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# 14th

# ONTARIO
# INDUSTRIAL WASTE
# CONFERENCE

## Proceedings

JUNE 1967

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**THE**

**ONTARIO WATER RESOURCES COMMISSION**

# 14th

# ONTARIO INDUSTRIAL WASTE CONFERENCE

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# C O N T E N T S

# KEYNOTE ADDRESS

D. S. Caverly,
General Manager,
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Conference Chairman

May I take this opportunity, first of all, to extend a personal welcome to the many delegates attending this 14th Ontario Industrial Waste Conference.

To start off this year's program I am going to speak on our new approach in Ontario to water quality objectives - a subject which, I trust, will be of interest to you all.

Before proceeding into this matter I would like to provide you with some background information as well as some remarks about water generally. I have had occasion to speak to a number of groups recently on Canada's position in the "water world" and of Ontario's position in particular. We are richly endowed with water in this Province. Never has this been brought home so forcibly to me as at the recent "Water for Peace" Conference convened in Washington by President Johnson. At this Conference experts and representatives of 73 nations assembled to talk about water. Their discussions ranged all the way from the philosophical approach to water resources to highly technical subjects. "Water and Environment", "Man's Control of Water", "Water and the Future of Man", "Water for Living" were some of the sophisticated subjects dealt with.

Other topics ranged from water resource planning and development - to education and training - and included such matters as water supply technology, water quality consideration, and the reclaiming of water. Finances and pollution control were also covered. There were meetings on organizing for water programs as well as on desalination.

Why am I taking the time to outline all of these subjects? Simply to emphasize two points: Firstly - the degree of refinement today in the field of water resource management, and secondly - how fortunate we are in Ontario in the abundance of the fresh water supplies which we have. Take for example, the Niagara River within a stone's throw of where we are now assembled with the millions of gallons of water which casade over the Falls every hour!

At the Washington Conference I listened to representatives of the emerging and developing nations talk about the importance of water and about their development plans. We heard from those countries where water is not only in short supply but in such short supply that it is held in reverence! Here, we have water in abundance. A map of Ontario will show the thousands of lakes and rivers which are scattered over this Province - and at our doorstep the Great Lakes, the largest body of fresh water in the world!

Such a natural resource must be wisely managed to preserve its value and to derive its full benefit. With this objective in view, the OWRC was founded in 1956 to develop and administer a water management program for Ontario. During the years which followed a program embracing both water quantity and quality has evolved. We have prided ourselves in always keeping abreast of the latest developments. Continually changing policies, therefore, have been adopted to take advantage of these developments and hence our announcement of a change in "Policy Guidelines" with respect to water quality objectives.

The present objectives for water quality control in the Province of Ontario have been in force since the Commission was formed, with only slight modifications having been made over the years. A number of general parameters have been used such as coliforms, BOD, phenols, pH, etc. Most of you are quite familiar with these objectives.

Experience has shown, however, that there is a number of technical and administrative problems associated with the application of the present objectives. Late in 1966 a committee on water quality objectives was formed within the Commission. The work of this Committee covered an appraisal of existing objectives as well as an examination of the problems to which I have just referred.

The Committee's task was very complex and one requiring comprehensive review and consideration of basic principles and possible policies preparatory to a thorough study of the many detailed technical areas.

In the course of its work the Committee reviewed key aspects of the technology of environmental water quality analysis and forecast. These basic considerations were followed by a review of the water quality objectives employed by various state, provincial, national and international agencies. Study was made of the concept of the beneficial use of water and the need for quality criteria to guide efforts aimed at preserving water for the desired uses. A review was then made of the legal and judicial aspects of the problem.

With the benefit of this background, the Committee developed conclusions on its initial work and formulated a series of suggested guidelines for future policy as well as a possible timetable for completion of the revisions to the objectives. The policy guidelines and the subsequent procedure comprise the preliminary report of the Committee on water quality objectives.

The procedure referred to above includes: the development of a statement on the basic objectives for water quality in Ontario, the development of plans for water quality control in drainage basins where higher than the minimum requirements are needed, and an interim procedure for the case by case management of pollution problems until specific plans for the major drainage basins or systems are evolved.

The work of the Committee led to the following conclusions upon which the policy guidelines have been founded:

1. Understanding of the polluting effects of both treated and untreated municipal and industrial wastes on natural ground and surface waters has been incomplete.

2. One set of quality objectives intended for application across the Province provides too broad a base for the planning of pollution control measures in areas where development is intensive or in drainage basins where low streamflows are common.

3. Although minimum requirements are helpful in many cases, these should be made more stringent in areas of intensive water use to make water available for all reasonable uses.

4. Objectives should be used as guides to develop alternative plans and designs for the best use of water. This will lead to:

   (a) care in the design and operation of waste treatment and other pollution control works for protection of public health and desired beneficial uses of water, and

   (b) judicious usage of waters for waste assimilation so that the orderly growth of municipalities and industries in desirable locations will be possible.

5. Meaningful long term plans for pollution control in the drainage basins of the Province will require the application of systematic methods of scientific and engineering analysis.

I wish to now outline in detail the policy guidelines that have been adopted by the Commission, and are now being made public for the first time today.

