4 in dil. HCl. Added as Na_2HPO_4 in NaCl. Meq. NaCl added to the controls. PO_4 in 800 mc/ml less than 6 ppm. No PO_4 added to controls.

(b) Pump line broke, spilling contents.

(c) Air leaked into recirculation lines.

tivity of 800 mc/l, within the limits of these experiments. It may be of interest to note that the value of the average difference for k-values is negative and that this signifies a greater reaction rate for the high activity digesters than those containing a low concentration or no activity at all. The difference would be expected to be negative, but when it is recognized that the total gas production, G, was significantly reduced, this increased average difference in the reaction rate simply means that the anaerobic fermentation was complete as far as radiation intensity would permit much sooner than when there was no radioactivity in the digesters.

From a similar comparison between the plain sludges and those containing an equivalent concentration of salt, the results from statistical analysis are also included in Table VII and show that there are some real differences.

To further examine this data and to find if there were any other variables affecting the values of k, besides the concentrations of carrier-free P^{32}, a multiple correlation analysis by means of an I.B.M. 650 High Speed Computer was performed. From the data of a total of 33 sets of values, the following regression equation was found:

$$k = -0.1424 + 0.2566M + 0.000069S_c + 0.00014P_c \qquad (8)$$

in which

M = proportion of sludge mixture based on fresh solids

S_c = concentration of NaCl, ppm; and

P_c = concentration of carrier-free P^{32}, mc/l.

The variable of temperature was not included in the correlation analyses for P^{32} since the temperature only varied from 91° to 92 °F.

The coefficient of multiple correlation R was found to be 0.73, which is highly significant. This shows that there is a significant dependence of k-values on any or all of the factors measured, or a significant correlation of k-values with the type of mixture, concentration of salt and activity level of P^{32}. The value R = 0.73 also shows that values of k may be predicted by substitution in the regression equation.

From the multiple correlation analysis, the coefficients of partial correlation, r, for the three variables with k were found to be:

TABLE VI

Average Differences and the Probability (p) of their Occurrences by Chance Alone for k, G and C Values at Various Concentrations of Carrier-free P^{32} and NaCl Added to Plain Sludge

(a) Comparing Plain Sludge vs. Carrier-free P^{32}

Plain Sludge vs. P^{32} (mc/1)	No. of Digester Pairs	Values of k		Values of G		Values of τ	
		$\bar{d} = \frac{\sum(k_c-k_h)}{n}$	P (%)	$\bar{d} = \frac{\sum(G_c-G_h)}{n}$	P (%)	$\bar{d} = \frac{\sum(\tau_c-\tau_h)}{n}$	P (%)
1.0 to 100	11	+0.0005	88.0	- 5.52	43.4	- 0.11	8.6
200 to 800	5	-0.0320	17.6	+69.10	1.9	+ 0.05	15.4
400 to 800	4	-0.0403	17.1	+102.08	1.8	+ 0.06	24.3
800	4	-0.0755	0.9	+106.88	0.9	+ 0.01	1.6

(b) Comparing Plain Sludge vs. Controls

Plain Sludge vs. Controls (NaCl, ppm)	No. of Digester Pairs	Values of k		Values of G		Values of τ	
		$\bar{d} = \frac{\sum(k_c-k_s)}{n}$	P (%)	$\bar{d} = \frac{\sum(G_c-G_s)}{n}$	P (%)	$\bar{d} = \frac{\sum(\tau_c-\tau_s)}{n}$	P (%)
0.23 to 584	10	+0.0028	4.6	- 1.64	30.5	- 0.01	33.6

TABLE VI (cont'd)

Average Differences and the Probability (p) of their Occurrences by Chance Alone for k, G and C Values at Various Concentrations of Carrier-free P^{32} and NaCl Added to Pla in Sludge

(c) Comparing Carrier-free P^{32} vs. Controls

P^{32}(mc/l) vs. Controls (NaCl, ppm)	No. of Digester Pairs	Values of k		Values of G		Values of τ	
		$\bar{d} = \frac{\Sigma(k_h - k_s)}{n}$	P (%)	$\bar{d} = \frac{\Sigma(G_h - G_s)}{n}$	P (%)	$\bar{d} = \frac{\Sigma(\tau_h - \tau_s)}{n}$	P (%)
1.0 to 100 vs. Controls	5	-0.0054	20.1	- 7.38	18.7	+ 0.004	90
200 to 800 vs. Controls	5	+0.0366	16.2	-70.66	14.6	- 0.05	14.6
1.0 to 800 vs. Controls	10	+0.0152	23.9	-39.02	1.2	- 0.03	13.8

$r_M = 0.62$ (partial correlation between type of mixture and k-values)

$r_S = 0.19$ (partial correlation between salt concentrations and k-values)

$r_P = 0.59$ (partial correlation between concentration of P^{32} and k-values)

Thus, both mixture and P^{32} concentration exert a significant influence on the reaction velocity constant.

The result from t-tests of the regression coefficient with the standard error of the regression coefficient, $b_j/S_{b_j} = t_{N-n}$, with 29 degrees of freedom, show that the regression coefficients for mixture and P^{32} concentration are highly significant ($t_{Mixture} = 4.17$; $T_{P-conc.} = 3.93$; $P < 1\%$). The strong influence of sludge mixture (seeding) is well established (15). Aside from this fact, the analysis of the partial correlation coefficients has clearly established that the effect of P^{32} is the only other significant variable affecting the k-values.

2. Ultimate Gas Production

The ultimate gas volumes, G, in terms of mls. per gm. volatile solids added and calculated as the ultimate value by the slope method were subjected to the same statistical analyses. The results from comparisons between plain, radioactive and control sludge digestion are shown in Table VI.

Significant reductions in the ultimate gas production were found when the results from plain sludge digesters were compared with those containing activities from 200 to 800 mc/l of carrier-free P^{32}. The average reduction of G-values was 70 mls/gm which is 28 per cent of the average ultimate gas produced by the plain digesters in Runs XIV and XV (244 mls/gm). Reductions of ultimate gas production values were found to be highly significant at the 95 per cent probability level for concentrations of P^{32} from 200 to 800 mc/l.

A comparison of G-values between the controls and those digesters containing 1.0 to 800 mc/l radiophosphorus produced similarly significant results.

No significant differences were found when G-values for plain or control digesters were tested against those containing from only 1.0 to 100 mc/l of P^{32}. Therefore, the effects of carrier-free P^{32} were shown once more to become operative only above the 100 mc/l level.

In a final t-test analysis, shown in Table VI, between the G-values for plain versus control digesters it was found that there exists no real difference between them.

In another attempt to examine if there was any real effect on G-values due to P^{32}, a multiple regression analysis yielded the following regression equation, expressing the functional relationship between G, mixture, salt and P^{32} concentration:

$$G = 375.04 - 113.79\,M - 0.0147\,S_c - 0.1507\,P_c \qquad (9)$$

in which the independent variables are defined exactly as for equation (8). The coefficient of multiple correlation, R, for equation (9) was found to equal 0.77. This shows that a highly significant correlation exists between G-values and type of mixture, salt concentration and activity level of P^{32} and that with equation (9) predicted G-values can be obtained.

The coefficients of partial correlation, r, for these variables with G were found to be:

$$r_M = -0.43,\ r_S = -0.06,\ r_P = -0.74.$$

The minus sign (negative correlation) simply means that the value of G is depressed as the seed, salt and P^{32} concentrations are raised. From an analysis of the partial correlation coefficients it is very evident that the effect of P^{32} concentrations is the greatest, single variable which decreased G, the ultimate gas production values.

This conclusion is further supported by the analysis of t-tests of the regression coefficients with their standard errors. With D.F. = 29, the results show a probability of only 1.7 per cent for the effect of mixture, as expressed by equation (9) and <1 per cent for the effects due to P^{32}.

It would therefore appear that since real differences in both k and G values were found with carrier-free P^{32} concentrations in excess of 100 mc/l, that both the rate of organic matter breakdown and the total organic matter available for decomposition was reduced.

Although a limited amount of qualitative and quantitative bacteriological work was carried out in conjuction with both Runs XIV and XV, the results were inconclusive. There seemed to be a smaller number of organisms surviving at the 400 and 800 mc/l levels which would indicate that the reason for toxic effects at the higher levels of P^{32} were due to the depletion of surviving microorganisms. This would be expected to manifest itself by a reduced gas production rate (as a result of the activities of microorganisms and enzyme systems) as well as a decrease of the accessible food for breakdown (as a result of the interference from toxic end-products).

3. Effect on Lag Period

As may be seen from Figures 10, 11 and 12 there is no appreciable increase in the lag period, τ, in the presence of P^{32} concentrations from 1.0 to 800 mc/l. From an analysis of τ-values between plain digesters and those containing various levels of P^{32} and controls with equivalent salt concentrations it was established that no significant differences exist, see Table VI.

From the multiple correlation analysis the following regression equation was determined.

$$\tau = -1.025 + 1.219M + 0.000053 S_c - 0.00027 P_c \qquad (10)$$

in which the terms M, S_c and P_c are defined as previously. The coefficient of multiple correlation, R, was found to be 0.89 which shows a highly significant correlation between any or all of the variables and τ. The partial correlation coefficients show that practically all the correlation is due to the type of mixture ($r_M = 0.87$) and that the concentrations of salt or P^{32} exert little influence ($r_S = 0.07$; $r_P = -0.07$) in this correlation within the limits of these investigations.

Similarly, the results from t-tests of the regression coefficients point to the mixture type as the significant variable ($t = 9.4$; $P < 1\%$) whereas salt and P^{32} concentrations are insignificant ($P = 71$ and 72 per cent, respectively) variables as far as the τ-values are concerned.

4. Reduction of Volatile Matter and Volatile Acids

The reduction of volatile matter values in Table V indicates that up to the 100 mc/l level of carrier-free P^{32} there was no real differences as compared to digesters containing plain or control sludges. Without the addition of any radiophosphorus, volatile matter reduction ranged from 34 to 40 per cent. In the presence of 800 mc/l of P^{32} the volatile matter destruction was decreased to about 30.8 and 32.4 per cent, respectively, during Runs XIV and XV. Reduced digestion efficiencies in the presence of high concentrations of P^{32} are expected from the foregoing discussions.

It is interesting to note that in those cases where digestion was significantly inhibited due to high concentrations of P^{32}, the level of volatile acids concentration (total as acetic acid) were higher than for the plain and control digesters at the end of the fermentation period. At the end of Run XIV the 800 mc/l activity sludge contained a concentration of 1014 ppm of volatile acids or a value approximately 10 times greater than the plain and control digesters which contained only between 92 and 129 ppm. representing a very narrow range of volatile acids values.

In Run XV the volatile acids ranged from 140 to 188 ppm for all digesters with the exception of those containing 400 to 800 mc/l. The latter digesters contained 330 and 352 ppm of volatile acids respectively, which represents a 100 per cent increase in volatile acids concentration. It is of interest to note that in no case the sludge reached a value close to the limit of 2,000 ppm, usually considered the volatile acid level at which normal digestion is upset.

B. Effect on Redox Potential, Liquid Conductivity and pH

With the identical procedures used during the I^{131} studies and previously reported in greater detail (9) (11) redox potential, conductivity and pH measurements were continuously recorded. As for the I^{131} studies there appear to be no measurable differences between the redox potentials obtained from the various digesters, regardless whether they contained plain or control sludge, or sludge to which P^{32} had been added. Figures 13, 14 and 15 show typical plots of cumulative gas production, ORP, conductivity, pH and temperature against time of digestion in days.(*)

(*) The redox potential measurements shown in Figures 13, 14 and 15 represent digesters 13, 14 and 15 of Run XV. This is in contrast to the rest of the data presented in these figures, which were obtained from Run XIV. During Run XIV no electrode systems requiring a KCl salt bridge could be used in order that the conductivity data would represent the changes occurring during the digestion of sewage sludge without any interference. When pH and ORP cells are introduced in the same flow line, together with a conductivity cell, there must always be some diffusion of KCl into the liquid medium, otherwise pH and ORP are not measurable. This slowly increasing concentration of KCl in the sludge would materially contribute to the gradual increase in conductivity values as digestion proceeds and thus lead to a false interpretation of the data. Since the measurement of conductivity is made between two platinum electrodes there is no need for KCl bridge.

There appear to be no real differences in the redox potentials between digesters 13, 14 and 15 (Run XV). The ORP value (based on E_h) of plain sludge at the end of the first day is -100 mv, rises and then falls off gradually to a value of -275 mv. For digesters 14 and 15 containing 10 mc/l of P^{32}, the ORP value at the end of the first day is about -100 mv and drops gradually to -245 mv and -295 mv, respectively.

The initial E_h value of the sludge mixture was zero. From the total change in magnitude during the digestion process, and the overall slope of the redox potential curves, it appears that no significant difference at the 10 mc/l concentration of P^{32} occurred. The redox potential for digester 16, not shown, had a value of about -100 mv, but decreased gradually to only -230 mv at the end of the 30-day period. Therefore it would appear that the reactivity of the system was reduced at the 100 mc/l concentration. Because of practical considerations none of the recirculating digesters were charged with a concentration exceeding 100 mc/l in any run. Leakage from flow lines would have contaminated the laboratory.

Conductivity during Run XIV was carefully monitored to measure the true changes in magnitude of this variable and to establish its value as a parameter describing the efficacy of the sludge digestion process. The table below shows that the conductivity of the sludge mixture rose rather rapidly during the first few hours and that the change during that period was about 10 per cent of the total change experienced over a 41-day period. This initial increase in conductivity may be ascribed to a rapid carbon dioxide saturation of the sludge.

For the same reason no pH electrodes were inserted in the flow lines during Run XIV. Thus, the pH values shown for digesters 13, 14 and 15 actually represent the pH from digester 17 which had pH electrodes but no conductivity cell.

Although this makes the interpretation of data presented in Figures 13, 14 and 15 a little more difficult, it was the only method by which to obtain true conductivity teadings.

TABLE VII . RUN XIV. Electrical Conductivity of Sludge

Dig. No.	Character of Sludge	Conductivity, umhos			
		0.9:1 Mixture(a)	At Start of Run(b)	Two Hours Later	At end of 41 Days
13	Plain	2580	3280	3500	8550
14	10 mc/1	2580	2090	3261	8330
15	100 mc/1	2580	3120	3195	8040
16	10 mc/1(c)	2580	2760	3100	7500

(a) Before dosing with activity;

(b) After dosing;

(c) Concentration of 10 mc/1 maintained throughout Run XIV by periodic feeding of carrier-free P^{32}.

There seems to be no significant effect on conductivity due to carrier-free P^{32} up to 100 mc/1 in Run XIV. However, at the end of the 41-day digestion period there is a trend of decreasing conductivity values with an increase in P^{32} concentration. This decrease from 8,550 µmhos to 8,040 µmhos amounts to six per cent. Digester 16, maintained at 10 mc/1 of P^{32} throughout the run, had even lower conductivity values, reaching a final value of only 7,500 µmhos at the end of 41 days. This represents a 12 per cent reduction from the plain sludge. The data is too meager to generalize these observations for finite conclusions, but it would appear that both ORP and conductivity bear some functional relationship to increasing concentrations of P^{32}, which probably could be better evaluated at higher levels of activity.

During Run XV the pH values were not affected in the presence of carrier-free P^{32} up to the 100 mc/1 concentration. The pH had an initial value of 6.8 and rose gradually to 7.5, after going through the normal acid fermentation stage. It follows that pH is not a sensitive measure of the effect of radiophosphorus on sludge digestion. activity.

C. Effect on Gas Quality

Chromatographic analyses of sludge digestion gases were carried out for all P^{32} studies. Samples from each of the digesters were analyzed daily to follow changes in gas composition with digestion progress. The chromatograms from representative digesters on two different days are reproduced in Figure 16.

Results from digesters 1 through 8 for the third day of Run XV show that the gas from the digester with 800 mc/l contained more CO_2 (44.4%) and less CH_4 (55.6%) than the control. The latter contained only 31.9% CO_2 but 68.1% CH_4 (digester 12). Digester 2 with 400 mc/l shows a similar difference, although less pronounced. Both digesters 3 and 4 (200 and 100 mc/l respectively) show only slight differences, compared to their controls. Digester 5 (1 mc/l) shows the same composition as digesters 6, 7 and 8 (plain sludge and its equivalent control).

On the tenth day a higher concentration of CO_2 remains present in digesters 1 and 2, but all others have the same gas composition. Therefore, it is concluded that up to 100 mc/l of carrier-free P^{32} there is no real effect on gas quality. From 400 to 800 mc/l levels of activity increasingly greater concentrations of CO_2 are exhibited, especially during the first few days of the anaerobic process. This further supports the fact that there is a significant effect on sludge digestion at the higher concentrations of P^{32}. A complete CO_2 analysis for all digesters in Runs XIV and XV is presented in Table VIII.

More nitrogen was found in the digesters on the tenth day than on the third day. On the third day the digesters were producing gas at a rapid rate, but gas production had fallen off by the tenth day. The same amount of air which is introduced into the digester through diffusion (when the gasometers are zeroed daily) was usually completely purged by sludge gas during early, high gas production. However, during the later period, the air introduced accumulated in the digesters and showed up on the chromatograms when gas production rate fell off. The gas composition, however, was calculated on a nitrogen-free basis.

D. Distribution of Activity between Liquid and Solid Phases

The results from studies of the distribution of carrier-free P^{32} between the supernatant and sludge solids have been summarized in three curves with a table of the data shown in each figure.

Figure 17 shows that the per cent uptake by the solid decreases with increasing initial activity (A_0) from 1.0 to 800 mc/l. These results indicate that more of the P^{32} activity will be in the liquid phase as the initial activity is increased.

TABLE VIII. PERCENT OF CARBON DIOXIDE IN SLUDGE GAS FROM CHROMATOGRAPHIC ANALYSIS

RUN XIV - P^{32} STUDIES

DIG. NO.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TYPE		800 MC/L	200 MC/L	100 MC/L	10 MC/L	1 MC/L	PLAIN	PLAIN	CONTROL (1)	CONTROL (10)	CONTROL (100)	CONTROL (200)	CONTROL (800)	PLAIN	10 MC/L	100 MC/L	10 (A) MC/L
DAYS	1	44.52	49.02	49.77	50.46	50.46	50.41	50.81	50.61	50.86	50.00	49.77	50.06	49.53	49.94	49.59	49.71
	2	35.51	35.89	36.32	36.23	36.50	36.12	36.50	36.23	36.36	36.78	35.40	35.32	39.48	39.53	38.92	39.02
	3	35.29	30.88	30.20	29.32	29.11	28.94	30.07	29.13	29.15	28.90	29.19	29.40	32.34	31.97	33.53	33.10
	4	36.45	31.41	30.07	28.83	28.80	28.89	29.02	28.88	28.98	28.98	28.41	28.92	28.01	28.67	30.58	28.99
	5	37.15	30.95	29.61	28.12	27.52	27.93	27.94	28.11	27.73	27.87	27.75	27.76	24.79	25.09	27.00	25.70
	6	36.09	29.12	29.52	27.68	27.60	27.68	27.50	27.71	27.71	27.95	27.81	27.81	27.06	26.74	25.89	25.50
	7	34.82	29.25	27.50	27.55	27.95	27.93	28.02	27.81	27.81	27.81	27.02	28.06	26.56	25.93	25.50	25.77
	8	34.32	28.98	27.31	28.05	28.05	28.20	28.05	28.12	28.01	28.30	27.90	28.08	26.69	25.18	25.00	24.91
	10	32.61	27.69	26.91	28.57	28.35	28.28	28.38	28.22	28.54	28.55	28.71	28.07	26.77	26.28	23.91	28.82
	11	31.77	27.46	26.41	28.36	28.17	28.29	28.40	28.34	28.21	28.14	28.31	29.91	23.94	24.84	23.73	26.20
	12	31.18	27.04	26.07	28.40	28.00	28.01	27.95	27.63	28.29	27.99	28.39	29.04	23.80	24.47	22.47	24.97
	13	29.95	26.14	25.31	27.61	27.55	27.59	27.29	27.56	27.83	28.17	27.97	28.68	23.03	24.18	22.13	34.33
	14	29.24	25.86	24.83	27.54	27.49	27.30	27.25	27.34	27.69	27.72	27.73	28.52	23.55	24.25	22.09	28.79
	15	30.00	26.81	25.51	28.11	27.80	27.94	27.62	27.63	28.05	28.03	28.32	28.29	24.14	24.77	22.77	100.00 (B)
	17	30.23	26.11	24.51	26.54	26.27	26.16	26.09	26.05	25.63	25.77	25.83	27.64	22.71	22.64	22.02	38.82
	42	27.29	20.25	19.34	18.97	20.35	20.77	20.24	18.81	20.47	21.26	21.76	22.94	15.77	15.62	13.88	22.03

(A) DIGESTER WAS OPENED PERIODICALLY TO FEED P^{32} (TO MAINTAIN 10 MC/L ACTIVITY)
(B) DIGESTER HAD JUST BEEN OPENED TO FEED P^{32}

TABLE VIII. PERCENT OF CARBON DIOXIDE IN SLUDGE GAS FROM CHROMATOGRAPHIC ANALYSIS

RUN XV – P^{32} STUDIES

DIG. NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TYPE	800 MC/l	400 MC/l	200 MC/l	100 MC/l	1 MC/l	PLAIN	PLAIN	CON-TROL (1)	CON-TROL (100)	CON-TROL (200)	CON-TROL (400)	CON-TROL (800)	PLAIN	10 MC/l	10 MC/l	1 MC/l
DAYS 1	35.9	37.3	37.2	40.4	41.8	42.1	42.2	45.7	42.7	42.9	43.1	42.7	38.0 -(c)	42.7 -(c)	41.2 -(c)	41.1 -(c)
2	44.30	40.68	38.69	37.60	42.06	36.50	36.50	36.69	36.50	36.42	36.60	36.51				
3	44.36	35.04	33.79	32.85	31.23	30.35	30.19	30.21	29.03	31.85 -(c)	31.98	31.91	38.93	32.75	33.25	40.80
4	37.71	35.43	33.29	32.67	31.70	31.88	31.92	32.05	32.10		32.02	32.10	46.10	32.66	47.22	38.77
5	34.79	32.89	31.29	31.05	30.56	30.89	30.88	30.79	30.86	30.96	31.06	30.71	35.06	30.17	62.50	31.91
6	34.24	32.06	31.10	31.49	31.46	31.07	31.55	31.31	31.48	31.64	31.39	31.55	31.63	30.77	33.71	19.51
7	31.79	31.41	30.66	31.24	31.62	31.65	29.84	31.67	31.94	32.16	30.75	31.97	33.40	28.10	38.22	28.62
8	32.12	31.31	30.16	31.58	31.62	32.21	31.96	31.78	31.97	32.08	31.61	31.62	32.91	27.81	37.19	41.81
10	31.19	30.61	29.60	31.21	31.69	32.07	31.79	31.87	31.93	31.91	31.62	31.91	30.59	36.05	29.17	31.64
11	30.14	29.97	28.53	30.58	30.49	31.55	31.29	31.18	31.52	30.75	31.33	31.64	28.19	55.34	36.84	25.64
12	28.47	27.27	27.88	30.17	30.35	30.81	30.63	30.07	31.04	31.23	32.13	30.92	27.39	47.12	32.17	25.69
13	23.94	23.61	27.58	29.73	29.87	30.60	30.14	30.01	30.49	30.43	30.40	30.58	27.55	42.85	28.85	25.83
14	32.83	23.95	31.19	29.31	28.80	28.94	25.92	29.49	30.17	29.78	29.92	30.01	27.91	39.44	27.52	25.80
15	29.21	26.38	27.12	29.06	29.02	31.05	29.42	29.40	29.76	29.22	29.54	29.64	27.73	43.55	26.13	25.46
18	28.50	27.50	25.53	27.67	27.45	29.02	28.15	28.24	28.63	28.79	28.95	29.37	26.39	31.08	20.87	25.55
25	28.77	26.46	23.31	24.22	23.77	26.51	26.23	25.35	26.60	26.25	26.50	27.10	24.45	33.98	25.19	20.06

(c) NO ANALYSIS AVAILABLE

The results are opposite from those previously reported (6) for P^{32} in the form of KH_2PO_4. With the di-H orthosphosphate salt the responsible mechanism may have been co-precipitation. The salt was mixed with and adhered to the sludge solids and was therefore counted as part of the solids activity. This mechanism is quite possible since concentrations of KH_2PO_4 greater than one per cent and as high as 22.9 per cent had to be used during those runs to obtain the desired high levels of radiophosphorus activity.

With use of carrier-free P^{32} the concentration of the phosphate radical in the digester was lower. A maximum of only six mg/l of PO_4 was added and it is safe to assume that all radiophosphorus present in the sludge was in the form of the phosphate radical. It is safe to assume that none of the radioactive phosphates precipitated since their concentration was well within their solubility range. This includes the soluble phosphates normally present in sewage and sludge.

A semi-log plot of the decontamination factor (D.F. = initial activity divided by the final activity) for concentrations of initial activity from 1.0 to 800 mc/l of P^{32} shows that the activity concentrates in the liquid phase with a maximum value of D.F. = 23 at the 1.0 mc/l level of activity. From Figure 18 it is apparent that this small ability of the liquid to concentrate carrier-free P^{32} decreases rapidly to decontamination factors with values from 2 to 3.

The D.F. for the solid phase is considerably lower than for the liquid for all concentrations of P^{32}. It decreases from 2.35 to 0.59 as A_o increases from 1 to 800 mc/l. From Figure 18 it appears that the decontamination factor is from 5 to 10 times greater for the liquid than for the solid within the range of carrier-free P^{32} studied.

Figure 19 represents the proportion of activity removed, expressed as the percentage of initial activity in µc/gm. On the basis of activity per unit weight, the efficiencies of decontamination by either liquid or solid phases could be determined. The resulting curves appear difficult to interpret at first but they do support findings from Figures 17 and 18, demonstrating that the P^{32} went to the liquid phase during digestion. The ratio $\frac{A_o - A_t}{A_o}$ for the solid phase is positive for values of A_o less than 2.0 mc/gm and for values above 800 mc/gm, but assumes a negative value between these points. If there was no gasification of solids during digestion, negative values would indicate an uptake by the solid. Since gas was produced and the solids concentration decreased during anaerobic digestion, this would increase the activity on a weight (milligram) basis. It is therefore reasoned that negative values would be expected from either (a) gasification or (b) uptake of P^{32} by the solid between 2.0 and 800 mc/l activities with the same unit gas production (cu ft/lb). Consequently, for an equal dgree of destruction of solids, the liquid must have taken up considerable activity at the 1.0 mc/l and 800 mc/l levels.

The ratio $\frac{A_o - A_t}{A_o}$ for the liquid is negative between approximately 40 and 200 mc/l, which means that with an increased amount of liquid during digestion (liquefaction) a considerable amount of activity was concentrated by the liquid phase. The negative values for the solid are meaningless, similarly the positive values in the liquid are misleading unless we interpret these results by observing both curves.

It should be noted that in the lower righthand side of Figure 19 there are three points at activity levels A_o between 200 and 800 mc/l which represent highly negative values of the liquid ratio. These provide further evidence for the strong tendency of the liquid to concentrate carrier-free P^{32}. Although these points were eliminated from the graph for clarity, they nevertheless represent significant data obtained in Run XV. The reason the data from Run XV is especially significant is because during that run experimental procedures, including sample preparation and radioassay work, were well established and greater confidence can be placed in the data obtained during this final run.

SUMMARY AND CONCLUSIONS

These investigations on the effects of radioactive materials and their distribution during anaerobic digestion included five runs of carrier-free I^{131} with concentrations up to 600 mc/l and two runs with high-specific activity P^{32} with concentrations up to 800 mc/l. On the basis of the analyses of the experimental data the following conclusions may be drawn:

Results from Carrier-Free I^{131} Studies

1. Rate of gas production from similarly prepared seeded mixtures with or without I^{131} was not significantly altered up to 300 mc/l. At 600 mc/l of I^{131} a significant reduction of the reaction velocity constant was found. There were no significant differences in the reaction velocity constant between plain sludge and controls (containing equivalent concentrations of salt solution, composed of $NaHCO_3$ and Na_2SO_3).

2. Ultimate production of gas, volatile acids concentration, reduction of volatile matter and pH were not significantly affected by concentrations of I^{131} up to 600 mc/l.

3. The redox potential measurements from digesters with up to 100 mc/l and without I^{131} showed some minor differences but they were insignificant. Similarly, conductivity measurements were not affected up to concentrations of 600 mc/l of I^{131}.

4. The gas quality in the presence of I^{131} up to 300 mc/l of I^{131} was not affected. At 600 mc/l the relative concentrations of carbon dioxide to methane were significantly displaced from the controls. On the average, the carbon dioxide concentration was found to be 3.4 per cent greater for the first twelve days during Run XII, which was statistically significant. However, smaller differences were noted for the same high level concentration of I^{131} during Run XIII.

5. The distribution of radioiodine between the liquid and solid phases in the sludge after digestion does not appear to be significantly changed from its initial distribution. However, with an increase in initial activity from 1 to 600 mc/l a definite trend of increasing uptake by the solid was shown. At the end of Runs XII and XIII, 143 per cent and 110 per cent of the initial activities, respectively, were found in the solids, based on gravimetric analysis, at the 600 mc/l level. Simultaneously, the proportion of activity removed by the liquid was found to decrease from 12 per cent (at 1.0 mc/l) to 7.4 per cent (at 600 mc/l). The greater uptake by the solid, which may be of further interest at high levels of I^{131}, may be due to the fact that iodine does not participate in the metabolism of anaerobic digestion.

Results of P^{32} Studies

1. The presence of high-specific activity P^{32} appears to have significantly affected the reaction velocity constant at 800 mc/l as compared with the controls or the plain sludge digesters. Up to 400 mc/l no statistically significant differences were noted.

2. The ultimate gas production was not significantly affected up to 100 mc/l. At concentrations of 200, 400 and 800 mc/l the ultimate gas production was very significantly reduced. This effect was also shown in Figures 10 and 11. Results from the equivalent controls, shown in Figure 12, proved that the observed effect from experimental evidence is valid. These decreases in ultimate gas production are probably due to injurious effects from ionizing radiation rather than due to chemical effects of the isotope, as evidence by the controls. Furthermore, the multiple correlation analyses and t-tests of regression coefficients confer additional significance on the reduced ultimate gas production at the high levels of carrier-free P^{32}.

3. The redox potential measurements from digesters up to 100 mc/l of P^{32} showed that this variable was not significantly affected. The trend of ORP values remained about the same. Some small, but insignificant, differences appeared.

4. Some reductions in digestion efficiency were found. The reduction of volatile matter, ranging from 34 to 40 per cent for plain sludge and controls, was found to be decreased to 31 to 32 per cent at 800 mc/l.

The volatile acids concentration at the end of Run XIV was about 100 ppm for plain sludge and controls, but was 1000 ppm in the presence of 800 mc/l. This ten-fold increase in volatile acids also shows the adverse effect on digestion at high concentrations of P^{32}.

5. Conductivity measurements, following the breakdown of solids with progress of digestion, showed that a definite reduction was experienced at 100 mc/l levels of P^{32}. In another digester, maintained throughout Run XIV at 10 mc/l even lower values of conductivity, compared to its control, were obtained. Since conductivity has been shown to follow the progress of digestion and the process was adversely affected by high activities this may offer an explanation for this phenomenon.

6. Gas quality probably showed the deleterious effect on sludge digestion due to carrier-free P^{32} most clearly . Up to 100 mc/l there was no effect, but at the 100 to 800 mc/l concentrations increasingly greater relative percentages of CO_2 were found. Concentrations of CO_2 as high as 44.5 per cent, compared to 32 per cent for the controls, were noted on the third day of Run XV, which again demonstrates that digestion was adversely affected.

7. The per cent uptake by the solid decreases as the initial activity increases from 1.0 to 800 mc/l, which is in contrast to the I^{131} studies. These results indicate that more of the P^{32} activity will be present in the supernatant than in the digested solids. Figures 18 and 19 provide further evidence of the strong tendency of the liquid to concentrate carrier-free P^{32}.

These findings are opposite to previous studies with P^{32} which used a high concentration of carrier salt in the form of KH_2PO_4. In the present "carrier-free" P^{32} studies it is safe to assume that all of the radioactive phosphates remained in solution and no coprecipitation, or phosphate coagulation, occurred. It appears that when the phosphate concentration is below its solubility, more of the activity is in the supernatant. If the phosphate solubility is exceeded more of the activity will be lodged in the solid phase. This may be of importance in disposal plants where the supernatant is recirculated through the aerobic parts of the treatment process.

REFERENCES

(1) National Committe on Radiation Protection,
"Regulation of Radiation Exposure by Legislative Means",
National Bureau of Standards, Handbook 61, U.S. Government Printing Office, Washington, D.C. (1955)

(2) Lowe, H.N. Jr., Lacy, Wm.J., Surkiewicz, B.F. & Jaeger, R.F.,
"Destruction of Microorganisms in Water, Sewage and Sewage Sludge by Ionizing Radiations",
JAWWA, 48, 1363 (1956)

(3) Mick, K.L. and Linsley, S.E.,
"An Examination of Sewage Solids Incineration Costs",
Water & Sewage Works, 104, 11, 479 (1957)

(4) Buswell, A.M.,
"Important Considerations in Sludge Digestion. II. Microbiology & Theory of Anaerobic Digestion",
Sewage Works Journal, 19, 1, 28 (1947)

(5) Buswell, A.M.,
"Fermentations in Waste Treatments",
Industrial Fermentations, Vol. II, Chapter 14, Chemical Publishing Co. Inc. (1954)

(6) Grune, W.N., Bartholomew, D.D. and Hudson, C.I. Jr.,
"Effects of Radioactive Materials on Anaerobic Digestion",
Part I. Radiophosphorus, Sewage & Industrial Wastes, 30, 9, 1123 (Sept. 1958); Part II. Radioiodine, Sewage & Industrial Wastes, 30, 11 1399 (Nov. 1958)

(7) Grune, W.N., Philp, R.H. Jr., and Cossitt, R.E.,
"Anaerobic Process Automation by ORP, Conductivity and Gas Chromatography",
Presented at 12th Industrial Waste Conference, Purdue University, Lafayette, Indiana, May 14, 1957, Proceedings, pp. 604-635 (May, 1958)

(8) Grune, W.N. and Lotze, T.H.,
"Redox Potentials in Sewage Anaerobiosis",
Water and Sewage Works, 105, 1, 37 (1958)

REFERENCES (continued)

(9) Grune, W.N., Philp, R.H. Jr. and Porsh, R.J.,
"Applications of O.R.P., Conductivity and Gas Chromatography on Sludge Digestion",
Presented at 2nd Bio-Oxidation Conference, Manhattan College, April 25, 1957 (New York N.Y.) "Biological Treatment of Sewage and Industrial Wastes", Vol. II, Chapter 1-8 p. 80-96, Reinhold Publishing Company, New York, N.Y. (1958)

(10) Grune, W.N., Carter, J.V. and Keenan, J.P.,
"Development of a Continuous Gas Chromatographic Analyzer for Sludge Digestion Studies",
Sewage and Industrial Wastes, 28, 12, 1433 (1956)

(11) Grune, W.N. and Peek, R.C. Jr.,
"Improved Techniques for the Design, Operation and Control of Sludge Digesters",
Wastes Engineering, 29 ; Part I. Chromatographic Analysis of Gas, p. 354 (July 1958); Part II. Electrical Conductivity Readings Trace Total and Dissolved Solids, p. 424 (August, 1958); Part III. Oxidation-Reduction Potentials for Checking Digester Activity, p. 468 (Sept. 1958)

(12) Fair, G.M. and Moore, E.W.,
"Heat and Energy Relations in the Digestion of Sewage Solids. II. Mathematical Formulation of the Course of Digestion",
Sewage Works Journal, 4, 428 (1932)

(13) Thomas, H.A. Jr.,
"Analysis of the Biochemical Oxygen Demand Curve",
Sewage Works Journal, 12, 504 (1940)

(14) Blauer, H.,
"Personal Communication",
Union Carbide Nuclear Company, O.R.N.L., Oak Ridge, Tennessee (August 15, 1957)

(15) Grune, W.N. and Sload, R.Q.,
"Biocatalysts in Sludge Digestion",
Sewage and Industrial Wastes, 26, 12, 1425-1442 (1954)

(16) Van Kleeck, L.W.,
"The How and Why of Operating Separate Sludge Digestion Tanks",
Wastes Engineering, 29, 22 (1958)

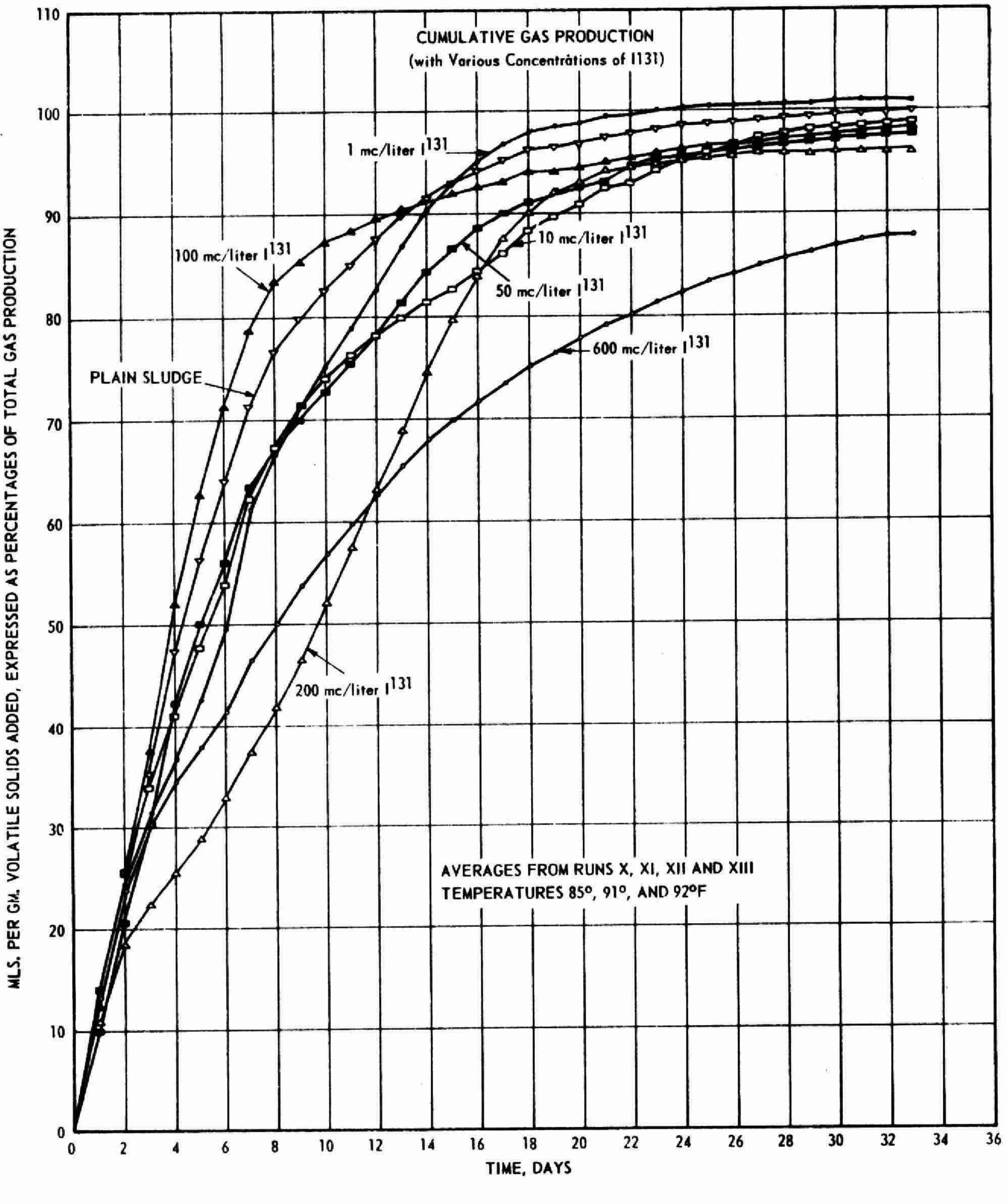

CUMULATIVE GAS PRODUCTION
(with Various Concentrations of I131)
1 mc/liter I131
100 mc/liter I131
10 mc/liter I131
50 mc/liter I131
600 mc/liter I131
PLAIN SLUDGE
200 mc/liter I131
AVERAGES FROM RUNS X, XI, XII AND XIII
TEMPERATURES 85°, 91°, AND 92°F
MLS. PER GM. VOLATILE SOLIDS ADDED, EXPRESSED AS PERCENTAGES OF TOTAL GAS PRODUCTION
TIME, DAYS
0
10
20
30
40
50
60
70
80
90
100
110
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36

Figure 1.

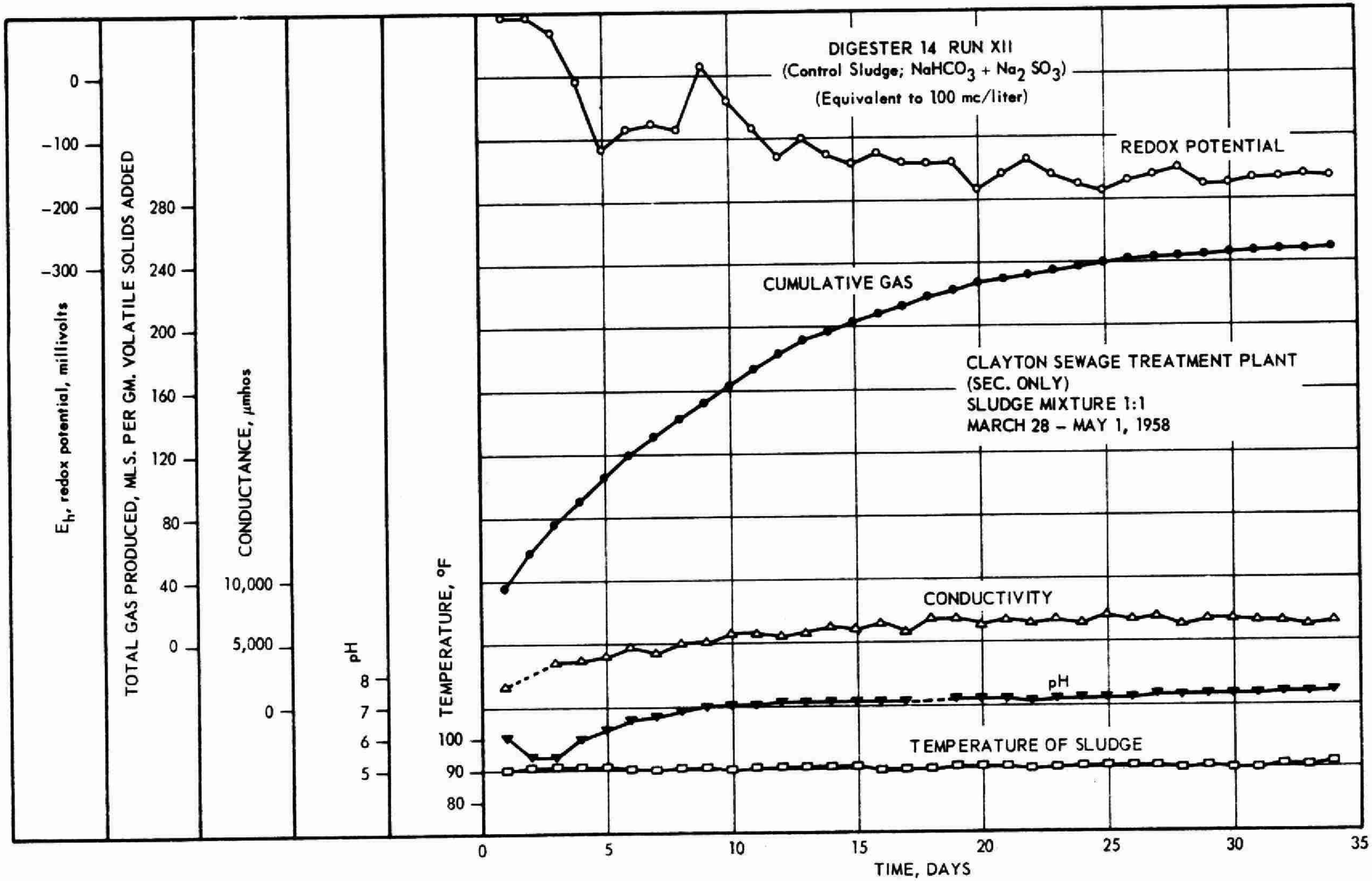

DIGESTER 14 RUN XII
(Control Sludge; $NaHCO_3 + Na_2SO_3$)
(Equivalent to 100 mc/liter)
REDOX POTENTIAL
CUMULATIVE GAS
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 1:1
MARCH 28 – MAY 1, 1958
CONDUCTIVITY
pH
TEMPERATURE OF SLUDGE
E_h, redox potential, millivolts
0
-100
-200
-300
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
280
240
200
160
120
80
40
0
CONDUCTANCE, µmhos
10,000
5,000
0
pH
8
7
6
5
TEMPERATURE, °F
100
90
80
0
5
10
15
20
25
30
35
TIME, DAYS

Figure 2.