## POLICY GUIDELINES

1. The provincial water resources will be utilized wisely in the best interests of the people of Ontario. This will require the restoration and maintenance of water quality for the greatest possible use. Towards this end, water quality objectives should take into consideration the use and value of water resources for public, agricultural and industrial water supplies, propagation of fish and wildlife,

recreational purposes, aesthetic enjoyment and other legitimate uses.

2. There will be a constant effort to improve the quality of water, for it is recognized that the improvement of the quality of water makes it available for more uses.

3. Minimum quality control objectives will be set to apply to all waters of the province; more stringent objectives can be set for any individual situation dependant upon use, and in the future, generally more stringent objectives may be set for specific drainage basins or drainage areas.

4. In general, beneficial uses of water will be the controlling factors in determining the water quality objectives in any drainage basin. Where the use of water for the assimilation of treated wastes in a properly controlled fashion within a drainage basin is recognized as a reasonable use, it should be compatible with the other uses of that water.

5. Economic, health, aesthetic and conservation values which contribute to the social and economic welfare of an area will be taken into account in determining the most appropriate use or uses of a water resource. Therefore, in the establishment of water quality objectives for specific drainage basins, the opinions of agencies or persons having an interest and/or responsibility in the present or future utilization of the water in a particular basin will be solicited and evaluated.

6. For each beneficial use, there are certain water quality requirements which must be met to assure that the water will be suitable for that beneficial use. The co-operative assistance of technically qualified persons who are specialists with regard to various water uses will be soughtin determining the requirements.

7. Caution will be exercised in selecting numerical values for parameters to be included in any objectives for water quality; only those values will be included for which sound information on applicable levels is available. In the absence of appropriate numerical values, the objectives will consist of verbal descriptions in sufficient detail as to show

clearly the quality of water intended.

8. Water quality objectives will be revised periodically as new information and conditions develop. Objectives will not be considered final or absolute as increases in scientific knowledge of the effects of wastes on the environment will inevitably require their improvement.

9. All wastes, prior to discharge to any receiving watercourse will receive the best practicable treatment or control. Such treatment must be adequate to protect and upgrade water quality in the face of population and industrial growth, urbanization and technological change.

10. Water quality objectives will provide an engineering base for design of treatment works by municipalities and industries. Such objectives will enable municipalities and industries to develop realistic plans for new plants or expanded facilities without uncertainties about waste disposal requirements.

11. Effluent requirements based on the applicable water quality objectives for a drainage basin will be established for each user by the Commission, in order to maintain acceptable water quality for all beneficial uses within the drainage basin. Requirements may be revised when necessary to allow for increasing or new uses of the waters of a drainage basin.

12. Any user who discharges wastewater that does not meet requirements established by the Commission, or otherwise impairs the quality of the water, will be subject to the provisions of the OWRC Act.

These new water quality objectives are to be established at once. In effect they will be materially the same as the existing objectives that are also the present declared policy of the International Joint Commission. They will be restated in the light of the <u>policy guidelines</u>, that I have just reviewed, and will be a statement of the minimum water quality requirements <u>applicable to all waters in Ontario</u>.

In drainage basins where the need for quality objectives <u>more stringent</u> than the minimum requirements described above is indicated the following procedure will be used:

(a) Definition of water use practices and evaluation of quality requirements throughout the river or drainage basin requiring this specific approach,

(b) determination of existing water quality and forecasts of quality under various conditions and combinations of water use, and

(c) establishment of specific water quality objectives within a comprehensive plan for the drainage basin.

Until definite plans for water quality control throughout heavily used drainage basins are developed, effluent requirements will be established for individual users.

This arrangement will permit determination of the effluent requirements on the basis of the effects waste discharges have on the local water environment. It will allow reasonable use of a stream or lake for waste disposal until an overall plan for pollution control in the drainage basin can be developed, while also providing assurance that the approved use will be reasonably compatible with the eventual plan.

How is this new program to be put into effect - and how will this affect the matter of industrial waste treatment?

Firstly, this will mean a substantial increase in our water quality monitoring and laboratory activities. There has been, of course, a tremendous increase in our surveillance program in the last few years. We are now in third year of our Great Lakes surveys with four chartered vessels covering all of the Great Lakes except Lake Michigan. Our inland fleet has been augmented with the addition of our latest pride and joy - the "Monitor" - a 19 foot "inboard - outboard" cruiser purchased last month and which will be assigned principally to harbour work.

We now have a research laboratory in London in addition to our main one in Etobicoke. Others are planned for the near future.

Planning and budgeting are already well underway to start the necessary additional field and laboratory programs associated with this enlarged program. In the meantime, a selection of drainage basins in southern and northern Ontario, requiring the establishment of specific water quality objectives and pollution control requirements, will be made.

What effect will this have upon industry? It will mean a more realistic approach to waste treatment keyed in to the use that is being made of the water. Treatment units can now be specifically designed to meet the needs of the receiving stream. Under these new guidelines unreasonable demands with respect to the degree of treatment will be eliminated. This is a point long made by industry - that demands for degrees of treatment higher than necessary should not be made.

Conversely, in some areas, higher demands <u>will</u> be made. This new policy is not stream classification. It is a scientific approach to the use of our waters based upon new trends and ideas. There will be no lowering of the present objectives for water quality presently in use in Ontario. No change is contemplated in our present policy regarding industrial waste treatment. The waste treatment program will continue and, in fact, will be accelerated.

It simply represents a more realistic approach to water use.

It has been a pleasure addressing you today, and I am glad to have had this opportunity of outlining our new policy guidelines with respect to water quality objectives in the Province of Ontario.

SESSION CHAIRMAN
K. H. SHARPE
ASSISTANT GENERAL MANAGER
ONTARIO WATER RESOURCES COMMISSION

# "POTATO PROCESSING WASTEWATER TREATMENT"

BY

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Potato processing waste treatment is complicated by the normally high organic load in the wastewater and the location of the plants. The plants are generally situated in rural areas which frequently do not have wastewater treatment facilities. Where plants are present, the high organic content of the waste may seriously overload them. A measure of the problem can be estimated when it is known that 1,220 million pounds of potatoes were processed into a frozen product in 1965 in the United States (1).

## Objective

It is the objective of this paper to present a review of the treatment methods for potato processing wastes with their design criteria and expected efficiency. It is intended that potato processing wastes be limited to those plants producing french fries, potato chips, potato flakes and other fried potato products but is to exclude potato starch production.

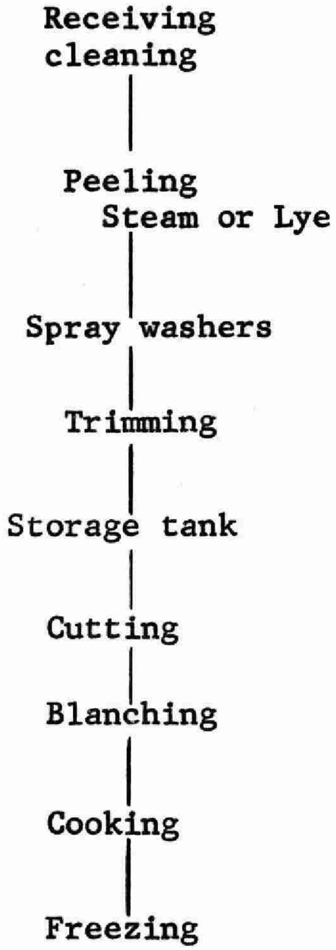
## Waste Characteristics and Plant Flowsheet

The general plant flowsheet for the production of french fries or related products is shown in Figure 1. The potatoes are washed and cleaned. This water is high in inorganic solids but relatively low in volume and BOD. The peeling operation by either the lye or steam peel method loosens the skin which is removed in the following washer. The major part of the plant BOD and suspended solids is created in this operation. The following operations are used to cut the potato and prepare it for frying. In many plants the water from these following operations is recycled within the plant. Small pieces resulting from the cutting operation are frequently screened out and used for a fried molded potato product.

The waste measurements of major importance are BOD, suspended solids and water quantity. (All gallons referred to in this paper are U.S. gallons). Data reported in the literature and from various investigations by the authors are shown in Table 1 on a per ton of raw potatoes processed basis. The data varies from one plant to another as is common in industrial operations. The average data indicates that the unit concentrations of BOD and suspended solids are 1450 mg/l and 1740 mg/l respectively.

The pH of the waste is near neutral if the steam peeling process is used but is from 10 to 12 if lye peeling is used. This high pH is caused by dragout of the sodium hydroxide from the lye peeling tank on the surface of the potatoes. Atkins and Sproul (2) showed that the total alkalinity of the spray washer from a lye peel operation was 3,360 mg/l. They also showed, however, that this alkalinity did not interfere with the biological oxidation of the waste. It has been widely noted, however, that the primary sedimentation tank sludge from lye peel plants does not dewater readily unless treated in a special fashion. This is discussed below in the section on sludge handling.

FIGURE 1 POTATO PROCESSING PLANT FLOWSHEET



# TABLE 1

## POTATO PROCESSING WASTE CHARACTERISTICS

| Plant location and type of peeling | BOD #/ton raw potatoes | Suspended Solids #/ton raw potatoes | Water Usage gal/ton raw potatoes | Reference |
|---|---|---|---|---|
| Maine, lye | 22 | 25 | 2310 | 2 |
| Maine, steam | 40<br>(after screening) | 55 | 7700 | Authors |
| Maine, steam | - | 28 | 3360 | 3 |
| North Dakota, lye | 79 | 70 | 2640 | 4 |
| Idaho, steam | 40<br>(approximately) | 35 | 2670 | 5 |
| North Dakota, lye | 49 | 75 | 5000 | 6 |
| North Dakota, lye | 50 | 83 | 7000 | 6 |
| North Dakota, lye | 79 | 114 | 3000 | 6 |
| (These N.D. data are for a coarse screened waste) | | | | |
| Average | 51 | 61 | 4210 | |

Nitrogen and phosphorus are present in sufficient quantities to support biological oxidation of these wastes. The phosphorus to BOD ratio of a lye peeled composite waste was 1 to 14 (2). Total nitrogen to BOD ratio of a screened steam peeled waste has been observed to be about 1 to 12.

In the estimation of plant waste quantities for a proposed new plant it is frequently necessary to use the expected product production furnished by management. It has been our observation that the ratio of product to raw potatoes used is about 0.5. In some plants it has been observed to be as low as 0.35. The major part of this loss, of course, is water which is displaced from the potato during processing.