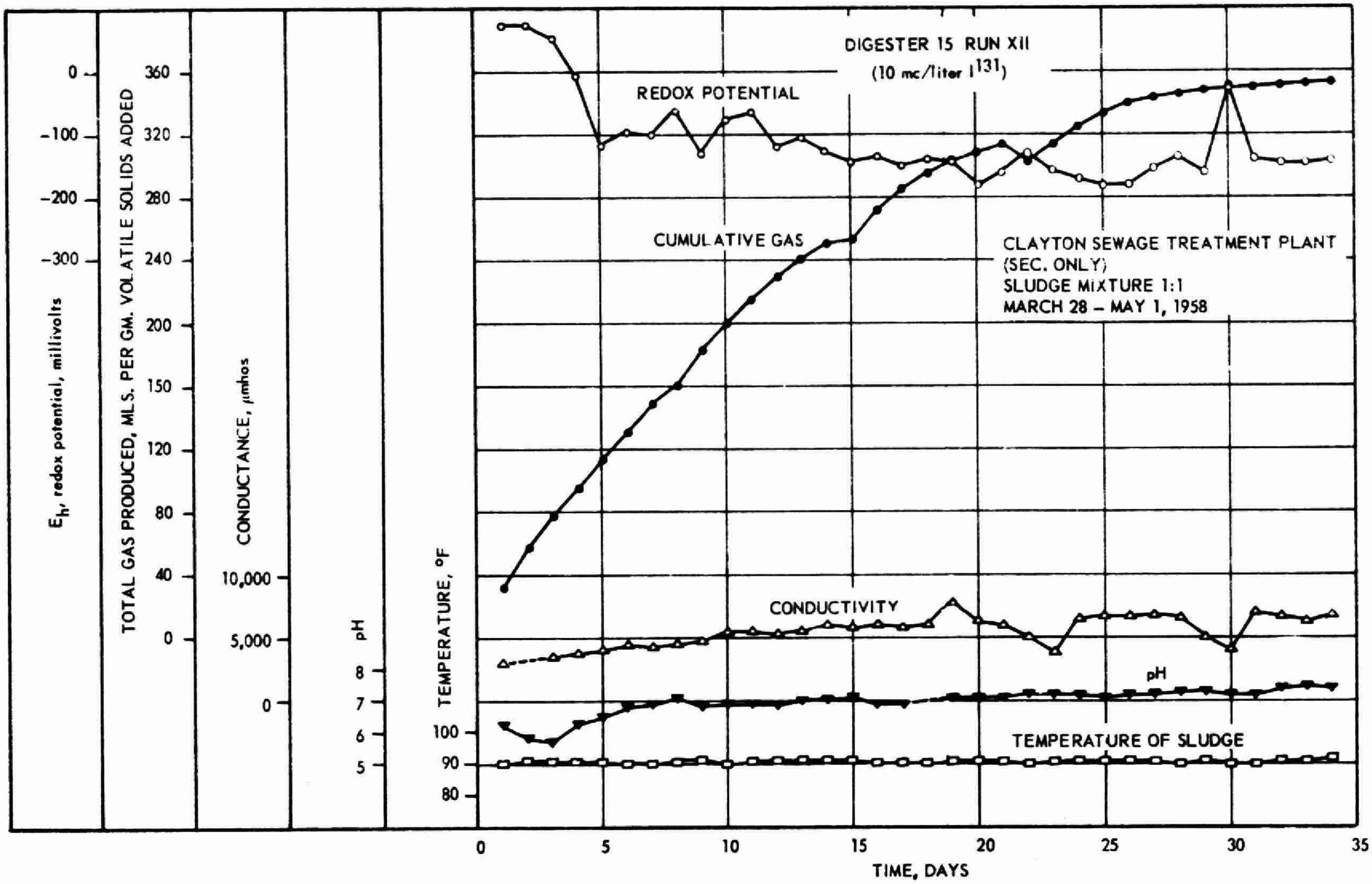

DIGESTER 15 RUN XII
(10 mc/liter I131)
REDOX POTENTIAL
CUMULATIVE GAS
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 1:1
MARCH 28 – MAY 1, 1958
CONDUCTIVITY
pH
TEMPERATURE OF SLUDGE
Eh, redox potential, millivolts
0
-100
-200
-300
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
360
320
280
240
200
150
120
80
40
0
CONDUCTANCE, µmhos
10,000
5,000
0
pH
8
7
6
5
TEMPERATURE, °F
100
90
80
0
5
10
15
20
25
30
35
TIME, DAYS

Figure 3.

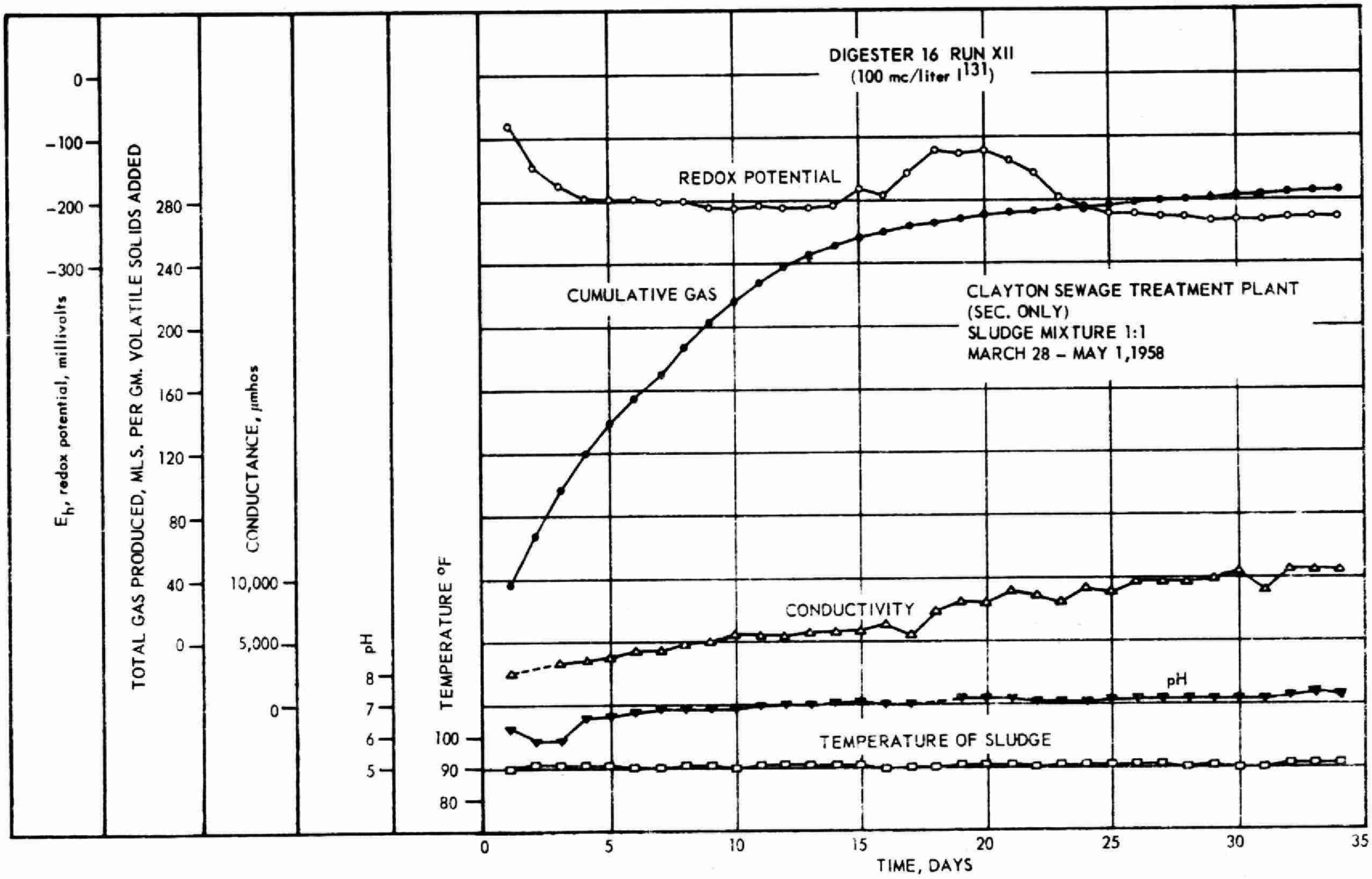
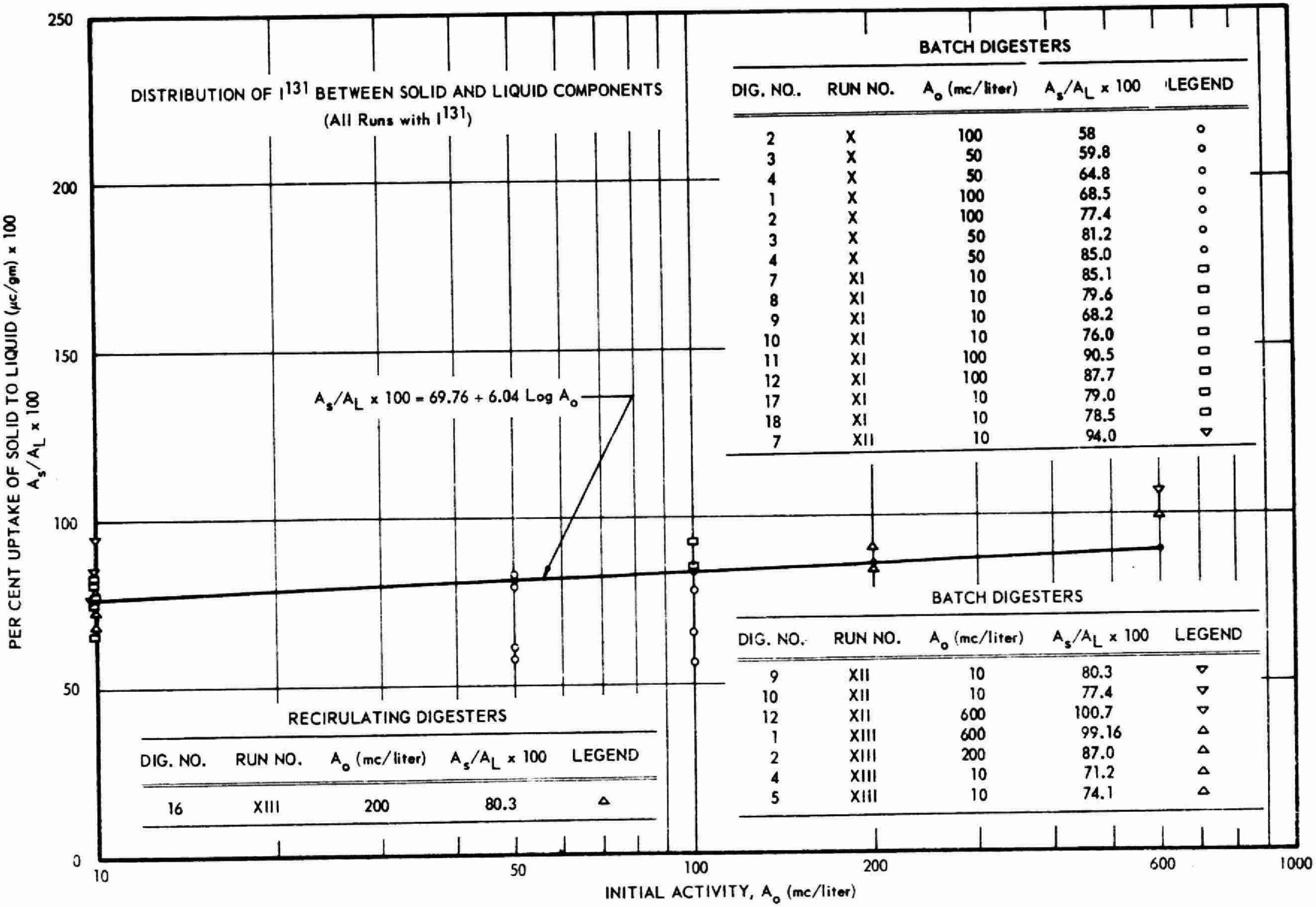

DIGESTER 16 RUN XII
(100 mc/liter I131)
REDOX POTENTIAL
CUMULATIVE GAS
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 1:1
MARCH 28 – MAY 1,1958
CONDUCTIVITY
pH
TEMPERATURE OF SLUDGE
Eh, redox potential, millivolts
0
-100
-200
-300
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
280
240
200
160
120
80
40
0
CONDUCTANCE, µmhos
10,000
5,000
0
pH
8
7
6
5
TEMPERATURE °F
100
90
80
0
5
10
15
20
25
30
35
TIME, DAYS

Figure 4.

GAS CHROMATOGRAPHIC ANALYSIS OF SLUDGE GASES, RUN NO. [illegible] - I^{131}
COLUMN 12 FT. SILICA GEL, 30-60 MESH
FLOWRATE 60 ML/MIN
SAMPLE SIZE 1.5 ML EACH
COLUMN TEMPERATURE 150°F

Figure 5.



BATCH DIGESTERS

DIG. NO.	RUN NO.	A_o (mc/liter)	$A_s/A_L \times 100$	LEGEND
2	X	100	58	○
3	X	50	59.8	○
4	X	50	64.8	○
1	X	100	68.5	○
2	X	100	77.4	○
3	X	50	81.2	○
4	X	50	85.0	○
7	XI	10	85.1	□
8	XI	10	79.6	□
9	XI	10	68.2	□
10	XI	10	76.0	□
11	XI	100	90.5	□
12	XI	100	87.7	□
17	XI	10	79.0	□
18	XI	10	78.5	□
7	XII	10	94.0	▽

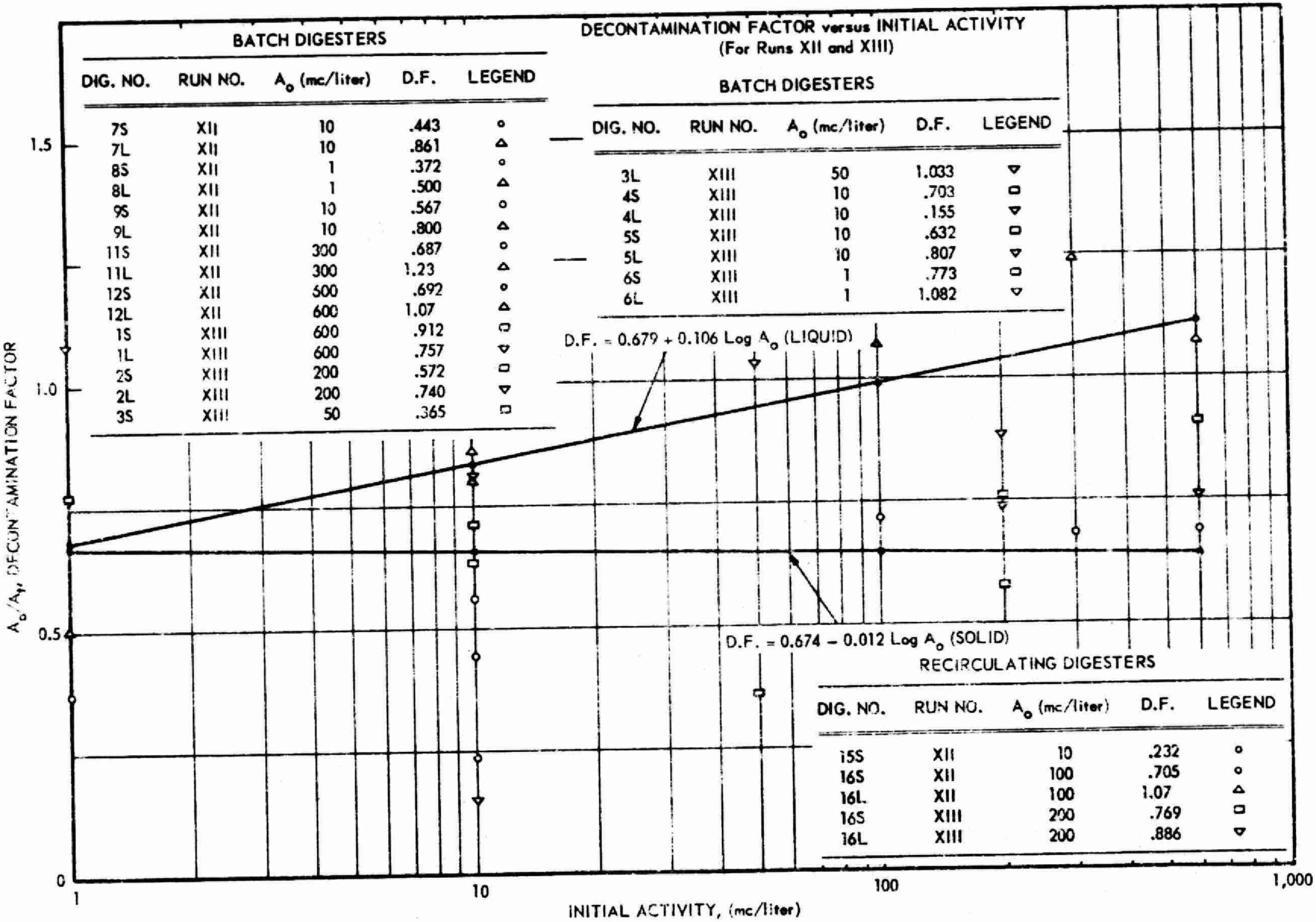
BATCH DIGESTERS

DIG. NO.	RUN NO.	A_o (mc/liter)	$A_s/A_L \times 100$	LEGEND
9	XII	10	80.3	▽
10	XII	10	77.4	▽
12	XII	600	100.7	▽
1	XIII	600	99.16	△
2	XIII	200	87.0	△
4	XIII	10	71.2	△
5	XIII	10	74.1	△

RECIRULATING DIGESTERS

DIG. NO.	RUN NO.	A_o (mc/liter)	$A_s/A_L \times 100$	LEGEND
16	XIII	200	80.3	△

Figure 6.



BATCH DIGESTERS

DIG. NO.	RUN NO.	A_o (mc/liter)	D.F.	LEGEND
7S	XII	10	.443	○
7L	XII	10	.861	△
8S	XII	1	.372	○
8L	XII	1	.500	△
9S	XII	10	.567	○
9L	XII	10	.800	△
11S	XII	300	.687	○
11L	XII	300	1.23	△
12S	XII	600	.692	○
12L	XII	600	1.07	△
1S	XIII	600	.912	□
1L	XIII	600	.757	▽
2S	XIII	200	.572	□
2L	XIII	200	.740	▽
3S	XIII	50	.365	□

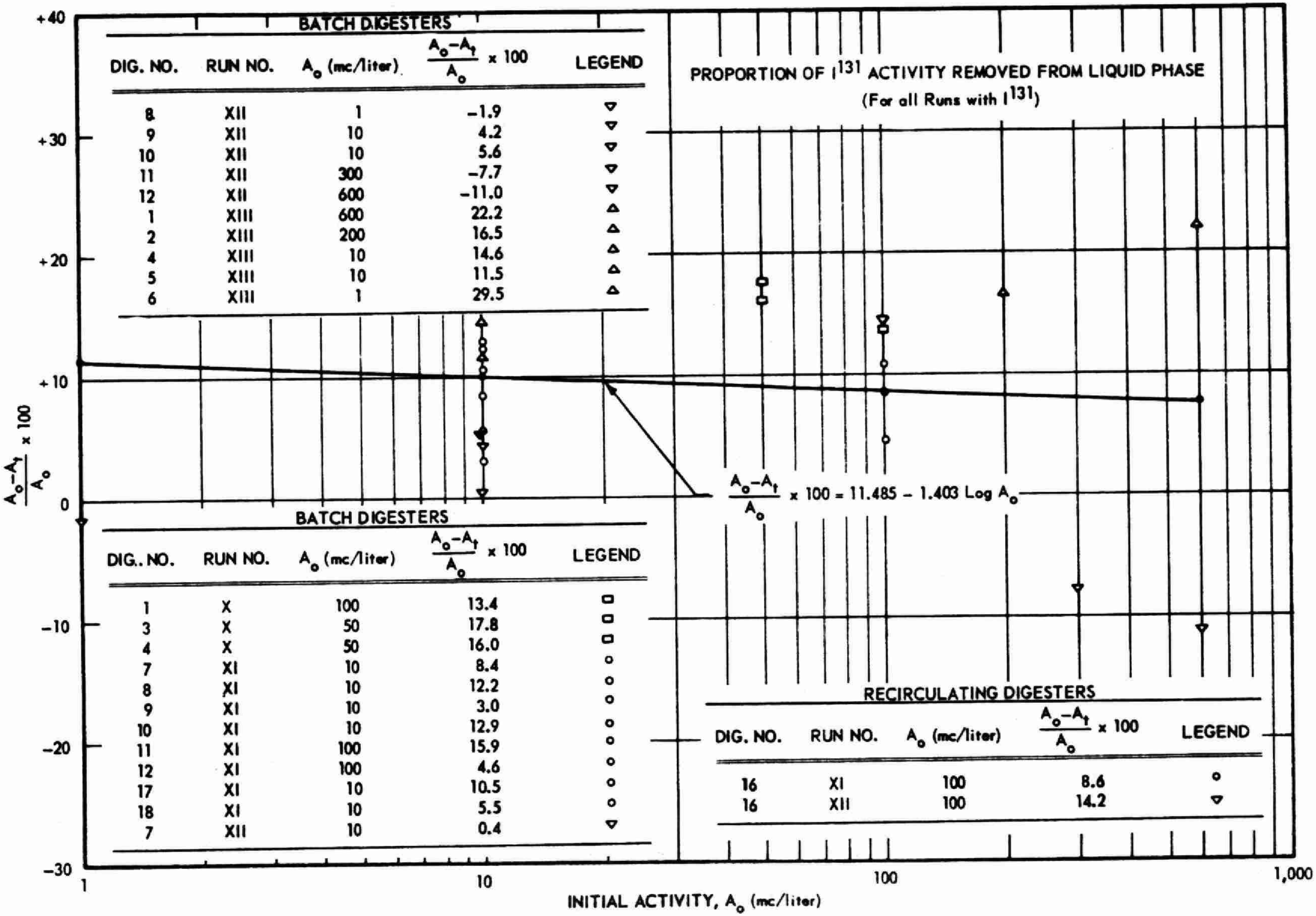
BATCH DIGESTERS

DIG. NO.	RUN NO.	A_o (mc/liter)	D.F.	LEGEND
3L	XIII	50	1.033	▽
4S	XIII	10	.703	□
4L	XIII	10	.155	▽
5S	XIII	10	.632	□
5L	XIII	10	.807	▽
6S	XIII	1	.773	□
6L	XIII	1	1.082	▽

RECIRCULATING DIGESTERS

DIG. NO.	RUN NO.	A_o (mc/liter)	D.F.	LEGEND
15S	XII	10	.232	○
16S	XII	100	.705	○
16L	XII	100	1.07	△
16S	XIII	200	.769	□
16L	XIII	200	.886	▽

Figure 7



PROPORTION OF I^{131} ACTIVITY REMOVED FROM LIQUID PHASE
(For all Runs with I^{131})

BATCH DIGESTERS

DIG. NO.	RUN NO.	A_o (mc/liter)	$\frac{A_o - A_t}{A_o} \times 100$	LEGEND
8	XII	1	-1.9	▽
9	XII	10	4.2	▽
10	XII	10	5.6	▽
11	XII	300	-7.7	▽
12	XII	600	-11.0	▽
1	XIII	600	22.2	△
2	XIII	200	16.5	△
4	XIII	10	14.6	△
5	XIII	10	11.5	△
6	XIII	1	29.5	△

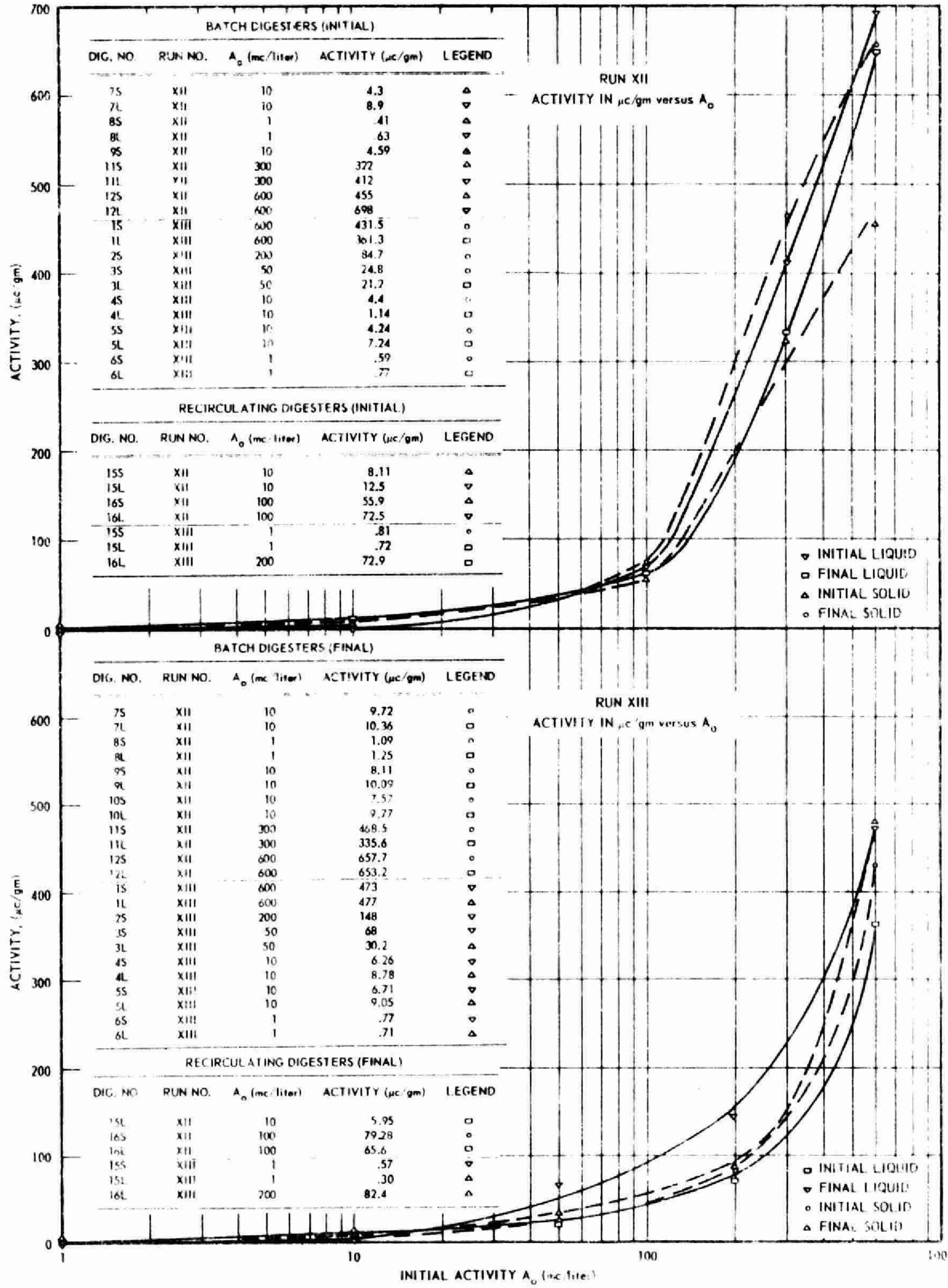
BATCH DIGESTERS

DIG.. NO.	RUN NO.	A_o (mc/liter)	$\frac{A_o - A_t}{A_o} \times 100$	LEGEND
1	X	100	13.4	□
3	X	50	17.8	□
4	X	50	16.0	□
7	XI	10	8.4	○
8	XI	10	12.2	○
9	XI	10	3.0	○
10	XI	10	12.9	○
11	XI	100	15.9	○
12	XI	100	4.6	○
17	XI	10	10.5	○
18	XI	10	5.5	○
7	XII	10	0.4	▽

RECIRCULATING DIGESTERS

DIG. NO.	RUN NO.	A_o (mc/liter)	$\frac{A_o - A_t}{A_o} \times 100$	LEGEND
16	XI	100	8.6	○
16	XII	100	14.2	▽

Figure 8.



BATCH DIGESTERS (INITIAL)

DIG. NO.	RUN NO.	A_o (mc/liter)	ACTIVITY (μc/gm)	LEGEND
7S	XII	10	4.3	△
7L	XII	10	8.9	▽
8S	XII	1	.41	△
8L	XII	1	.63	▽
9S	XII	10	4.59	△
11S	XII	300	322	△
11L	XII	300	412	▽
12S	XII	600	455	△
12L	XII	600	698	▽
1S	XIII	600	431.5	○
1L	XIII	600	361.3	□
2S	XIII	200	84.7	○
3S	XIII	50	24.8	○
3L	XIII	50	21.2	□
4S	XIII	10	4.4	○
4L	XIII	10	1.14	□
5S	XIII	10	4.24	○
5L	XIII	10	7.24	□
6S	XIII	1	.59	○
6L	XIII	1	.77	□

RECIRCULATING DIGESTERS (INITIAL)

DIG. NO.	RUN NO.	A_o (mc/liter)	ACTIVITY (μc/gm)	LEGEND
15S	XII	10	8.11	△
15L	XII	10	12.5	▽
16S	XII	100	55.9	△
16L	XII	100	72.5	▽
15S	XIII	1	.81	○
15L	XIII	1	.72	□
16L	XIII	200	72.9	□

BATCH DIGESTERS (FINAL)

DIG. NO.	RUN NO.	A_o (mc/liter)	ACTIVITY (μc/gm)	LEGEND
7S	XII	10	9.72	○
7L	XII	10	10.36	□
8S	XII	1	1.09	○
8L	XII	1	1.25	□
9S	XII	10	8.11	○
9L	XII	10	10.09	□
10S	XII	10	7.57	○
10L	XII	10	9.77	□
11S	XII	300	468.5	○
11L	XII	300	335.6	□
12S	XII	600	657.7	○
12L	XII	600	653.2	□
1S	XIII	600	473	▽
1L	XIII	600	477	△
2S	XIII	200	148	▽
3S	XIII	50	68	▽
3L	XIII	50	30.2	△
4S	XIII	10	6.26	▽
4L	XIII	10	8.78	△
5S	XIII	10	6.71	▽
5L	XIII	10	9.05	△
6S	XIII	1	.77	▽
6L	XIII	1	.71	△

RECIRCULATING DIGESTERS (FINAL)

DIG. NO.	RUN NO.	A_o (mc/liter)	ACTIVITY (μc/gm)	LEGEND
15L	XII	10	5.95	□
16S	XII	100	79.28	○
16L	XII	100	65.6	□
15S	XIII	1	.57	▽
15L	XIII	1	.30	△
16L	XIII	200	82.4	△

Figure 9.

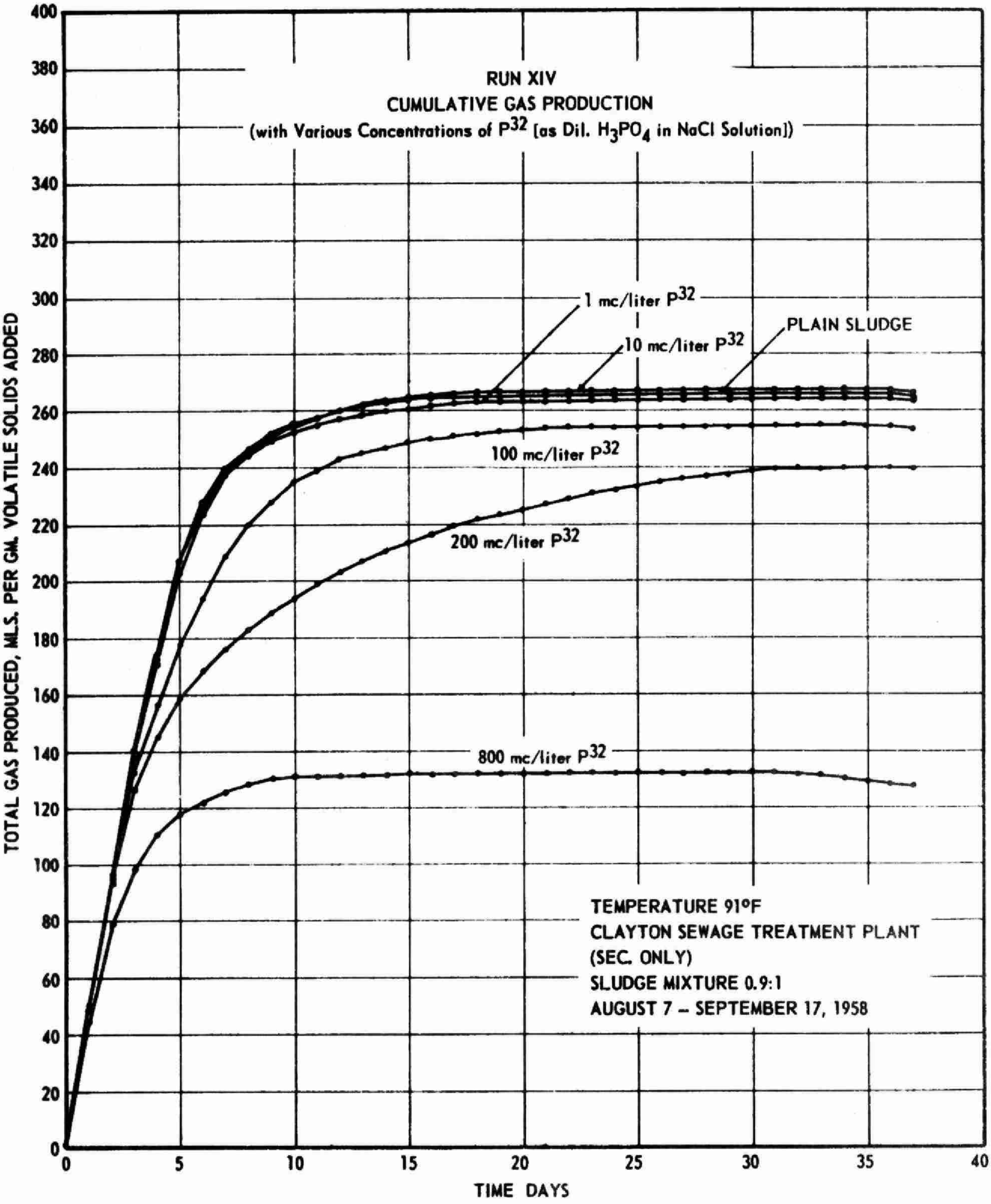

RUN XIV
CUMULATIVE GAS PRODUCTION
(with Various Concentrations of P32 [as Dil. H3PO4 in NaCl Solution])
1 mc/liter P32
10 mc/liter P32
PLAIN SLUDGE
100 mc/liter P32
200 mc/liter P32
800 mc/liter P32
TEMPERATURE 91°F
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 0.9:1
AUGUST 7 – SEPTEMBER 17, 1958
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
TIME DAYS
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
0
5
10
15
20
25
30
35
40

Figure 10.

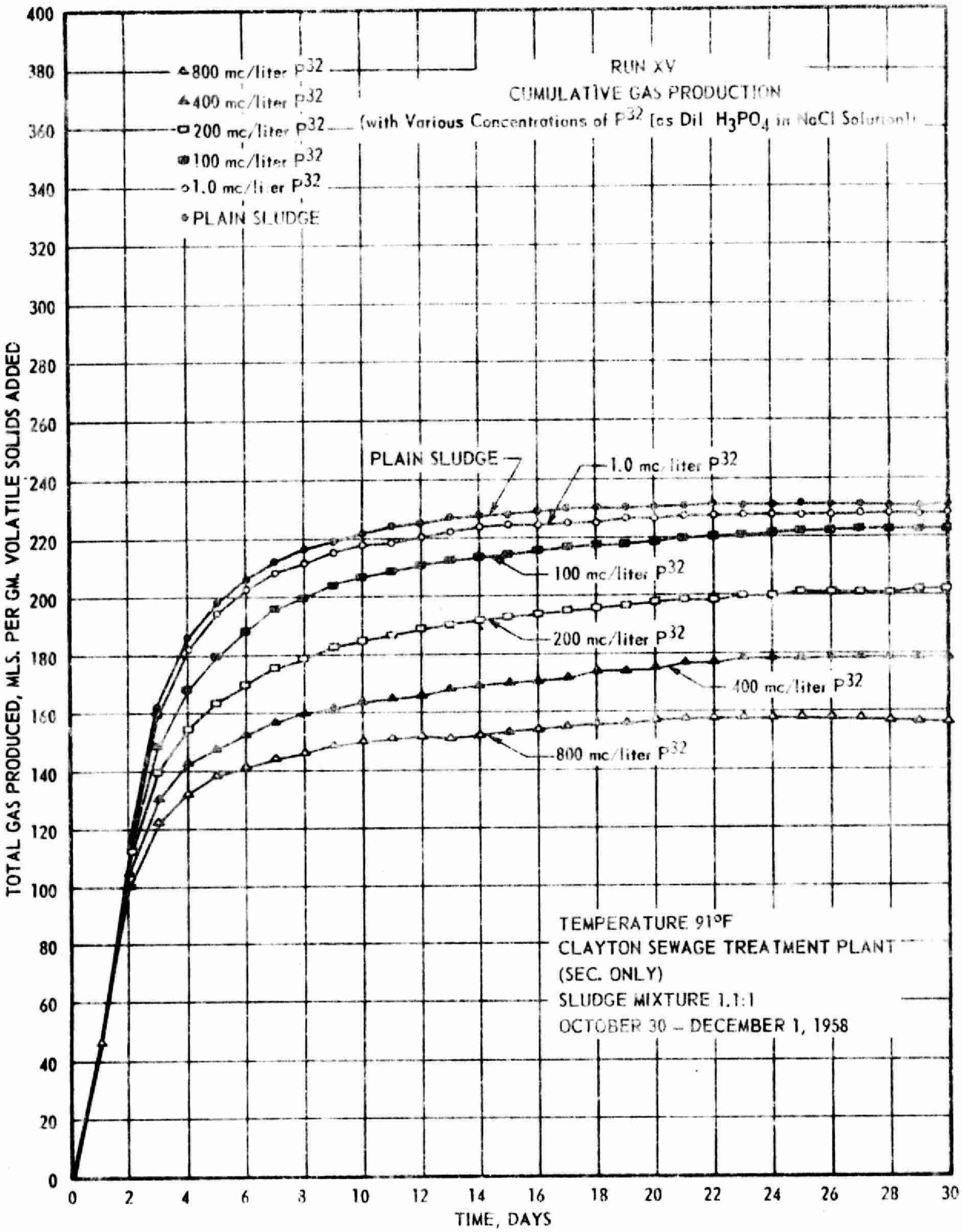

▲800 mc/liter P^{32}
▲400 mc/liter P^{32}
□200 mc/liter P^{32}
●100 mc/liter P^{32}
○1.0 mc/liter P^{32}
● PLAIN SLUDGE
RUN XV
CUMULATIVE GAS PRODUCTION
(with Various Concentrations of P^{32} [as Dil H_3PO_4 in NaCl Solution])
PLAIN SLUDGE
1.0 mc/liter P^{32}
100 mc/liter P^{32}
200 mc/liter P^{32}
400 mc/liter P^{32}
800 mc/liter P^{32}
TEMPERATURE 91°F
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 1.1:1
OCTOBER 30 – DECEMBER 1, 1958
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
TIME, DAYS
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Figure 11.

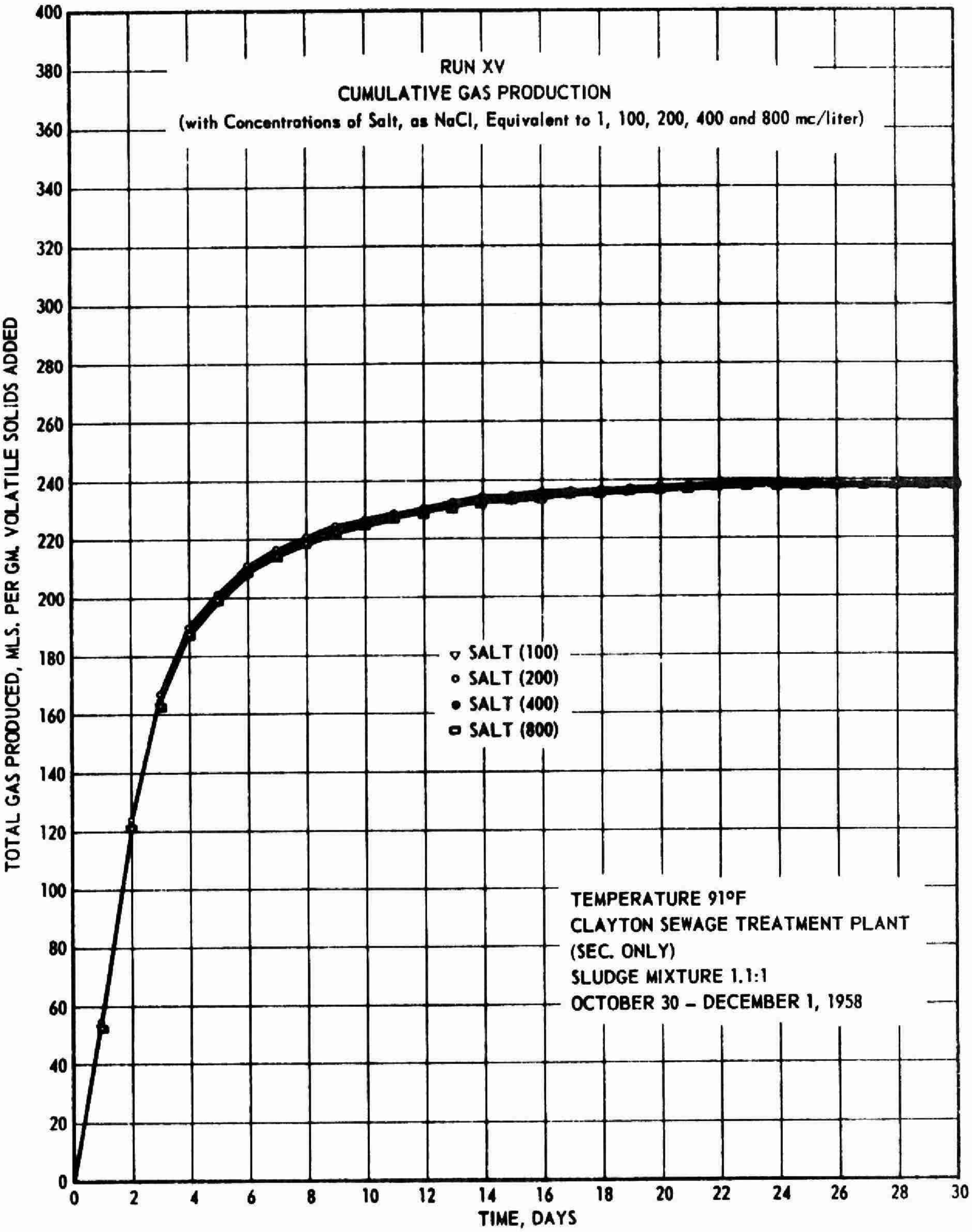

RUN XV
CUMULATIVE GAS PRODUCTION
(with Concentrations of Salt, as NaCl, Equivalent to 1, 100, 200, 400 and 800 mc/liter)
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
TIME, DAYS
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
▽ SALT (100)
○ SALT (200)
● SALT (400)
▭ SALT (800)
TEMPERATURE 91°F
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 1.1:1
OCTOBER 30 – DECEMBER 1, 1958

Figure 12.