## Inplant Waste-Reduction

Inplant reduction of waste quantities should be made before proceeding to wastewater treatment. Generally, potato processing plants today use the small pieces resulting from slicing for the production of other products. If this is not being done it should be examined for its feasibility. Water recycle within the plant should be practiced. Cleaner water from the operations following the slicing can be used in the spray washers.

Highlands et al (3), in a study of water conservation in potato processing plants, have suggested that the water from the refrigeration condensers and compressors could be reused. This volume amounted to about 810 gallons per ton of potatoes processed. It appeared to be of high quality with no suspended solids nor coliform bacteria.

Plant management should also attempt to prevent, or minimize, the time of contact of the sliced potato with water. The data in Table 2 is for an experiment to determine the extent of leaching of solubles from potato pieces. Maine Russet potatoes were cut into one quarter inch cubes and 150 gms (drained wet weight) placed in a beaker with 1 1/2 liters of distilled water. The starch liberated during the cutting was also added. The potatoes were mixed for the indicated times and BOD determinations made. Five minutes of contact increased the BOD by 12 percent over that for the 2 minute time and by 50 percent for the 30 minute time.

It is obvious from this data that potato pieces should be removed from the wastewater as soon as possible within the plant.

## Treatment Methods

The usual treatment processes employed for potato processing wastes include screening, primary sedimentation and biological treatment by activated sludge and trickling filtration.

### Screening

Screening with mechanical vibrating screens is widely used as a preliminary treatment device. Large quantities of the relatively large pieces of potato material can be removed in this process. Work done by one of the authors (Barnes) at the New Brunswick Water Authority on a steamed peeled waste showed that 35 percent removal of suspended solids could be obtained by screening through 10 mesh laboratory sand screens. The corresponding removal of BOD was 27 percent. Preliminary sampling of the screenings from an inplant 30 mesh screen on a steam peel waste showed a solids content of 11.2 percent. Blinding of the screen has been controlled by steam cleaning several times a day.

### Primary sedimentation

Primary sedimentation presently is the single, most widely used treatment process. Reported efficiencies vary somewhat from plant to plant as indicated in Table 3 but BOD removals of from 50 to 70 percent and suspended solids removals as high as 80 percent might be expected. These removals were obtained with overflow rates of about 600 to 1000 gpd/sf. The authors, in a settling column study, observed occasional removals of up to 50 percent of the suspended solids but a removal of only 20 percent of the BOD. When the suspended solids removal increased to about 70 percent, the BOD removal increased to 40 percent. In these cases a large part of the suspended solids was evidently inorganic which had no BOD but which settled very readily.

## TABLE 2

## LEACHING OF ORGANIC MATERIAL FROM SLICED POTATOES IN WATER

| Time of mixing minutes | BOD mg/l |
|---|---|
| 2 | 200 |
| 3.5 | 210 |
| 5 | 225 |
| 10 | 230 |
| 30 | 300 |

Conditions: Potatoes - Wet drained weight - 150 gms
Dry weight - 26.4 gms
One quarter inch cubes
Water - 1 1/2 liters

## TABLE 3

## PRIMARY SEDIMENTATION RESULTS FOR POTATO PROCESSING WASTES

| Type of Waste | Overflow rate gpd/sf | BOD Removal % | COD Removal % | Suspended Solids Removal % | Reference |
|---|---|---|---|---|---|
| Steam peel | * | 70 | 76 | 92 | 5 |
| Lye peel | * | - | 57-73 | - | 5 |
| Steam peel | NR | 51 | 59 | 83 | 7 |
| Steam peel | 1000** | 45 | - | 80 | Authors |
| Either | 600-800 | 50-75 | | | 8 |

NR - Not reported
* - Cannot be determined from reference
** - Based on settling column study with a scale-up factor of two.

Certain operational problems in primary sedimentation facilities have been observed. Rising sludge problems in sedimentation tanks have been observed. This has occurred primarily in those facilities which have not had automatic or close manual supervision over sludge withdrawal. Similar difficulties have also been experienced in tanks without mechanical sludge scrapers. Foam problems in sedimentation tanks with these potato processing wastes have not been observed. It has been the author's experience, however, that the addition of potato starch protein water to these processing wastes will cause severe foaming. In this case the suspended solids float to the top with the rising foam rather than settling. In one case an Idaho plant, dewatering its sludge with a centrifuge, experienced an excessive wear rate in the centrifuge (5). This was attributed to the removal of grit in the primary clarifier which subsequently passed through the centrifuge. It was planned to modify the existing clarifier by adding a grit chamber for grit removal and alleviation of the problem.

The successful dewatering of a lye peeled potato sludge is dependent upon the use of chemical conditioning agents or pH adjustment of the sludge (5) (8). The pH adjustment can be accomplished by an anaerobic fermentation of the sludge in the bottom of the primary clarifier. Clarifiers with a 12 foot sidewater depth and with a picket fence raking mechanism have been used successfully (8). Detention times have been on the order of 2-3 hours. The optimum pH for this is about 6-7 (9). This fermentation produces high local concentrations of organic acids on the bottom of the tank and acid protective treatment of the tank is necessary.

## Biological Treatment

Biological treatment of potato wastes has not been practiced on a large scale as yet. Full scale plants are being designed, however, for this type of treatment. Activated sludge, aerated lagoons and trickling filtration are being considered.

## Activated Sludge

Atkins and Sproul (2), in bench scale studies, have shown that complete mix activated sludge treatment is capable of high BOD removals at high loading rates. Table 4 presents a portion of their results. These data are for a lye peel waste which had received prior sedimentation. BOD removals as high as 99 percent were obtained with organic loadings of up to 263 pounds of BOD per day per 1000 cubic feet of aeration tank capacity. It should be noted that the sludge volume index (SVI) approached 200. This was indicative of a sludge which would need close attention in the design of its sedimentation tank.

Additional studies have been made by the authors to determine the activated sludge growth rate constant, Ks, in the equation (10):

$$\text{Percent BOD removal} = \frac{100\ Ks\ S\ T}{1 + Ks\ S\ T}$$

Where:

Ks = growth rate constant
S = mixed liquor volatile solids
T = time

The growth rate constant from these studies for a settled steam peel waste was about 0.0005 1/mg hr. This would indicate a removal of 92 percent with an aeration time of 6 hours and a mixed liquor volatile solids of 3500 mg/1.

## Trickling Filtration

Preliminary data from pilot plant treatment of a lye peel waste has been presented by Pailthorp and Filbert (11). This study was run on a settled waste using Dow Chemical Company's Surfpac. BOD removals from 1,680 mg/1 to 280 mg/1 (after settling) were obtained with a recirculation rate of 6 to 1. Loading rates on the filter were not given. It was indicated that these studies were continuing.

## TABLE 4

## ACTIVATED SLUDGE TREATMENT OF UNADJUSTED LYE PEELED POTATO WASTE WITH A SIX HOUR DETENTION TIME

| Oper. Day | BOD (mg/1) |  | BOD Removal % | BOD/1000 cu.ft. aeration, capc./day | COD (mg/1) |  | COD Removal % | Susp.Solids (mg/1) |  | Susp. Solids Removal % | MLSS (mg/1) | MLVSS (mg/1) | SVI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | In | Out |  |  | In | Out |  | In | Out |  |  |  |  |
| 1 | 1230 | 55 | 96 | 294 | 1800 | 117 | 94 | 430 | 15 | 96 | 3600 | 2700 | 115 |
| 2 | 900 | 22 | 98 | 215 | 1800 | 130 | 93 | 420 | 30 | 93 | 4100 | 3550 | 122 |
| 3 | 1100 | 51 | 96 | 263 | 1650 | 137 | 92 | 400 | 40 | 90 | 4100 | 3500 | 100 |
| 4 | 1100 | 24 | 98 | 263 | 1595 | 94 | 94 | 400 | 35 | 91 | 4300 | 3500 | 120 |
| 5 | 1100 | 18 | 99 | 263 | 1595 | 144 | 93 | 420 | 35 | 92 | 4500 | 3600 | 120 |
| 6 | 1100 | 20 | 99 | 263 | - | - | - | - | - | - | 4000 | 3200 | - |
| 7 | (see Note below) |  |  |  |  |  |  |  |  |  |  |  |  |
| 8 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 9 | 800 | 20 | 98 | 191 | 1000 | 290 | 71 | 400 | 175 | 56 | 3600 | 3400 | 180 |
| 10 | 800 | 20 | 98 | 191 | 1600 | 290 | 80 | 415 | 150 | 64 | 3800 | 3100 | 170 |
| 11 | 800 | 15 | 98 | 191 | 1000 | 120 | 88 | 450 | 55 | 88 | 4100 | 3500 | 170 |
| 12 | 1000 | 10 | 99 | 239 | 1000 | 105 | 90 | 450 | 45 | 90 | 3800 | 3300 | 175 |
| 13 | 1500 | 20 | 99 | 358 | 3000 | 150 | 94 | 450 | 40 | 91 | 3900 | 3200 | 180 |
| 14 | 1000 | 30 | 97 | 239 | 1000 | 108 | 90 | 425 | 30 | 93 | 4200 | 3700 | 190 |
| 15 | 1000 | 10 | 99 | 239 | 1270 | 135 | 90 | 430 | 30 | 93 | 4200 | 3700 | 180 |
| 16 | 1000 | 10 | 99 | 239 | 1200 | 108 | 91 | 430 | 35 | 93 | 3800 | 3200 | 160 |
| 17 | 1000 | 10 | 99 | 239 | 1200 | 120 | 89 | 410 | 40 | 92 | 3900 | 3200 | 175 |

NOTE: For some unexplained reason pH dropped without warning in aeration compartment to pH 1.5 on the seventh day. MLSS dropped to 2000 mg/1. Feeding was reduced to allow solids buildup and return to normal pH.

Table 8 from reference 2.

Sludge Dewatering

Primary sludges from potato processing may be dewatered by either vacuum filtration or centrifugation. Steam peel sludges may be dewatered without chemical conditioning while lye peel wastes must be conditioned either with chemicals or by pH adjustment. It has been indicated above that lye peel sludges can be fermented biologically in the primary clarifier and the pH lowered by this action to the 6-7 range. They can then be dewatered without chemicals. Both lye peel and steam peel sludges may become difficult to dewater if the pH drops to 4 to 4.5 or less. The authors have observed that ferric chloride in concentrations of about 2 percent will condition a soured sludge and make it dewaterable. Consideration should be given to the provision of these conditioning facilities in a plant design.