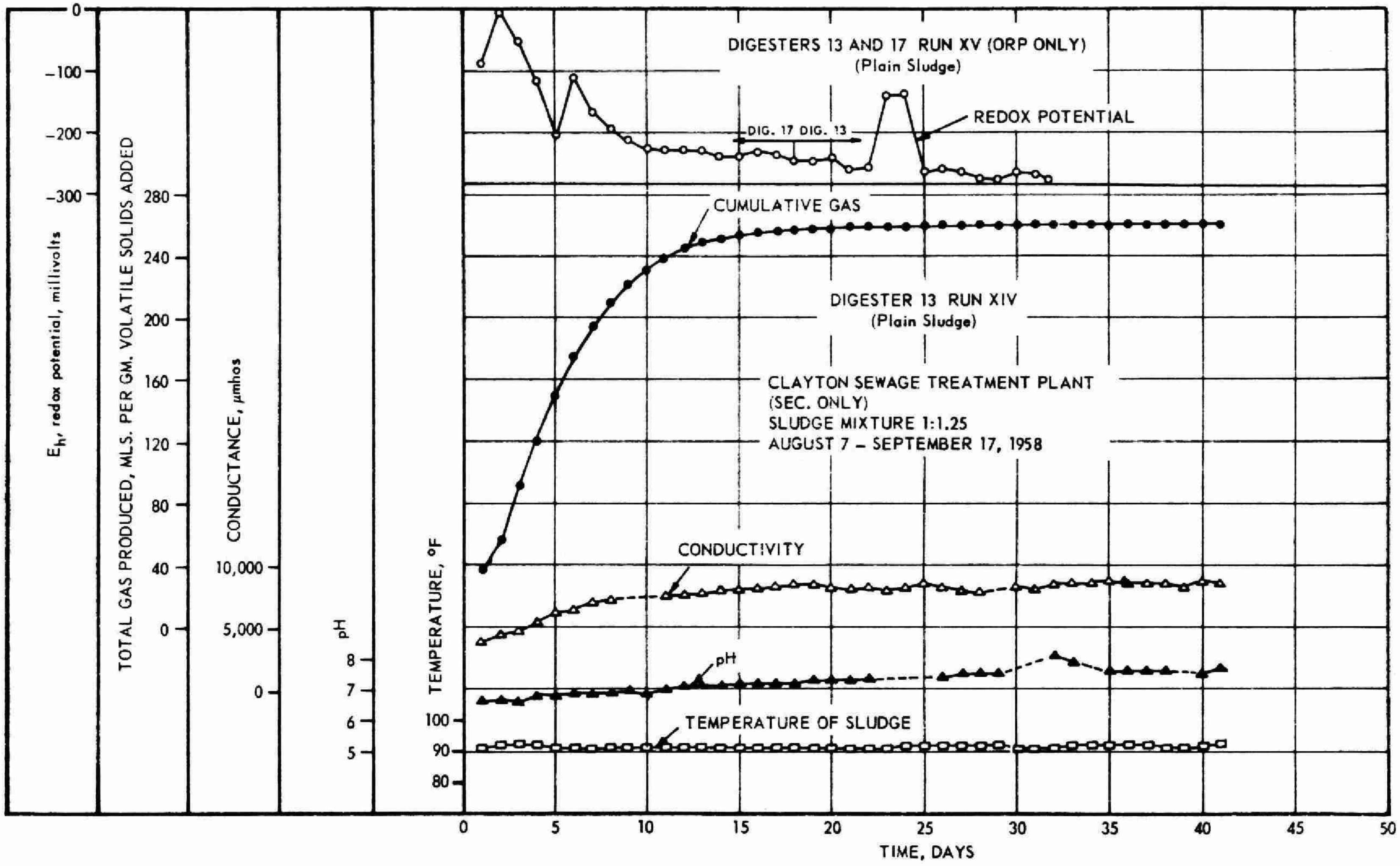

DIGESTERS 13 AND 17 RUN XV (ORP ONLY)
(Plain Sludge)
DIG. 17 DIG. 13
REDOX POTENTIAL
CUMULATIVE GAS
DIGESTER 13 RUN XIV
(Plain Sludge)
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 1:1.25
AUGUST 7 – SEPTEMBER 17, 1958
CONDUCTIVITY
pH
TEMPERATURE OF SLUDGE
E_h, redox potential, millivolts
0
–100
–200
–300
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
280
240
200
160
120
80
40
0
CONDUCTANCE, µmhos
10,000
5,000
0
pH
8
7
6
5
TEMPERATURE, °F
100
90
80
TIME, DAYS
0
5
10
15
20
25
30
35
40
45
50

Figure 13.

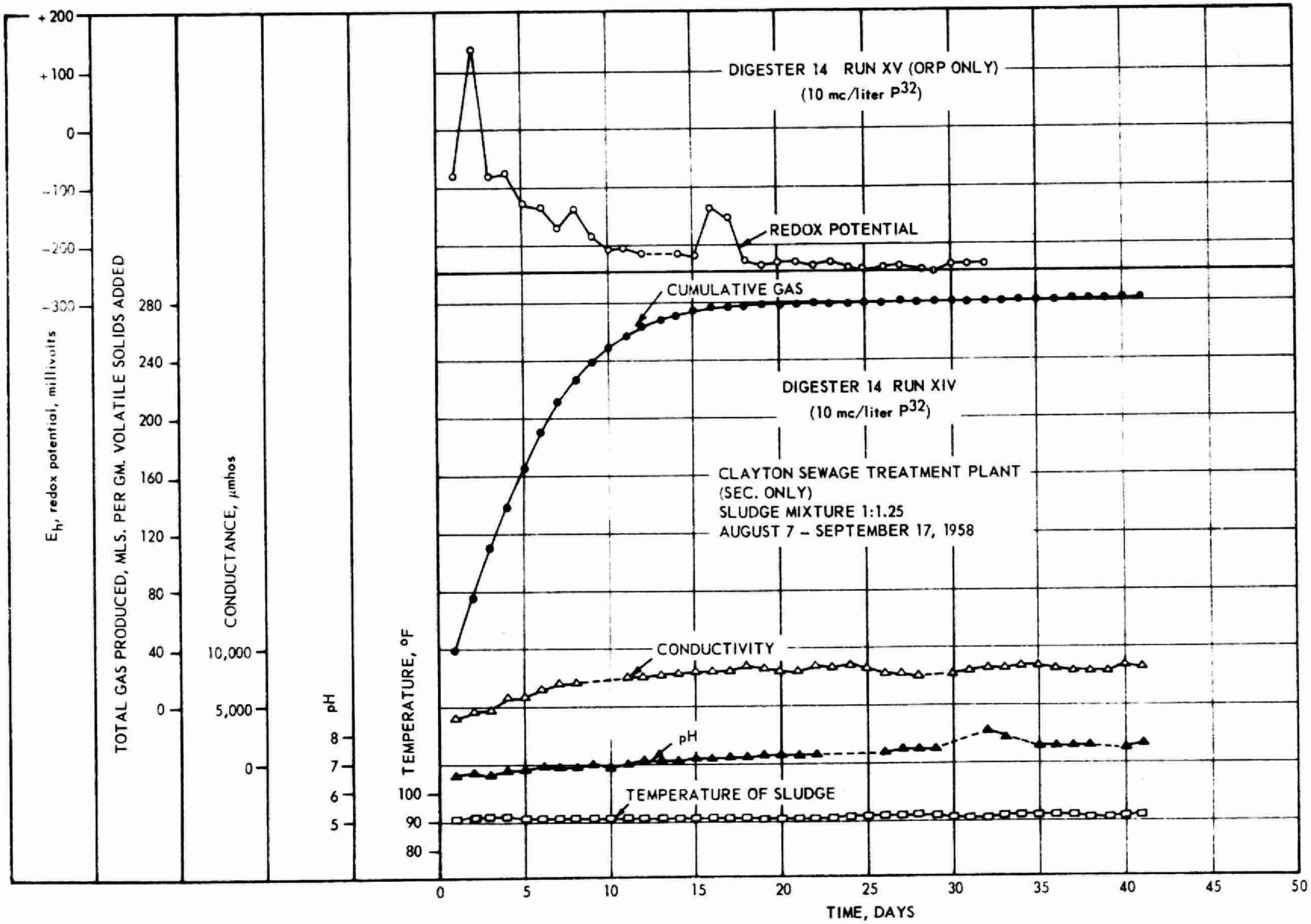

DIGESTER 14 RUN XV (ORP ONLY)
(10 mc/liter P32)
REDOX POTENTIAL
CUMULATIVE GAS
DIGESTER 14 RUN XIV
(10 mc/liter P32)
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 1:1.25
AUGUST 7 – SEPTEMBER 17, 1958
CONDUCTIVITY
pH
TEMPERATURE OF SLUDGE
Eh, redox potential, millivolts
+200
+100
0
-100
-200
-300
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
280
240
200
160
120
80
40
0
CONDUCTANCE, μmhos
10,000
5,000
0
pH
8
7
6
5
TEMPERATURE, °F
100
90
80
0
5
10
15
20
25
30
35
40
45
50
TIME, DAYS

Figure 14.

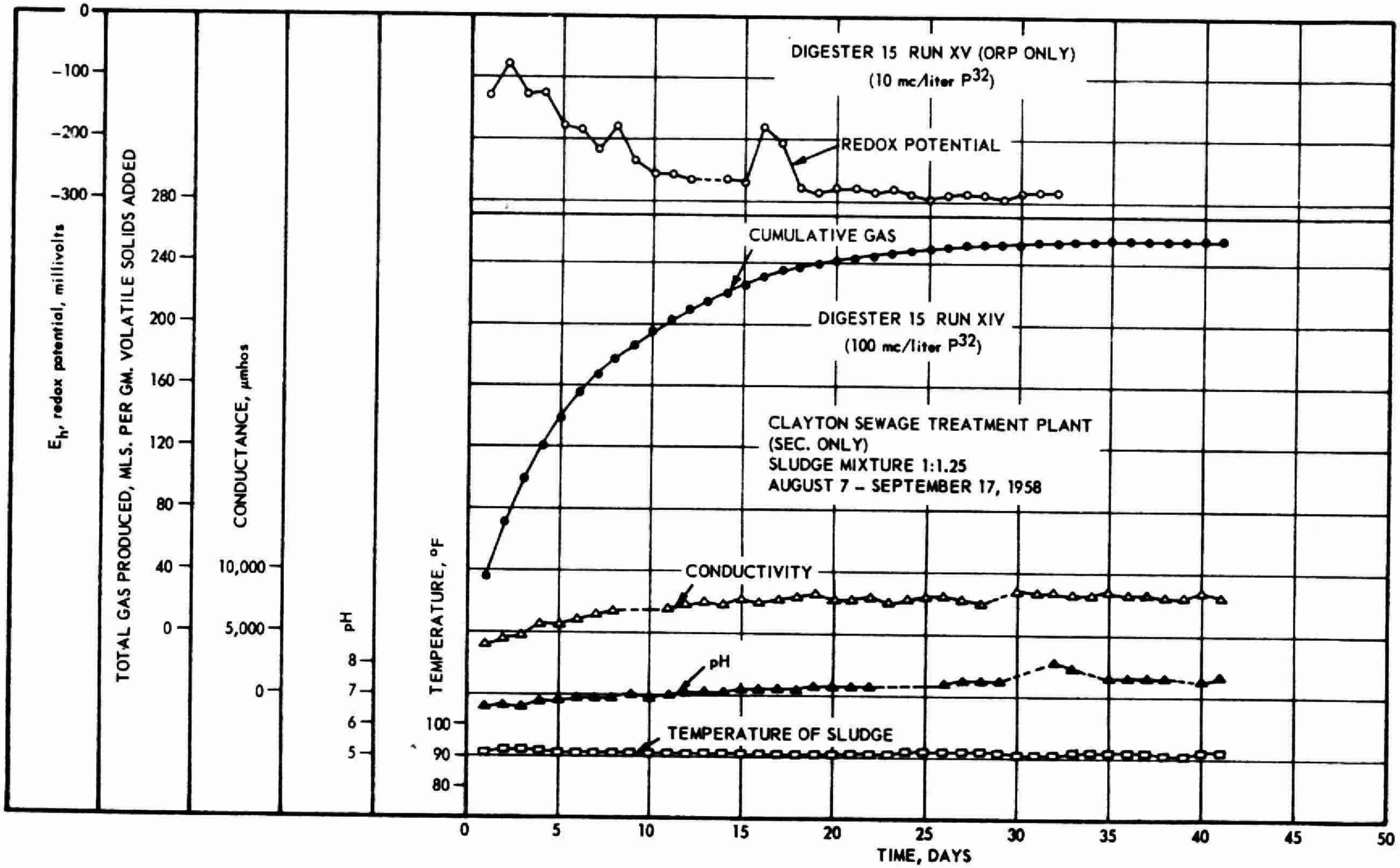
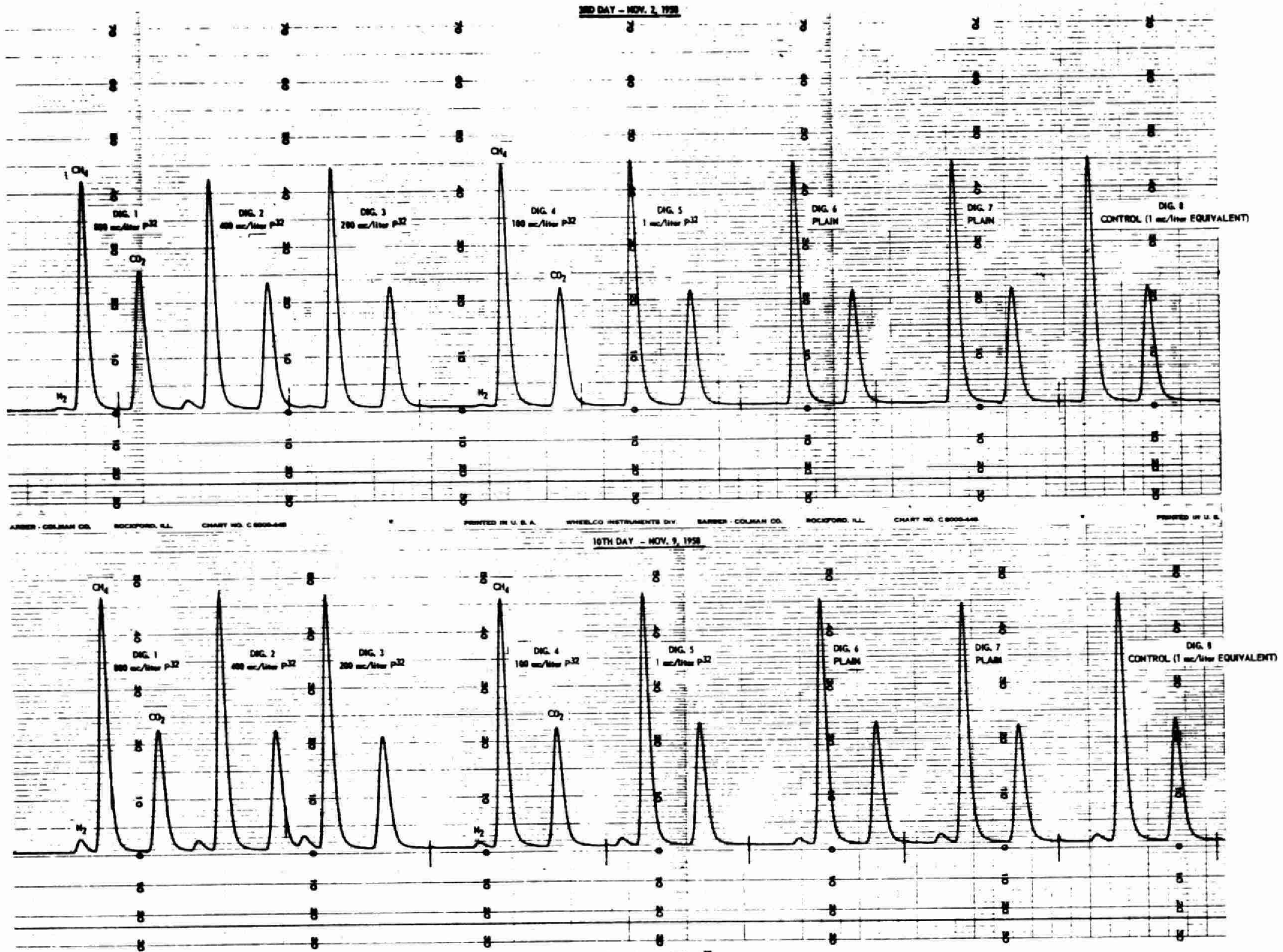
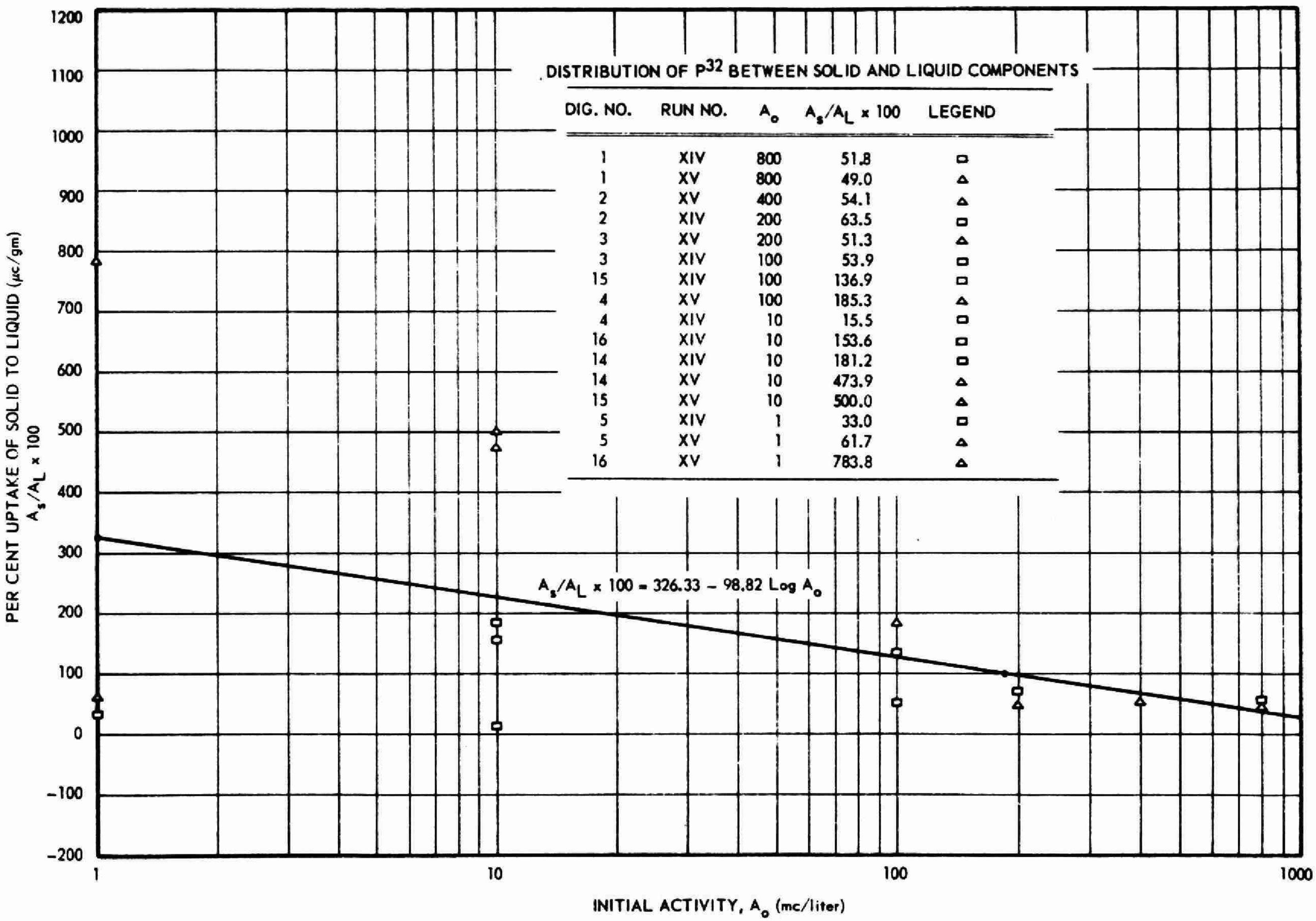

E_h, redox potential, millivolts
0
-100
-200
-300
TOTAL GAS PRODUCED, MLS. PER GM. VOLATILE SOLIDS ADDED
280
240
200
160
120
80
40
0
CONDUCTANCE, µmhos
10,000
5,000
0
pH
8
7
6
5
TEMPERATURE, °F
100
90
80
DIGESTER 15 RUN XV (ORP ONLY)
(10 mc/liter P^{32})
REDOX POTENTIAL
CUMULATIVE GAS
DIGESTER 15 RUN XIV
(100 mc/liter P^{32})
CLAYTON SEWAGE TREATMENT PLANT
(SEC. ONLY)
SLUDGE MIXTURE 1:1.25
AUGUST 7 – SEPTEMBER 17, 1958
CONDUCTIVITY
pH
TEMPERATURE OF SLUDGE
0
5
10
15
20
25
30
35
40
45
50
TIME, DAYS

Figure 15.



GAS CHROMATOGRAPHIC ANALYSIS OF SLUDGE GASES, RUN NO. XX – P^{32}
COLUMN: 60 FT. TETRA-ISOBUTYLENE COATED ON 20–40 MESH C–22, RATIO OF LIQUID TO SOLID : 40 : 100
FLOW RATE: 120 MLS/MIN
SAMPLE SIZE: 1.5 MLS EACH
COLUMN TEMPERATURE: 79°F

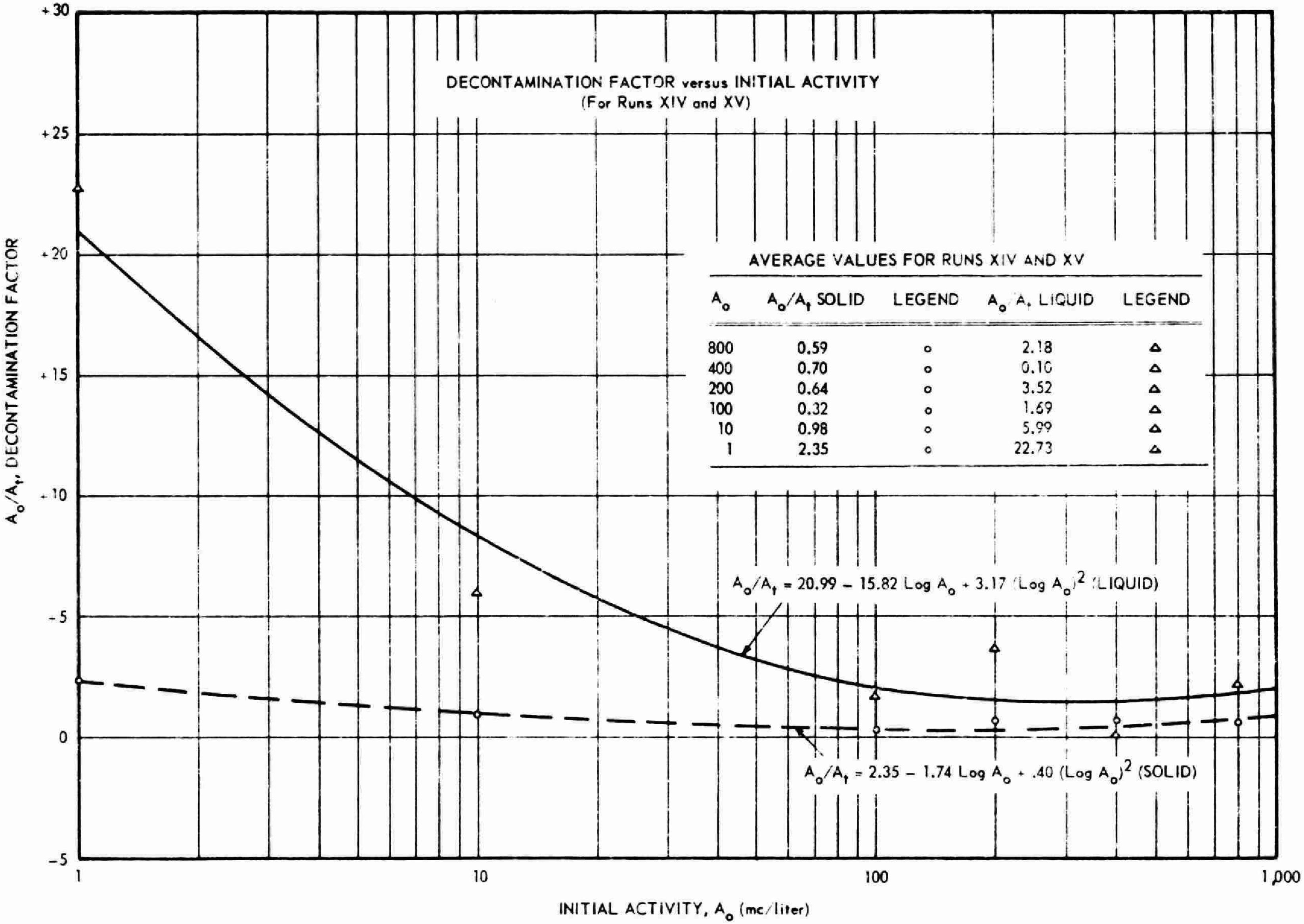
Figure 16.



DISTRIBUTION OF P^{32} BETWEEN SOLID AND LIQUID COMPONENTS

DIG. NO.	RUN NO.	A_o	$A_s/A_L \times 100$	LEGEND
1	XIV	800	51.8	□
1	XV	800	49.0	△
2	XV	400	54.1	△
2	XIV	200	63.5	□
3	XV	200	51.3	△
3	XIV	100	53.9	□
15	XIV	100	136.9	□
4	XV	100	185.3	△
4	XIV	10	15.5	□
16	XIV	10	153.6	□
14	XIV	10	181.2	□
14	XV	10	473.9	△
15	XV	10	500.0	△
5	XIV	1	33.0	□
5	XV	1	61.7	△
16	XV	1	783.8	△

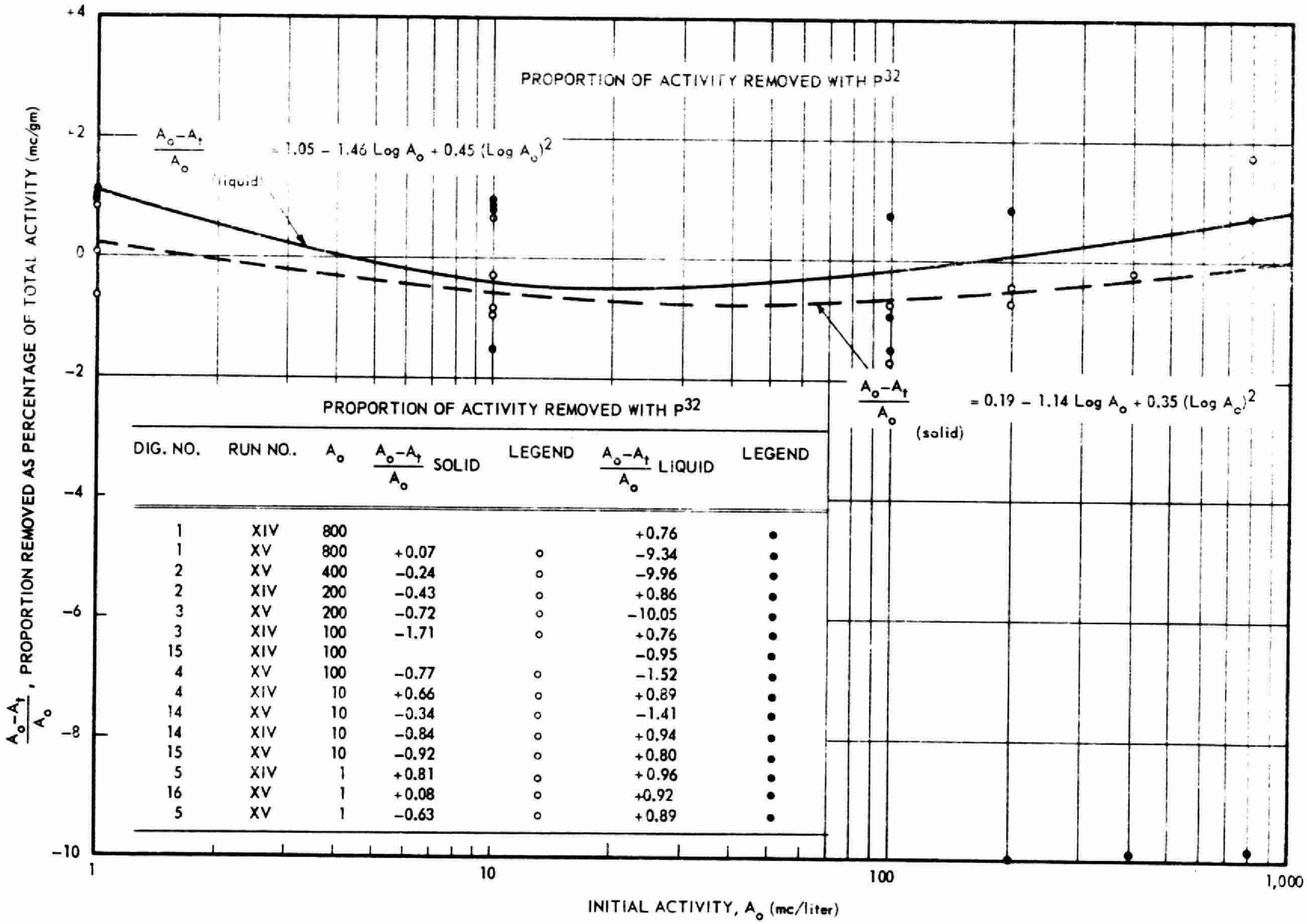
Figure 17.



AVERAGE VALUES FOR RUNS XIV AND XV

A_o	A_o/A_t SOLID	LEGEND	A_o/A_t LIQUID	LEGEND
800	0.59	○	2.18	△
400	0.70	○	0.10	△
200	0.64	○	3.52	△
100	0.32	○	1.69	△
10	0.98	○	5.99	△
1	2.35	○	22.73	△

Figure 18.



PROPORTION OF ACTIVITY REMOVED WITH P^{32}

DIG. NO.	RUN NO.	A_o	$\frac{A_o-A_t}{A_o}$ SOLID	LEGEND	$\frac{A_o-A_t}{A_o}$ LIQUID	LEGEND
1	XIV	800			+0.76	●
1	XV	800	+0.07	○	-9.34	●
2	XV	400	-0.24	○	-9.96	●
2	XIV	200	-0.43	○	+0.86	●
3	XV	200	-0.72	○	-10.05	●
3	XIV	100	-1.71	○	+0.76	●
15	XIV	100			-0.95	●
4	XV	100	-0.77	○	-1.52	●
4	XIV	10	+0.66	○	+0.89	●
14	XV	10	-0.34	○	-1.41	●
14	XIV	10	-0.84	○	+0.94	●
15	XV	10	-0.92	○	+0.80	●
5	XIV	1	+0.81	○	+0.96	●
16	XV	1	+0.08	○	+0.92	●
5	XV	1	-0.63	○	+0.89	●

Figure 19.

TREATMENT OF PACKING HOUSE WASTES

A. L. Van Luven

Foreword

It is necessary to explain that my affiliations have changed since being asked to give this paper.

For over 10 years previous to 1959, I was engaged by Canada Packers in either the Toronto plant or Toronto Head Office, (general superintendent's office).

Since late in 1958 I have been engaged in a consulting engineering business with H. E. McKeen and Company, Ltd. at the job of building a Waste Treatment Division.

Naturally my interests in the treatment of wastes from packing houses and associated industries have kept me closely in touch with developments in this field.

Introduction

In dealing with any industrial waste problem, the peculiarities of the industry and the special features of the particular plant in question are very important. It is necessary to become familiar with an industry to recognize these features and then to fully understand their relationship to the waste treatment problem.

For example, the strength, amount and nature of packing house wastes are governed considerably by such factors as:

1. general facilities of the plant and the type of business being conducted.
2. methods of killing.
3. material handling equipment and methods.
4. rendering facilities and methods.

Frequently packing house wastes are discharged with a high population equivalent. In my opinion it is possible to reduce the strength of these wastes so that the municipal sewage treatment plant can handle them at reasonable cost and, simultaneously, the packer will be pleased with the extra fat, protein, blood, and improved water economy that his waste-control program will yield.

Some Keynotes To Packing House Operations

Without making excuses for the meat packer, I would like to point out some of the factors behind the high B.O.D.'s, high suspended solids, and grease.

If the meat packer hopes to deliver a high grade product to the consumer, he must do certain things quickly and well.

Some of these processing "MUSTS" increase his wastes considerably. Some examples follow.

(a) Avoid Bacterial Decomposition

This is paramount and the constant bacterial war requires vast amounts of water, which unfortunately, frequently carry fat, meat and blood to the sewers.

Both the packer and the sanitary engineer fully realize that bacterial decomposition begins at the instant an animal is slaughtered and that bacteria usually grow according to a logarithmic curve.

To the packer, this means rapid processing with the bacterial problem in mind at every step. All meats (cooked and fresh), packaging materials, knives, product chutes, cutting room tables, conveyors, plant trucks, scales, coolers, freezers, and other equipment must be clean and reasonably free of bacteria. Packers must control sanitation, processing, and environmental conditions (especially temperature) with great care. Frequently materials must be rerouted to avoid impending trouble.

(b) Costs Must Be Competitive

No industry that I know of must be as careful of costs as the meat packing industry. Net profits are rarely more than 1.5% of sales and are usually less than 1%. This means a net profit of about 1/5 cts. per pound for the large packing house.

Therefore, the packer must handle large volumes with maximum efficiency. It is essential that he keep his costs in line with his competitors. It would be serious if he were forced to install waste treatment facilities which might place him in a non-competitive position.

(c) Good Housekeeping

The meat packer must be concerned with the cleanliness, order, and arrangement of equipment, supplies, machinery, piping, floors, walls, ceilings, windows, clothing (in fact all parts of the plant), even when these objects do not come into direct contact with his products.

(d) Flexibility

Successful packers must keep their operations flexible in order to meet the widely fluctuating demands of their business. Frequently the plant superintendent is expected to alter his work plans on short notice to cater to the demands of the market; for example, he may suddenly be expected to kill 1,000 cattle on a day that his forces had already set out to kill 800.

This sort of demand has a serious unbalancing effect and, of course, affects the waste problem.

Size of the Problem

The following fugures indicate the scope of the problem.

(a) Water Consumption is High

We have measured the water consumption in several packing houses with a mixed kill and we have observed the 24 hour volume of water to vary from:

450 to 1,100 I.G. per animal
or 360 to 800 I.G. per hog unit.

To convert animals killed to hog units killed use a factor of 1.0 for hogs, sheep, lambs, calves and use 2.5 for cattle.

These figures check reasonably well with those given in the literature by the U.S. Public Health Service for a survey of 16 American Packing Houses. (Reference #1).

(b) Water Consumption Fluctuates Widely

The following data were obtained from a packing house operation.

	Max. Kill Rate per Hour	Peak Kill Per Week - Number	Peak Kill Per Week - Hog Units
Cattle	70	2400	6000
Hogs	360	7044	7044
Calves	50	902	902
Sheep	50	723	723
TOTAL			14669

TIME	IMPERIAL GALS. USED
12:00 P.M.	0
1:00 A.M.	15000
2:00	12500
3:00	21875
4:00	14375
5:00	16250
6:00	16875
7:00	25000
8:00	50000
9:00	55000
10:00	51250
11:00	59375
12:00 A.M.	71875

	TIME	IMPERIAL GALS. USED
	1:00 P.M.	67500
	2:00	87500
	3:00	59375
	4:00	66250
	5:00	62500
	6:00	56250
	7:00	60625
	8:00	60000
	9:00	56875
	10:00	51250
	11:00	49687
	12:00 P.M.	48437
Total	24 Hours	1135624

These figures are fairly typical and indicate that there is a comparatively low flow from 1:00 A.M. to 7:00 A.M., then the water consumption rapidly increases and remains high all day.

The peak flow rates and time of occurrence are usually quite changeable as now shown from the following data for a moderately sized operation in a normal season.

DAY	TOTAL GALLONS 24 HOURS	TIME OF PEAK USAGE	PEAK GALS/HR. DURING DAY	KILL HOG UNITS
1	866,250	7 - 8 A.M.	63;100	2,403
2	1,084,375	11 - 12 A.M.	80,000	2,187
3	232,751	12 - 1 A.M.	27,500	Saturday
4	226,960	11 - 12 A.M.	15,000	Sunday
5	1,135,624	1 - 2 P.M.	87,500	2;143
6	1,258;754	10 - 11 A.M.	82,500	1;926
7	1,185,208	11 - 12 A.M.	75,625	2,027
8	1,208,664	3 - 4 P.M.	76,250	1,817
9	255,994	4 - 5 A.M.	33;125	Saturday
10	43,920	10 - 11 P.M.	6;375	Sunday
11	1,020,625	10 - 11 A.M.	76;250	1;629
12	1,256,825	2 - 3 P.M.	78,875	1;633
13	1,383,117	3 - 4 P.M.	125,000	2;324
14	1,259,349	8 - 9 A.M.	72,500	1;983
15	1,149,124	9 - 10 A.M.	71;250	1,892
16	210,000	12 - 1 A.M.	23;125	Saturday
17	105,842	8 - 9 A.M.	8;750	Sunday
18	925;644	11 - 12 A.M.	75;000	1;418
19	1,128;548	7 - 8 A.M.	86,250	1,926
20	1,141,875	9 - 10 A.M.	81,250	1,844

From these data, which are representative of many packing houses, it is noted that:

1. Peak water usage can occur at several different times.
2. Water usage is considerable on Saturdays and Sundays (when no killing is done). This is the result of requirements for refrigeration, steam, canning operations, and normal maintenance.
3. Even when the unusual peak flow rates (such as 125;000 g/hr) and the week-end figures are excluded, there is considerable variation in the peak hourly flow rate, i.e. from 63,100 to 87,500 gals. per hour.
4. The daily water consumption varied from 360 to 654 Imp. Gals. per hog unit.

(c) <u>The Industry Often Uses Old Buildings</u>

Frequently this industry has premises for which there are no sewer plans and with the sewers so inter-connected that the job of segregating wastes is very difficult.

It is even more frustrating to see new buildings being built without full consideration to proper waste handling.

(d) Government Inspectors Emphasize the Use of Water

In government-inspected packing houses, cleanliness, housekeeping, and sanitation are emphasized as these items should be. Therefore, attempts to reduce water consumption, or reuse water may be misinterpreted by both the Inspectors and the Packers.

An Approach to the Problem

(a) Plant Survey

This is the first job. The object of the survey is to obtain:

- up-to-date sewer and drain plans for the plant.
- analysis and measurement of significant waste flows.
- data on total water consumption.
- data on water being used that will not require waste treatment facilities, by the packer. This includes domestic sewage, refrigeration water, steam condensate, gardens, ice manufacturing.
- data on water that could be reused if segregated.
- data on water that could be reused if filtered through such as a rapid sand back wash filter if practical.
- data on the volume, nature and general facilities of the business.
- knowledge of facilities and methods of handling paunch manure.
- knowledge of facilities and methods of handling hog hair, deads, slunks, condemned carcasses.
- knowledge of facilities, volumes and general requirements for poultry, vegetable oil processing and other operations, that may be part of the packing house.
- knowledge of the blood drying and rendering facilities and methods.
- knowledge of future construction plans.
- forecast of the business contemplated in 10 years or so.
- knowledge of the town sewerage and sewage treatment system, future plans for the town population, population forecasts and other industries.

The survey must attempt to answer such questions as:

- Is the plant water usage being controlled properly?

- Would a different schedule of operations be helpful if practical?
- Economics of segregating the wastes.
- Proportions of total water usage in each flow when segregated.

(b) <u>"In-Plant" Changes</u>

Wherever possible and practical, packers should consider making changes in operational procedures before large expenditures are made for waste treatment facilities. However, if major waste treatment facilities are installed first, the "In-Plant" work must be completed before the final effluent from a packing house will be of reasonable strength.

Some of these changes are:

1. Keep fats and meats off the floors in cutting rooms, boning rooms, curing cellars, cook rooms (kitchens) and coolers.

2. Teach the workmen proper clean-up methods. For example kill floors and floors in roto-cut rooms should NOT be hosed down until congealed blood, bone sawdust, meat, fat and dewclaws are shovelled into buggies for rendering.

3. Install concrete curbs in the killing floor stunning and bleeding area to segregate manure from blood as much as possible.

4. Do not allow water to run continuously in the blood saving areas. This overloads the blood dryers and may cause serious foaming losses during the drying operation.

5. Install collector boxes under bone saws wherever possible, especially on beef killing floors.

6. Reuse the water (for condensers, gut washers, or other equipment) from such as:

    - deodorizers in oil refining operations
    - carcass washers (calf and beef)
    - water in condenser systems if it is being used excessively.
    - cooling water from canning retorts.
    - cooling water from milk pasteurizers in margarine plants.
    - refrigeration water.
    - steam condensate if not returned to boilers.
    - poultry chilling water.

These changes require piping work but they may pay off well.

7. Change the piping so that all toilets, showers, wash basins and other domestic-type wastes go directly to sanitary sewers.

8. Install quick acting hand and foot valves wherever possible to reduce water consumption.

9. Install automatic valves for such operations as gang washing of calves so that water is not being used unnecessarily.

10. Adjust operations and equipment to reduce delays in rendering which increases fatty acids and expeller fines, thus increasing the loss of product to sewers.

11. To the greatest degree possible, effect segregation of the waste into the following streams and treat each separately:

    a. waters carrying fat and protein
    b. waters carrying manure
    c. clear water for reuse
    d. blood with a minimum of water
    e. domestic directly to city sewers
    f. roof and yard water to storm sewers (if any), with provision for keeping pen and truck manure out of drains.

12. Supervise operations and adjust equipment to minimize fat getting into the manure water.

(c) <u>Establish Design Basis for Each Flow Requiring New Facilities</u>

1. <u>The Split</u>

From the measurement of waste flows the rough percentages of total water to be treated by fat or manure catch basins can be calculated.

Experience indicates that these percentages vary quite widely, depending on such factors as the nature of the business and amount of clear water being wasted. For example, some packing houses purchase a large percentage of carcasses rather than killing in their own plant.

The normal well integrated packing house will split the total waste water, at about

53% to fat catch basin
47% to manure catch basin.

2. Expansion

The management must suggest the amount that they propose to expand their business in say 10-15 years.

3. Establish Peak Hourly Flow to be Handled

From the water consumption data, the peak hourly flow rate is determined (unless there are special circumstances) then using numbers for the corresponding and maximum possible hog units killed, obtain a prorated peak hourly flow rate. It is advisable to prorate on the basis of weekly kills to minimize the effect of fluctuations.

From this figure subtract the water not requiring treatment. This gives the peak hourly flow rate for that year.

Next allow for expansion, and also add a safety factor to insure adequate preliminary treatment facilities. We suggest from 20% to 30%.

(d) Waste Treatment Facilities

1. Description of Wastes

Fat Wastes

These should include water from departments, such as; hog head boning, beef boning, pork cutting; rendering, casings after manure removed, fancy meats; cook room, smoke houses, smoked meats hanging, lard manufacture; pre-packaging, curing, canning, ham boning, sliced meats, oil refinery.

Manure Wastes

These should include water from departments, such as, hog scalding tank, hog dehairing machine (after removing hair and toes) stunning area, shackling pens (or alternative areas when washed down) stock runways, pens, casing flushing, paunch opening if impractical to dump paunches directly to a screen or truck set up, neck washing, gut washers (all or part depending on fat separation) tripe washer (possibly with a fat interceptor) hide cellar, power house, machine shop, roller washing, poultry receiving area, poultry offal and feather separators.

Clear Water for Recirculation

This includes all water which is reasonably clear. Some sources are listed under the heading "IN-PLANT" changes on Page 7 item 6.

Sometimes clear water can be reused several times. For example, it may be first reused for indirect cooling, then used again in gut washers.

Blood Saving

Blood from all killing floors must be saved as completely as possible to the advantage of both the packer and the municipalities if the waste is to go to the municipal sewer. Blood must be saved with as little water dilution as possible, for the packer's benefit.

2. Flowsheets

The following flowsheets (pages 11 and 12) describe:

CANADA PACKERS, WINNIPEG JOB which was installed in 1958. It began operation in June, 1958.

Notes on Flowsheet for Fat & Protein Wastes

(a) NEW catch basins are each 50' x 14' x 7' - 6" average depth, giving one hour retention time to the future peak fat flow of 115,000 gals/hour. It was desired to build these basins with an average depth of 6.5 feet, but length was limited because of physical location.

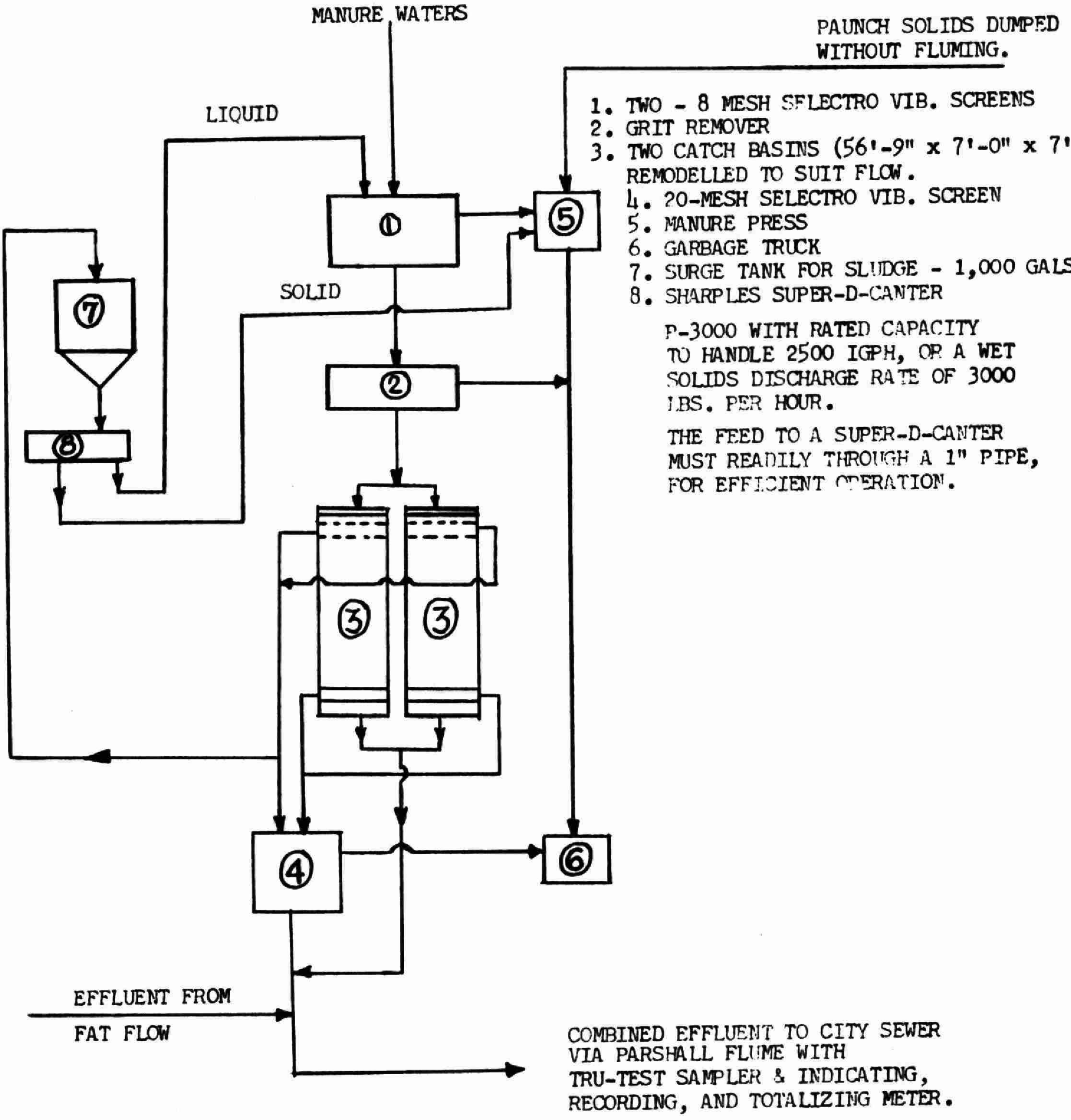
Each basin has double sump pits which are pumped 10 minutes in each hour at 50 GPM.

(b) The air flotation tank was installed for future use, if necessary.

(c) Sharples Super-D-Canter - This is a P-3,000 with capacity to discharge up to 3,000 lbs. per hour of wet solids. We found that the S. D. C. is able to produce solids, at 50% to 60% moisture.

The resulting dry material from the bottom of the fat catch basins, when manure is excluded reasonably well, will analyse approximately as follows:

FLOWSHEET OF TREATMENT FOR MANURE WASTE
CANADA PACKERS WINNIPEG PLANT
AS REVISED OR ADDED TO IN 1958

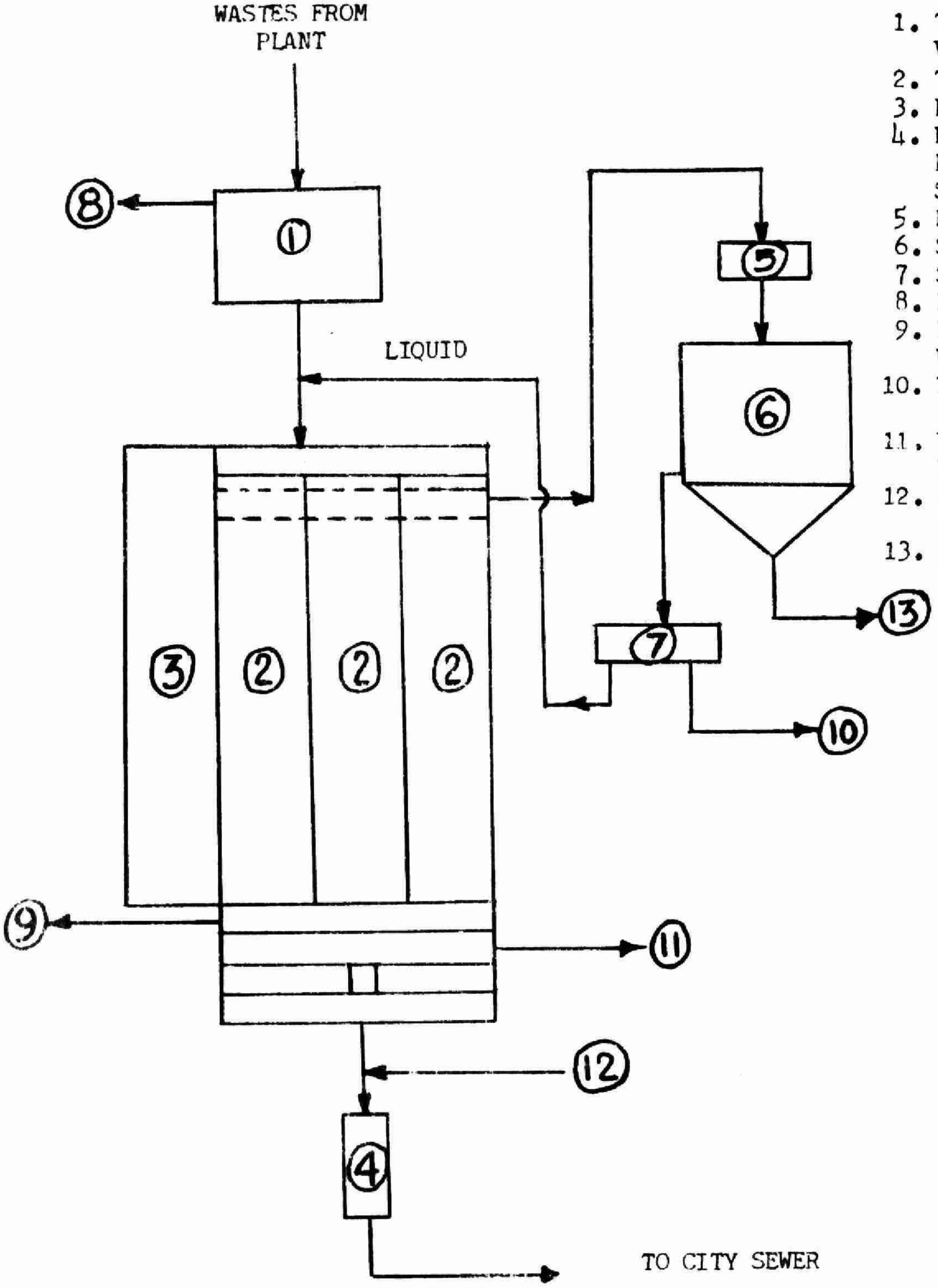


1. TWO - 8 MESH SELECTRO VIB. SCREENS
2. GRIT REMOVER
3. TWO CATCH BASINS (56'-9" x 7'-0" x 7'-6"de
   REMODELLED TO SUIT FLOW.
4. 20-MESH SELECTRO VIB. SCREEN
5. MANURE PRESS
6. GARBAGE TRUCK
7. SURGE TANK FOR SLUDGE - 1,000 GALS.
8. SHARPLES SUPER-D-CANTER

   P-3000 WITH RATED CAPACITY TO HANDLE 2500 IGPH, OR A WET SOLIDS DISCHARGE RATE OF 3000 LBS. PER HOUR.

   THE FEED TO A SUPER-D-CANTER MUST READILY THROUGH A 1" PIPE, FOR EFFICIENT OPERATION.

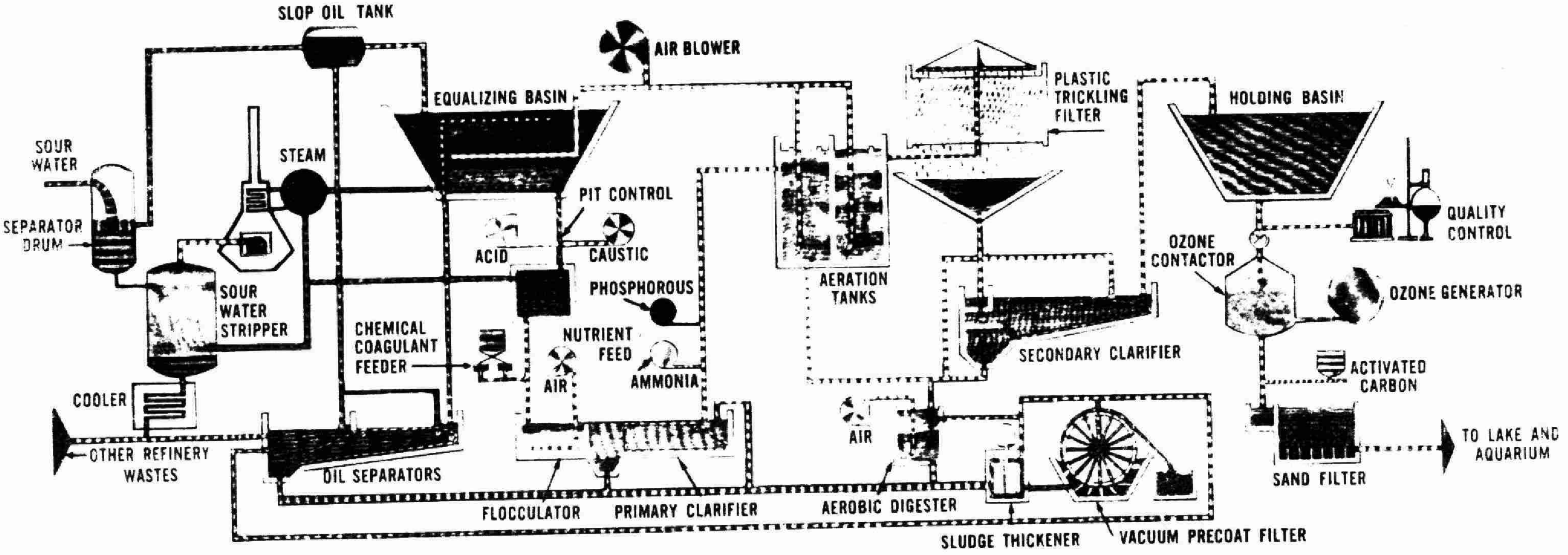
FLOWSHEET OF TREATMENT FOR FAT & PROTEIN WASTES
CANADA PACKERS WINNIPEG PLANT
AS CONSTRUCTED IN 1958

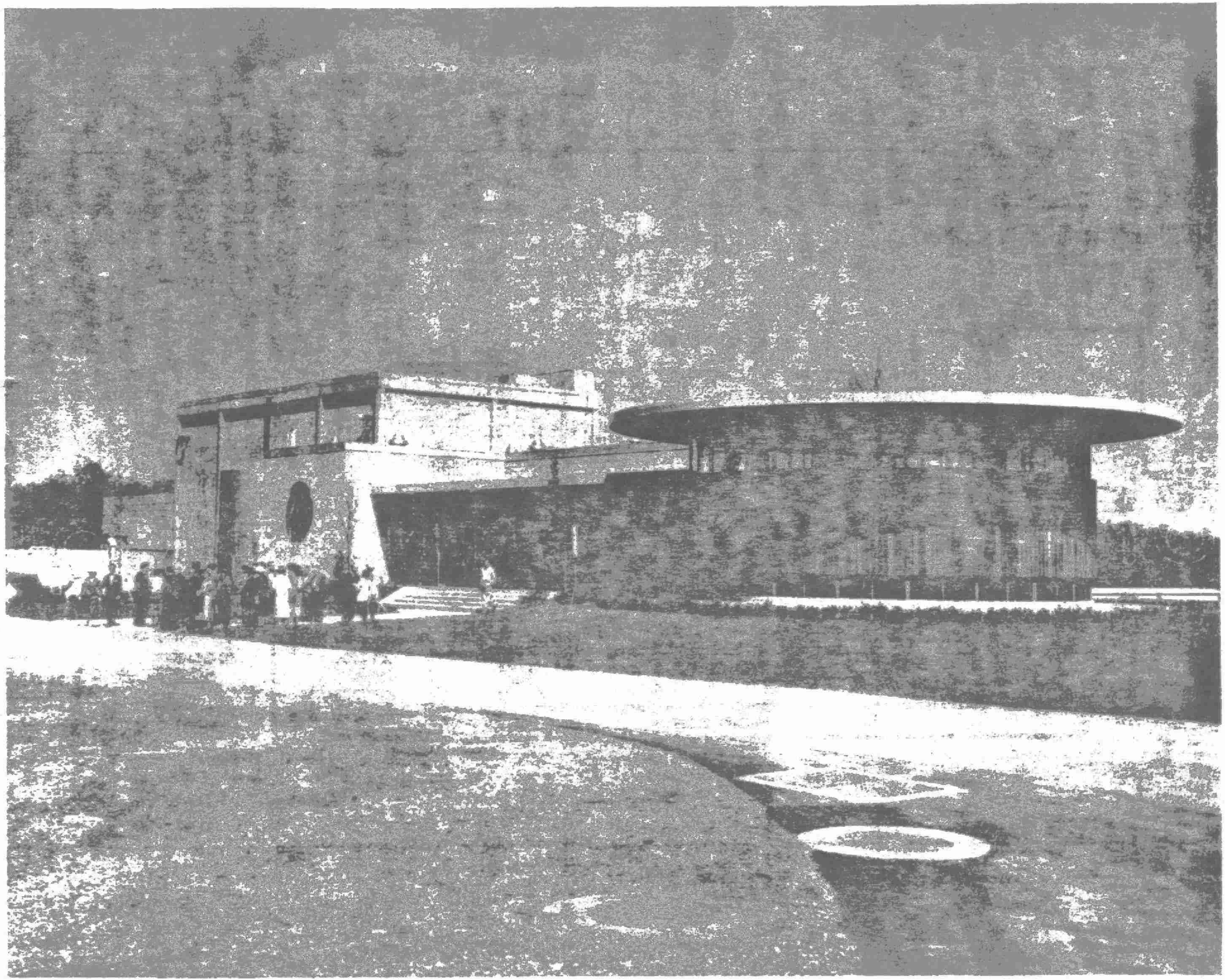


1. TWO - 20 MESH SELECTRO VIBRATING SCREENS
2. THREE CATCH BASINS
3. FUTURE AIR FLOTATION TANK
4. PARSHALL FLUME & MEASURING DEVICE LINKED TO AUTOMATIC SAMPLER.
5. MORLEY HAMMER MILL
6. SURGE TANK FOR SLUDGE
7. SHARPLES SUPER-D-CANTER
8. FAT TO DRY RENDERING
9. FAT SKIMMINGS TO WET RENDERING
10. PROTEIN SOLIDS TO BLOOD DRYER.
11. WASTE WATER RECIRCULATED TO PLANT
12. MANURE WATERS AFTER TREATMENT
13. SAND AND GRIT TO DISPOSAL

FOR NOTES ON FLOWSHEET SEE PAGE

RETURN WATER TREATMENT SYSTEM OF CITIES SERVICE ONTARIO REFINERY





Protein	- 30%
Fat	- 10%
Fibre	- 11%
Ash	- 13%
Carbohydrates, etc.	- 36%

This material can be mixed (wet) with blood and dried, for animal feeds. Incidentally, some results show protein analysis up to 54% on this material.

(d) At Winnipeg the effluent from the fat basins is reused in parts of the plant without further treatment.

(e) The Chicago Pump Tru-Test Sampler takes samples over any desired time interval (usually 24 hours). Each portion of the total sample is taken on command of the totalizing meter so that the sample is proportional to flow. The sample is held in a refrigerated chamber until collected for analysis.

RESULTS OF C.P. WINNIPEG INSTALLATION (completed by June, 1958)

EFFLUENT ANALYSIS P.P.M.
OFFICIAL SAMPLES OF GREATER WINNIPEG SANITARY DISTRICT

DATE OF SAMPLE	NOVEMBER 1957	JUNE 1958	DECEMBER 1958
B.O.D.	1267	874	988
SUSPENDED SOLIDS	843	422	485
FAT	577	191	300

For the calculations of the surcharge levied by the Greater Winnipeg Sanitary District, refer to Winnipeg By-law 80. This exacts a surcharge from industry whenever

B.O.D.	Exceeds	300 ppm by weight
Suspended Solids	"	350 ppm by weight
Fat	"	100 ppm by weight
	"	

From these analyses it is evident that there are still losses of fat in the combined waste flow which presently has peaks of 145,000 gals. per hour.

However, the recovery system has not been operating very long and there are still "IN-PLANT" changes to be made.

From the available data it appears that the settling basins are removing

65% to 95% of the fat loading
60% to 85% of the suspended solids loading.

Special Comments on Treatment of Packing House Wastes

Sampling

Proper sampling is probably the most important single feature of the system described above. The automatic sampler at this packing house is expensive but it is doing an important job.

The samples are obtained continuously, proportional to the flow at all times and as representative as possible. The sample portions are accumulated in a refrigerated compartment for any time interval up to 24 hours - waiting for the convenience of the chemical laboratory.

For years, packing house superintendents have looked for a good method of policing their losses. In my opinion, this type of sampling is the packer's answer and if used fully will give him an excellent return on his money even when there are no surcharges.

Sewering of Packing House Wastes

In my opinion, packing house wastes should definitely go into municipal treatment plants wherever possible. No packing house, unless it is extremely large should be asked to bear the full costs of a separate complete treatment plant, and then only when the packing house is located in a relatively small centre.

It must be understood that, in my opinion, all packing houses should be asked to reduce the strength of their sewage before discharging it to a sewer. It is definitely possible to eliminate most of the blood, paunch manure, hog hair, fat. The volume of sewage can be reduced considerably by reusing water but packing houses must have large amounts of water to operate properly, therefore, some of the local by-laws that restrict volumes should be examined very carefully.

Need for Equitable Charges

It is suggested that the municipal authorities should combine with the packers, probably through the Packers' Council to arrive at more equitable charges for sewered wastes from packing houses.

The charges should be based on adequate, quantitative, and accurate measurements of flow and strength of waste, for large, medium and small packing houses. Such measurements and sampling should be carried out by a neutral party using plants with automatic, proportional, representative samplers.

The proposed work must be related to the operation of the municipal sewerage and treatment system so that the actual effect of the packing house wastes on the town plant could be fully assessed.

Proposals for Improvements

No report is complete without recommendations or a statement of plans. In my opinion, the following ideas should be strongly considered for packing houses.

Fat and Protein Wastes

(1) Air Flotation

It is quite likely that air flotation would effect a considerable reduction in the strength of the settled effluent. It must be realized that, to-date, no one seems to know how to render the fat obtained by flotation methods; i.e. a fat emulsion is formed that cannot be readily broken.

In my opinion, every possible "IN-PLANT" change should be completed before air flotation is installed.

It should be realized that, to date, those who claim the air flotation products are renderable, are talking about mixing these emulsions with relatively large quantities of other packing house material. By this procedure their actual results are well hidden.

(2) Recirculation

In my opinion, packers should investigate the possibility of using rapid sand back wash filters on the effluent from the fat side settling basins. This filtered water might improve water economy considerably over that obtainable by recirculating only the presently clean water. Certain paper mills are using this equipment with apparent good results in the Toronto Don Valley area.

Manure Wastes

(1) Settling Basin

We recommend 30 to 45 minutes retention time on the manure waste flow.

At this time I would like to point out that we use the following design criteria on these rectangular basins: (of course, concessions are sometimes unavoidable)

weir loading - not more than 1250 I.G./FT/HR
surface loading - not more than 1000 I.G./SQ.FT./DAY
Flow-through velocity - not more than 1 F.P.M.
Bottom slope at least 1/8" per foot
Depth - not more than 7 feet
Length to width ratio at least 3:1.

We are not absolutely fixed on rectangular basins, but circular tanks are certainly harder to fit into the space that is usually available for an industrial waste installation. The flow should always be divided into at least two basins, for each waste.

(2) Grit Remover

In my opinion this is not required.

(3) Paunch Manure

Handling of this material undoubtedly creates one of the worst housekeeping problems in packing houses. In plants where it is screened out of the sewers, the screening can be done well with vibrating screens using a pan of bouncing balls.

Some very good results have been obtained with Sweco vibrating screens which have been provided with under pans supplied with 1-3/8" diameter pure gum rubber balls. These bouncing balls keep the 40 mesh screens from blinding.

In my opinion, packers should thoroughly evaluate circular vibrating screens versus rectangular vibrating screens. However, the paunches certainly should be dumped to the screens with an attempt being made to keep the flushing water out of the chute.

In my opinion, it would be better to flume the paunch manure to a manure catch basin system and provide sufficient capacity for the additional load of sludge. This method would improve plant housekeeping considerably.

(4) Atomized Suspension Technique (A.S.T.)

The Atomized Suspension Technique is a process patented by the Pulp & Paper Research Institute of Canada which seems to have wide application in the treatment or destruction of sludges and slurries. Particularly noteworthy, has been the first commercial installation to treat municipal sewage which has been designed and installed by the National

Welding Company of Montreal for the Town of Beaconsfield, Que.

The same company has sponsored confidential research work which was carried out by the Pulp & Paper Research Institute of Canada and which has shown that paunch manure can be handled by A.S.T. Tests have shown that all the requirements which must be satisfied, for disposal of the material can be met with considerable safety margins.

The tests run to date have been made on paunch manure as dumped from the paunches; i.e. at approximately 90% moisture content, and have been made in a reactor 8" diameter x 10' high. They have shown:

(a) No objectionable odours.

(b) Under the test conditions the mixture of condensate and ash had a maximum B.O.D. of 100 p.p.m. Where regulations and operating conditions permit, this figure could be raised resulting in reduced equipment, size and cost.

On the other hand, if more efficient comminution equipment could be found it would be possible to produce condensate and ash having an almost zero B.O.D.

(c) An estimated capital cost range of $80.00 to $120.00 per head killed per day. This capital cost depends on layout, availability of services, type of heating and the desired extent of heat recovery equipment to reduce operating costs.

Use of this process might offer considerable advantages to the packing houses. Further development work should be carried out to determine what variants if any, are required in a unit designed to handle all wastes from the manure catch basins including the paunch manure that has been flumed to the basins and other oxidizable wastes such as paper. National's Beaconsfield Unit which handles domestic sludge containing grit, sand and clay would indicate that a combination of wastes in the feed may not present any appreciable problem.

(5) New Construction

To repeat many engineers, may I strongly suggest that the packing industry provide facilities for handling wastes at the time of construction. This aspect should be reviewed by experienced engineers.

In conclusion, I would like to thank Canada Packers for letting me use their data and the information concerning their plants.

Particularly, I would like to pay sincere respects to my good friend, Professor Gerard A. Rohlich for his able assistance in this work over the years and for his help on this paper.

In addition I wish to acknowledge my gratitude to National Welding Company of Montreal and Separator Engineering Limited of Montreal, for the data which they supplied to me.

References

(1) Ohio River Pollution Survey
Appendix VII of Supplement D
published in 1942 by U.S.P.H.S. Cinncinnati, Ohio.

(2) A. H. Beard, Jr.
Design of a Grease Recovery Plant for a Meat Packer
Proceedings of the 4th Industrial Waste Conference
at Purdue University.

CONTINUOUS TREATMENT OF HIGH PHENOLIC WASTES

Dr. G. Gutzeit

The treatment of phenolic wastes represents an important and most difficult problem facing industry in areas where water supplies are scarce or where domestic water requirements depend heavily on streams used for process water discharge. While the toxicity threshold of pure phenolic compounds for aquatic life is relatively high -- 10 to 15 p.p.m. (parts per million) for phenol and 15 to 20 p.p.m. for cresol(1) -- even traces of aromatic chemicals of this class impart unpleasant tastes and odors to the water. Some persons can detect phenol at a concentration of 0.1 p.p.m., while the medicinal taste of chlorophenols can be identified when present in amounts between 3 and 5 p.p.b. (parts per billion).* Consequently the pollution control institutions of several of the more densely populated states have demanded complete removal of phenols from wastes to be discharged into their streams. This is obviously an unrealistic requirement, because the expense for treatment is an exponential function of dilution, and increases considerably when the phenol content is below the order of 1 to 2 p.p.m.(2,3) Moreover, in many cases, dilution and natural oxidation in the river will take care of a phenol residual of the order of about 1 p.p.m., which can be obtained with a fair degree of consistency and at reasonable cost in a properly treated final effluent.

Various removal methods range from simple separation of phenolic wastes which are permanently stored, to adsorption of phenols by finely ground bituminous coal. Often, several methods are used in series. Whatever method is used, all treatment plants are designed to prevent the discharge of phenols above the permissible concentrations at all times, and to keep operating expenses to a minimum.

---

* An interesting and original organoleptic semi-quantitative test for traces of phenol (in the order of parts per billion) has been based on the low limit of perception by fish for this type of compound. Minnows, kept in an aquarium, are conditioned by adding to their food, supplied within a defined area, a known small volume (0.02 cc, for instance) of a weak phenol solution. In order to test a waste, identical volumes of successively decreasing dilutions of same are added to the continuously renewed aquarium water within the defined area. If phenol is present (about down to the concentration previously used to trigger the conditioned reflex), the minnows will converge toward the limited area of addition.

These two goals are conflicting, for to keep costs down, plants should be operated continuously; however, to be certain that no dangerous amounts of phenols are ever discharged untreated, wastes should be treated in batches. Batch treatment permits laboratory analysis of each batch before it is discharged and allows time for additional treatment if required.

Continuous treatment reduces the holding capacity required for accumulated wastes, permits the use of smaller size equipment, and employs pumps, motors and other operating equipment more efficiently. Most state pollution control agencies prefer batch treatment of phenolic wastes, while industries prefer continuous methods -- if they are not prohibitively costly and complicated in order to obtain the approval of pollution control agencies.

The principal continuous processes for the removal of phenol from an aqueous waste can be compared using various criteria, each of which is important for the choice of the method best adapted for the case under consideration.

A useful classification may be based on the unit operations involved and on the original concentration of phenol in the waste as follows:

I. Original phenol concentration 2000 p.p.m., effluent phenol concentration 200 p.p.m.

  A) Steam Distillation
  B) Simple Solvent Extraction - (Single Stage, Concurrent)
  C) Adsorption by activated carbon in static column (desorption with benzol or superheated steam)

II. Original phenol concentration 2000 p.p.m., effluent phenol concentration 50 p.p.m.

  Countercurrent Solvent Extraction (in RDC column)*

---

* Processes I and II are stripping methods, and can be used for the recovery of phenols, if the required capital investment is justified by the value of the product. This additional step, which is well established, will not be discussed in this article.

III. Original phenol concentration 500 p.p.m., effluent phenol concentration 20 p.p.m.

Adsorption by bituminous coal or lignite followed by flotation of same. (4)
(Note: This range also can be treated by Method II)

IV. Original phenol concentration 100 p.p.m., effluent phenol concentration 1 p.p.m.

- A) Biological Oxidation
- B) Chemical Oxidation
    - 1) Ozone
    - 2) Chlorine dioxide
    - 3) Hyperchlorination

The processes listed under (I) never result in final liquors which can be discharged directly into a water course. Their efficiency is 95% or less, so that wastes with 2.5 to 3 g/l of phenol will yield effluents containing at best 200 p.p.m. When already installed, they may be acceptable as a first treatment step, but require usually two additional stages, which makes the combined operation quite expensive from an investment point of view.

Process (II) is believed to be the most economical and most efficient treatment for wastes with relatively high phenol concentrations (particularly if the proper solvents are used). Process (II) may be used alone when less than complete destruction is required or may be combined with one of the secondary methods (IV), to result in substantially complete treatment of phenolic liquors with aromatic compounds content up to 50,000 p.p.m. In other words, the complete treatment of relatively large volumes of a high phenolic waste (2000 p.p.m.) -- including eventually recovery of the chemicals contained therein -- should, in our opinion, comprise a two-step system, namely solvent extraction in the RDC column, followed by oxidation of the effluent by biological methods.

Process (III) is limited by the adsorption capacity of coal, respectively of lignite. (6,7,8,9) In other words, the weights of adsorbent ground to an acceptable size for flotation recovery required are roughly proportional to the phenol content of the waste in a ratio of 1:200. Consequently, unless powdered coal can be utilized locally in large quantities or unless the volume of waste is small, this method cannot be generally recommended.

Among the processes listed under (IV), it can be generally stated that chemical oxidation is expensive, unless the original total concentration of phenol and other organic compounds present in the eventually pre-treated waste is very low. We believe that biological oxidation should be generally preferred, although controlled conditions are required for its satisfactory operation.

Solvent extraction of phenol (and other hydroxy-aromatic derivatives) can be performed in suitable equipment. The Turbo-Mixer Rotating Disc Contactor (R.D.C.)* has proven during the last three years to be particularly efficient and economical for the removal of phenolics from waste liquors in full-scale industrial installations.

Table I shows removal of up to 99.9% of phenol as reported by Mr. A.N. Heller & Associates(4) with residual phenol content lowered to 1.6 ppm-9 ppm depending upon the solvent flow rate. These results were obtained on the 3'-0" diameter by 17' tall Turbo-Mixer RDC installed at the Detroit plant of the Barrett Division, Allied Chemical & Dye Corporation, using the Barrett phenol recovery process.

TABLE I(4)

TURBO-MIXER ROTATING DISC CONTACTOR-DEPHENOLIZATION EFFICIENCY#

Flow Rate Gal/hr/ft.^{2} Column Cross Section		Phenolic Concentration ppm		Dephenolization Efficiency %
Barrett Solvent "103"	Waste	Waste Feed	Waste Effluent	
68	68	5800	9	99.85%
102	51	5400	3	99.95
102	34	5400	1.6	99.97

Reported by Barrett Division, Allied Chemical & Dye Corp.

---

* The Turbo-Mixer RDC is manufactured by the Turbo-Mixer Division of General American Transportation Corporation under exclusive license from Shell Development Company under Shell Patent No.2,601,674.

A typical rotating disc contactor consists essentially of a vertical column which is subdivided into a number of compartments by horizontal stationary ring baffles or stators. In each of the compartments formed by the stators, a flat circular, horizontal disc is centrally mounted on a common vertical drive shaft. This shaft is normally provided with a variable speed drive. When the shaft is rotated, the discs by a combination of skin friction and centrifugal force will circulate liquid radially from the shaft with a superimposed swirling motion. This action is similar to that of a turbine mixer without wall baffling control. The discharged liquid travels horizontally to the wall of the vessel, then circulates upwards or downwards along the wall and is deflected back toward the shaft by the adjacent stator ring. The liquid returning to the disc, is recycled over a flow pattern which is essentially toroidal.

With a two phase system, one of the immiscible liquids is dispersed as droplets in the second phase. These drops when contacting a rotor will be centrifugally thrown out in the toroidal flow pattern of the continuous phase. The circulating drops are flexible and are continually distorted by the combined action of disc friction, wall impact and liquid turbulence. This distortion causes mixing patterns to occur inside each drop, while simultaneously creating fresh surface for interfacial transfer. The energy transferred from the rotor discs to the liquid creates a sufficient turbulence and flow in the continuous liquid phase to scrub the surface of the drops, thereby creating high mass transfer rates, i.e., high efficiencies.

The difference in densities of the two phases causes the lighter phase to rise counter-currently through the column and the heavier phase to settle to the bottom outlet. This directional separation of the light and heavy phases occurs at the outward horizontal flow stream from the rotors as it moves toward the wall and at the inward flow stream returning to the discs along the stator surfaces and across the stator central openings. Thus no interstage coalescing or redispersion of the two phases is required in the Turbo-Mixer RDC column. The maximum rate of this counter-current flow or slip velocity of the two phases is controlled by the rotor speed. The higher the rotor speed, the smaller are the drops created and the more slowly do they rise or separate from the opposite flow of the continuous phase.

The light phase is fed just below the bottom rotor compartment and the heavy phase to the top side of the upper rotor compartment. Above and below the compartmented extraction section separating zones are provided for disengagement of the effluent streams.

The open construction and the flexibility afforded by the variable rotor speed result in a high thru-put capacity for the RDC, with high stage efficiency. The simple, flat surfaces and open spacing of rotor and stator members permits the RDC to operate without plugging or fouling when solids are present.* The relatively low rotor speeds required, combined with the simple mechanical construction, contribute to reduce maintenance to a negligible factor.

Because energy input is controlled by rotor speed rather than by flow rates, the efficiency of the Turbo-Mixer RDC can actually be maintained or increased over a range of thru-put rates varying from 100% to 10% of design flow. This is of special benefit for commercial operations in which waste products streams vary in quantity with plant production rates.

Power requirements are extremely low for the volume of thru-put, varying from 1½ to 7½ HP in commercial unit sizes.

Simple controls, such as a liquid level controller, enable the column to operate essentially automatically.

Choice of solvent is influenced by the need for a specific gravity difference, immiscibility and method of recovery of phenol from the solvent. The most common methods are distillation and caustic scrubbing of the rich solvents. Many factors, such as availability of steam, losses of solvent, demand for sodium phenolate or phenol, regulate the choice of solvent recovery.

Table I (previously referred to) gives typical extraction efficiencies for a Turbo-Mixer RDC when using Barrett Solvent 103 (sp. gr. 1.03).

---

* Recent pilot tests have demonstrated that the RDC is effective for countercurrent washing of solids with a liquid.

The results demonstrate that countercurrent extraction can be efficiently performed in this Turbo-Mixer RDC extraction with a specific gravity difference between phases of as low as 0.03.

Table II shows performance to be expected from economical sizes of Turbo-Mixer RDC's ranging from 6" to 8' in diameter and from 20' to 35' tall when extracting a waste stream containing 48,000 ppm phenol using phenol-free benzene as solvent. As the flow rates are lowered, the increase in the degree of phenol recovery results from increasing the rotor speed.

TABLE II

TYPICAL MAXIMUM DEPHENOLIZATION EFFICIENCY FOR TURBO-MIXER RDC DESIGNS (6" -8'0" dia. x 20' -35' Tall)

Flow Rate Gal/hr/ft^2 Column Cross Section		Phenolic Concentration ppm		Dephenolization Efficiency %
Benzene	Waste	Waste Feed	Waste Effluent	
413	552	48,000	192	99.600
273	365	48,000	48.0	99.900
172	230	48,000	12.0	99.975
91.5	122	48,000	5.8	99.988
57.2	76.4	48,000	1.44	99.997
22.9	32.8	48,000	2.9	99.994

When used in conjunction with Process IV, the Turbo-Mixer RDC can be designed in the smaller diameter and shorter height range which discharges higher residual phenol to the final oxidation stage for destruction of the last traces of phenol.

Adsorption of phenol (as well as other polar and non-polar organic compounds) on bituminous coal or lignite, followed by froth flotation (Process III) is a method developed in 1949 by the R & D staff of General American Transportation Corporation for the purpose of treating a complex waste resulting from the cleaning of tank cars. While the plant and its operation have been described previously in the literature, (6,7,8,9,10) a brief summary will be useful for our present purpose.

Two tracks with separate underdrains are used for cleaning the tank cars, so that the liquid wastes and wash water are divided into two classes. One class includes water-insoluble liquids, toxic organic compounds, and acids.

The second class includes all other liquids and solids -- mostly bases and salts -- that are miscible or soluble in water. Free insoluble oils and fats are mechanically separated from the aqueous solution of the wastes in the first class. The aqueous underflow from the separator is stored in a basin to equalize the flow and then pumped to a series of Turbo* Conditioner mixing tanks.

Finely ground coal is mixed with the wastes and the pH is automatically adjusted to 4.5. As the coal adsorbs oils and phenols, it becomes water repellent. The coal and wastes flow to a series of Turbo flotation cells where a frothing agent and minute bubbles of air are added. The foam, which contains all the solids, is scraped from the liquid wastes, dewatered on a G.A.T.C. rotary drum filter, dried, and burned as fuel.

The liquid wastes are mixed with the second class wastes which have been equalized in a holding basin. After the pH is automatically adjusted to 5.5 - 6, the combined wastes are treated in three Turbo aerator cells together with sufficient ferrous sulfate to form a floc.

Lime is automatically added to the effluent from the aerators, so that the pH is 6.5 - 7 for optimum biological treatment and to ensure a satisfactory stabilized discharge to the stream. The wastes then flow to a Dorr thickener, where the sludge settles in a hopper and is periodically and automatically removed according to a schedule set up on a timer.

---

* Trade-mark of Turbo-Mixer Division of General American Transportation Corporation.

The clear liquid wastes overflow to a lagoon affording five days' retention to prevent slugs of toxic liquids from reaching the final stages of treatment, where they would destroy the biological life on which the last stages depend. From the lagoon, the wastes are mixed with sanitary sewage and pumped continuously to a trickling filter where organic compounds, including any remaining phenols, are consumed. The effluent from the filter is clarified and discharged to the river.

Whether one or the other of these primary treatment methods is chosen (depending mainly on the initial concentration in phenol of the waste and on economic, respectively geographic conditions), it will usually be necessary to provide secondary treatment, i.e., biological or chemical oxidation, in order to produce an effluent acceptable for discharge into an inland water body.

Before this can be successfully accomplished, the phenol content of the pretreated waste should be determined by analysis. Even more advantageous for that purpose is automatic monitoring by means of a device developed by the G.A.T.C. staff.

This instrument is similar to the pH controllers in that it is an ElectroniK potentiometer with Air-O-Line control; however, it is actuated by a photoelectric instead of a pH cell. Essentially, the combined photoelectric circuit and measuring system is the same as a standard absorption colorimeter used in analytical laboratories except that it operates on a continuous basis.

A sample of the waste is pumped through a small sand filter and proportioned between two cells. An excess of a color reagent is added to one of the cells, and when a color due to the presence of phenols appears, a voltage differential is created between the two photoelectric cells. This differential is proportional to the phenol concentration and is measured by the potentiometer.

The color reagent is a modification of Millon's Reagent. To increase sensitivity, a single light source having a wavelength of 400 Angstrom units is used. Variable resistors are included so that the instrument can be adjusted for any range of phenol concentration. Sensitivity is in the order of 0.1 percent of full scale, and reproducibility is 0.03 percent.

The instrument was improved by the staff of Imperial Oil Company, Sarnia, Ontario, and a less expensive, more stable reagent was substituted for the one used originally (Ref. "Detection and Monitoring of Phenolic Waste Water" by A.D. McRae et al, 14th Annual Purdue Industrial Waste Conference, May 1959).

The controller can be used to operate motorized values to admit variable amounts of chemical oxidizing agents, or to regulate the quantity of dilution water, or even to dump directly into the receiving stream (by-passing the secondary treatment system) wastes containing an acceptable concentration of phenol.

Concerning secondary treatment processes (IV), biological oxidation is usually to be preferred over chemical methods, particularly from the point of view of operating costs as has already been mentioned. The necessary conditions for successful operation (which have been discussed quite extensively in the recent literature) may be summarized as follows:

1. The dephenolizer effluent should be neutralized (lime).
2. It is important to equalize as much as possible the feed to the biological filter, and to avoid the presence of suspensoids by preliminary clarification, if required.
3. During the starting period, and whenever required thereafter, the extraction effluent should be seeded with sewage sludge or with mixed cultures of phenol-resistant aerobic organisms. (Pseudomanas, Subtilis)
4. It is essential to feed nutrients (nitrogen and phosphates) -- either as chemicals (ammonium nitrate and ammonium phosphate) or as natural products (human or animal sewage) -- into the final treatment stage.
5. Means for continuous re-circulation of a portion of the waste should be provided. High-rate filters appear to be most adequate.
6. Proper temperature range -- as is the general rule in biological oxidation processes -- is important for efficient operation. If any waste heat is available, it should be utilized to raise the temperature of the liquors during cold weather.

According to our experience in the Saegerstown, Pa., waste treatment works, a recirculating trickling filter fed with a mixture of phenolic waste and human sewage (as nutrient) was able to reduce the phenol content by an average figure of 78.95% (over a period of one year), with peak efficiencies better than 99%. Phenol concentrations ranging from 0.5 p.p.m. to over 270 p.p.m. were handled. Table III gives data obtained in this installation during the month of July 1951, showing the results of biological oxidation at abnormally high phenol levels in the feed.(9)

References

(1) Eldridge, E.F.
Eng. Experiment Station Bulletin, 60, p. 49 (1934).

(2) Cleary, E.J., and Kinney, J.E.
Proc. Sixth Ind. Waste Conference, 1951, 158-70, Purdue University.

(3) Ohio River Valley Water Sanitation Commission (June 1951).
"Phenol Wastes: Treatment by Chemical Oxidation."

(4) Heller, A.N. Clarke, E.W. and Peiter, W.M.
Proc. Twelfth Ind. Waste Conference, 1957, Purdue University.

(5) Reman, G.H. and Olney, R.B.
Chem. Eng. Progress, 51, No. 3, pp. 141-6 (1955).

(6) Gutzeit, G.
Chem. Eng. Progress, 46, 335-42 (1950)

(7) Gutzeit, G.
Petroleum Processing, 7, No. 6, 828-32 (1952)

(8) Gutzeit, G and Enyart, G.
Wastes Engineering, 22, No. 1, pp. 18-22 (1952).

(9) Gutzeit, G and Enyart, G.
Proc. Seventh Ind. Waste Conference, 1952, 105-29, Purdue University.

(10) Gutzeit G. and Enyart, G.
Instrumentation, 8, No. 3, pp. 7-9 (1955).

TABLE III

MAXIMUM EFFICIENCY OF TRICKLING FILTER FOR PHENOL REMOVAL AT VERY HIGH PHENOL LEVELS

	Phenol Content in Lagoon		Flow from Lagoon to Filter		Phenol Content in Clarifier Overflow		Total Lbs. of Phenol Removed by Filter	Lbs. of Phenol Removed by 1000 cu. ft. of Filter	% Reduction
	P.P.M.	LB.	GPM	Total Gal.	PPM.	LBS.			
July 13 ...	155	13.43	7.2	10,380	0.3	.03	13.40	3.63	99.7
14 ...	204	17.66	7.2	10,380	0.3	.03	17.63	4.78	99.8
16 ...	272	28.80	8.8	12,680	0.3	.03	28.77	7.79	99.8
18 ...	278	33.45	10.0	14,400	0.3	.04	33.41	9.06	99.8
24 ...	44	9.00	17.0	24,500	0.3	.06	8.94	2.42	99.4

FROM REFINERY WASTES TO PURE WATER

AT THE CITIES SERVICE TRAFALGAR REFINERY

Dr. J. D. Frame

On May 26, Cities Service Oil Company Limited officially opened its Trafalgar Refinery in Bronte Ontario. Alone remarkable for its integrated and economical operation, the new refinery boasts still another outstanding feature---a waste treatment plant that is the most modern, complete, and effective in the world today.

The basis for this claim rests, oddly enough, on a process that is at least a billion years old, but one which has only recently come of age. Scientists call it biological oxidation. It calls into action billions and trillions of microscopic organisms. These bacteria thrive on the plant's waste and convert it into a clear, harmless solution.

The Trafalgar plant is designed to treat a variety of wastes---everything, in fact, from the water used in the refining process, to tank drawoffs and sanitary waste, as well as leakage from equipment, pump glands and pipelines---in other words, all the waste that occurs in a large, modern refinery.

In refinery wastes there are two substances that cause more trouble than all the other wastes combined. These are the phenols and waste oil. Both are pollutants. Phenol compounds make water smell and taste like carbolic acid. They are so potent that one pound of phenol can be detected in 12,000,000 gallons of water. Oil, of course, is unsightly and makes water taste peculiar. Phenols are, moreover, very "stubborn" compounds: it is exceedingly difficult to coax them out of water. But it can be done by enlisting the action of bacteria. And in doing so, we remove all the other wastes as well.

Strictly speaking, there are two kinds of waste water in the Trafalgar Refinery: storm water runoff and process wastes. Storm water runoff from non-contaminated areas drains through an independent system. All other wastes require complete treatment.

Here's how Trafalgar's process works. A network of underground pipelines gathers the contaminated water and refinery waste into one main sewer running to the treatment area. The flow averages 300 gallons per minute, although it may vary considerably from one moment to the next. The actual flow is measured by a Parshall Flume. This is simply an open channel so shaped that the depth of waste inside the channel varies directly with the amount of waste entering the system. Once measured, the waste flows into a large rectangular basin called the oil separator. Here the waste water is allowed to stand long enough so that runaway oil can float to the top and heavy material settle to the bottom. Mechanical racks then skim the oil off the top and scrape the sludge off the bottom. The oil is sent back to the refinery for processing. The sludge is pumped into a thickener. Here water is removed, and the residue dried and hauled away for safe and proper disposal.

The water in the separator basin has now been rid of sludge and free oil. But it still contains dissolved chemicals and finely dispersed waste along with oil that is emulsified or bound to minute particles of matter.

From the oil separator, the water is conducted into an equalization basin --- a rectangular pit large enough to hold one day's flow of waste. The basin has several functions. In the first place, refinery wastes do not flow at a constant rate. The flow of sanitary waste, for example, is greatest when each labor shift goes off duty. Certain other wastes are added to the system only during breakdown or repair. Secondly, the chemical nature of refinery wastes will obviously vary considerably over any 24-hour period. Strong acids predominate at certain times, and powerful caustics during others. Clearly, if we had to treat these wastes immediately on their arrival, we would have to make abrupt, continuous and extensive readjustments in our treating methods.

However, by running all the wastes into one large basin, we can obviate these extreme variations. The acids and bases, for example, can undergo partial dilution and neutralization. Suspended solids can be uniformly dispersed throughout the basin. Finally, and equally important, the flow of waste water into the treatment units can be maintained at a fairly constant rate. Thus, the waste water entering the treating plant will vary only slightly over a 24-hour period --- and allow the operator sufficient time to make the necessary and minor adjustments.

In our Trafalgar operation, three sets of pipe enter the equalization basin: one carries steam; another carries air; and the third brings in the waste water from the separation tank. This third pipe is perforated and centrally located so that it distributes the incoming waste down the full length of the basin. Air is bubbled in to aid oxidation and insure thorough mixing. Steam pipes prevent the waste water from freezing in the winter. Provision is made to skim off any free oil that may have escaped the separator tank, and there is a spare equalization basin in case the flow becomes too great for one basin to handle.