Vacuum filter production rates of about 6 pounds per square foot per hour can be obtained on either type of sludge. The solids content in the cake will be about 14 percent. Centrifugation has given a cake with 16 to 20 percent solids (5). The centrate, however, contained from 2 to 4 percent solids which was returned to the clarifier for resettling. These results were obtained with sludge concentration of 5 to 6 percent solids from the primary clarifier.

## Future Trends

The most obvious factor when one examines the future of the potato processing industry is its growth rate. It has been predicted that the United States processing of potatoes for frozen products will increase over three times in the next 10 years from 1,220 million pounds in 1965 to 3,780 million pounds in 1976 (1). This increase in production, coupled with more restrictive effluent requirements, will increase the wastewater treatment needs of this industry.

It would appear that the industry will find it necessary to consider more carefully the waste treatment aspects of its operation. Consultation should be sought before plant location and during plant design in an effort to ameliorate the subsequent waste treatment problem.

The development of a peeling method which will be entirely waste free is needed. This development would decrease the cost of waste treatment by a factor of one half or more since from 50 to 90 percent of the BOD in a plant comes from this operation.

## Summary

This paper can be summarized in the following statements:

1. Average BOD and suspended solids discharges of 51 and 61 pounds per ton of raw potatoes processed have been observed.
2. Suspended solids removals of 35 percent or more have been obtained by screening through a 10 mesh screen.
3. Primary sedimentation has given removals of suspended solids and BOD of 80 and 50 percent at overflow rates of 600 to 1,000 gpd/sf.
4. BOD removals in excess of 92 percent have been obtained with 6 hours of aeration in a complete mix activated sludge bench scale study.

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# "CHARACTERIZATION OF INDUSTRIAL WASTES BY INSTRUMENTAL ANALYSIS"

BY

H. A. CLARKE

DIVISION OF INDUSTRIAL WASTES

ONTARIO WATER RESOURCES COMMISSION

The material for this talk was gathered from my association with the OWRC Laboratories in Toronto. I propose to describe briefly the work functions of the two Chemistry Branches, with special emphasis on the application of instrumental analysis to the characterization of industrial wastes.

The instrumentation is described, some basic principles and general methods outlined briefly, and a few actual problems discussed. Polarography and atomic absorption spectrophotometry are reviewed as techniques for the analysis of metals. The use of ultraviolet and infrared spectrophotometry is illustrated by a number of examples in the identification of organics, mainly of petroleum hydrocarbons. Chromatographic methods such as gas, thin layer and paper are outlined with special mention made of pesticide residue analysis. Finally, the application of much of the above instrumentation to carbon adsorption studies is shown.

The nature of this talk is very broad in scope and is not meant to probe the subject in any great detail. Rather, I hope to show that the analysis of industrial wastes is a complex matter requiring sophisticated instrumentation for achieving best results.

## OWRC LABORATORIES

This building was opened in 1960 and provides approximately 30,000 square feet of working laboratory space. Over 100 persons, including bacteriologists, biologists, chemists, engineers and other disciplines, are active in the technical appraisal of samples pertaining to the aquatic environment and related research. In excess of $150,000 of instrumentation of all types are available for chemical analysis. In 1966, almost 300,000 chemical determinations were performed on slightly over 43,000 water samples.

## CHEMISTRY BRANCH I - Water and Sewage Analysis

This Branch performs chemical analysis of water and sewage samples collected by the various field staffs of the OWRC and other agencies. Water samples are obtained from rivers, lakes, wells, and industrial and domestic water supplies. Analyses include chloride, hardness, iron, fluoride, sodium and alkalinity. Sewage samples are obtained mainly from municipal water pollution control plants and tests include BOD, COD, suspended and dissolved solids, pH, phosphate, detergents and nitrogens as ammonia, nitrate, nitrite and total kjeldahl. Industrial wastes, on which the above tests are requested, are analyzed in this Branch to avoid expensive duplication of equipment and other facilities peculiar to these tests.

### 1. Autoanalyzers

The large numbers of routine analyses performed in this Branch present the challenge of introducing automated techniques in order to stay on top of the situation. Towards this end, two Technicon Autoanalyzers have been purchased recently. At present, ammonia and soluble phosphate are being determined, with future application to total phosphate and kjeldahl nitrogen. This type of equipment potentially lends itself to any parameter amenable to colorimetric analysis.

### 2. Titralyzers

Two Fisher Titralyzers with print-out are used, one for chloride and alkalinity (potentiometric titration), and the other for hardness and calcium (colorimetric titration).

### 3. Flame Emission Photometry

An automated flame emission photometer (EEL) is used for sodium and potassium analysis. This model internally compensates for random fluctuations in emission and has digital read-out.

Finally, a simple dropping mercury polarograph is being used successfully for the determination of dissolved oxygen in the BOD test, a distinct advantage over the time-consuming titration procedure.