From these equalization basins, the waste flows by gravity to a pump pit in the treatment building. By this time, the acid and caustic wastes probably will have neutralized each other. However, if the waste is still too caustic or acidic, it can be neutralized in the pump pit. Following this, the neutralized waste is pumped through a heat exchanger and brought up to 95°F. A solution of ferrous sulfate is prepared and mixed together with the waste in one of two rectangular basins called the flocculation-clarification tanks. Each of these tanks is divided by a perforated wooden wall into two sections. In the first section, air is bubbled up through the water to insure thorough mixing of the waste and ferric sulfate. Ferric sulfate breaks down the oil-and-water emulsions and joins with the oil to form heavy particles known as floc. At the same time, the chemical collects all the finely suspended solid matter in the waste. The constant stream of air bubbles keeps the floc and heavy particles near the surface. The waste then passes through the perforated divider into the "quiet" half of the tank. Here the heavy particles settle to the bottom where they can be scraped to one end and collected in a hopper. All floating material is skimmed into an open pipe near the outlet end of the tank. The remaining waste water passes beneath the skimming pipe, out into a channel, and thence to the primary aeration tanks --- and the center of the treatment process.

On arriving at the primary aeration tanks, the waste water overflows from troughs running the full length of each tank. Near the bottom of the tank, on the other side, are pipes that release air in such a manner that it gives the waste water a rolling, over-and-under motion. The incoming waste drops into this rolling mass and is quickly dispersed.

Just what goes on in these aeration tanks? The answer is a simple one. The tanks contain a wide variety of bacteria. Like other animals, bacteria have special tastes: some require particular chemical foods --- especially phenol compounds --- in order to grow and reproduce. And in our primary aeration tanks these bacteria enjoy a rich repast.

Our purpose, however, is not simply to feed bacteria. The point is this: when bacteria eat and digest waste chemicals, they convert noxious substances into simple, harmless compounds. Most importantly, they do it more effectively and more economically than any process man can devise.

Bacterial conversion of chemical waste takes time, so we pass the waste water into a secondary aeration tank where the bacteria are given further opportunity to feed without new waste being added. Effective though bacterial oxidation is, however, the process still does not remove all the chemicals. A few of these compounds --- particularly some of the phenolics --- remain unchanged. Consecuently, they must be removed by further processing.

From the secondary aeration tank, the waste is pumped into one of two filters. Actually, these units are not filters in the strict sense of the word. That is to say, they do not strain the waste. They consist rather of gigantic cylindrical tanks containing corrugated sheets of plastic arranged in a "honeycomb" pattern. Waste water is pumped to the top and distributed over the "honeycomb"by means of rotating perforated pipes. The waste then trickles down over the plastic surfaces --- hence the name, trickling filters. Because of the plastic "honeycomb," we will refer to the units as Dow-Pac filters.

The action of the Dow-Pac filters is similar to the aeration process in that it also makes use of bacteria. In this case, however, bacteria adhere to the plastic sheets. As the water waste trickles down over them, the bacteria absorb most of the remaining chemicals --- particularly the phenol compounds.

From these filters, the waste water flows into a sump. If little raw waste is being added to the treatment plant as a whole, then the filtered waste will be repumped to the Dow-Pac units. This will keep the bacteria moist and provide them with whatever food is left. In any event, some of the filtered waste is always recirculated in this manner. Generally, however, the bulk of the filtered waste is conducted into the secondary clarifiers.

In these tanks, all solid matter and excess bacteria settle to the bottom and are scraped away to hoppers on the inlet side. Floating material is skimmed to a slotted pipe on the outlet side. The clear waste water passes under this pipe, into a trough, and out through a pipe that carries it to the holding basin, located near the equalization basins outside the building.

At this point, let us return our attention to the treatment plant and follow the various minor and subsidiary processes to their end. You will remember that in the primary clarifier, ferrous sulfate combined with suspended matter to form sludge. The sludge was then scraped from the bottom. To pick up where we left off, the sludge then proceeds to a sump from which it is pumped into the sludge thickener, a tank unit outside the building. You may also recall the floating material in the primary and secondary clarifiers. In both cases, the material was skimmed into slotted pipes. To continue, this material is also ultimately pumped into the sludge thickener. Here water is removed. The thickened sludge is then piped back to the building, partially dried on a vacuum filter, and conveyed away by truck.

The bacterial sludge in the secondary clarifier passes, however, to another sump --- the return sludge sump --- from whence it is pumped to a concrete chamber. This chamber has a special wall to divide the flow into two streams. One stream returns the sludge to the primary aeration tanks to maintain and replenish the bacterial population. Here it is absolutely essential that we have an adequate supply of bacteria to cope with the incoming raw waste. On the other hand, when the supply of bacteria exceeds our day-to-day requirements, we must dispose of the excess. This is achieved by adjusting the second stream in the concrete chamber. Thus if we have too many bacteria, we send the excess into either one of two tanks --- the aerobic digesters. Here the bacteria are kept in constant motion, but they are deprived of chemical food. As a result, they devour each other, the debris settles to the bottom, and is conveyed to the sludge thickener outside the building.

In addition to the carbon and hydrogen present in refinery wastes, the recirculating bacteria also require phosphorous and nitrogen. These elements (in the form of phosphoric acid and anhydrous ammonia) are therefore added to the waste water just before it enters the primary aeration tanks.

Now let us return to the holding basin. At this point, the waste water should be clear. Most of the original phenols and other chemicals should be absent. Samples are taken to make sure that the water meets certain rigorous standards. If the analyses prove unacceptable, the water will be run through the entire plant again. The Trafalgar plant has, in fact, been designed to handle the usual daily flow of raw waste plus an equal quantity from the holding basins should such a procedure prove necessary.

Assuming, however, that the water in the holding basin does meet the standards, we then let it flow back into another sump in the building. From here, it is pumped to a large stainless steel tank where it is mixed with ozone. Effective though the aeration process is, it still does not completely oxidize <u>all</u> the phenolic compounds in the raw refinery waste. It <u>is</u> possible, however, to oxidize most of the remaining phenolics by supplying oxygen in the form of ozone.

The waste in the holding basin is discharged into the top of the ozone reaction tank and flows down through the vessel. Ozone is pumped to the base of the tank and diffused into the liquid through carborundum pipes. In this way, the ozone is dispersed in fine bubbles so that the contact between gas and liquid will be at a maximum.

Ozone also serves a second purpose. At the same time it oxidizes the phenolic compounds it also disinfects the water. In other words, the gas destroys bacteria that are harmful to human beings. Normally, in most water disinfection procedures, the chemical chlorine is used. But since we are dealing with phenolic compounds, the use of chlorine could be detrimental. For chlorine and the phenols usually combine to form compounds that taste far worse than the phenolic compounds themselves.

The waste water leaving the ozone reaction tank will now have the smell and taste of fresh spring water. But it will still contain a trace of phenol compounds and a slight turbidity.

To rid the water of these last defects, we subject it to two simple and final treatments. In the first we add finely pulverized, activated carbon to absorb the last of the phenols. Then we filter the water through a bed of graded sand and gravel to make it crystal clear.

Since the carbon will be retained on the surface of the sand filter, it will eventually build up and hinder the flow of water. Periodically, then, we must back-wash the filter and remove the compacted carbon. Back-washing simply involves pumping sufficient water up through the filter bed so that the sand and carbon are dislodged. The turbulence of the up-flowing water will scrub the sand and flush away all the debris along with the water. By controlling the velocity of the water, we can limit the height to which the sand will rise and drain off only the water that is above it. This scrub water is then piped back to the equalization basin for processing along with the raw refinery waste. The fine material and carbon will ultimately be removed by the ferrous sulfate treatment mentioned earlier.

With this final treatment, we obtain water that is clear and sparkling, free of odor and taste, rid of pathogenic organisms, and rich in dissolved oxygen --- water that is eminently fit to drink. Following this final step, the water is pumped out into Lake Ontario, better in many respects than the raw waters from which it originally came.

Cities Service's Trafalgar Plant is yielding many benefits --- direct and indirect. It is recovering several thousand barrels of "lost" oil every month. Even more important, it is securing the goodwill of townspeople, farmers, and sportsmen. The plant has set for all industry a new standard in pollution control.

WASTE DISPOSAL FROM
THE IMPERIAL OIL LIMITED
PETROCHEMICAL PLANT

B.J. Ryan

Introduction:

The commissioning of the 28 million dollar Chemical Products Cracking Unit of Imperial Oil Limited, Sarnia in September 1958 presented some new waste disposal problems and aggravated certain existing disposal methods common to the refinery. Main waste streams are the sour pehnolic waters drained from distillate drums and caustic scrubber, water containing dissolved copper from the Butadiene Extraction process and spent caustic purged from the gaseous hydrocarbon treating plant. In addition a lesser problem exists in the disposal of spent activated charcoal and clay. To date we have been successful in our pollution control program and the satisfactory disposal of waste material.

This report is intended to outline the reasons for efficient control and the measures taken to adequately dispose of these pollutants.

Petrochemical Pollution Background:

This newest of the processing plants at the Imperial Oil, Sarnia Refinery produces such products as ethylene, propylene, butylene and butadiene as well as naphtha, aromatic tar and a polymerized viscous oil. Although controlled from a central point there are in reality four distinct processes in operation at this plant. In the order of their magnitude from a waste disposal standpoint these are (a) the Cracking & Light Gases Recovery Section, (b) the Butadiene - Butylene and Acetylene Removal Section, (c) the Naphtha plant and (d) the Ethylene section.

Since start-up of this unit the feed has varied in sulphur content with corresponding effects on the sulphide content of the condensate waters. In order to remove additional sulphur from light hydrocarbons, additional caustic was required causing an increase in the volume of spent caustic for disposal. Pump gland leaks, minor spills and other upsets have caused fluctuations in the copper content of the water from the Butadiene section necessitating further treatment to precipitate the copper before discharging this water to public waterways.

Sour-Alkaline Water Disposal:

In the different types of petroleum cracking operations, water is an inherent component appearing in the lighter hydrocarbons following fractionation. Water is sometimes introduced indirectly to the process as steam, to provide a dispersant and cooling effect before cracking occurs. Also water in the form of steam, is essential in stripping naphtha type hydrocarbons from heavier oil fractions so the litter may meet flash temperature specifications. Often water is employed directly as a finishing step following caustic scrubbing in order to wash away any residual alkalinity from the treated hydrocarbon stream. In any case water in contact with untreated hydrocarbons leaches phenolic compounds and sulphides from the oil and becomes contaminated. Since anti-pollution legislation has stipulated definite phenol concentration limits in the St. Clair River steps must be taken to stay within these limits. At the Petrochemical plant all sour water streams are directed to a central storage drum where entrained hydrocarbon liquid separates out to form an upper layer. This upper oil layer spills over a baffle in the drum and collects in the smaller part of the drum from whence it is pumped to slop tankage for rerunning. (1)

The bottom sour water layer is pumped through heat exchanger equipment to pick up heat and into the top of a stripper tower. (This is a vertical steel vessel containing a packed upper section and bubble-cap trays at the bottom.) The liquid flows down through the packed section and descends bubble-cap trays to the bottom of the tower. While flowing downward it contacts a counter-current steam flow, entering the bottom of the tower, which strips out the hydrogen sulphide in the water. The overhead vapors flow to an incinerator where they are burned. The stripped water is then pumped to our Biological Oxidation Plant where the phenol content is reduced to 200 ppb phenol suitable for discharge to the St. Clair River. Daily laboratory analysis indicate the degree of stripping and phenol removal.

Steam or flue gas stripping of sour water is a common means employed to remove sulphides and mercaptans from water. In general the temperature of the feed to the tower is maintained at 170 to 180°F. at the design feed rate, for best results. Experience has shown the more stripping steam there is per pound of sour water the better is the stripping. Care should be taken, however, not to use excessive steam for fear of overloading the stripper and eventually overloading the incinerator.

Butadiene Section Waste Water Disposal:

At Sarnia the extraction of Butadiene from a hydrocarbon mixture is accomplished using a copper extraction solution. During normal operation a certain amount of this copper solution is lost from leaking pump glands, corrosion of copper solution lines, Butadiene area surface drainage and minor process upsets. Since copper in concentrations above 0.1 ppm is harmful to organic and marine life great care must be exercised to prevent escape of this copper solution to a natural waterway. For this reason a maximum copper concentration limit has been set on plant effluent which must be carefully observed.

(1) As part of the precautions taken, all water containing copper solution, so called "blue water", is directed to a concrete collecting basin, referred to as the "Blue Pond ". Dimensions of this basin are approximately 50' by 60' by 10' deep. This basin is also sized to accomodate the water from 3" of rainfall extending over the concrete pad of the Butadiene area. The "Blue Pond" in turn is presently connected direct to an Impounding Basin capable of containing several days non-sour water from the entire Petrochemical Plant before pumping to the river.

Analysis for copper in the "Blue Pond" water determines when the water should be treated to precipitate the copper as cupric oxide and cuprous hydroxide. Following this operation the clarified water is pumped to the Impounding Basin and then to the river by pumps actuated on controlling different levels in this Basin. Since traces of copper will always be present it is planned to employ a continuous copper analyzer and recorder-alarm between the Blue Pond and Impounding Basin. Water containing copper above a pre-set level will trip the alarm and retain the contents of the collecting basin for additional copper removal.

Spent Caustic Disposal:

Caustic soda in water solution is contacted with hydrocarbons varying from methane to naphtha distillates in order to remove sulphur compounds as well as phenols and other organic acids. Petrochemical products must be virtually sulphur free to insure trouble free processing later. Lye treatment is affected by means of mixers and scrubbing towers in order to provide the best contact possible between caustic and hydrocarbon.

(1) Since disposal of spent caustic is still necessary, facilities have been provided for neutralization with spent sulphuric acid. This is accomplished by introducing the acid, in the proper ratio to give a neutral mixture, upstream of a mixer through which caustic is pumped. Since dilute sulphuric acid is very corrosive to steel the mixer and neutralized caustic lines up to the settler are made of duricon alloy. Acid oils are released and continuously skimmed off the surface in

the settling drum following the mixer and evolved hydrogen sulphide is vented to the incinerator. The neutralized solution can then be sent to the Sour Water Stripper and eventually to the Biological Oxidation Plant.

Direct disposal is the cheapest method of handling alkaline solutions, these methods include disposal ponds, sale of spent solutions.

(2) Approximately one hundred disposal wells are located in lower Michigan. In this area industry is permitted to use the Sylvania and Detroit River sands formation for waste disposal. At Bay City, Michigan, these formations are found at a depth of 4500 ft. Before their development these deep wells require careful study of underground rock formations, compatability studies of the waste materials with rocks and waters in the strata and the approval of the appropriate governmental pollution and oil control organizations.

Waste Solids Disposal

"Char" or activated plant charcoal is required to remove polymeric material from the copper solution at the Butadiene section and other treating streams. In time it loses its filtering effectiveness and must be removed. This involves taking the drum out of service, pressuring out liquid and allowing the char to drain for 16 hours. After the drainings are pressured back to the system the char is dumped into loadlugger buckets for transportation to the solids disposal area. Here the charcoal is fed to an enclosed hearth for incineration.

As previously mentioned cupric oxide and cuprous hydroxide precipitates are obtained during reduction of the copper in Butadiene section waters. This sludge material is retained for possible sale to smelters.

Spent Clay is also another waste solid from the Petrochemical area and must be disposed of via dumping into buckets for delivery to the incinerators. The ash from this material can be used as road fill around the refinery. A portion of the Petrochemical waste solids are being contracted to commercial disposal organizations and so removed from the refinery.

Conclusions:

Waste disposal is one of the major problems faced by the Petrochemical industry as a result of the greater contamination potential of its spent chemical wastes. Constant surveillance of plant effluent streams is necessary to remain within stream control regulations. A partial solution to the problem will be realized as sales of spent chemicals increase. Meanwhile the industry is studying alternate methods with direct safe disposal holding the greatest possibilities.

References

1. Operating Manuals No. 2 and 5 for the Chemical Products Cracking Unit,
   Imperial Oil Limited,
   Sarnia Refinery.

2. McRae, Alex D.,
   "Disposal of Alkaline Wastes in the Petrochemical Industry",
   Presented at the 31st Meeting Federation of Sewage and Industrial Wastes Association.

3. Dyble, R.H.,
   "Disposal of Liquid Refinery Wastes in Deep Wells",
   Report No. 1M-6R-59, Imperial Oil Limited.

FEDERAL ACTIVITIES IN ATMOSPHERIC POLLUTION

Dr. Morris Katz

Introduction:

In view of the growing importance of atmospheric pollution, the Department in January 1956, established an Atmospheric Pollution Service within the Occupational Health Division and appointed a consultant to assume responsibility for the program. This program involves the provision of advisory and more direct services to the provinces, municipalities, federal departments and other agencies investigating harmful or potentially harmful industrial and community pollution situations; assistance to the International Joint Commission in problems involving transboundary flow of air contaminants between Canada and the United States; research into specific problems involving the health effects of toxic components of air pollution; standardization of methods of sampling and analysis and the development of improved techniques for the separation, identification and analysis of pollutants; and the coordination of data gathered at field sampling stations maintained by provincial and municipal organizations into a national air sampling network for the correlation and exchange of information. All these efforts are directed towards the primary purpose of providing means to safe-guard and improve the health of the population of Canada.

During the past several years assistance has been rendered on an increasing scale to a number of provincial health departments and municipal agencies in the study of atmospheric pollution problems. These have involved toxic waste products from a variety of industrial operations, such as gases, odorous components and aerosols from oil refining, nickel and copper smelting, fertilizers, steel and chemical plants and miscellaneous furnace operations.

Environmental Studies of Air Pollution:

1. The Greater Windsor-Detroit Study: The problem of air pollution and its effects in the Greater Windsor-Detroit Area has been under investigation by staff of the Department, the U.S. Public Health Service and various co-operating organizations at federal, provincial, state and municipal levels for a number of years under the terms of a Reference to the International Joint Commission. A final report on this study was presented to the Commission in 1958 and is now being printed for publication. This document consists of 13 chapters that deal with the organization and conduct of the study; the sources of pollution from industrial and public activities on land and marine traffic on the Detroit River; concentration levels, nature

and chemical composition of urban air contaminants and the influence of meteorological factors on diffusion and dispersion; the transboundary flow of pollution; the effects of existing contaminant levels on public health, vegetation and property; and recommendations as to remedial measures and regulations for the federal control of air pollution from Great Lakes and foreign vessel traffic on the Detroit River. The information and findings will be generally useful in the study of other urban and industrial air pollution problems. Levels of major contaminants on the much more highly industrialized and thickly populated Detroit side of the river were considerably higher than on the Windsor side and at several points there was a marked flow of pollutants across the international boundary from the United States to the Canadian side.

In a pilot health study of a number of high and low pollution areas covering a period of two years, it was found that the monthly rates of sickness in all areas under study followed a similar chronological pattern, although at differing levels. However, two areas in Detroit showed a pattern of sickness rates that differed substantially from each other, the rates in the high pollution area being generally at a higher level than those in the low pollution area. In other groups of households of Detroit and in those of Windsor, the results were inconclusive. Clearly, this subject represents, as yet, a relatively unexplored field of research and requires much further study before the quantitative relationship between atmospheric contamination in the urban environment and the sickness experience and health status of exposed populations can be elucidated.

A number of polynuclear aromatic hydrocarbons, some of which possess carcinogenic properties, were isolated from the Windsor atmosphere. However, this is another field where much more research is required to establish the effects on health of such cancer-producing, toxic compounds at the relatively low concentration levels encountered in community atmospheres. Other aspects of the pollution problem that represent an almost virgin field include the synergistic effects of the relatively large numbers of gaseous and aerosol contaminants that have been identified. It is now known that photochemical and other reactions between waste products discharged to the air may lead to the formation of new compounds, more irritant or harmful than the original reactants.

2. <u>Sydney, Nova Scotia</u>: An air pollution survey has been in progress in Sydney for more than a year. This survey is being carried out in co-operation with the Provincial Department of Health, the City of Sydney and the management of the Dominion Steel and Coal Corporation Limited. The problem involves, principally, the extent of contamination of the city, particularly the northeastern part, by dust discharged from

the blast furnaces during "slips" of the charge when the resultant, sudden increase in pressure causes relief valves to vent considerable quantities of gaseous and particulate matter to the atmosphere. This dust situation was greatly aggravated when Labrador iron ore became available and was introduced into blast furnace operations, along with the Wabana iron ore, in 1956. Although the Labrador iron ore was found to produce a distinct improvement in pig iron and steel manufacturing operations, the physical properties of the ore, including its higher content of fine material, and the inferior strength and hardness of the metallurgical coke prepared from Nova Scotia coal, have been responsible for a relatively high frequency of blast furnace "slips" in 1956 and the first six months of 1957. Control measures introduced since then have resulted in a marked reduction in frequency of such dust discharges to the atmosphere.

After a preliminary period of planning and preparation, the field survey was commenced in February 1958 with the sampling of fallout at eleven stations distributed over the area of Sydney. The dust samples from each monthly collection are subjected to extensive chemical analysis for eight components, the iron and ash components being the principal ones employed to distinguish between the influence of blast furnace and steel mill operations and that of other general industrial, commercial and domestic activities in the City of Sydney.

Over a period of about one year, the average rate of fallout over the city has amounted to 42.9 tons per square mile per month. The two most highly polluted sampling stations in the northeastern part of Sydney show an average dustfall rate of 110.8 tons per square mile per month, six stations of moderate pollution have an average rate of 33.4 tons and at three relatively clean stations the rate is only 15.2 tons on the average. Somewhat similar trends are shown in the distribution of iron and total ash components of the dust. The results are being correlated with meteorological records. It is planned to extend this survey in 1959 to 15 sampling stations and other equipment will be placed in operation to determine the concentrations of smoke and fine aerosols in the air on a continuous basis. The main objective in this work is to facilitate the control of the dust nuisance but the data will also be employed for the purposes of the national sampling network.

3. <u>Winnipeg, Manitoba</u>: The Bureau of Industrial Hygiene of the Manitoba Department of Health and Public Welfare has completed the second year of an air pollution survey of the Greater Winnipeg Area, with assistance under the Federal Health Grants, and advisory services of the

Consultant, Atmospheric Pollution. The main part of this study has been devoted to the measurement of fallout or dustfall at 30 different locations within the Greater Winnipeg Area. For comparison, measurements have also been made at the rural station established at Morden, Manitoba. Other observations have dealt with the concentrations of smoke or aerosols on a continuous basis and with continuous monitoring for sulphur dioxide and hydrogen sulphide.

The average dustfall for the Greater Winnipeg Area, over the period April, 1957 to March, 1958, was 40.3 tons per square mile per month. Dustfall in the Greater Winnipeg Area is much higher during the spring, summer and autumn months than during the winter months. The maximum dustfall level of 57.3 tons per square mile per month attained in June fell to a low of 27.0 tons in February. This trend is contrary to that of many other cities in Canada and the United States, which do not have constant snow coverage of the ground during the heating season, among other factors, and show an increase in dustfall over that found during the non-heating season. With the coming of spring and the disappearance of snow, however, the land and roads are laid bare. Mainly during spring but also during summer and autumn, swirling clouds of grit are raised off roads by high winds and also by motor vehicles. In addition, drifting topsoil and dust are blown off the prairies towards the city and serve to augment the dust from industrial and public activities. The influence of serious drifting of soil in the spring months has been shown by comparatively high dustfall levels attained at the Morden rural station. The yearly average for this station was 21.6 tons per square mile per month.

Smoke concentrations in Greater Winnipeg, unlike dustfall, exhibit the usual seasonal trend, increasing rapidly with the approach of the heating season and falling sharply with the advent of spring. The highest average smoke concentration was reached during the month of February. The smoke concentrations also show a diurnal variation with peaks in the early morning and late evening hours. This daily cycle is common to a number of other cities and can be attributed, in part, to the influence of meteorological factors such as the daily variation in turbulence and vertical temperature gradient of the air. The peaks of smoke concentration coincide with the periods of the early morning and night when the air at the surface of the ground is cooler than the warmer air aloft and the inversion layer tends to prevent the rapid diffusion of smoke. Soon after sunrise, on clear days, the incoming solar radiation raises the temperature of the ground and the air in contact with it begins to warm up. This breaks up the inversion layer, turbulence increases and the smoke concentration begins to fall off so that the minimum concentration coincides with the early afternoon period of the day when turbulence is at a maximum.

The results of the survey to date have served to delineate the air pollution levels for various districts classified broadly into industrial, central business, light industry and residential. The survey has provided the means of comparing air cleanliness of different communities and of different parts of the same city. Thus it can serve to assess the effectiveness of a general air pollution abatement program and of control measures designed to remove nuisances from single or multiple sources. Eventually, the data will be of considerable assistance to agencies concerned with town planning, improved zoning and community development.

4. The Sudbury District and Other Communities in Ontario: Close liaison has been maintained with the newly organized Air Pollution Control Branch of the Ontario Department of Health and since April 1st, 1958, a senior chemist from the Occupational Health Division of the Department of National Health and Welfare has been assigned, under a National Health Grant, to assist in the organization of the laboratory and field survey facilities of this Branch. The Ontario Department of Health has assumed certain responsibilities related to research investigation, testing procedures, training of local staff and assistance to municipal officials in the preparation of by-laws and the development of control programs in the field of air pollution, with the passage of the Air Pollution Control Act, 1958.

In the winter of 1957-58, the Ontario Department of Health, with the assistance of a National Health Grant and the co-operation of the Ontario Department of Mines and the two large smelters in the Sudbury Area initiated a survey of sulphur dioxide pollution in the residential areas of Sudbury, Copper Cliff, Coniston and Falconbridge. Continuous records of sulphur dioxide concentrations were made at four sampling sites, one in each of the above communities. This study has been continued in the winter of 1958-59 and expanded to include measurements of fallout on a monthly basis, airborne particulate matter by means of high volume filtration equipment and aerosol or smoke concentrations on a continuous basis.

The Air Pollution Control Department of Metropolitan Toronto and the Department of Municipal Laboratories of the City of Hamilton have forwarded data from their sampling stations to be coordinated with the National Air Sampling Network. A considerable body of information is also available from sampling stations in Windsor that have been operated under the International Joint Commission. Arrangements are under way to have the maintenance of the Windsor stations taken over by a local organization under the supervision of the Ontario Air Pollution Control Branch. Where additional sampling stations are established in cities and towns of Ontario that have, hitherto, had no survey programs in progress to assist them in the control of air pollution, it is anticipated that such stations will be added to the National Network with the consent of the municipal officials concerned.

5. Air Monitoring Programs in Quebec, Alberta and British Columbia: Under a National Health Grant, the Division of Industrial Hygiene of the Quebec Ministry of Health is being assisted in the planning and organization of an air pollution survey in the City of Montreal. The air monitoring program of the Industrial Hygiene Division will be concerned, initially with measurements of concentration levels of sulphur dioxide, hydrogen sulphide, aerosols and dustfall at a number of sampling sites.

During the past several years, advisory assistance has been rendered to the Province of Alberta in a number of air pollution problems connected with the growing industrialization of this province. The main problems presently under investigation by the Alberta Department of Health, the Alberta Research Council and some local organizations are the extent of contamination of air and vegetation by fluorides from a phosphate fertilizer and nitro-chemical plant; sulphur dioxide, hydrogen sulphide and other odorous compounds released in the recovery of elemental sulphur from the purification of sour natural gas, and the discharge of waste chlorine from a brine-caustic soda process.

Alberta is rapidly becoming a major producer of elemental sulphur and hydrocarbon by-products through the processing and purification of natural gas supplied to the Trans-Canada Pipe Line system and for export. Problems related to the control of pollution from waste sulphur compouhds and other products will multiply. In anticipation of such air pollution control responsibilities, the Alberta Department of Public Health has undertaken to establish a mobile testing laboratory and other facilities for survey purposes, with assistance under a National Health Grant. Future plans include the establishment of air monitoring stations in the City of Edmonton which has a large oil refinery and petrochemical complex.

In British Columbia, the City of Vancouver has maintained eleven sampling stations for the measurement of dustfall since September 1949. In the early part of 1957 a monitoring program for the regular sampling of aerosol concentrations was begun with the operation of two low-volume and one high-volume air filtration instruments. This work has been expanded to include mean sulphur dioxide pollution levels on the basis of an exposure method developed by the Department of Scientific and Industrial Research of Great Britain.

The 9-year average rate of dustfall over the City of Vancouver for the period 1949-1957 has been 22.9 tons per square mile per month as compared with 30.9 tons for the industrial section of the city. The dustfall rates show a distinct seasonal trend, increasing during the period September to April. This increase during the colder months of the year is especially evident in the industrial zone and the commercial and central business district. Observations of smoke or aerosol concentrations indicate both diurnal and seasonal trends. Aerosols in increasing concentration tend to lower the range of visibility markedly. The mean sulphur dioxide exposure values also rise during the colder months of the year. It is anticipated that the trend toward increased consumption of natural gas both by domestic and industrial users in Vancouver will result in the future in a considerable reduction in smoke and sulphur dioxide pollution from fuel combustion sources.

Air Pollution Climatology of Canada

The frequency of occurrence and intensity of air pollution levels are influenced markedly by topography, broad-scale features of climate and micrometeorological factors. In view of the growing importance of air pollution in its relation to meteorology in problems of industrial site selection, town planning and zoning, a study has been commenced of the air pollution climatology of Canada, with the assistance of a senior meteorologist from the Meteorological Branch of the Department of Transport. It is hoped that this report, when published, will form the logical basis on which to build more carefully planned local air pollution surveys and to provide estimates of air pollution potential by climatic regions so as to enable industries, planning to locate in various parts of Canada, to select appropriate sites more effectively.

The study deals with a number of meteorological parameters that influence atmospheric diffusion of matter, the rainout and washout of impurities, re-entrainment of particulate matter, corrosion, and the influence of atmospheric photochemical reactions in the production of smogs that cause eye and skin irritation and plant damage.

Air pollution climatic subdivisions of Canada have been considered separately as follows:- The Pacific coastal strip, the Rocky Mountains, the Prairies, the Laurential Shield, the southern Great Lakes area, the Atlantic Provinces, and the Arctic. Within these subdivisions there are discussed the main general circulation patterns, temperature, precipitation and sunshine, and the possibilities of occurrence of inversions of various types. Available air pollution data are employed to emphasize certain favourable or unfavourable situations.

Pollution from Railway Diesel Engines

At various times since 1957, certain staff members of the Occupational Health Division of this Department have assisted the Research and Development Division of the Canadian National Railways in a joint study of the extent of contamination of the air from diesel locomotive powered trains in railway tunnels and in the assessment of the toxicity of various components of diesel exhaust. Conditions in the Sarnia-Port Huron tunnel were investigated in the fall of 1957 and more recently the Mount Royal tunnel in Montreal has been under study. Responsibility for the planning and coordination of the work and choice of methods of sampling and analysis has rested with the Consultant, Atmospheric Pollution. The results of this study to date have been made available to the Board of Transport Commissioners and a scientific paper on the Sarnia-Port Huron (St. Clair Tunnel) investigation was presented at the national meeting of the American Industrial Hygiene Association at Chicago, April 25-May 1, 1959.

The mean concentrations of toxic gases in the St. Clair Tunnel during the period of the trials, when all train movement was dieselized, were generally below the threshold limit values adopted by the A.C.G.I.H. No abnormal health symptoms were observed on participants during 8-hour exposures to the tunnel atmosphere, with the exception of some minor cases of reported eye and throat irritation on three brief occasions. Nevertheless, in view of the levels of oxides of nitrogen, aldehydes, smoke and particulate matter attained under conditions of maximum concentration, adequate forced draft ventilation of this tunnel was recommended and installed prior to the replacement of electrical operation of trains by diesels.

Control of Radioactive Emissions from Nuclear Power Plant

Assistance is being rendered to the design engineers of the Canadian General Electric Company of Peterborough, Ontario, in the control of radioactive emissions that might be discharged to the atmosphere, accidentally, from the nuclear power plant undergoing construction near Des Joachims. This has involved a study of the topographical and meteorological features in the vicinity of the site, an assessment of the extent of diffusion of radioactive matter under various weather conditions and the estimation of maximum ground concentrations. The project is designed to provide the maximum possible safeguards to health of people living in the vicinity, in the event of accidental failure of any part of the equipment that would liberate radioactive matter to the atmosphere.

Railway Air Pollution Regulations

After a series of consultations over a period of two years with staff of the Board of Transport Commissioners for Canada, provincial and municipal authorities, and representatives of railway companies, a suitable draft of revised air pollution and smoke control regulations was prepared. This was accepted by the Board and promulgated as General Order No. 838 on February 2, 1959. This Order supersedes previous regulations on this subject. The regulations apply to all railway companies subject to the jurisdiction of the Board but they apply only in municipalities that have passed, or may hereafter pass, by-laws for the regulation, control or prohibition of smoke or other air pollutants, and that have, or may hereafter have, a municipal control officer.

Research and Staff Training

Current research in this field within the Occupational Health Division is directed towards studies relating to improvements in methods of analysis, instrumentation, identification of contaminants by chromatographic, spectrographic and x-ray diffraction techniques, and toxicological investigations of the effects of various aerosol and gaseous systems on health of small mammals. An important phase of this program is the isolation of carcinogenic substances such as polynuclear aromatic hydrocarbons from particulate solid and liquid contaminants in diesel exhaust and urban air and the study of their relative toxicities.

Basic sampling and analytical equipment is being set up to provide facilities within the Division for a training and demonstration course in air pollution. In this connection, it is planned to organize, in 1959, a demonstration and training unit in which there will be participation for limited periods by certain members of the Division and by a senior meteorologist recently assigned by the Department of Transport to assist the Atmospheric Pollution Services of the Department. The duties of this unit would be to aid in the instruction of provincial and municipal personnel in the operation of basic scientific equipment and in analytical methods to determine the levels of common air pollutants and to assist in staff training courses on chemical and physical properties of aerosols and gases, methods of measurement and identification; diffusion of matter in the atmosphere as influenced by meteorological factors; toxic effects of various contaminants on health and vegetation; influence on visibility; economic aspects and methods of control of pollution.

As part of the above training project and for research purposes also, it is planned to set up a model air pollution sampling station in Ottawa, with associated meteorological equipment installed on a 200-foot tower to study the influence of vertical profiles of wind, temperature and humidity on pollution levels and diffusion of matter in an urban area.

Conclusion

It is planned to publish, this year, the first report on the data gathered at sampling stations that can be related to the National Air Sampling Network. The information will be disseminated to provincial health departments, municipal control agencies, universities, research and other organizations interested in the health effects of air pollution and in methods of regulation and control.

BIO-OXIDATION OF BREWERY WASTES

Dr. W. Eckenfelder

(Presented by
Mr. C.G. Bueltman)

This paper is to present the data obtained as the result of a field laboratory study, made to determine the applicability of treating liquid brewery wastes, by means of the activated sludge process.

Batch laboratory experiments were carried on to determine the degree of organic removal by aerobic biological methods. It is the purpose of this report to describe the experimental procedures, to evaluate the results of the investigations and to recommend treatment methods.

Source and Characteristics of Wastes

Water is used in the brewhouse in the brewing operation and for cleaning and washdown of processing equipment. Water is also used in the bottling plant for the sterilization and washing of bottles. Over the period of the test, the water use in the brewhouse averaged 7.1 gallons of water/gallon of brew and in the bottling plant 8.0 gallons of water/gallon of brew. The total water use in the brewery averaged 15.1 gallons/gallon of brew and the waste discharged to the sewer approximately 14 gallons/gallon of brew. Published data from breweries in the United States indicates a waste water flow of 9-13 gallons/gallon of brew and a BOD of 420 to 1200 ppm.

Wastes emanate from the brewing and washing operations, shown in figure No. 1. In the brewing operation malt is prepared in the mash tun at elevated temperature with water containing calcium and phosphate salts. After the malting operation the mash is discharged to a screen filter (Lauter tun) from which the spent grains are removed to a hopper and trucked away. The malt liquor is then discharged to the kettle to which the hops are added. Following heating in the kettle, the mixture is sent to a filter (hop jack) for removal of spent hops. The filtered mixture is pumped to a settling tank (hot wort tank), then cooled and sent to storage (cold wort tank). The wort from storage is filtered through diatomaceous earth and passed to the fermentation tank. Yeast is added to the fermentation tank, in which a temperature of $61^{\circ}F-70^{\circ}F$ is maintained. After fermentation the beer is removed to warm storage. The beer from warm storage is carbonated and filtered through diatomaceous earth and sent to cold storage. Carbonation and filtration follow and the beer is then bottled.

Since the final composite waste flow is the result of several batch operations, its constituency can vary markedly. In order to take these variations into account, treatment studies were conducted on varying combinations of the individual constituents. These combinations were composited from samples collected of the sampling stations shown in figure No. 1. Figure No. 2 summarizes the characteristics of the wastes.

Description of Experimental Procedures

Preliminary process design criteria for biological oxidation of industrial wastes were developed from laboratory studies. The factors which were evaluated in these studies are as follows:

1. BOD removal at various sludge solids levels and times of aeration.
2. Oxygen demand rates of the sludge at various BOD loadings.
3. Sludge production
4. Oxygen transfer characteristics of the waste
5. Sludge sedimentation
6. Sludge disposal
   (a) Thickening
   (b) Vacuum Filtration
7. Effect of pH on the bio-oxidation performance.

Mixtures of the various waste streams were prepared from samples taken from stations shown on figure No. 1. The first wash of each waste source was diluted with water to approximate the concentration which would be discharged to the sewer. The pH of each mix was adjusted to 6.0-8.0 by the addition of NaOH or HCl. Since the measured ammonia nitrogen content of the waste composite was less then the minimum for optimum biological activity, ammonia, as NH_4Cl, and phosphorus, as K_2HPO_4, were added to each mix to maintain a COD:N:P ratio of 100:5:1.

A bacterial culture was started by innoculating the composite waste mixture with activated sludge. The acclimitization unit was operated on a daily loading schedule of 1.0 lbs. BOD/day/lb. sludge. Waste was fed once daily on a batch basis, aerated 23 hours, settled one hour, and a volume equal to the volume fed decanted. When consistent BOD removals were obtained, the waste was considered acclimitized and the testing program was started.

BOD removal levels were determined from bio-oxidation tube studies conducted in tubes as illustrated in figure No. 3 at various BOD loading levels and sludge solids concentrations. Oxygen utilization rates were determined after various times of aeration employing a polarograph. The BOD was found to be directly proportional to the COD as shown in figure No. 4. Figure No. 5 is typical of the plotted data obtained from the tube runs.

Solids buildup was measured over the course of the oxidation process. The settling characteristics of the sludge were measured under various loading conditions. For ultimate disposal of the sludge, thickening and vacuum filtration studies were conducted.

BOD Removal Relationships

The removal of BOD in biological systems may be classified according to concentration of initial BOD. When the initial concentration is low (100-200 ppm) the removal is concentration dependent while at high concentrations, the removal rate is a constant.

Figure No. 6 shows that for concentrations in excess of 150 ppm the average removal rate was 100 ppm/hr./1000 ppm of sludge. This is compared on the slide to pharmaceutical and refinery wastes which are of the same relative order of magnitude. For BOD concentrations less than 150 ppm the removal rate varied from 10% to 16% per hour for a sludge solids range of 2,350 to 3,000 ppm. The rate constants for other wastes are shown on the slide for comparison purposes.

Oxygen Transfer

The constituents of industrial wastes will affect their oxygen transfer characteristics. Surface active and other organics will influence the liquid film coefficient, kL and the interfacial area for transfer.

Studies were conducted in 1 liter cylinders in which oxygen transfer characteristics of difused-air aeration were evaluated for the mixed waste and the treated effluent. The transfer coefficient (kLa) was compared to that of a standard 1% KCl solution for various air flows. The results are summarized in figure 7. The Ratio of the transfer coefficient of water averaged 0.97 for the mixed waste and 0.52 for the treated effluent.

Secondary Sedimentation

Laboratory analyses of the settling characteristics of the suspensions of mixed liquor solids were conducted in order to establish the process design criteria for the separation of the activated sludge from the supernatant liquor. The test consisted in measuring the height of the sludge layer at various time intervals for different concentrations of mixed liquor solids.

The settling curves for the various waste mixtures are shown in figure No. 8. The initial settling velocities varied from 6.1 to 15.6 ft./hr. over the concentration range of 2100 to 4100 ppm initial solids. This range is equivalent to 1100 to 2500 gal, per day per square foot. The free settling rates of domestic sewage activated sludge has been found to vary from 6 to 16 ft./hr. After the initial period, the sludge undergoes compression. The parameter to define the settling facilities to obtain a given underflow concentration in the unit is expressed as square feet per pound solids per day. The unit area for an underflow concentration of 1% solids was found to vary from 0.03 to 0.05 square feet per pound/day. This range compares favorably with domestic sewage values.

Effects of pH

The pH of the mixed waste varied from pH 5.5-7.4. During the course of the bio-oxidation process the pH and alkalinity was reduced. pH values as low as pH 2.8 were encountered in some runs. The results indicated that the activity of the microbial culture was not affected by these changes in pH. This pH range is beyond the limits encountered for most industrial wastes. The effect of pH and alkalinity on process efficiency is shown on figure 9. This data was obtained on the same waste with and without a buffer present.

In the more dilute concentrations which may be encountered in the treatment operation, variations in pH will be less severe than those indicated in figure 9.

Sludge Thickening

The thickening characteristics are shown in figure 10.

Laboratory compression studies conducted on the sludge from the oxidation of mixed brewery waste indicated a maximum compression concentration of 2%.

Figure No. 11 shows the BOD removal for the various waste mixtures.

Process Design

The tube run data is summarized on figure No. 12. From the tube run data the process design is summarized in figure No. 13.

Conclusions

In consideration of the analysis of the problem and the laboratory investigations made, it may be concluded that:

1. All of the waste waters from the brewing and bottling operations are amenable to biological oxidation.
2. BOD Reductions in excess of 90% can be attained in aeration periods of 3-6 hours.
3. Depending upon the suspended solids content of the final waste mixture primary sedimentation may be required.
4. The bio-oxidation process proceeds over a wide pH range. The tendency of the system is to reduce the pH progressively with oxidation.
   Corrosion may be a consideration in the final selection of treatment structures.
5. The design parameters developed from the laboratory bio-oxidation studies are consistent with results obtained for other organic wastes.

FIGURE 1

Process Flow Diagram of Brewing Operation
Showing Sampling Stations for Waste Study

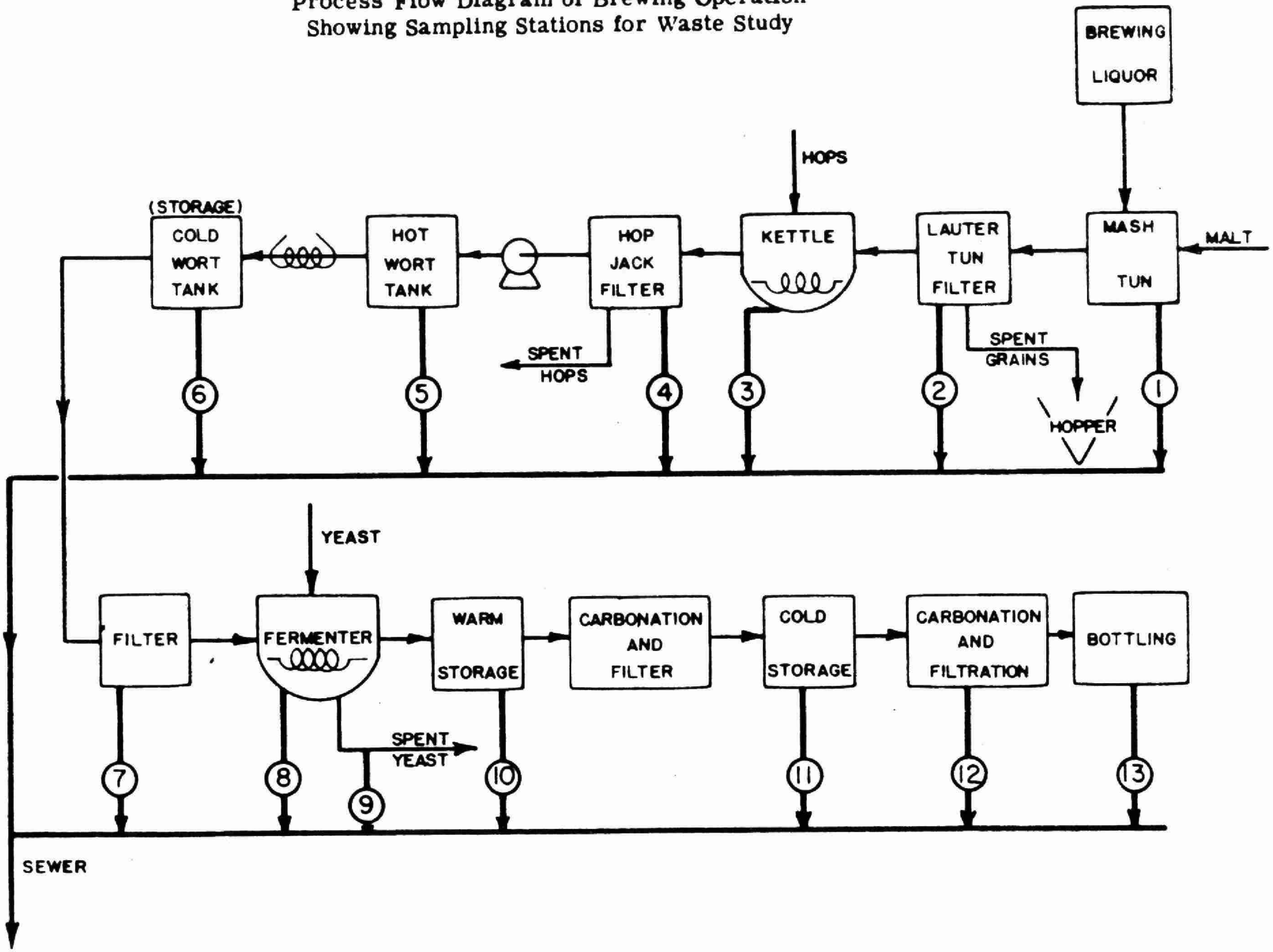
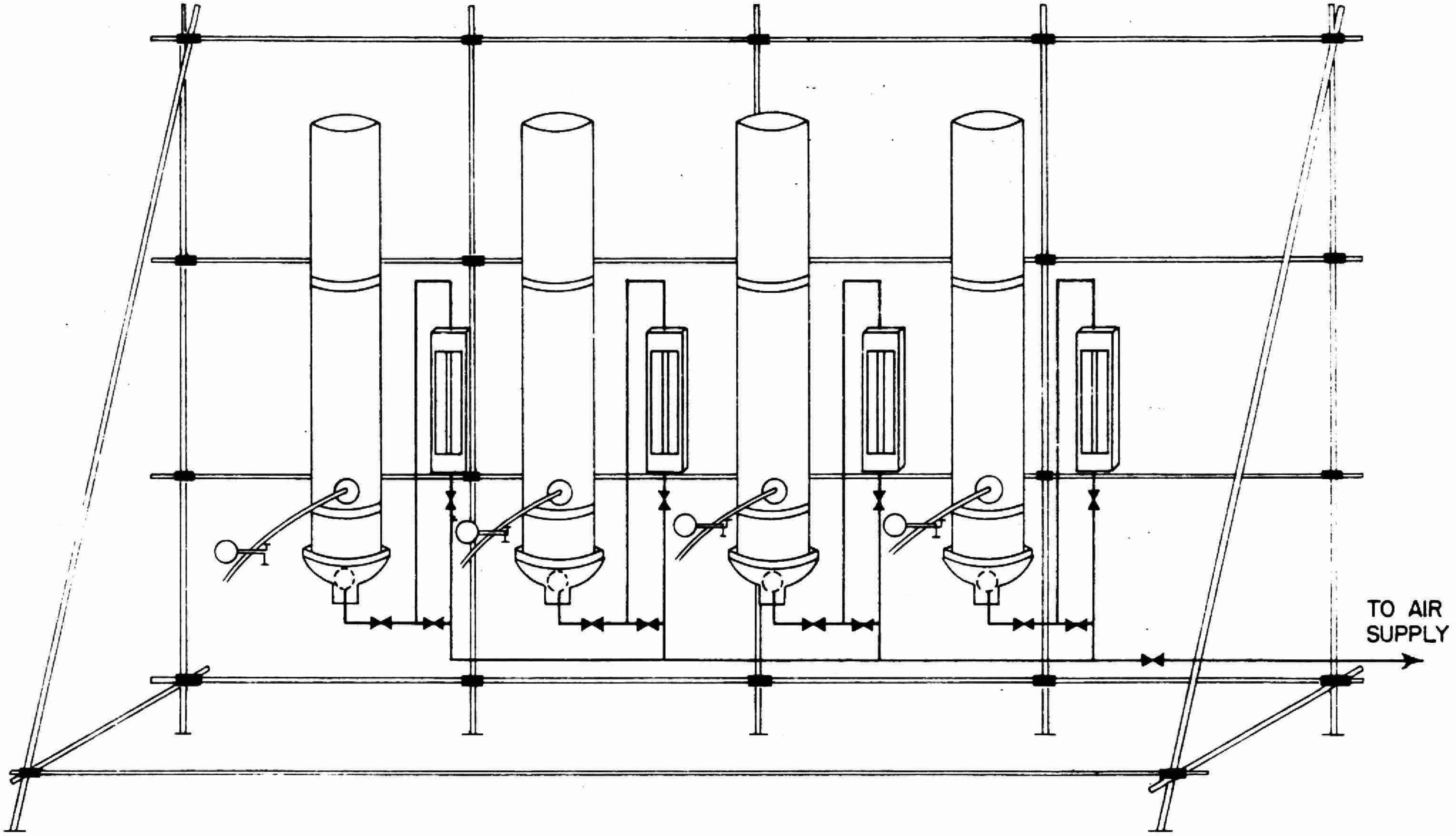


Figure 2
WASTE CHARACTERISTICS

WASTE	SAMPLING STATION	pH	Alk.	COD	BOD	SS	TS	ESTIMATED DILUTION
Mash Tun	1	6.5	82	1,360				1:20
		4.1	-	6,360	5,030	540	4,520	
Lauter Tun	2	4.9	112	54,000	-	7,400	18,500	1:20
		5.25	119	45,200	44,000	5,200	38,300	
Kettle	3	9.35	143	890	375	220	330	1:10
		8.4	152	15,600	-	-	-	
		2.3	-	-	-	5	4,640	
Hop Jack	4	6.3	83	11,250	10,000	-	-	1:20
		6.45	65	5,540	-	-	-	
Hot Wort	5	5.1	191	147,500	135,000	2,050	117,500	1:10
Fermenter	9	3.95	2,300	115,000		48,000	69,000	1:20
Mix 1		5.25	104	1,540	1,000	50	1,500	
2		6.40	324	15,600	10,000	2,020	17,400	
3		2.50	-	740	157	80	2,280	
4		2.80	-	8,050	3,750	-	6,530	
7		6.80	80	2,280	-	230	2,080	
8		6.40	130	17,000	-	5,500	17,400	
9		1.95	800*	4,100	-	1,900	3,200	

*Acidity



PORTABLE BIO-OXIDATION APPARATUS

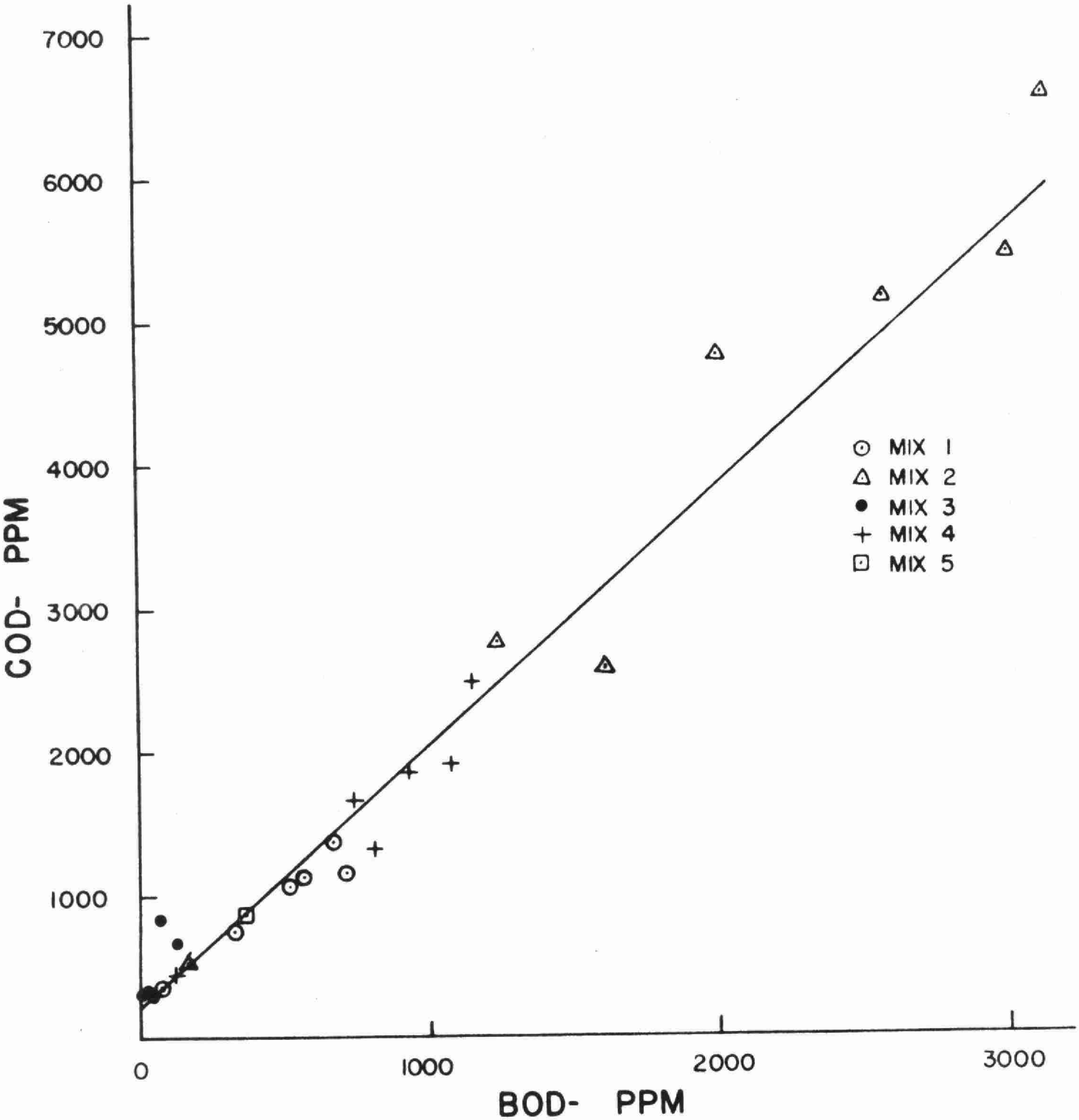


FIGURE 4

BOD-COD Relationship

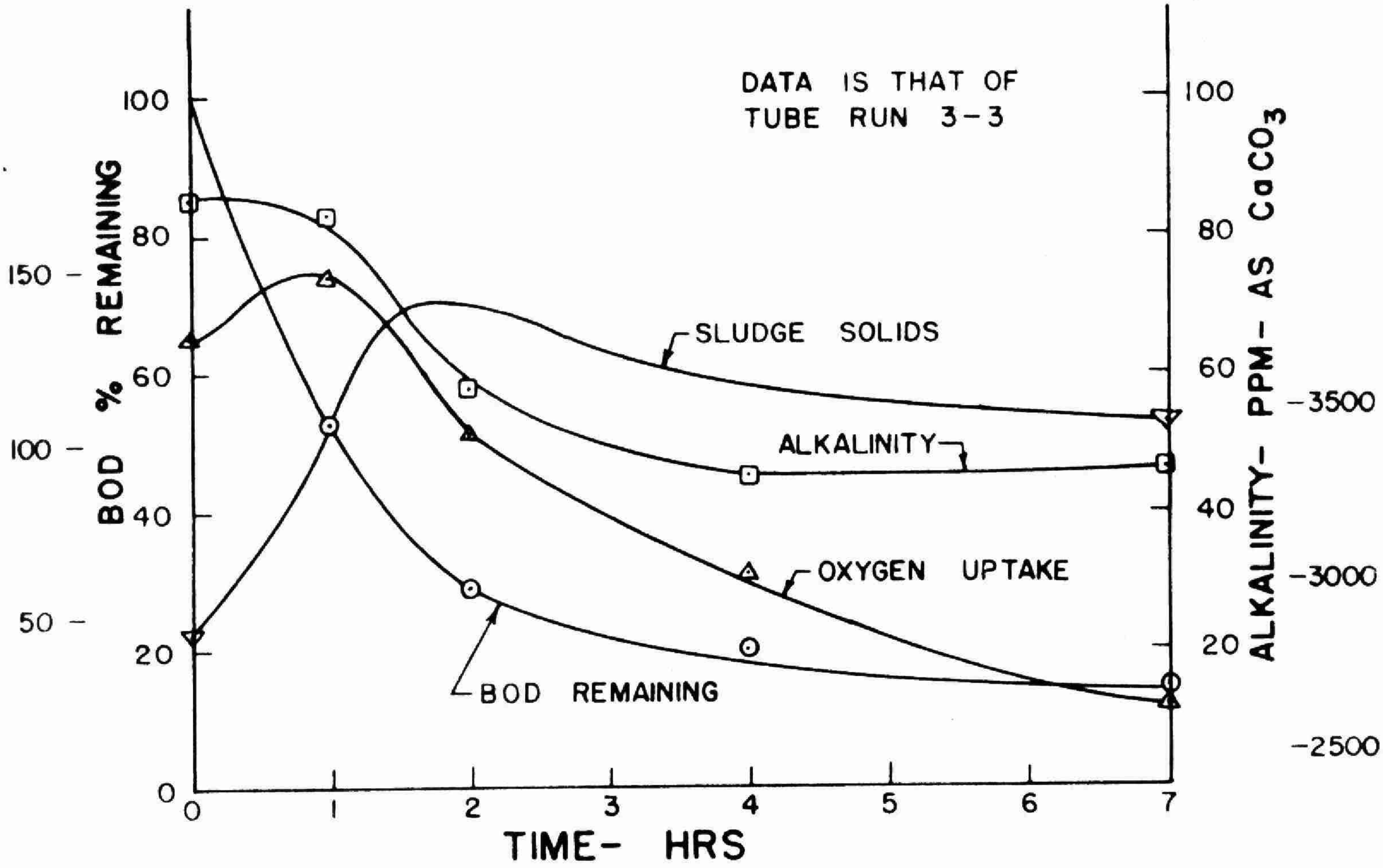


FIGURE 5

Typical Bio-oxidation Parameters

Figure 6
BIO-OXIDATION RATE COEFFICIENTS

Low BOD Concentrations

WASTE	k per hour	S	Temp
Pulp & paper	0.20	1200	25
	0.38	2550	25
	0.45	3800	25
	0.88	5200	25
Boxboard	0.44	2000	24
	0.89	4000	24
Oil Refinery	0.113	1450	20
	0.186	6000	20
Kraft Pulp Mill	0.68	2350	30
	0.23	1170	24
	0.90	3030	24
Pharmaceutical	0.168	1900	25
	0.115	1825	25
Brewery	0.16	3000	26
	0.10	2350	26

HIGH BOD CONCENTRATIONS

	k per hour	Rate of BOD Removal ppm/hr./1000 ppm sludge
Pharmaceutical	0.07	143
Pharmaceutical	0.066	109
Refinery	0.057	131
Brewery		100

k = sludge growth rate constant.

Figure 7
OXYGEN TRANSFER CHARACTERISTICS

Substance	Temp °C	Air Flow CCM/liter	Cs	k_{la} per hour	k_{la} per hour C20°	a
KCl	22	34	8.0	13.5	13.0	1.0
Mix 4	20	34	5.0	12.6	12.6	0.97
Effluent (Mix 4)	25	34	7.5	7.4	6.8	0.52

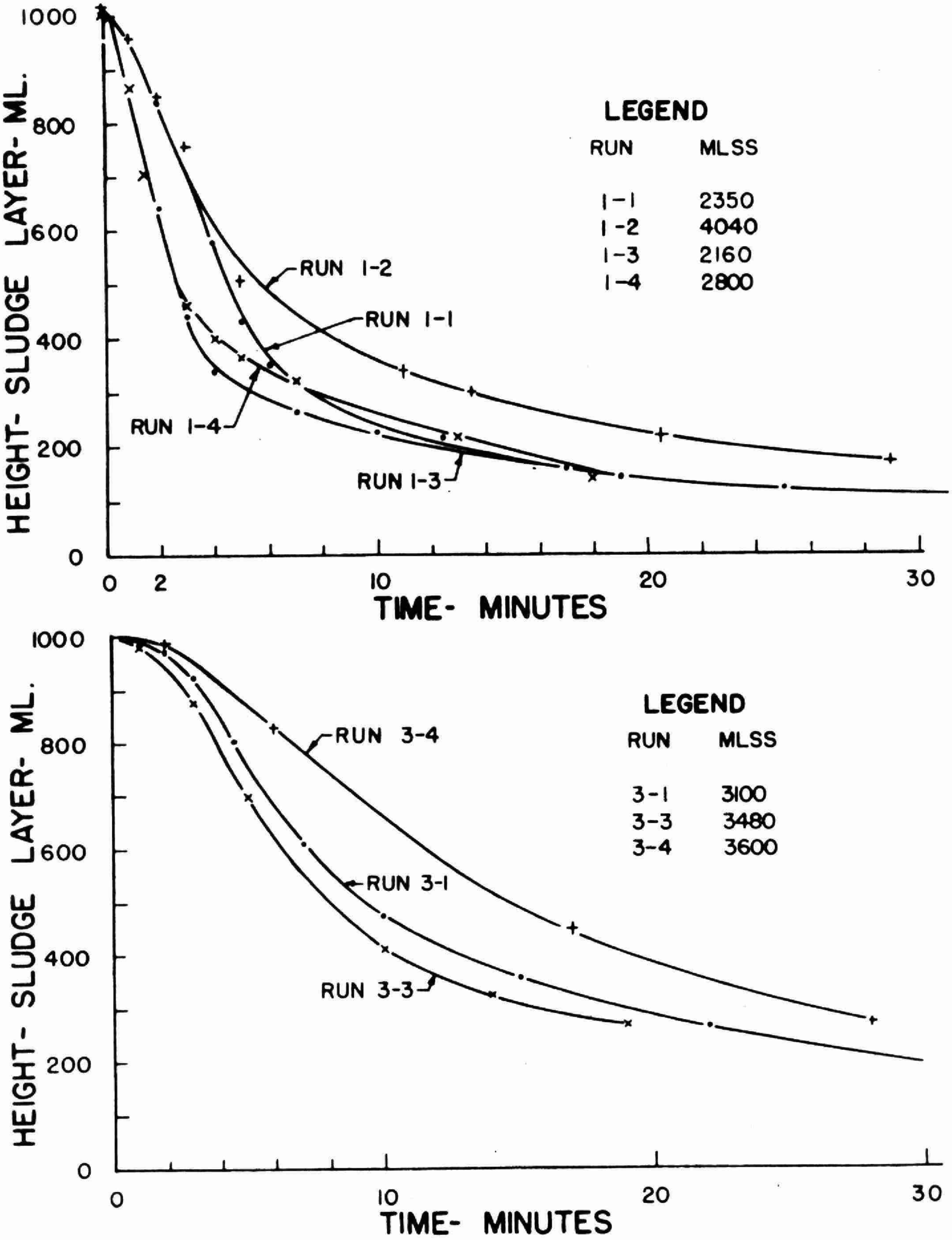


FIGURE 8
Sludge Sedimentation

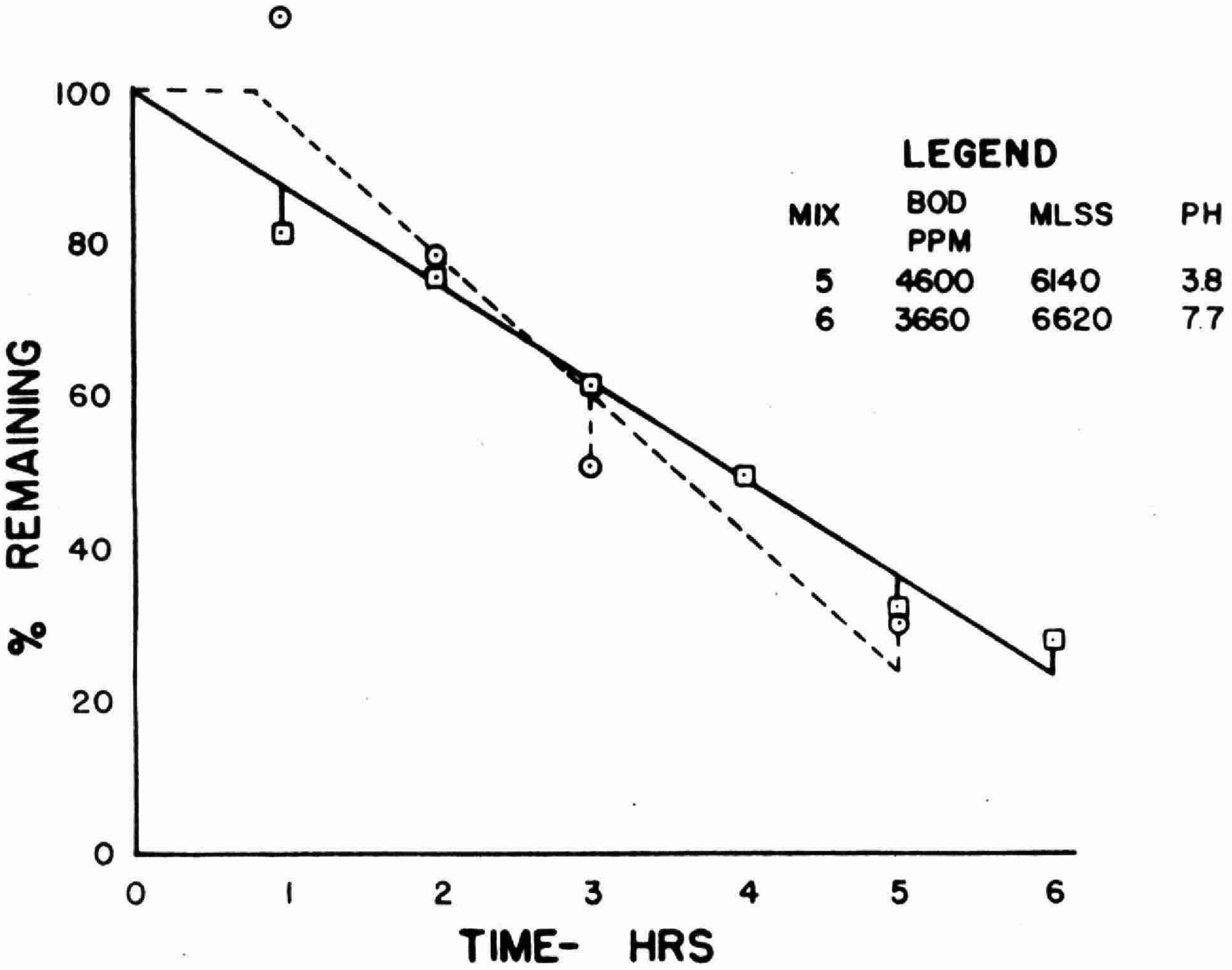


FIGURE 9

Effect of pH on Treatment Efficiency

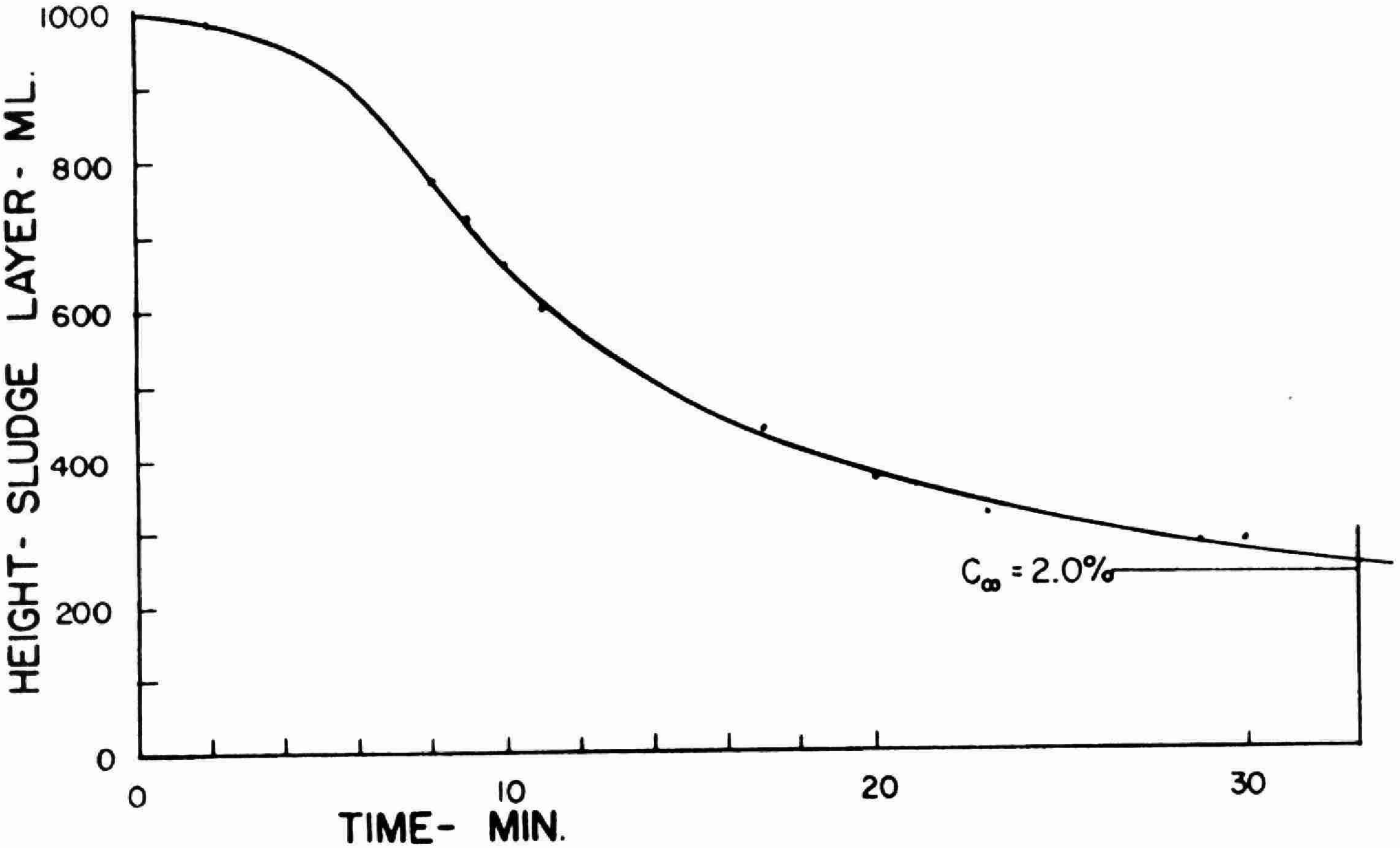


FIGURE 10
Sludge Thickening Characteristics

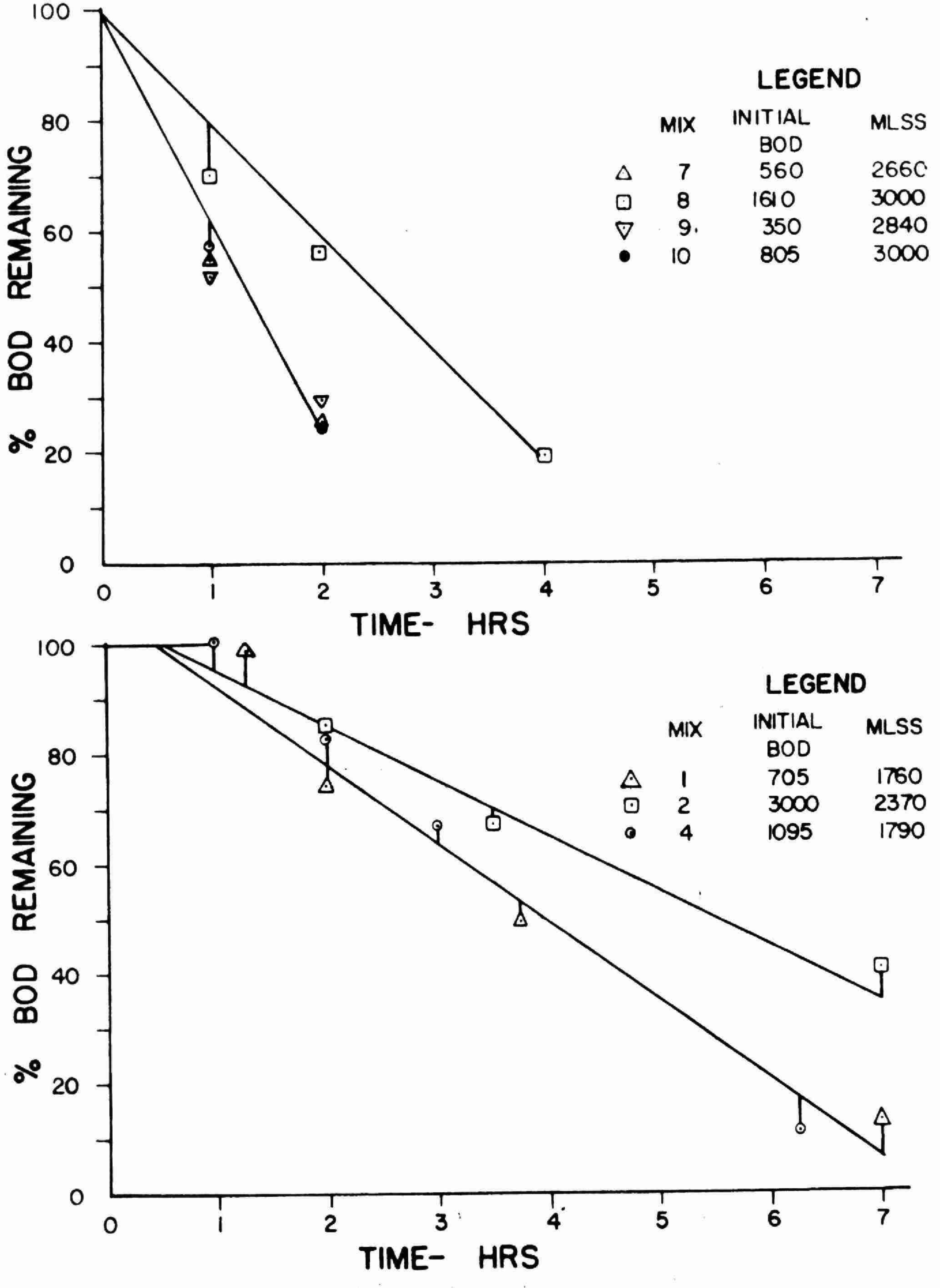


FIGURE 11
BOD Removal Characteristics

FIGURE 12

TREATMENT PARAMETERS

RUN	MIX	INITIAL BOD PPM	BOD REMOVAL RATE; PPM/HR/ 1000 PPM SLUDGE	KR MG. O_2/HR/ GM. SL.	Vs FT/HR	UNIT AREA SQ.FT./LB/ DAY	So	ST (7 HRS. AERATION)	$\frac{\Delta O_2}{\Delta BOD}$	$\frac{\Delta S}{\Delta BOD}$	NOTE
1-1	1	705	57	38	7.8	0.040	1760	2350	0.67	0.95	
1-2	2	3000	113	46	7.8	0.034	2370	4040	0.40	0.94	
1-3	3	890	-	-	15.6	0.035	1420	2160	-	-	
1-4	4	1095	88	54	15.6	0.037	1790	2800	0.62	1.03	
2-1	5	4300	98	55		-	6140	9130	0.56	0.93	
2-2	[illegible]	3660	100	40		-	5620	8000	0.40	0.54	FOAMED OVER
3-1	7	560	79	-	6.1	0.052	2600	3100	-	0.98	
3-2	8	1610	100	40	-	-	3000	3560	0.40	0.39	
3-3	9	350	46	46	7.0	0.039	2840	3480	1.00	2.2	
3-4	10	805	100	42	-	-	3000	-	0.40		

Figure 13

AERATION TIMES FOR INDICATED BOD REMOVAL

	PERCENT BOD REMOVAL			
Initial BOD	60	70	80	90
		So-2000ppm		
1000	3.4	3.9	4.5	5.0
800	2.6	3.1	3.5	5.8
600	2.0	2.3	2.6	7.1
400	1.4	1.5	2.3	9.2
		So = 4000 ppm		
1000	1.7	2.0	2.3	2.7
800	1.3	1.5	1.8	3.0
600	1.0	1.2	1.3	4.2
400	0.7	0.8	2.2	5.8

Based on a return sludge concentration of 10,000 ppm

COMPLETE MIXING ACTIVATED SLUDGE

Dr. R. E. McKinney

One of the most interesting modifications of the activated sludge process is complete mixing. It is not a new process but it has only been recently that the complete mixing concept has received the attention it has long deserved. The need for small treatment plants to handle domestic sewage from subdivisions and industries as well as strong industrial wastes has served as the impetus in the full development of the complete mixing process.

Complete Mixing

Complete mixing is a basic process in which the incoming wastes are completely mixed with the entire contents of the aeration tank. There are many different modifications of the basic process involving endogenous respiration with combination aeration-sedimentation units or separate aeration tanks and sedimentation tanks and varying rates of synthesis. All of these modifications fall within the general concepts of the basic process thus greatly simplifying the engineering and operations.

In order to obtain complete mixing in the aeration tank it is necessary to introduce the incoming wastes into a relatively small tank volume with violent agitation so that the time for complete dispersion is a minimum. Normally, the agitation is supplied by aeration. In small tanks the wastes can be introduced at a single point but in large tanks multiple inlets will be required.

The key to complete mixing is the fact that the aeration tank acts as a surge tank and tends to level out the wide fluctuations in the organic load. The use of the entire mass of the activated sludge to stabilize the organic load distributes the load uniformly over the entire aeration tank and permits better utilization of the air blown into the mixed liquor.

Effluent Quality

The desired effluent quality determines the size of the complete mixing system. It is possible to produce an effluent of any desired organic level from wastes of any desired organic strength. An effluent of 15 mg./l. B.O.D. can be produced from wastes having 100, 1000 or even 10,000 mg./l. B.O.D. This high quality effluent can be produced in a system with minimum excess sludge production or with a large excess sludge production.

The effluent B.O.D. is made up of two components, the soluble B.O.D. and the suspended B.O.D.. The soluble B.O.D. is a function of the total organic load within certain ranges of MLSS concentrations. The suspended B.O.D. is a function of the sedimentation tank efficiency.

Microbial Activity

The stabilization of organic matter in any waste treatment system is brought about by the biochemical activities of the microorganisms in the system. The bacteria are primarily responsible for the stabilization of the organic matter in activated sludge systems. It has been shown that the bacteria remove organic matter from wastes in order that they might obtain sufficient energy to remain alive and to produce new cells and to obtain the chemical components for the new cells. The wastes must supply both the energy and the building blocks. A deficiency of any element will result in reduced microbial activity and hence reduced stabilization from the engineering viewpoint. For the purpose of this paper it is assumed that the wastes are all nutritionally stable.

One of the most important aspects of biological metabolism is that there is a definite quantitative relationship between the organic protoplasm produced and the energy expended in its production together with the organic matter removed from solution. If a few bacteria were placed into a rich nutrient solution, the bacteria would begin to grow at a rapid rate. If the mathematical function of growth were determined, it would be found to approach a log growth rate. The bacteria growth is limited only by the microorganisms' ability to reproduce. Food is definitely unlimited. Examination of the growth of bacteria in the log growth rate has shown that the bacteria convert approximately 57 percent of the ultimate B.O.D. removed into protoplasm while oxidizing 43 percent of the ultimate B.O.D. removed to obtain the energy for the synthesis reactions.

A point is eventually reached where the mass of active microorganisms exceeds the food available and growth becomes limited by the lack of food. The rate of growth is proportional to the available food per unit of microorganisms. This can best be expressed as a food:microorganism ratio (F:M). Data on pure cultures has shown that log growth rate ceases when the F:M ratio drops below 5.0. As the F:M ratio decreases, a point is eventually reached where there is just enough food present to keep the microorganisms alive without the production of additional protoplasm. This is the so-called endogenous metabolism. A further drop in food level results in autodigestion of the protoplasm to furnish the necessary energy. Thus, a drop in food gives a corresponding drop in microorganisms. The F:M ratio actually remains constant at 0.25.

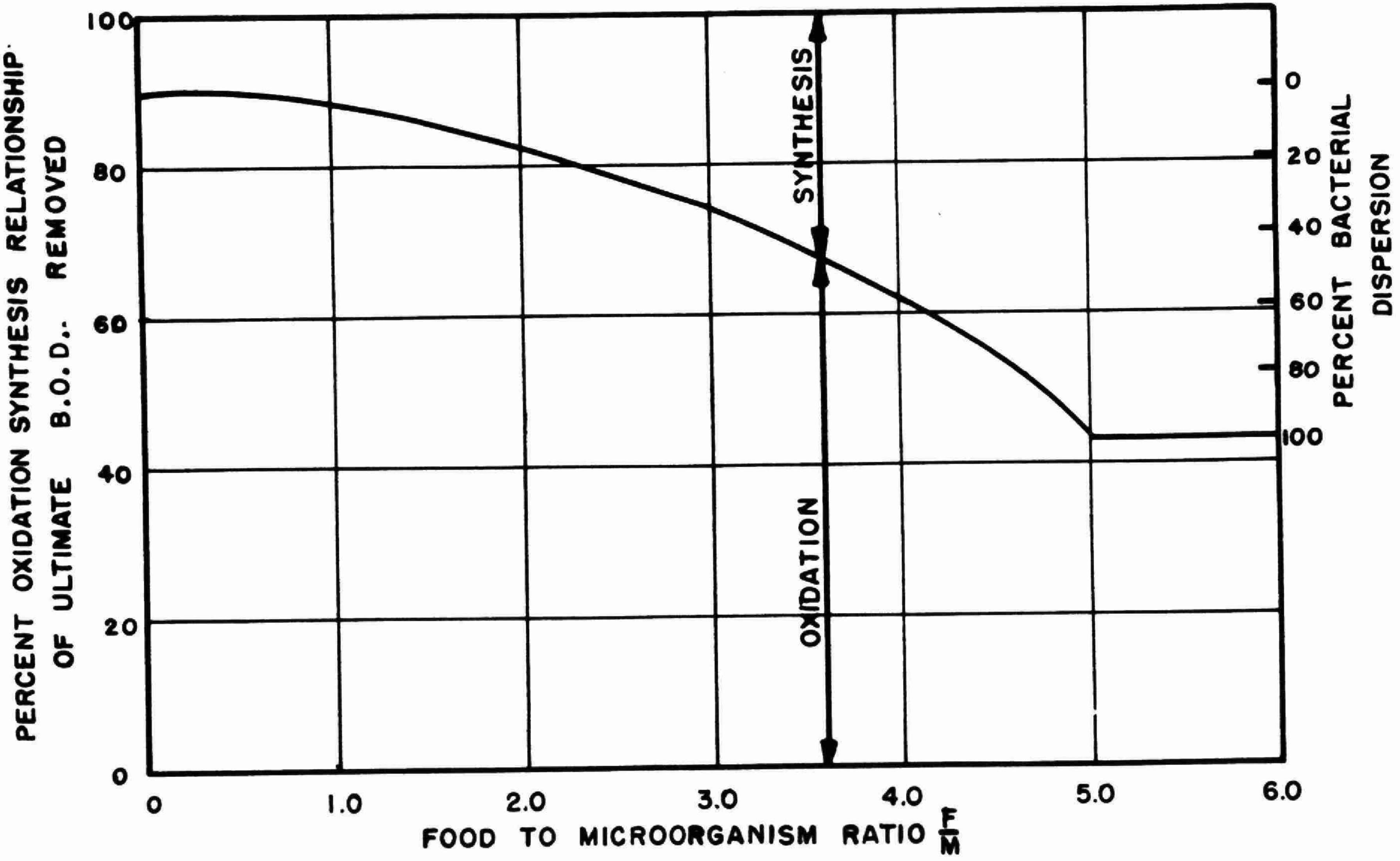


FIGURE I THE EFFECT OF VARYING THE FOOD:MICROORGANISM RATIO ON THE SYNTHESIS-OXIDATION RELATIONSHIP AND BACTERIAL DISPERSION

It is immediately apparent that the rate of excess sludge production in the complete mixing system will be dependent upon the F:M ratio. A high F:M ratio will result in a large excess sludge problem while a low F:M ratio will result in a minimum of excess sludge. A plot of the oxidation-synthesis relationships for varying F:M ratios is shown in Figure 1. One of the most important aspects of this diagram is the fact that the synthesis drops from a maximum at log growth to a minimum at engodenous metabolism. It can be seen that there is some synthesis in endogenous metabolism even though there should be no synthesis. The synthesis of active protoplasm reaches zero in the endogenous phase but there is the production of an inert polysaccharide material which builds up mass in the sludge without affecting the biological activity. The production of the inert polysaccharide is the reason why it is theoretically impossible to have an activated sludge system operating in endogenous metabolism with no sludge build-up. All so-called complete oxidation systems result in some build-up of inert organic matter which must either be removed or discharged in the effluent.

Flocculation

In order for an activated sludge system to operate continuously at any level of efficiency, it is necessary for the sludge to floculate well and to settle quickly in the sedimentation tank. In most biological treatment systems the effluent B.O.D. is directly related to the efficiency of the final sedimentation tank, Good suspended solids removals will produce effluents of low B.O.D..

It has been shown in previous research that flocculation of activated sludge is related to the energy level of the microorganisms as they enter the sedimentation tank. A high residual organic level will result in poor flocculation and hence poor sedimentation. On the other hand, a low residual organic level will yield good flocculation and a clear effluent with efficient sedimentation. When activated sludge is young and growing rapidly, flocculation is related to the F:M ratio. Bacteria in the log growth phase will not flocculate or settle but as the F:M ratio decreases, flocculation increases until complete flocculation occurs in the endogenous phase. Once activated sludge has formed, there is a residual of inert floc which acts as a flocculating agent even though the F:M ratio might rise to 4 or 5. Flocculation is related at these high F:M ratios to the actual organic concentration surrounding the dispersed microorganisms. A B.O.D. level of 10 mg./1. will produce good flocculation regardless of the F:M ratio as long as the MLSS concentration exceeds 500 mg./1.. As the B.O.D. level rises to 25mg./1., bacterial dispersion increases slightly above normal. A B.O.D. of 50 mg./1. will cause the effluent suspended solids to rise to 50 mg./1. regardless of the sedimentation tank efficiency. A B.O.D. of

100 mg./l. will yield an effluent with between 100 and 150 mg./l. suspended solids.

Total Oxidation

Most sedimentation tanks will yield effluents containing between 20 and 25 mg./l. volatile suspended solids when operating at maximum efficiency. With the total oxidation modification of the complete mixing process loss of 10 to 25 mg./l. vol. suspended solids is very important in the solids control. Operation of the complete oxidation systems in the endogenous phase yields a sludge growth of approximately 11 per cent of the 5-day B.O.D. removed. An effluent with 25 mg./l. suspended solids would be in equilibrium if 240 mg./l. 5-day B.O.D. were being removed from the wastes. A waste with less than 240 mg./l. 5-day B.O.D. would lose solids until the F:M ratio increased to the point where synthesis equaled the solids being lost. A waste with more than 240 mg./l. would yield an increase in solids greater than that being lost in the effluent. Eventually, such a system would fill up completely with sludge and the effluent suspended solids would increase unless solids were removed from the aeration tank.

The addition of inert suspended solids such as occur in domestic sewage and some industrial wastes will have a definite effect on the solids balance. If 25 mg./l. or more inert volatile organic suspended solids are added in the influent, these inert solids must either be discharged in the effluent or removed from the aeration tank at periodic intervals. With weak domestic sewage having only 100 to 150 mg./l. 5-day B.O.D., it would be possible to discharge all excess sludge in the effluent without creating nuisance conditions.

One of the prime bases for design of complete mixing activated sludge systems operating on the total oxidation principle has been 24 hours' aeration. The use of 24 hours' aeration is not a rational design concept anymore than 20 hours' aeration or 40 hours' aeration. Design of total oxidation units should be related to the strength of the wastes and not to an arbitrary aeration period. Total oxidation units preclude that the system will be operating in the endogenous phase which means an F:M ratio of 0.25. For any F loading, M is automatically determined. If the wastes contain 250 mg./l. 5-day B.O.D., the MLSS would be 1500 mg./l. if the aeration period were 24 hours; 3000 mg./l. with 12 hours' aeration, 6000 mg./l. with 6 hours and 12,000 mg./l. with 3 hours' aeration. It can be seen that the organic loading in terms of pounds 5-day B.O.D./1000 cu. ft. aeration capacity/day would be 15, 30, 60 and 120 respectively. It appears possible to maintain a system in endogenous metabolism as long as the organic load does not exceed 40 pounds 5-day B.O.D./1000 cu. ft./day. At this loading it would be necessary to maintain 4000 mg./l. active MLSS, which would require a system capable of handling approximately 6000 mg./l. total MLSS. The effluent from such a system would contain approximately 4.4 pounds volatile solids/1000 cu. ft. aeration capacity/day. If the wastes were retained for 24 hours, the influent would have contained 670 mg./l. 5-day B.O.D. and the effluent would have contained 73 mg./l. vol. suspended solids. A 12 hour retention period at 40 pounds loading would have had 335 mg./l. 5-day B.O.D. and an effluent with 36 mg./l. vol. suspended solids. A 6 hour aeration period would have an influent B.O.D. of 168 mg./l. and an effluent with 18 mg./l. vol. suspended solids. The 5-day B.O.D. of the effluent from these units would be approximately 52, 26, 13 and 7 mg./l. respectively.

If the wastes had a 5-day B.O.D. of 168 mg./l. and were treated for 24 hours in the aeration tank instead of 6 hours' aeration in the previous section, the organic loading would be 10 lbs. 5-day B.O.D./1000 cu. ft./day. The effluent would contain 1.1 lbs. volatile suspended solids which would yield a concentration of 18 mg./l. and a 5-day B.O.D. of 13 mg./l., It is immediately obvious that the effluent quality is the same for 6 hours' aeration as for 24 hours' aeration. A system designed on the basis of 24 hours' aeration would in effect be overdesigned by 18 hours. Needless to say, the question arises as to why the effluent quality is the same when the aeration periods differ by a factor of four. The difference between the two systems lies in the active microbial mass carried in the aeration tank. At the 40 lbs. B.O.D. loading the active MLSS would be in equilibrium at 4000 mg./l. while at the 10 lbs. B.O.D. loading the active MLSS would only reach 1000 mg./l.,

Intermittent Flow

The previous analyses were made on the basis that the wastes were added continuously 24 hours a day, 7 days a week. Many waste flows are not continuous and often the organic load is not uniform. With industrial wastes it is often possible to discharge the wastes to a surge tank and to feed the waste treatment plant at a uniform rate on a continuous basis. With domestic sewage from small industrial buildings, motels, etc., it is possible to add an aerated surge tank ahead of the aeration unit to level out waste flows and waste strength. Economics determine the validity of surge tanks to reduce the size of the treatment plant.