## CHEMISTRY BRANCH II - Industrial Wastes Analyses

Specific identifications of the wide variety of pollutants to be found in industrial wastes are performed in this Branch, in contrast to the general parameters that describe pollution such as BOD, COD, solids, etc., which are done in Chemistry I. Attempts are made to determine the soluble organics which contribute to BOD values such as proteins and sugars, and the nature of suspended solids such as metal hydroxide flocs and clays. This Branch is divided into two sections, namely inorganic and organic analysis.

The Inorganic Section deals primarily with the analysis of metals such as zinc and chromium, and anions such as cyanide and arsenic. Detailed analysis of sludges, sediments and other solid deposits are also carried out in this section.

The Organic Section can be divided into four fields of work:

a. Specific organic determinations such as phenolic compounds, ether solubles, protein, lactic acid, tannins and lignins, etc., which are asked for regularly on a routine basis.

b. Identification of unknown organics such as petroleum hydrocarbons, natural fats, synthetic compounds, etc.

c. Carbon adsorption studies which provide a measure of the organic content of waters subject to industrial pollution by means of the carbon chloroform extractables (CCE).

d. Pesticide residue analysis in the aquatic environment mainly with respect to the chlorinated hydrocarbons such as DDT and its metabolites, and the chlorophenoxyacetic acids and esters.

As an example, to illustrate the magnitude of the workload in 1966, in excess of 5,000 analyses were performed for heavy metals which arose from industrial operations such as plating, anodizing, mining and tanneries. In metal analysis, the industrial waste sample is usually digested first with sulphuric and nitric acids to oxidize organics off to the atmosphere and then further screened to remove the presence of any interfering ions (co-precipitation, extraction, etc.) where necessary. The actual identification and measurement of the particular metal desired is then determined by one of three methods, namely colorimetry, polarography or atomic absorption spectrophotometry.

## POLAROGRAPHY

### a. Instrument

Southern Analytical Model K-1000 cathode ray polarograph with dropping mercury electrode.

### b. Basic Theory

Polarography was discovered more than fity years ago. It is well-suited to the analysis of a wide range of compounds and especially to metal ions in aqueous media.

### 1. Conventional polarography

A polarograph determines the concentration of reducible ions in a solution by measuring the current which flows when the ions are reduced electrolytically. A variable voltage is applied across the cell in which an aliquot of the aqueous sample is contained with a suitable supporting electrolyte. The cathode is formed by a drop of mercury which drips off a capillary immersed in the solution. The total current variation is proportional to the concentration of metal ions in solution. The half-wave potential is characteristic of the type of metal ions being reduced.

### 2. Cathode ray Polarography

This is also called "derivative polarography". A linear voltage sweep is applied late in the life of each drop, and a complete polarogram is obtained. The drop velocity is set approximately at seven seconds, comprising a rest period of five seconds with a deflection period of two seconds, and the deflection voltage is synchronized with the life of the drop. The height of the peak is directly proportional to the concentration of the specific metal ion of interest, which reduces at that particular half-wave potential.

### c. General Method of Analysis

A suitable aliquot of the industrial waste sample is digested to oxidize any organic material which may be present. The digested sample is made up to a fixed volume, a suitable supporting electrolyte added (usually hydrochloric acid) and a small amount of ascorbic acid to suppress oxygen. The sample is placed in glass cells, purged with hydrogen and scanned over a fixed voltage range. The metal ion is tentatively identified by the half-wave potential of the resultant curve and the concentration estimated by the height of the curve. Then, the sample is spiked with a known concentration of the specific metal and the solution scanned again. The increased peak height at the same potential proves the existence of the specific metal and aids in the determination of the original concentration of metal in the industrial waste.

### d. Advantages and Limitations of Method

Several metals can be scanned for in one solution providing that the supporting electrolyte is common to all; for example, zinc, copper, lead and cadmium if present. Specificity is excellent, accuracy is good and sensitivity is fair (0.1 mg/1).

### e. Application at OWRC Laboratories

Over 3,000 analyses were performed in 1966 on the polarograph for a variety of metals. These included zinc, lead, tin, cobalt, nickel, cadmium and copper. Confirmatory tests by colorimetry or atomic absorption are performed on the same sample when considered desirable as in the cases where legal action is involved.

The analysis of lead and tin in the same waste presents an interesting problem as both metal ions are reduced at the same potential. Ammonium citrate is used as the suppressor for tin in ammonium hydroxide. First, the sum of the peak heights of both tin and lead are measured, after which the suppressor is added which eliminates the tin peak. Lead is obtained from the reduced curve and tin is calculated by difference. The concentrations are read off standard curves prepared for each metal.

Anion analysis has been done on a limited scale to this point in time. For example, the anodic conversion unit has been used in investigations into cyanide analysis. However, in this particular instance, it would appear that the sensitivity of the polarographic method is much inferior to colorimetric procedures.

## ABSORPTION SPECTROPHOTOMETRY

Absorption spectrophotometry is based on the principle that certain displacements of electrons or atoms within a molecule are permissible according to the quantum theory. When radiant energy of the same energy required to bring about this permissible change is supplied to the molecule, the change occurs and energy is absorbed.

The wide versatility of visible spectrophotometric procedures (colorimetry) in the field of inorganic and organic analysis is briefly outlined. Atomic absorption techniques are becoming increasingly popular in metal analysis. The application of ultraviolet and infrared spectroscopy to qualitative and, to a lesser extent, quantitative analysis is illustrated by a number of problems which were solved in the laboratory.