If it is not possible to have uniform flow, the treatment plant must be designed on the basis of the load arriving and not on the average daily load. Because of the complete mixing systems' leveling action it is possible to make the design on the basis of the maximum hourly load. Consider an industrial building operating on a single 8 hour shift, 6 days a week. The domestic sewage flow arrives at the treatment plant over the 8 hour period and is quite strong, approximately 500 mg./l. 5-day B.O.D.. The average daily organic load on the treatment plant is only 30 lbs. B.O.D./1000 cu. ft./day; but the actual load is 90 lbs. B.O.D./1000 cu. ft./day over an 8 hour period and 0 lbs. B.O.D. over the remaining 16 hours. The microorganisms are going to respond to the actual organic loading and will grow accordingly. The oxygen demand and synthesis rate will be governed by the F:M ratio at the 90 lbs. B.O.D. loading and at the 0 lbs. B.O.D.,

The microorganisms will grow more rapidly than if the load were uniform since the addition of the food will result in an increase in the F:M ratio. The system will attempt to re-establish equilibrium but will not be able to do so since the food suddenly stops and starvation sets in for the 16 hours without food. The microorganisms will undergo endogenous respiration and decrease in active mass for the 16 hours until the organic load starts again. One of the most important facts about endogenous metabolism is that cells fed continuously in the endogenous phase will produce less excess sludge than cells which are fed the same amount of food in a slug and allowed to starve for the same period. The net result is that the feed-starve cycle of intermittent operations results in more sludge for ultimate disposal than the continuously fed system. This is most important in any design.

The effluent B.O.D. concentration from the intermittent system and the continuously fed system will be quite close on an average value. Anyohe wanting to show better operations of the intermittently fed system can do so by the use of grab samples of the influent and effluent just after the wastes have started into the plant at the start of a feed cycle. The effluent will be at a minimum since the microorganisms have had 16 hours to utilize all of the available food and the influent strength will be a maximum. Control authorities should always take their grab samples at the end of the feed cycle when the effluent quality is poorest. If the effluent quality is satisfactory at the end of the feed cycle, it can be certain that the effluent quality was satisfactory during the remainder of the operation period, barring extreme fluctuations in flow beyond design capacity.

Final Sedimentation

The key to the operation of any biological treatment system lies in the efficiency of the final sedimentation tank. The effect of the final sedimentation tank operation on the total oxidation modification of complete mixing has already been discussed with regard to effluent quality. There are two types of sedimentation tanks in use with complete mixing systems, the vertical flow and the horizontal flow. The vertical flow sedimentation tanks either introduce the flow upward from the bottom of the tank or downward from the top. In both cases the velocity of the flow into the tank is the most important factor in the design of the sedimentation tank. The upward flow tank has been used primarily where the aeration tank and the sedimentation tank are built into a single unit. The upward flow tank must have a sufficiently high flow rate to keep the contents of the sedimentation tank always turning over but not great enough to carry the sludge over the weir. The shape of the sedimentation tank controls the hydraulic patterns as does the turbulence created by the aeration device. Generally speaking,the hydraulic overflow rate should be approximately 500 gal./sq. ft./day. With intermittent flows provision must be made to return the sludge to the aeration tank to prevent septicity. If the sludge in the sedimentation tank should become septic, denitrification could result with nitrogen gas lifting the sludge to the tank surface. The sludge carried to the sedimentation tank surface becomes quite concentrated and can create a definite nuisance by either going out in the effluent or producing obnoxious odors.

The downward flow sedimentation tank must have an overflow rate below 500 gal./sq. ft./day in tanks with a water depth of 8 ft. or less and below 800 gal./sq. ft./day in deeper tanks. The reason for the variation in flow rates lies in the fact that the flow of the mixed liquor entering the tanks will disturb the sludge which is being concentrated and removed just below the point of introduction of the mixed liquor. All of the downward flow sedimentation tanks use continuous return of sludge with either air lift or motor driven pumps. The rate of return must be great enough to handle the sludge as quickly as it settles. With total oxidation systems the MLSS concentrations reach 6000 mg./l. which requires sludge return rates of from 100 to 200 percent of the waste flow. With the high rate of sludge return care must be taken to use the hydraulic energy to help concentrate the sludge.

Horizontal flow tanks do not have as much turbulence due to the introduction of the mixed liquor and can be designed with hydraulic overflow rates up to 800 gal./sq. ft./day. With high flow rates density currents can be a problem and care should be exercised in design.

High Synthesis

Although most of the use of complete mixing has been with the total oxidation modification, it is well suited to high sludge synthesis. For a given food loading, synthesis can be stimulated merely by reducing the MLSS concentration. For wastes with low B.O.D, concentrations it is possible to convert half of the organic matter into sludge and still produce a satisfactory effluent. The advantages of high synthesis of sludge are a smaller treatment plant and lower air requirements; while the disadvantages include excess sludge disposal facilities and more complex operations. With small treatment plants the economics favor the total oxidation units while in large treatment plants the economics are in favor of high synthesis units.

Inert Solids

It has already been indicated that inert solids in the wastes will have an adverse effect on total oxidation systems. Generally speaking, the total oxidation systems take the entire waste flow into the aeration tank, eliminating primary sedimentation tanks and anaerobic digestion. A portion of the organic matter added to the aeration system in the form of suspended solids is inert to biological degradation. These inert suspended solids are incorporated into the activated sludge and become part of the MLSS. Unless the inert solids are discharged from the aeration tank, they will build up in the MLSS causing much of the MLSS to become inert solids rather than active solids. The system will eventually fill up with sludge and discharge it in the effluent. When the excess solids are discharged in the effluent, a portion of the suspended solids discharged will be active cells. This results in an increased F:M ratio and increased sludge synthesis. The net result in a total oxidation system is that instead of converting 11 percent of the B.O.D. removed into sludge, 30 to 50 percent of the B.O.D. is being converted into sludge. The system breaks down as far as total oxidation is concerned and becomes a high synthesis system. The only way that the system can be maintained as a total oxidation unit is to periodically remove most of the MLSS and to start anew. An example is that if the aeration tank contains 10,000 mg./l. MLSS when the system is full of sludge, the MLSS should be reduced at least 90 percent to 1000 mg./l. to insure removal of most of the inert solids. The active mass will quickly build back to equilibrium and then the tank will slowly fill with solids. The rate of sludge removal will be a function of the inert solids concentration. Since the sludge is predominantly inert solids, it will dewater directly on sand drying beds and will not require further treatment.

Oxygen Utilization

The complete mixing system obtains maximum utilization of the oxygen added to the aeration tank. With a uniform organic loading on the aeration tank, the oxygen demand in the entire system will be constant as a result of complete mixing. In the total oxidation systems the demand for oxygen is very low. Sufficient oxygen must be added to meet the entire demand of the ultimate B.O.D. removed. The ultimate B.O.D. is normally 1.5 times the 5-day B.O.D.. Since a small fraction of the organic matter is not oxidized but winds up in solids, the calculation of air on the total B.O.D. removal will give 10 percent excess air.

The efficiency of oxygen transfer is very important in complete mixing systems since the power requirements and hence the cost of operations are largely related to this factor. In total oxidation systems the demand for oxygen seldom exceeds 40 mg./l./hour. At this air rate most diffused aeration devices will not yield more than 5 percent oxygen transfer efficiency. It has been found that steel pipe with drilled holes will yield 5 percent efficiencies in complete mixing systems and will perform as well as any proprietary air diffusion devices.

With the high synthesis systems the demand for oxygen increases quite sharply. The proprietary oxygen diffusion equipment definitely show up at an advantage when the increased oxygen demand permits higher efficiencies of transfer. Up to oxygen demand rates of 100 mg./l./hour most of the non-clog air diffusion devices will be satisfactory. Higher rates of oxygen demand will require the use of turbine aerators.

Prefabricated Units

There are many prefabricated complete mixing treatment plants being marketed by equipment manufacturers. The prefabricated units will yield results consistent with their design and operation. The tendency with the prefabricated units has been for the engineer to allow the equipment company to recommend the desired unit. The net result is that the engineer becomes nothing more than a middle man collecting a fee which he has not earned. It is the responsibility of the engineer to check the design criteria of the prefabricated plant to determine that it will meet the desired operating specifications. It is the engineer's responsibility to see that the plant is started and operates satisfactorily. The current tendency on the part of the engineers has been to let the equipment company selling the prefabricated plant start the plant and see that it is running properly. Most engineers responsible for the selection of the prefabricated treatment plants definitely lack sufficient experience and understanding to determine if the treatment units are operating properly and what to do if they are not. Problems with some of the small prefabricated plants has caused some state health departments to look with disfavor on their use and other health departments to refuse to approve the use of the small treatment plants.

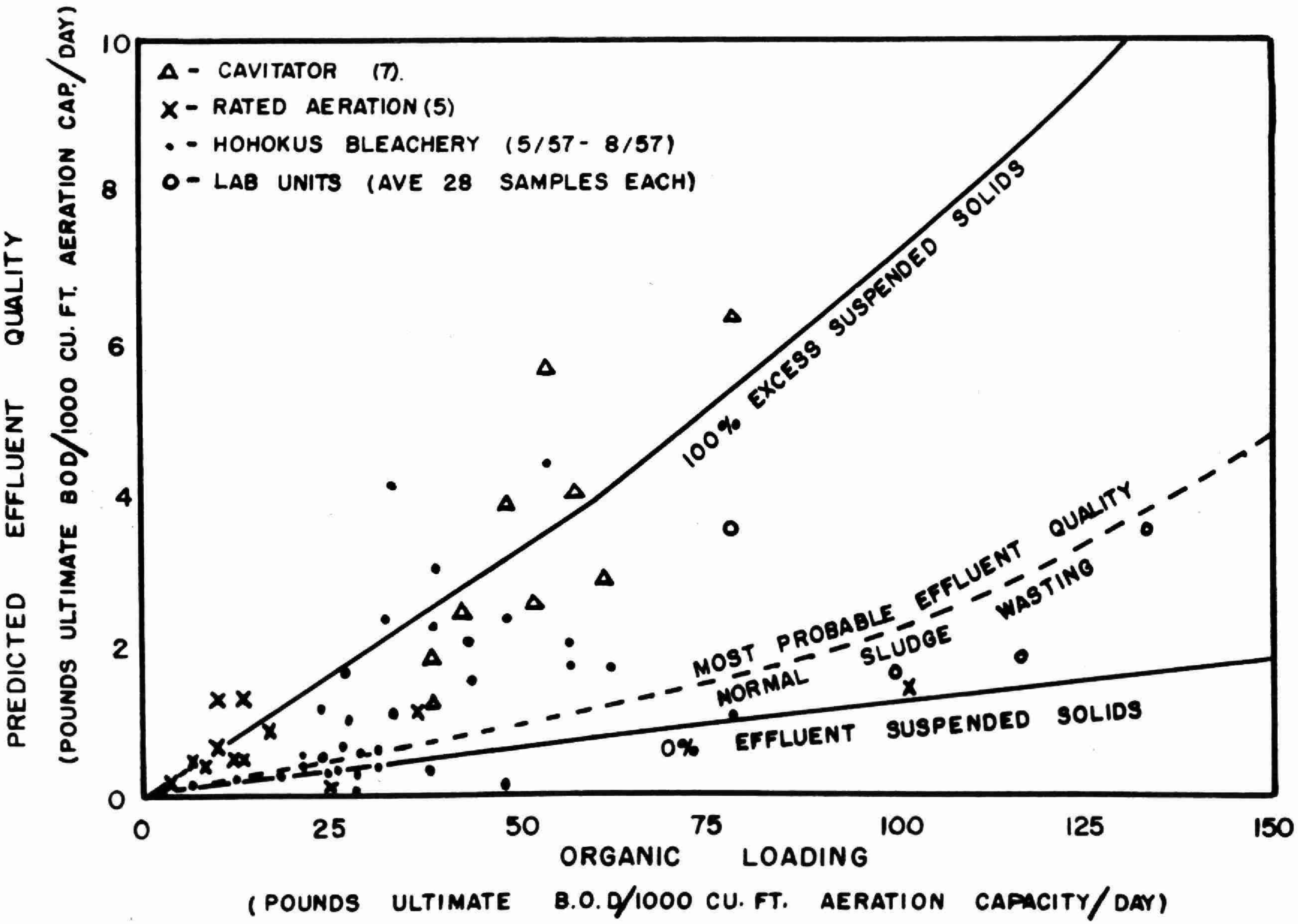


FIGURE 7 PREDICTED EFFLUENT QUALITY AT VARIOUS ORGANIC LOADINGS OF SEVERAL COMPLETE MIXING ACTIVATED SLUDGE SYSTEMS

The prefabricated treatment plants give results consistent with the criteria cited for the design of the complete mixing units in the previous sections. Although there are not much data available on complete mixing plants in the field, some of the data which are available are shown in Figure 2. It can be seen that the actual field results are consistent with the design criteria already cited. Studies are currently being conducted on several complete mixing plants treating domestic sewage and industrial wastes to determine the operational characteristics of these plants so that the design criteria can be fully evaluated. The data which have been obtained to date are consistent with the concepts of design given in previous sections. Cost figures indicate a capital cost and operational costs 25 to 50 percent below that of conventional activated sludge treatment.

Summary

One of the newest basic processes for biological waste treatment is complete mixing activated sludge in which the wastes are intimately mixed with the entire contents of the aeration tank in a minimum of time. The two modifications of complete mixing systems are total oxidation and high sludge synthesis. The basic operations and design criteria for both modifications are discussed briefly. The most important advantage of complete mixing is its ability to take a waste of any B.O.D. concentration and to produce an effluent of any desired B.O.D. concentration in a single stage unit. Other advantages include the ability to absorb shock organic loads, to be unaffected by surge hydraulic loads, to obtain maximum utilization of the air used, to produce little excess sludge or lots of excess sludge, to give a standard design for domestic sewage or industrial wastes regardless of the chemical nature of the wastes and lower capital costs than conventional activated sludge.

THE VALUE AND ECONOMY OF TREATMENT PLANT RECORDS

Edmund B. Besselievre

The three phases of an industrial waste treatment project are:

Design
Construction
Operation

Of these the most important in the achievement of the result desired by the regulatory agent and the owner of the plant is--operation.

Proper operation may be obtained by constant attention from human operatives or from devices and apparatus which reduces the number of humans involved.

It has been said that "automation is a way of getting things done without doing them." In this discussion we are not basing our argument on the strict term "automation" which is carrying out mechanized operations without <u>any</u> attendance, but on the basis of applying developed means for carrying out tedious and recurring operations without the <u>constant</u> supervision of human attendants.

It goes without saying that those of us who are charged with the design of waste treatment facilities recognize fully the importance of proper and consistent records of the performance of the component parts of the facility. But I am not so sure that the plant owners and operators appreciate the value and economy of such records.

Too frequently the owners of an industrial waste treatment facility will balk at the amount of money provided in the estimate of cost for automatic recording devices. In one specific case of a very large automotive plant where automation is a necessity in turning out cars and keeping down costs, one of the officials in charge made strenuous objections to the recording devices incorporated in the waste treatment facility.

In many cases the plant owner feels that the regulatory agency or the designer of the waste treatment is over-zealous in emphasizing the need for instrumentation and recording devices and that he could do with less. But in many cases it has been definitely found that proper instrumentation and records can and do result in very decided economies. These economies frequently more than offset the cost of the devices provided. This is particularly true in cases (1) where chemicals are required in the treatment of the wastes; and (2) where charges are made against the industry for the discharge of wastes into municipal sewerage systems. The following examples will illustrate these two points.

(1) In a large plant for the treatment of plating room wastes, flow meters and other recording instruments were provided to measure the chlorine and other chemicals. Despite the fact that ample resources for chlorine supply were furnished, based on experience as to the possible needs, it was found that instead of the recognized need of between 8 and 9 pounds of chlorine per pound of cyanide destroyed, the daily logs showed that up to 28 pounds of chlorine were being used per pound of cyanide. Obviously something was wrong. Investigation showed that each of the three chlorinators had a rated capacity of 6000 pounds per 24 hours and that they were set to operate at that rate regardless of the actual need. Operating control was not adjusting the rate of supply to the need. It was pointed out that this lack of control was costing the plant management close to $100 per day in unnecessary expense in waste chlorine. Closer control was initiated and the chlorine feed reduced to within accepted limits of about 9 pounds of chlorine per pound of cyanide.

(2) In numerous municipalities charges are made against industries for discharge of liquid wastes into the sewerage systems. In many cases these charges are based on: (1) volume of flow; (2) excess of components over arbitrary standards set by the municipality; (3) requirements of treatment at the municipal sewage treatment plant to bring the ultimate effluent within limits set by a State or other authority, or all three. If the industry does not meter the discharge of wastes into the municipal system, the City frequently imposes a charge based on a percentage of the water bill paid by the industry.

In one case in the writer's experience a plant discharged its treated industrial wastes into a large storm drain which emptied directly into a river. For the sanitary sewage of the employees it had several septic tanks. The State authorities suggested that the company do away with the septic tanks and discharge the sanitary sewage into a sewer of the municipality which passed the plant. The company used about 1 million gallons per day of city water, but the actual volume of sanitary sewage to be discharged into the sewerage system would amount to only about 25,000 gallons per day. The plant owners approached the city to carry out the wishes of the State, but the city said the cost would be based on a charge of 50 per cent of the water bill. As this was obviously an inequitable charge for the small amount of sewage to be handled, the company decided, against its desire, to build its own sewage treatment plant. The annual costs for this would be much less than the exorbitant charge set up by the City.

In other cases, unless the plant owner knows, by means of proper analytical procedure or measuring devices, just what he is putting into the sewerage system or streams, he may be unduly penalized by such arbitrary charges, or stringent requirements.

Many municipalities set up standards for the content of toxic or polluting elements that may be acceptable in industrial waste effluents. If the plant owner does not keep his own proper records and make his own analyses, he is at the mercy of the municipality or regulatory agency, or both. If a penalty is attached to the discharge of effluents containing excesses of components over established limits, he may pay several times the cost of proper control equipment in fines and penalties.

Instrumentation can be overdone. All instrumentation and recording equipment should have a relation to the needs of the particular case. For instance, in a small plant where a single operator must be on hand, and his duties are small, he can carry out many operations himself without overdoing. In such a case the automatic equipment should be tempered to the needs. An operator with certain duties to perform will be much more efficient than one who has a lot of recording devices to do his work and he can sit back and take a nap.

There are three general classes of information needed to control the operation of a waste treatment plant. These are:

1. Necessary
2. Informational
3. Interesting

The necessary records are those which show whether the plant is being operated:

1. To produce the desired and designed results in the treatment.
2. To do so at an economical rate.

These necessary records cover the following points:

1. Volume of flow, entering the plant from all sources, and particularly the volume of effluent entering the municipal sewerage system, or the stream. This is especially important if a volume charge is levied against the plant for discharge into the sewerage system.
2. Components of the waste effluents to ascertain if they are within the limits set by the regulatory authority. This is important if surcharges are applied for overages of components or fines for overages.
3. Measuring of chemical coagulants or reagents to assure economical operation of the plant, and to ascertain need for additional supplies.
4. Analyses of the raw wastes to determine the amounts of treatment reagents required and of the final effluents to assure that the requirements have been met.
5. Printed records from the automatic recording devices to act as acceptable proof to the regulatory agency and owner that the plant is doing the job it was designed for. Automatic recording devices when properly maintained are not subject to the common human errors of misreading, slipped decimal points, etc.

The informational records are those not required to indicate to a regulatory agency the main points of compliance with their demands, but are valuable information for the plant cost departments and budgeting officials. The construction and operation of a waste treatment facility usually adds a cost item, many times a heavy one if the wastes are complex, which enters into the production cost of the item produced by the factory. Such costs must be kept to a minimum in a competitive market, and they are closely scrutinized in the Cost Department. If they seem to be inordinately high or out of line, someone is going to be called on the executive carpet.

These records are:

1. Amount of each chemical used each day in the treatment of the wastes.
2. Cost of the chemicals.
3. Comparison of costs and usage, day against day and against volume and concentration of the wastes.
4. Available supply of chemicals on hand, to avoid running out when most needed.
5. Condition of the equipment in the plant, and repairs and cost of repairs and replacements.
6. Hours of labor used, and types of labor or attendance. This establishes the labor cost per day or per unit of flow, etc.
7. Amount of electrical current used in the plant operation.
8. The weather conditions. This may explain the reason for excess flow rates, if surface or roof drainages enters the waste system, or why certain operations could not be carried out on a particular day.
9. Record of outside visitors. This is a check on inspection by regulatory agents, etc.

The interesting type of record is one that does not materially assist in maintaining the plant at its optimum efficiency, but may be desired or required by the plant management for one reason or another. These are:

1. The call on other departments for plant services by plant operation, to determine if this cost is a charge against the department supplying the service.
2. The condition of the plant units, equipment, etc. to determine the need for maintenance, servicing, painting, renewal of parts, etc. This may indicate the need for more personnel.
3. Cumulative records of the volume of flow of the sev-

eral waste lines, amounts of chemicals used, in a given period.

4. Description of the plant units, and additions to the plant, for the use of the plant executive departments for taxing purposes and inventory of supplies, and additions to capital investment.

To illustrate the economy of keeping records of usage of chemicals may be cited the case of a water treatment plant, for an industry. The client felt that the costs were exorbitant and called on the writer's firm to make a study. Scrutiny of the plant records for an entire year showed that during the first months of initial operation, the amount of chemicals used varied from day to day, according to the changes in water conditions. Then, suddenly, after six months, the same amount of chemicals was entered each day for the following six months. If this had varied a little from day to day it probably would not have been noticed. But each day for the six-month period, regardless of the water characteristics which were entered on the same log, 150 pounds of lime and 100 pounds of alum was entered. It was easier for the operator to add this than to measure it, as a weighing feeder would have done.

The designer of a waste treatment plant should accept as part of his responsibility the preparation of a proper log sheet for each plant. This should be tempered with judgment, based on the needs of the case, the class and size of the plant, the scope of treatment and the class of operators.

In one case our firm prepared a log sheet with 126 items that fell into the three classes of information referred to earlier. To keep such a log meant an inordinate amount of paper work, so the final log, for a very complex plant treating six different types of wastes, was simmered down to 52 items which answered all purposes.

The regulatory agency is mainly concerned with the plant results and usually requires that records indicating that be kept and be available to representatives of that agency. These are not normally a burden and may save the owner considerable money. The records that tell of the economical operation of the plant are essential for the owner and may lead the way to revision of methods, procedure, etc. Well-kept records are always a credit to the operating personnel and may go far in enabling the Chief Operator to obtain the help and supplies he needs.

Modern science is continually developing automatic devices which assist materially in the objectives of this paper. In the analysis of wastes to determine final concentrations of cyanide, hexavalent chromium, etc. the usual laboratory procedure may take two hours to make one test. If during that test period something happens that might bring about a discharge of improperly treated waste, this may be caught by the municipal or regulatory agency men and may result in a fine, regardless of the fact that there was no actual intent to discharge untreated waste. By use of the modern auto-analyzers now made by a number of companies, one of these can be out on each effluent stream and will make an analysis in from 5 to 15 minutes and provide a printed, indisputable record on a chart. Not only does this provide insurance against the discharge of improperly treated waste, but it releases the laboratory personnel for other work. This saving alone may easily pay off the entire cost of the analyzing system in a year or two. These analyzers can be so connected to the waste system that in the event of an improperly treated waste the device will automatically start the pumps which will return the waste to the proper tank for retreatment.

Records are valuable, as illustrated, both for the plant owner and the regulatory agency. If found to be truthful and accurate and based on automatic recording devices, the regulatory agency will gain faith in the operator of the plant and will reduce the number of visits to the plant. The submission of the printed record and charts will suffice.

A plant owner may say, "Why should we make an effort to save time for the regulatory agency men," It is very simple. If every plant kept poor or inadequate records which required the agency men to make frequent periodic inspections to assure that the plant was producing the proper results, the force required would be tremendous and the owner would pay for it in the increased taxes necessary to support the agency. Government bodies in all countries being what they are, it would probably be difficult for them to obtain the extra staff due to budget limitations. The result: unchecked pollution, more stringent laws, and more cost later for the plant owner and lessened benefit to the public health.

Records of flows frequently indicate losses, spills or carelessness on the part of plant production personnel. These can usually be corrected to the economical advantages of the owner. The needs for water are constantly increasing and by watchfulness on the part of industrial plant users the available supply can be more adequately apportioned. Waste treatment costs money and records frequently indicate preventable losses and wastes.

The Plant Operator

Another important factor in the economical and successful operation of a waste treatment plant is the selection of the operator. The average industrial waste treatment plant is a complex entity, it has cost the owners considerable money and it deserves the best operation to protect the investment. If the plant is one requiring the use of chemicals, then the Chief Operator, or at least one of his assistants, should be an industrial chemist skilled in the reactions to be attained, with a knowledge of the operations in the production departments of the company, able to make chemical analyses and determinations to assure results and economy. If the owner does not have such a man available, he should engage one. To quibble about such an item when the investment of thousands of dollars is at stake is penny wise and pound foolish. The difference between an operator who wants, say $7500 per year as against one at $5000 per year, may easily cost the company more than the difference, in waste of chemicals in a year. Quality is not cheap but is usually worth its cost. I recall a very prominent sanitary engineer, now deceased, who questioned the cost of a piece of very important equipment by comparing its cost per pound to that of an automobile. The representative of the equipment manufacturer stated that if his company could turn out that particular piece of equipment at the same rate as the automobile in question, they could materially reduce the cost per pound also. He then asked the consultant, "When you want a man for your staff, do you go out into the street and pick out the heaviest man you can find so that you can get more weight per dollar--no, you take a man for his ability regardless of his avoirdupois." The consultant agreed, and the argument was closed.

If you plan to mechanize the operations, then be sure to get an operator who can interpret the information on the dials and charts and perform the necessary manual functions, or push the proper buttons indicated by the record.

Most instruments record in lines on a chart and indicate degrees or percentages, levels, etc. When a plant is performing normally, these lines will be at certain points. It is when they depart from the normal lines that the operator must know what the divergence means and take the necessary steps to get the operation back in step.

It is a familiar theory of mine that the operators, or at least the chief operator, of an industrial waste treatment plant should be licensed, the same as operators of sewage and water treatment plants. In practically every State of the United States and the Provinces of Canada it is obligatory for the operators of water and sewage plants to be licensed by the proper authority. This not only assures that the man is fitted for his job, but also removes him from the petty annoyance of being under the control of some other company official who may not agree with his ideas or methods. It enables the licensed operator to be steadfast in his plan of operation and get the desired results from the plant. The regulatory agencies, particularly the States and Provinces, claim the right to tell an industrial plant management what they must do to reduce or eliminate pollution, what records must be kept, etc. Therefore, I feel that they have the same right to require the licensing or certification of the operators of these plants. Actually industrial wastes have a greater pollution effect on streams, with toxic elements, etc. than does normal municipal sewage, and the effect on public health, comfort and recreation is greater, and therefore the need for licensed, competent operators is even greater. I believe also that the industries themselves would welcome such a requirement as it would relieve them of some of the responsibility.

Centralization of Instruments

In a plant with operations scattered over a large area, all of the instruments which show condition of the various steps should be centralized where a principal operator can keep his eye on them and be ready to correct any malfunction in one part that may have a serious effect on another or on the whole plant. He should be able to interpret the meaning of the various alarms and to locate the trouble instantly and take the necessary steps before damage can result.

It is desirable to have all important recording instruments and controls on one panel board with individual controls at the individual units for emergencies. But it is only confusing to have on that same panel a lot of instruments or recording devices which do not actually have to do with the operation of the plant, but produce data of an interesting or historical value only. Instruments of this kind should be on a separate panel adjacent to the main panel.

If possible the main and secondary panels should be in a cubicle by themselves with a large window between that cubicle and the chief operator's office where he can see the entire panel at all times. To avoid missing the alarms, the bell, sirens, lights, etc. should be in the room of the chief operator, preferably in front of him to attract his immediate attention.

Preferably all instruments on a panel should not be lower than normal desk height. If an operator has to stoop to look at a recording device he may misread the dial and fail to correct a malfunction. All instruments should be clearly indicated by a proper label or on their face as to what they are recording or controlling and all push-buttons should clearly indicate what they control. To avoid mistakes, the meters, recording devices, or their cases or enclosures, should be painted in the same color as the unit they control.

This is another important point. All pipe lines, pumps, valves, etc. should be clearly marked to indicate their contents and all control elements for the same units should bear the same color scheme. The best way to do this is to develop a scheme of colors for the various materials to be handled and mark each pipe, each valve, each component part of that line, including the equipment, with stripes of the color, and every three feet on the pipe line a label with the name of the material handled and an arrow pointing in the direction of the normal flow. There are several firms who make these stick-on labels at low cost. The extra expense of this refinement may often be justified in saving accidents, and in enabling the staff to locate troubles instantly.

I wish to inject another matter here which while not entirely germane to the subject of records, is important in getting industrial waste problems solved. For a long time there has been a complaint on the part of industry, "we are made to expend large sums of money to provide waste treatment facilities, but no financial help is given us to share the burden." In the United States, under the authority of Public Law 660, the Federal Government assists municipalities to provide sewage treatment facilities by making grants of a total of 50 million dollars per year to accredited municipalities. These grants provide up to 30 per cent of the cost of a sewerage project, or a maximum sum of $250,000. Also, provision is made for loans for the preparation of studies and plans. But no one helps the industrial plant for any part of a project. It must pay the entire cost out of its own treasury or borrow the necessary funds.

To correct this position, which in my mind and that of many others, has retarded the construction of industrial waste treatment facilities, the Pollution Control Commission recently appointed by the President of the United States has recommended that the Congress initiate legislation to permit industries faced with the construction of an industrial waste facility to write off this investment in a five-year period. To foster this, several bills have already been presented to the Congress to permit this. This legislation is also favored by large commercial organizations, such as the National Chamber of Commerce, and other industrial bodies. If the legislation is enacted it would stimulate more rapid progress in the clean streams program. Pennsylvania has also made a progressive step by establishing the right of industrial firms in that state to condemn additional land that may be needed for their industrial waste facilities. Such measures all help, and if more political bodies could be brought to see the advantage of encouraging industry to build plants, they would benefit in the end.

In combination with this effort to encourage industry to build plants there should also be a cooperative effort on the part of the regulatory agencies. No regulatory agency wants to be arbitrary in its demands on an industry faced with a waste problem, but a combination of elements is required to accomplish a willingness on the part of the industry to comply with the demand. These elements are:

1. Realistic requirements.
2. Complete exposition to the plant owner and his advisers of the actual needs which will satisfy the agency.
3. Willingness of the regulatory agency to discuss the problem with the plant owners to arrive at the actual needs.
4. Willingness of the regulatory agency to consider progressive construction of the needed facility over a period rather than requiring the complete construction if the immediate needs of the case do not require it.
5. Willingness of the regulatory agency to make changes in requirements if it is found that certain items enttail an inordinate expense on industry without good reason.
6. Competent technical advice on the means of treatment to achieve the desired result.
7. Unbiased and unprejudiced advice on the part of the consultant to provide the most economical facility under the requirements set up.
8. The use of established expert consulting advice of a private nature, not a manufacturing concern, to design the facility.

To illustrate the item 5, may be cited the case of a city which had as one item in its requirements for discharges of wastes into its sewerage system the requirement that "no waste with more than 1000 p.p.m. total solids" should be admitted. In one case in this city the treatment of a given waste produced a water-white effluent, from which nothing whatever settled in a period of six months, but the total solids were over 4000 p.p.m. The public officials were entirely satisfied to accept the waste as shown, but the requirement of 1000 p.p.m. total solids could not be attained without additional plant at the cost of a quarter of a million dollars. However, as the requirement was in a municipal ordinance, council action was required. It was done and the requirement changed to "1000 p.p.m. precipitable solids" and everyone was happy.

It should be the duty of the designer of the plant to pro vide a complete, detailed manual describing the various operations, with flow diagrams and a point by point description of the operation, with reference to numbered items on the drawings and identically numbered units in the actual system. This manual should endeavor to crystal gaze and foresee possible troubles and advise what action to take when they occur. Also it should give the name and address, and, if possible, the telephone number of the nearest representative of every manufacturer or agent who has supplied any major equipment in the plant. If chemical analyses are involved, then the manual should list the sources and standard methods normally used in those analyses, and in each phase of the system should list the essential records that are to be kept.

To sum up the basic theme of this paper it may be said: Records are a guide to performance. They demonstrate the efficiency of the processes and of the personnel. Charts and records signal the approach of possible malfunction of units or upsets of processes that may be stopped before they become serious. Signal lights tell at a glance when units are functioning properly.

The benefits of automatic controls:

1. Significant increase in operating efficiency.
2. Reduction of labor costs.
3. Elimination of potential human errors.
4. Decrease in waste of material and usage due to overdosage.
5. Maintenance of proper tank levels without manual attention.
6. Highly skilled, well-paid personnel have more time to attend to more important tasks.
7. Safety for operators and the community.
8. Controlling discharges of wastes to achieve dilution for reduction of treatment and cost.

BANQUET ADDRESS

Dr. R. R. McLaughlin

It seemed to me that to-night I might vary a little the pattern of after-dinner speeches. Generally, the speaker attempts to put his audience in a good mood by telling some jokes, or what are alleged to be jokes, to which the audience heroically responds with laughter that is sometimes compounded mostly of sympathy for the speaker, and self-pity. I thought I would reverse this procedure and get such few serious remarks as I have to make out of the way first and then relate to you some episodes that have occurred at the University that have seemed amusing to me, and that might be more suitable than much seriousness on an occasion like this.

It would be out of place for me to speak to such a group of experts as is assembled here on any specific problem of pollution, but as a chemical engineer I can claim an understanding of what you are trying to do, and applaud you for it. I can also claim some direct contact with, and great interest in, the general situation through membership on one of the committees of the now defunct Research Council of Ontario. Though defunct, that Council performed a useful function and initiated programmes that have proved of lasting benefit - among them one on pollution. Pollution is like sin - we are all against it. If waving a wand would do away with pollution, we should all scramble for the honour of waving it. But it is not that simple. Instead, we must do as you are doing and work hard at it, detail by detail. Legislation alone is not the answer, though legislation is necessary, and I think the appointment of the Ontario Water Resources Commission was a great forward step. It was heartening to attend the laying, or rather placing, of the cornerstone of the nearly-completed splendid new laboratories of the Commission. It would be entirely presumptuous for me to tell the Commission how it should run its affairs, but I hope it won't be either presumptuous or considered bad form if I remark that I think they are developing a sound policy, judging by what has so far been done. As "laissez-faire" has in effect been the policy, or lack of it, with respect to pollution in this province since the first small beginnings of industry here, it would be quite unrealistic to try to change matters overnight. At one extreme it would be folly to point a loaded gun at an industry and say, "cease and desist forthwith from the pollution you are causing", especially if the only known way of stopping the pollution is to stop the industry. We all know that this is in some respects a quantitative problem-what could be tolerated when industries were small and scattered, cannot be tolerated when they are large and concentrated. At the other extreme it would be equally unreasonable for an industry to say, "We have always done things this way - our procedures are hallowed by time. We don't intend to change". Clearly, answers to any particular problem must be found, and generally can be, given time. And surely the best way to find these answers is by co-operative endeavour carried out in an atmosphere of mutual trust. I feel sure that that is the basic policy of the Commission, if for no better reason than that we all know that more is accomplished by kindness than by force, given good will on both sides. Sometimes, of course, recalcitrant children have to be dealt with firmly.

Naturally, I know something of the operations of chemical companies, and I am therefore heartened by what I believe to be increasingly common and I should say, essential policy. That is, when a new product or process is in the developmental stage (and new products and processes are the hall-mark of chemical industry), potential pollution must be recognized and methods for obviating it worked out before a decision to go ahead with the development is taken. An important consequence of this is that the cost of avoiding pollution appears where it should appear - namely, in the cost of the product. Of what avail to provide the public with a product at a lower price, if the difference between that price and the pollution-free price is to be paid for many times over by the public in either direct damage or in impairment of amenities? Surely we can expect new development to take place on a pollution-free basis, and you are just the gentlemen to tell us how to do it.

As indicated by the remarks just made, you have weighty problems before you, as you know full well. I thought on this occasion you might feel happier, in a relative way, to know that the universities also have a problem or two, in the solution of which you have a vital stake. I venture to say that a very high proportion, I hesitate to put a number on it, of the people taking part in this conference are university graduates. Quite clearly as your work continues and expands you will need many more. You will look to the universities for them. We must be prepared to handle much larger numbers than heretofore, and soon. We have been talking about this as hard as we could for several years past in an endeavour to have the necessary buildings ready when they will surely be needed. I should like to paraphrase a remark made by our late President, Dr. Sidney Smith. "The universities are not mendicants, seeking largesse. They are the places, and the only places, where the young people educated to a high level who will be so sorely needed by this country, can be so educated." Perhaps you will keep this in mind when the universities make their appeals to the public - (the University of Toronto, this autumn for 12.6 millions) - to enable them to cope with the expected flood of students, whose universtiy education will be a necessity for the country; and use your influence with your company when the direct appeal is made to industry.

We must all take our problems seriously, but that does not mean that we must take them solemnly. Many a good laugh can arise from ordinary experiences. All the little episodes I am about to relate occurred to me, and have a university setting.

POLLUTION MONITORING AND PREVENTION BY THE USE OF BIVARIATE CONTROL CHARTS

Mr. T. W. Beak
Mr. C. de Courval
Dr. N. E. Cooke

At Millhaven, Ontario, Canadian Industries Limited owns a large industrial site. At present there are only two plants at this location, but it is possible that in the course of time there will be a very large complex of chemical plants there. The site is about fifteen miles west of Kingston bordering on the north channel of Lake Ontario across from Amherst Island. At present the lake front is very much in its natural state and it is the company's desire to keep this in that unspoiled condition.*

As a consequence of this desire, pollution control measures were taken into account when the plants were being designed and a careful check is being kept on all the waste water streams in order to keep harmful material out of the lake. However, it is reasonable to expect that no matter how carefully the pollution control apparatus were designed and no matter how carefully the waste streams are monitored, some materials of a harmful nature will get into the lake. Of course, the escape of relatively small amounts of waste materials does not usually cause pollution because of the dilution which occurs when the waste stream mixes with the lake water. With these thoughts in mind, it was decided that some method must be worked out to test the efficacy of the pollution prevention program and that such a method should be capable of detecting any incipient pollution so that corrective measures could be taken promptly.

In 1956 when this study was initiated, the only plant operating at the site was the "Terylene" plant in which synthetic textile fibres are made. It discharges only a small quantity of treated sanitary sewage diluted by large amounts of cooling water; hence it does not present a pollution problem. The purpose of the study was not so much to keep a check on the efficiency of the Terylene plant as to establish a basis for comparison after the second plant in which ammonia was to be made, came on stream.

Briefly the following information was at hand. The Sanitary Engineering Division of the Ontario Department of Health had carried out a fairly complete chemical and

---

* Figure 1 is an aerial photograph showing the site.
Figure 2 is a photograph taken from the water and shows the foreshore.

bacteriological survey of the lake in that area in September 1953. The findings indicated that the lake was free from any gross contamination; was slightly alkaline, had a pH between 8 and 8.5, and that a slight degree of turbidity existed. The Dominion Hydrographer of the Department of Mines and Technical Surveys had conducted a study of the currents in the lake between Amherst Island and the mainland. He reparted that in the winter of 1951, there were no noticeable currents. The study was carried out by lowering measuring instruments through the ice.

Properly to understand the problem, it is appropriate to discuss the nature, purpose, and limitations of biological surveys carried out to obtain information as to the state of life in a lake. Ideally we would like to have a continuous record of the numbers of each species occurring in the body of water under study. With several years of records such as this, any abnormal change in the numbers of animals or plants in the lake would be detected and an immediate investigation could be undertaken to find out the cause of such a change.

However, in developing a practical system, the problem of how much information must be collected to give a clear picture of the state of the life in the lake is one which requires considerable thought and experience and must be considered in the light of the use to which the data will be put, as well as the local aquatic conditions which prevail.

As stated before, the primary purposes for these data were: (1) To check on the efficacy of the waste treatment arrangements and apparatus within the works and (2) in the event of a malfunctioning or inadequacy of the equipment, to permit detection of the onset of pollution so that corrective measures could be taken before any real damage resulted. In order to have data satisfactory for these purposes, it is necessary to satisfy the following conditions::

I. Sampling must be on those animal populations which will respond most markedly to the effects of pollution.

II. The sampling pattern must be arranged in such a manner that the results from certain points will indicate the occurrence of pollution long before the results from other points indicate anything except normal behaviour and thereby differentiate between a change brought about by pollution and one brought about solely by natural causes.

III. The results of the surveys must be of a form such that they can be assessed quickly and yet clearly indicate the presence or absence of pollution.

IV. Enough sampling must be done so that variations caused by chance, season, and difference between sampling location can be accounted for statistically.

V. The surveys must be carried out at intervals short enough so that if pollution is inadvertently initiated the indication can be quickly noted and steps taken to correct the situation before any real damage is done.

Consideration has been given to the use of a number of biological survey methods described in the literature.

Most of the methods used or advocated in the past have been either qualitative, (no attempt having been made to take numbers of individual animals into account), or at best have been only very roughly quantitative, (numbers having been described by such terms as "abundant", "frequent", "scarce" and "occasional"). Few if any surveys have been reported in which numbers of animals have been given with sufficient detail to enable the results to be represented statistically. One reason for this is that the taking and counting of quantitative samples involves a great deal of labour and in most cases facilities for this have not been available. Surber (4) has given a good review on this subject.

On the other hand, a group at the Philadelphia Academy of Natural Sciences had developed a quantitative survey (2). This type of survey studies all aspects of a river i.e. chemical, physical and biological with the intention of furnishing data so that any future change in the state of the river can be assessed.

The Philadelphia Academy has also developed an instrument known as a Diatometer (3) which permits the collection of data which can be analyzed statistically for a significant change. In this case, however, it was not considered advisable to restrict the monitoring to Diatoms.

Without wanting to discuss the relative merits of biological surveys versus bio-assays (Douderoff et al (1)), we would like to state that for the case at hand, a biological survey in the lake itself gives more information. Bio-assays are excellent for determining the proper concentration to which a waste stream must be diluted before discharge, but it is incapable of assessing the long term effect of the wastes on the life in the lake itself. In addition, at present no discharge stream from either of the plants contains any material in concentrations strong enough to do any damage to any organisms. However, if in future the situation should change and some waste streams containing materials known to be toxic were to be discharged, then the bio-assay method with captive animals would probably be used to monitor these streams in order to ensure that they are harmless before final discharge.

The five conditions which should be satisfied in developing a practical survey system were enumerated above more or less in order of increasing complexity. The first condition as to which animal populations are suitable indicators for pollution control studies has been resolved many times, and is very well put by Patrick (2) who states "From a consideration of the literature, it became evident that the best type of biological measure would be one which was based on all groups of plants and animals living in the stream, particularly the sessile or attached forms or those which move about in only a relatively small area". Since in the case of Millhaven the intention is to keep any pollution which might occur localized to a very small area, any observations concerning free swimming forms such as plankton or fish would tend to be very unreliable. Therefore, it was felt that the first condition would be adequately satisfied by confining attention to the benthos or organisms living in the mud on the bottom of the lake.

The second condition as to the sampling pattern also was not difficult to satisfy. Since there is very little current in the lake, the spread of any pollutant would be largely by diffusion and by wind or wave action. Since the discharge streams enter the lake in a relatively small area, the sampling points were placed on rings concentric with the outfall; the inner ring with three points at about 100 yards, the middle ring with two points at about 1/3 of a mile, and an outer ring with three points at about one mile distance. Figure 3 is a chart which shows the sampling locations and the directions to various landmarks which were used to locate the positions on the lake.

The third condition dealing with the form in which the results of the survey should be arranged in order to be readily assessable is somewhat more complex than the first and second conditions. Because of the widespread and highly successful use of quality control charts in industry, and since this problem is really very similar in that an attempt is being made to keep the lake water within certain control limits using the organisms as indicators, it was decided to adapt the control chart method to this application. An outline of the necessary modifications is given in the sections dealing with the preparation of the charts.

The fourth condition dealing with the amount of sampling necessary is one which cannot be answered a priori. At the outset it was arbitrarily decided to condust surveys of two sizes: a large survey, consisting of six samples being taken at each sampling point; and a small survey consisting of one sample taken at each point. Naturally the greater the number of samples taken, the greater the reliability that can be placed on the conclusions drawn from the data. Our experience has shown that adequate information can be obtained by taking only one sample at each point each time a survey is conducted.

The fifth condition is the most difficult to deal with and it can never be really settled definitely. The best that can be hoped for is that by sampling reasonably often the onset of any pollution will be detected soon after it starts and it can be stopped before much damage is done. During the first fourteen months of work, twelve surveys were carried out. Regular sampling now takes place at approximately three month intervals. If any condition arises, such as a large spill of some solution, a special sampling survey is carried out to assess the effect.

Experimental Procedure

The depth of water in the part of the lake concerned varied from 80 to 150 feet. Except for one point, the bottom was uniformly covered with a thick layer of mud, all of which passed through a 30 mesh sieve. The exception was one station w hich contained about 10% of sand mixed with the mud.

The invertebrate fauna found on the bottom consisted almost entirely of oligochaete worms, snails, bivalve molluscs and chironomids (tendipedidae). There were two specie s of oligochaetes, seven species of snails, of which only five occurred in significant numbers, three species of bivalve molluscs, of which two belonged to genus Sphaerium and one was a large clam of genus Elliptio. Fourteen different species of chironomid larvae were recognized, but only seven occurred in significant numbers.

For the purposes of the major part of the survey the animals were not identified to species, but were divided into the four groups: oligochaetes, snails, bivalve molluscs and chironomids. The exact number of animals of each group occurring in each sample was counted and recorded (See tables 1 to 4). All samples were preserved and stored so that they could be re-examined at any time, and in addition, representative samples from each station were identified to species, or at least to genus where species identification was difficult.

All samples were taken by means of a Petersen dredge. The jaws were 11 inches across and 15 inches apart in the fully open position. Allowing for the fact that the jaws probably move inwards about one inch from each side before they commence to sample accurately, this is taken to include one square foot of bottom. The samples were taken from a 32 foot motor boat, the usual type of hand crane being used to manipulate the dredge.

All samples were sieved immediately after they were taken. A large size sieve with a special copper gauze of approximately 30 mesh rating was used. The sieve retained all animals of the macro-invertebrate fauna and a small quantity of fibrous material mostly of plant or animal origin. Except for one station, all the mud passed through the sieve.

The sieved samples were placed in jars and taken back to the laboratory. The animals were removed, sorted into groups, and counted while they were still alive. All animals were preserved, each sample being kept separate.

Preparation of the Control Charts

Originally it was planned to prepare a standard control chart from the background information collected during the first year to plot the data collected from succeeding surveys on this chart and to observe if the points stayed within the control limits. When this was done as in Figure 4 it was found that the natural seasonal variation forced the control limits to be somewhat wider than had been anticipated. Since the seasonal variation is not exactly chronological it is impossible to remove this variation on the basis of time alone. This is to be expected since the same number of animals will not be present on the same date each year because, for example, in one year Spring may be earlier than in other years or the amount of rain one year may be greater than normal.

One would expect, however, that the effect of the weather and season on the animals found in two different places in the lake should be the same. Using this fact it should be possible to find a general relationship between the two groups of animals from different positions which is independent of seasonal variation.

It is well at this point to digress slightly and discuss the fundamental concepts involved in control charts. A standard control chart is simply the projection or plant view of an infinite prism with the upper surface in the shape of a normal curve. Figure 5a shows the prism. Figure 5b is the projection or plan view which constitutes the control chart. A similar control chart can be made for the joint distribution of the two variables but it is somewhat more difficult to represent. Figure 6a is an isometric drawing of a series of bivariate normal distributions.. This corresponds to the infinite prism shown in Figure 5a. Figure 6b is the projection into three dimensions and is in general an elliptical tunnel, the boundaries of which are the control limits of the distribution. This tunnel is the control chart and corresponds to Figure 5b. The system is considered in control if the point is inside the tunnel and out of control when the point passes outside the boundary. This is exactly analogous to the normal control chart. Since it is somewhat cumbersome to plot results in three dimensions, it is usually quite sufficient to sacrifice the time dimension and work only with the boundary of the tunnel plotted as a closed curve on a graph as in Figure 6c.

In a chart there is no necessity for the variable to be normally distributed although in the ordinary control chart it is usually so distributed. Likewise the bivariate control chart need not be constructed from joint normal distributions. The important thing to find in all control charts is the control limit inside which 95% (or 99%) of the points will fall under normal circumstances. In general these control limits are not necessarily ellipses but will be some closed curve.

The mathematical details involved in the construction of these charts are straightforward but somewhat beyond the scope of this present paper and they will be reported elsewhere. It is sufficient to say that the data must be resolved into two independent distributions which then can be multiplied together to give the joint distribution.

Having reviewed this general concept of bivariate control charts the next step is to indicate how they can be used in the particular application at hand.

As mentioned above, the outer sampling stations are about one mile from the sewer outfall, and as a consequence, should be little affected by incipient pollution. They should be affected, however, by seasonal variations in a manner similar to that by which samples on the inner ring are affected since all stations are at approximately the same depth and the habitat is similar.

A bivariate control chart can be constructed using the number of animals collected at two different sampling stations (at various times throughout the year) as x and y co-ordinates. In subsequent tests the points fall inside the control limit 99% of the time under normal conditions. If, however, the animals at one sampling station are fewer (or greater) than what would be normally expected then the point will pass beyond the control limit and indicate an abnormal condition. Figures 7, 8, 9 and 10 are such control charts which have been prepared for the work carried out at Millhaven. Both the 95% and the 99% control limits are shown on these charts. When a point is inside the 95% limit the situation is considered normal. If the point falls outside the 99% control limit another survey is carried out as soon as feasible to check the findings. If the point should still lie outside then action would be taken inside the works to find the cause. If several consecutive points taken at normal intervals fall between the 99% and 95% limit again the situation is presumed to be abnormal and the same corrective action would be taken.

Figures 7 and 8 use chironomids as the test animals. The ordinate in both cases is the average number of animals per square foot of bottom from the samples taken at the outer ring. The abscissa in Figure 7 is this same average number of animals from samples taken at the inner ring. In Figure 8 the abscissa is used to plot corresponding values for those samples taken at the middle ring. Figures 9 and 10 show the same charts using bivalve molluscs as the test animals. Similar charts have also been constructed for the gastropods and oliogate worms.

Use and Application of the Charts

A brief study of the Figures shows that during the initial part of the survey the control point wanders in a truly random fashion. Figure 7 shows four points outside the 99% control limit all within a relatively short period of time. The chances of this happening by natural causes alone are less than 1 in 100,000,000. As can be imagined this finding caused considerable concern, and a concerted effort was made inside the works to find out what was being put into the lake to cause this change. The answer was not found until a sample of mud brought up from the bottom of the lake during the sampling procedure was noticed to have a peculiar smell. This odor was identified as Dowtherm. Further investigation showed that a Dowtherm tank in one of the buildings was spilling into a sump and this sump drained into the sewer outfall. The spillage was stopped and as can be seen the control point moved back within the control limits. The behaviour of the control point on the Figure 9 shows similar but less pronounced behaviour during the same period.

This spill of Dowtherm provided an exceptionally good test of the monitoring system. The temporary upset in the life of the lake around the outfall was so small when it was detected that it would not have been detected at all if it were not for these control charts.

Undoubtedly other methods of statistical control can be developed for this application, but the one described is more than adequate in indicating whether the system is in or out of control, and it is exceedingly simple to understand and use.

Conclusions

1. A general method of monitoring the effect of the waste discharge from an industrial plant has been presented.
2. The method can detect the onset of pollution and give adequate warning so that corrective steps can be taken before real damage is done.
3. The method is exceedingly simple to use.
4. The method has been tested by an inadvertent spill of Dowtherm and it performed as predicted.

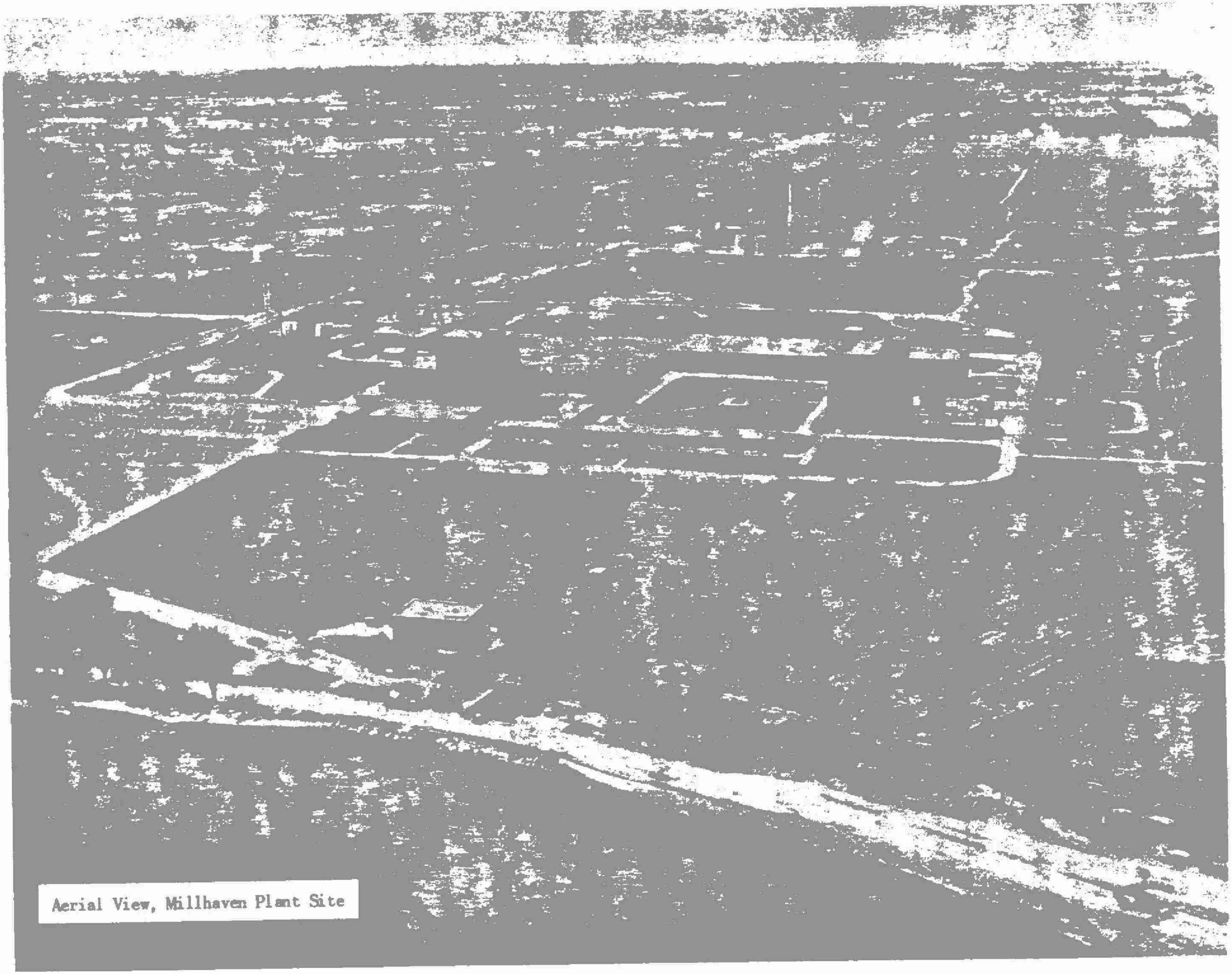
References

(1) Douderoff, P., Anderson, B. G., Burdeck, G. E., Gallstoff, P. S., Hart, W. B., Patrick, R., Strong, E. R., Surber, E. W., and Van Horn, W. M.
"Bio-Assay Methods for the Evolution of Acute Toxicity of Industrial Wastes to Fish."
Sewage and Industrial Wastes 23 1380 (1951).

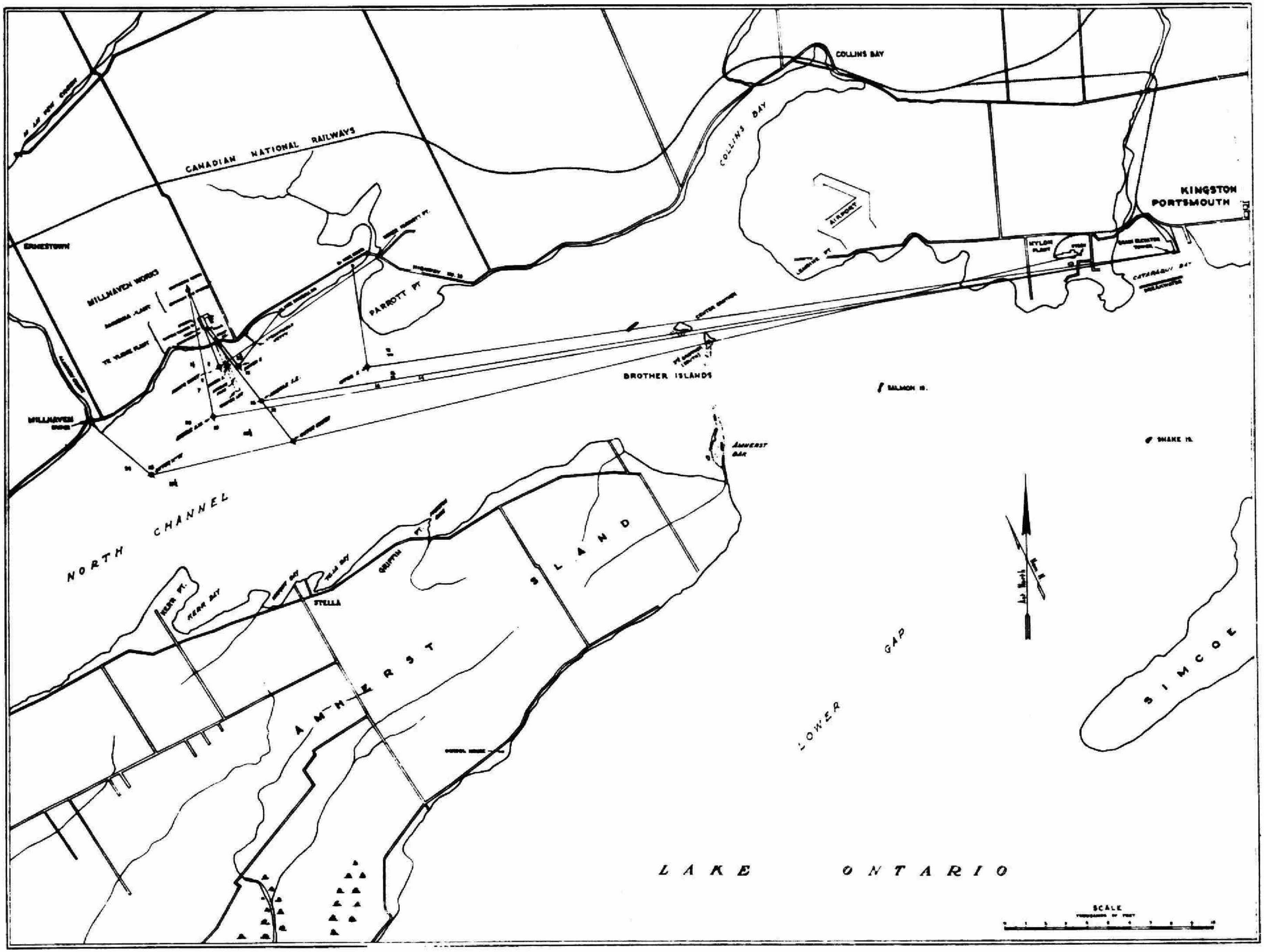
(2) Patrick, R.
"A Proposed Biological Measure of Stream Conditions Based on a Survey of the Conestoga Basin , Lancaster County, Penna."
Proc. of Acad. of Natural Sciences of Philadelphia 51 277-341 (1949).

(3) Patrick, R., Hohn, M. H., and Wallace, J.
"A New Method for Determining the Pattern of the Diatom Flora."
Not. Nat. of Acad. of Natural Sciences of Philadelphia 259 1-12 (1954).

(4) Surber, E. W.
"Biological Criteria for Determination of Lake Pollution."
Trans. of a Seminar on Biological Problems in Water Pollution.
U.S. Department of Health, Education and Welfare, (1957).

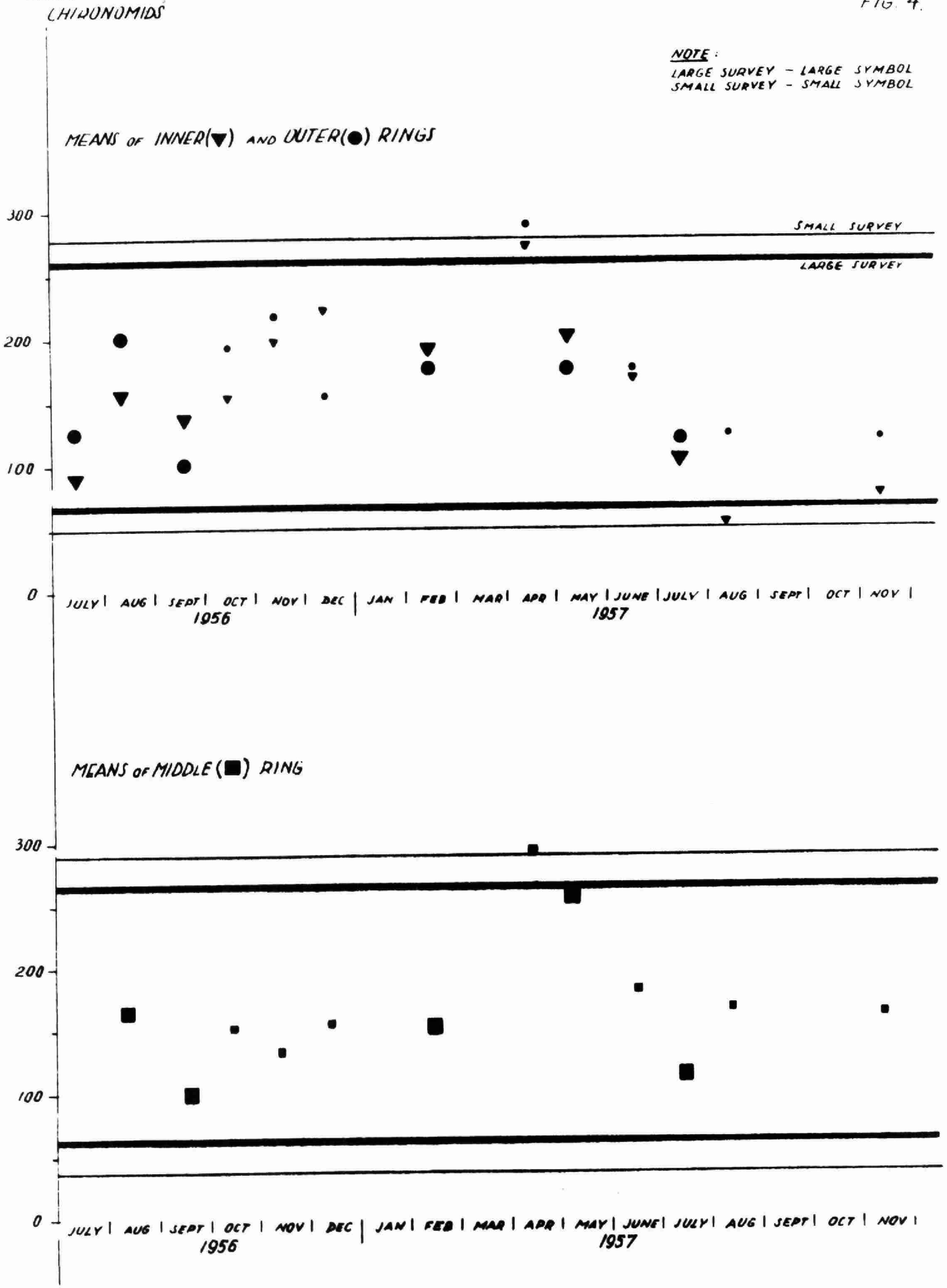


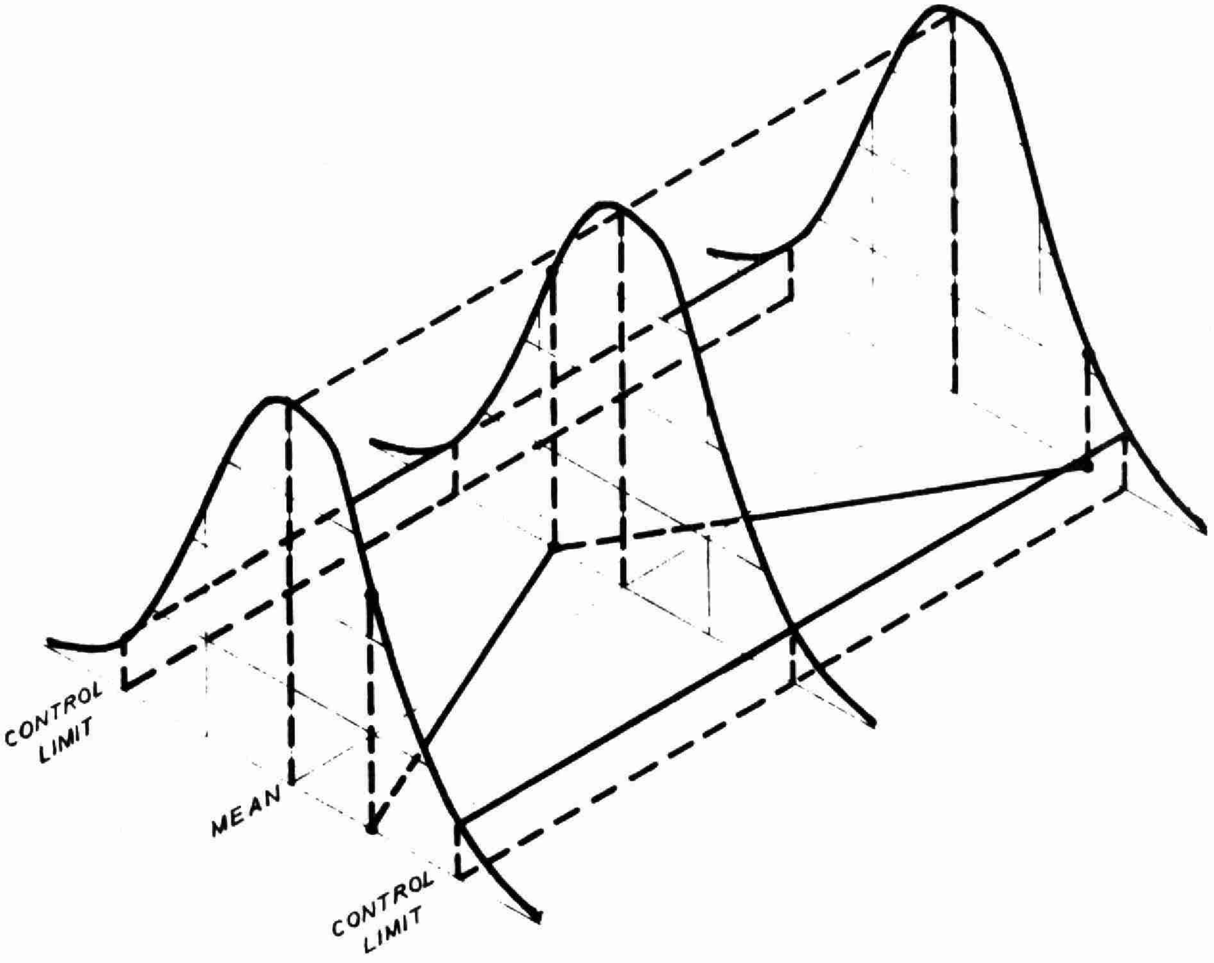
Aerial View, Millhaven Plant Site

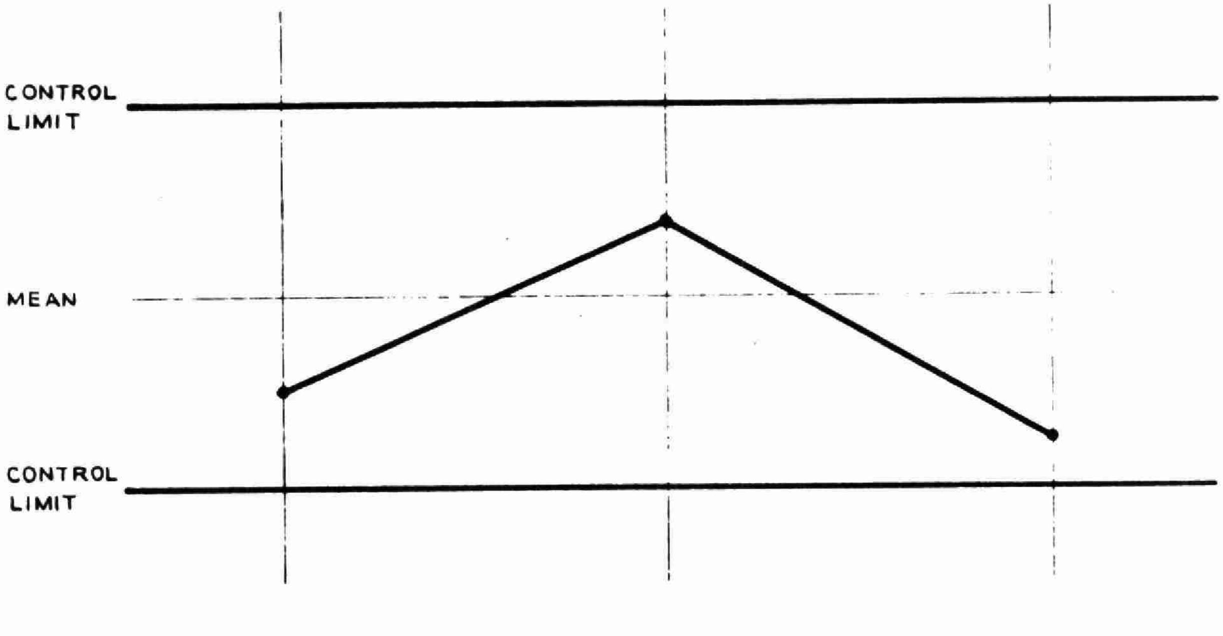


Map Showing Location of Stations for Biological Survey in the Water, Millhaven Plant Site

Fig. 4.


CHIRONOMIDS
NOTE:
LARGE SURVEY - LARGE SYMBOL
SMALL SURVEY - SMALL SYMBOL
MEANS OF INNER(▼) AND OUTER(●) RINGS
300
200
100
0
SMALL SURVEY
LARGE SURVEY
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
1956
1957
MEANS OF MIDDLE (■) RING
300
200
100
0
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
1956
1957


CONTROL LIMIT
MEAN
CONTROL LIMIT


CONTROL LIMIT
MEAN
CONTROL LIMIT

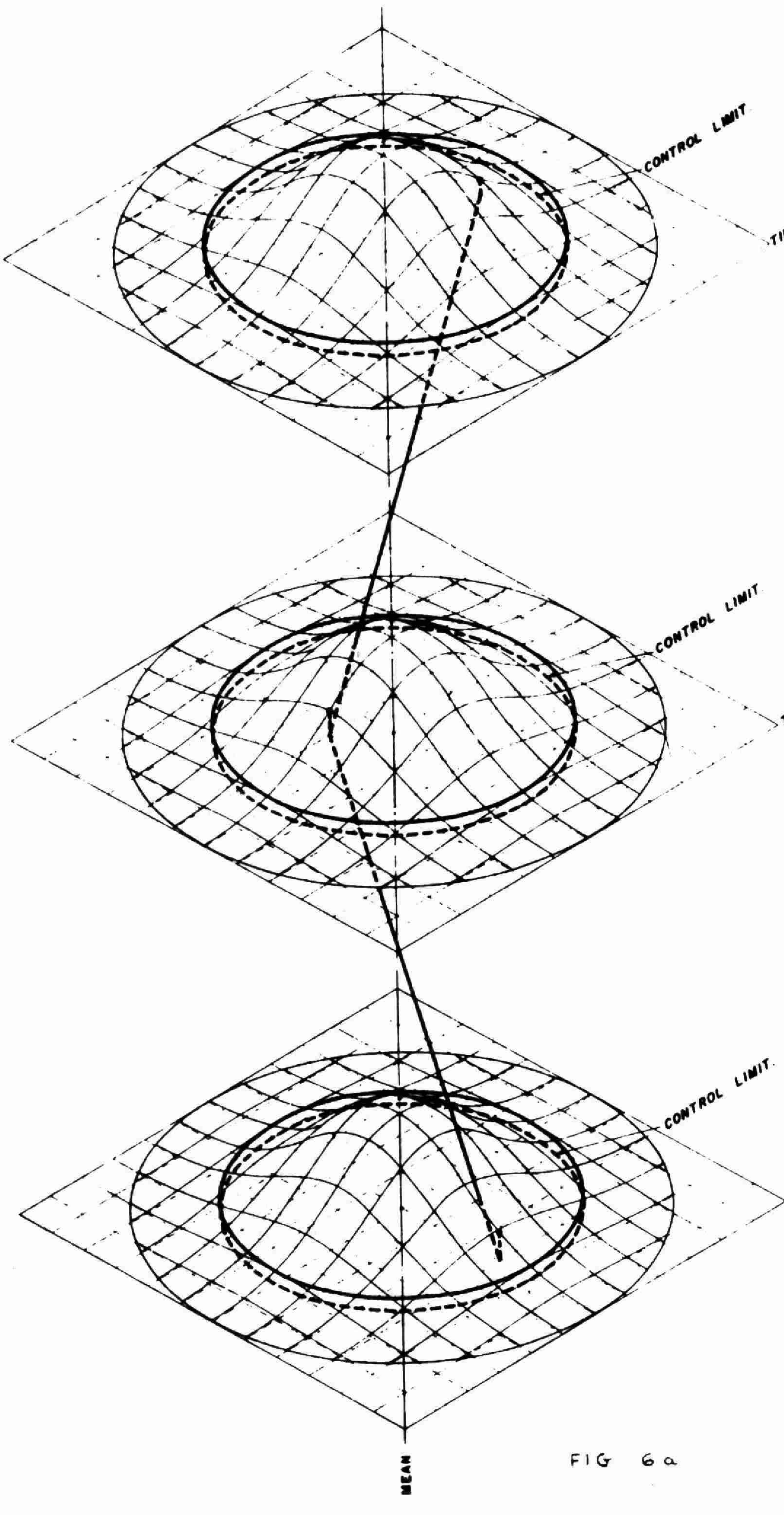

CONTROL LIMIT
TIME 3
CONTROL LIMIT
TIME 2
CONTROL LIMIT
TIME 1
MEAN

FIG 6a

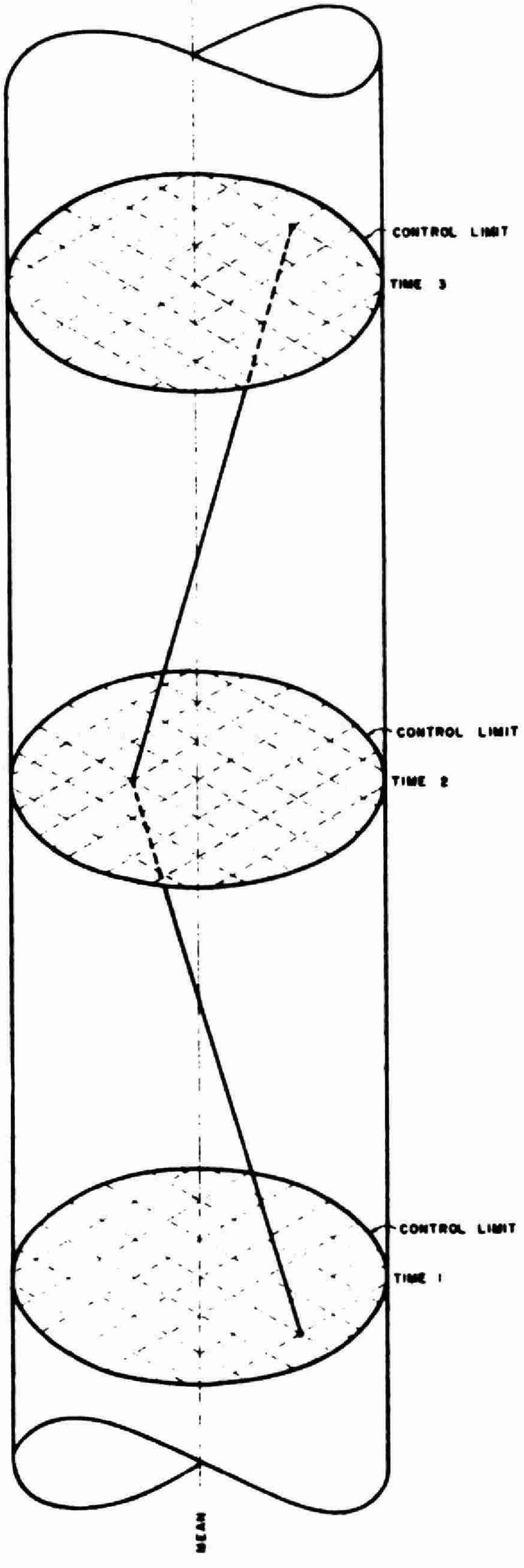

CONTROL LIMIT
TIME 3
CONTROL LIMIT
TIME 2
CONTROL LIMIT
TIME 1
MEAN

FIG. 6 b

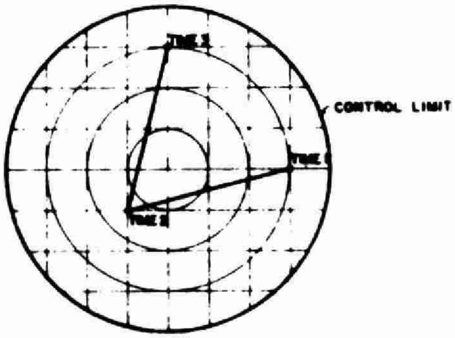
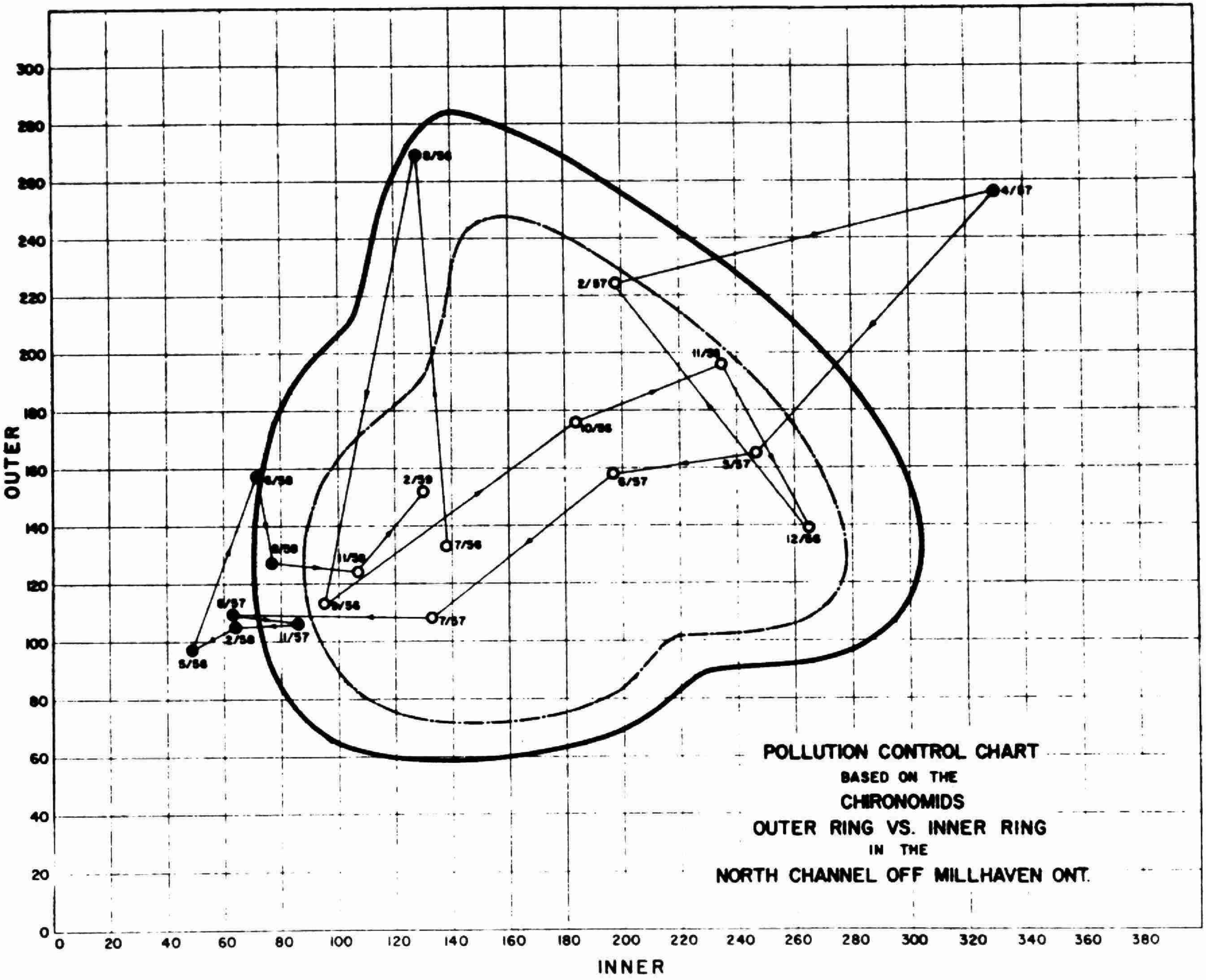
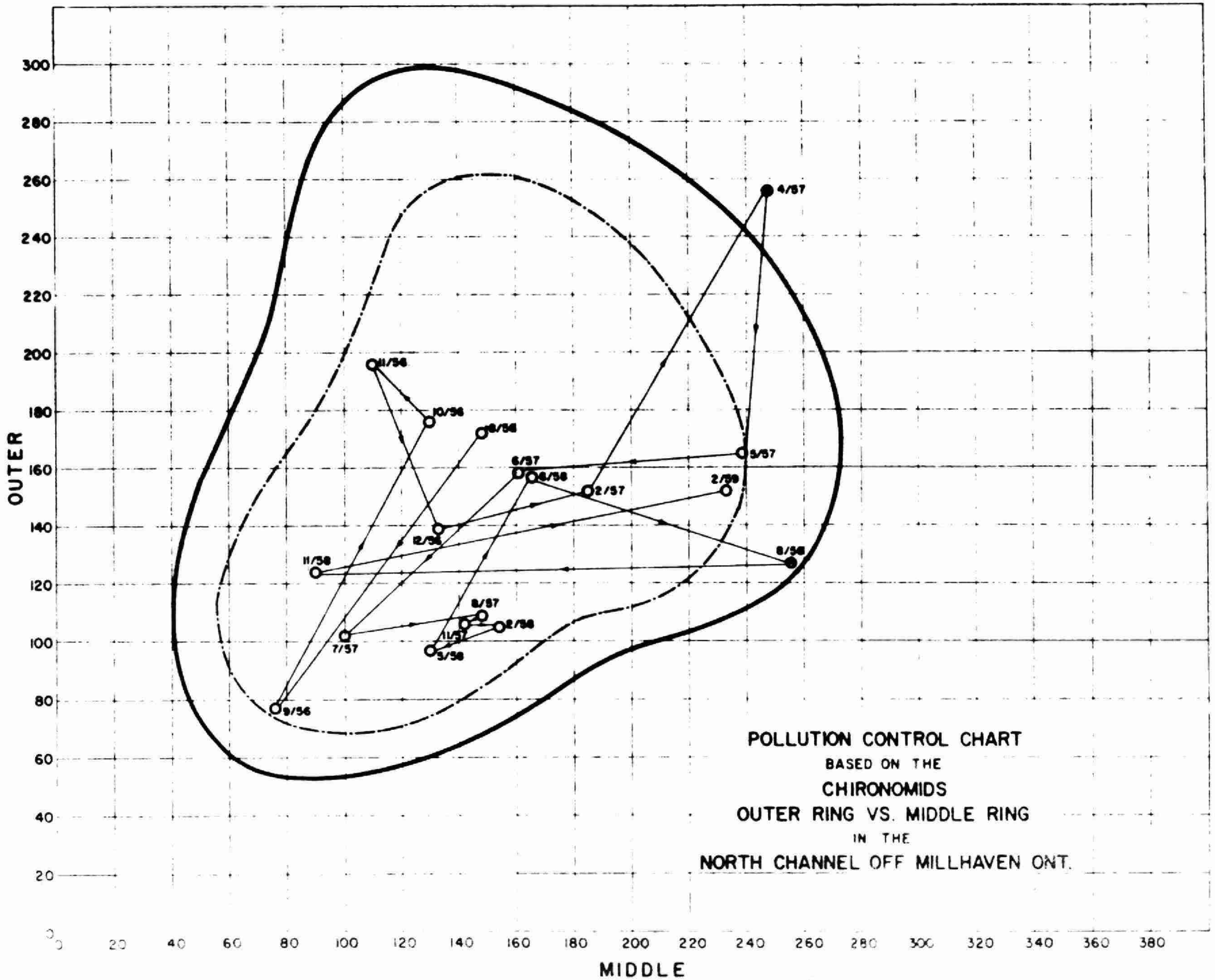

TIME 3
CONTROL LIMIT
TIME 1
TIME 2

FIG 6 c

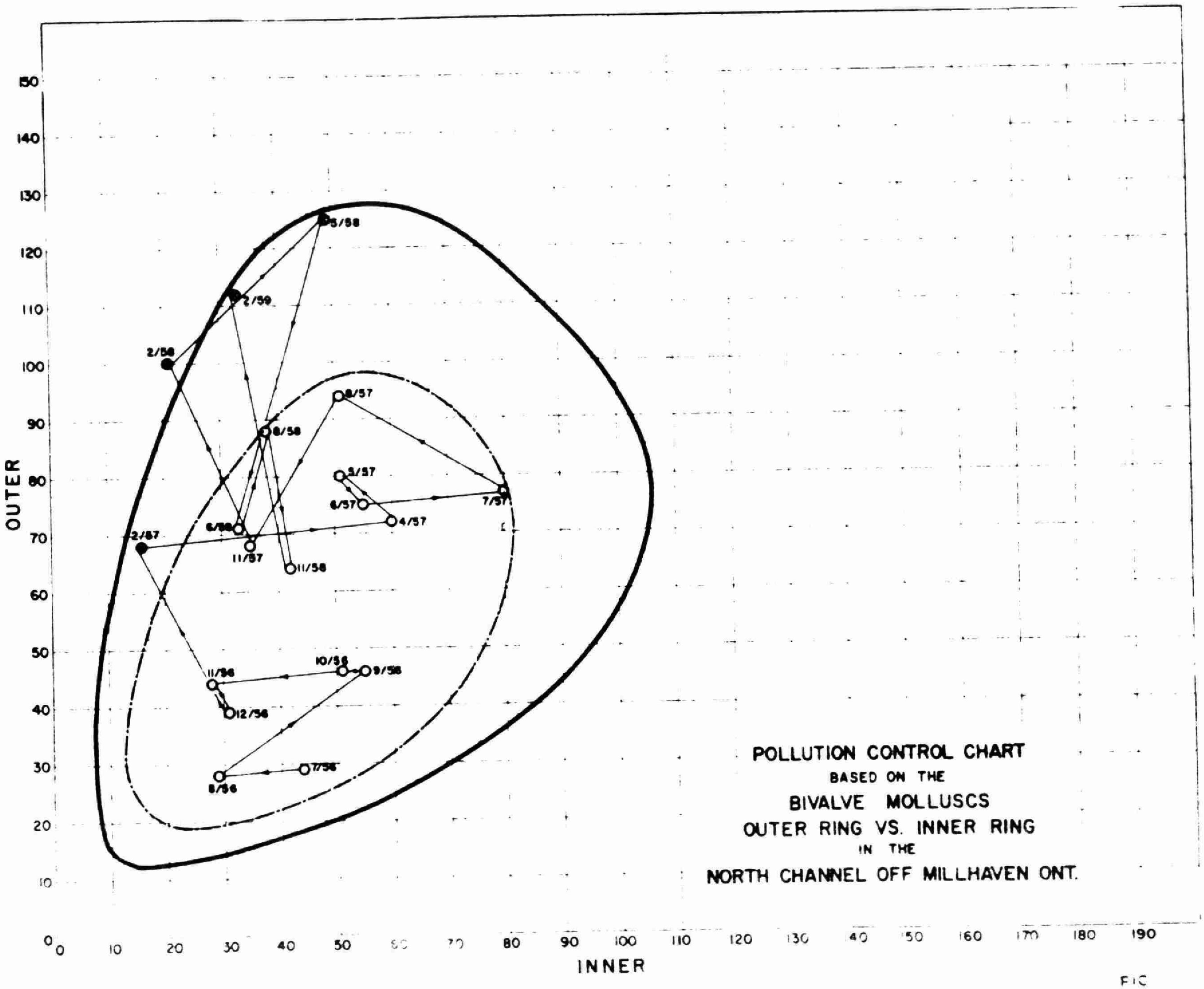


POLLUTION CONTROL CHART
BASED ON THE
CHIRONOMIDS
OUTER RING VS. INNER RING
IN THE
NORTH CHANNEL OFF MILLHAVEN ONT.

FIG 7



POLLUTION CONTROL CHART
BASED ON THE
CHIRONOMIDS
OUTER RING VS. MIDDLE RING
IN THE
NORTH CHANNEL OFF MILLHAVEN ONT.



POLLUTION CONTROL CHART
BASED ON THE
BIVALVE MOLLUSCS
OUTER RING VS. INNER RING
IN THE
NORTH CHANNEL OFF MILLHAVEN ONT.

FIG