### 1. Colorimetry

The Bausch and Lomb Spectronic 20 is the popular instrument used for visible spectrophotometry. The transistorized model has been found to be a reliable, inexpensive, sturdy instrument which gives excellent reproducibility.

In metal analysis, after oxidation of the organics and removal of other interfering ions, the metal in question is complexed with an organic dye to give a characteristic colour of that particular metal chelate. The intensity (optical density) is read off the spectrophotometer and compared to a standard curve to determine the concentration of the metal in the original waste sample. Metals such as chromium, manganese, iron and aluminum are done routinely by colorimetric analysis.

Anions in industrial wastes cover a wide range of interest such as arsenic, cyanide, sulphide, silica and phosphate. Colorimetric measuring methods are used after suitable wet chemical preparation of the sample. Some organic compounds such as certain herbicides (chlorophenoxyacetic acids e.g. 2,4-D and the s-triazines e.g. atrazine) have been determined by complex wet chemical analysis involving final colorimetric measurements. However, these results are usually checked by other available methods such as gas chromatography, if possible.

## 2. Atomic Absorption Spectrophotometry

### a. Instrument

Techtron AA-4, single beam optics, grating monochromator, laminar flow burner - from Aztec Instruments Inc.

### b. Basic Principles

Atomic absorption spectrophotometry (AAS) is one of the newest analytical techniques available to the water chemist. Discovered in Australia in the early 1950's the technique has become popular only recently due to the advances in instrumentation. The basic principles of AAS are surprisingly simple and common to all forms of absorption spectroscopy.

In AAS, the element of interest in the sample is dissociated from its chemical bonds, and placed in an unexcited, unionized "ground" energy state. The atoms are then capable of absorbing radiation at the same wavelength that they would emit if they were excited.

The source of radiation is generally a hollow-cathode lamp, whose cathode is made of the element being determined and which emits the line spectra of that element. This energy traverses the flame where some energy is absorbed by the atoms in moving from the ground state to a higher energy state. The less intense radiation falls upon a monochromator which separates and selects the pertinent resonance line for subsequent detection and measurement. AAS obeys Beer's Law and by comparison with standards, the concentration of the desired element can be calculated in the original sample.

### c. General Method of Analysis

All industrial waste samples are digested unless the samples are clear. Chelate formation of the metal to be analyzed with subsequent solvent extraction increases the sensitivity of the method many times. The sample is aspirated into a flame (a mixture of acetylene and air generally) and the absorbance recorded. Comparison against standard curves gives the required result.

### d. Advantages and Limitations

The advantages of AAS are many and varied. The instrumentation is moderately priced, simple and easy to operate, spectral interference is minimal and few chemical interferences occur. The technique is specific for a particular element and sensitivity is equal to and better than most other methods. Oxide formation by the refractory metals such as aluminum, boron and silicon in the low-temperature air-acetylene flames have been successfully eliminated by nitrous oxide-acetylene mixes.

### e. Application at OWRC Laboratories

The AA-4 has only just arrived and work has been going on for about two months. Lead, copper, cobalt, manganese and zinc have been analyzed to date. In time, it is expected that all metals of interest to be found in industrial waste samples will be analyzed by AAS.

## 3. Infrared spectroscopy

The instrument used is the Perkin-Elmer Model 221, double beam, recording spectrophotometer (2-15 micron range). Sample preparation for infrared analysis (IR) includes the use of fixed and variable thickness cells, nujol mulls, casts, smears, and KBr pelletizing techniques. Pyrolysis of certain organic compounds and subsequent examination of the pyrolysate liquors has been practised with some success.

All samples that require organic analysis are subjected, if at all possible, to IR analysis at some stage in the proceedings. As is well-known, the IR spectrum of a pure compound provides a "fingerprint" peculiar to that particular compound and therefore specific. Infrared analysis is the most powerful technique in the OWRC Laboratory for the identification of organics.

The greatest problem involved is the separation of a pure compound from all other organic material present in the original sample in order to obtain a clean spectrum. Towards this end, techniques of multiple solvent extraction, column chromatography, preparative thin layer chromatography (where applicable), gas chromatographic separations (for micro pellets), fractional distillation and other separation procedures are all utilized.

## Typical Problems Solved at OWRC Laboratories

### a. Dowtherm Analysis

A manufacturer of synthetic fibres using Dowtherm as a heat transfer medium was inadvertently losing appreciable quantities of Dowtherm to a Bay. Commercial fishing was done to a limited extent within this Bay. The off-tastes in the flesh of fish caught in the Bay alerted the Company and the OWRC to the problem of organic losses in the industrial effluent. In-plant surveys pointed to the loss of Dowtherm as the possible source of the taste problem. Mud samples from the Bay after intensive clean-up showed the presence of Dowtherm by means of infrared analysis and attempts to isolate this compound from the fish were successful. Gas chromatography provided additional confirmatory evidence.

### b. Oil Pollution

This particular case resulted in a prosecution against a cargo ship on the Great Lakes. Incidentally, oil pollution on the Great Lakes by ships has been a major problem in the past. Strict legislation and sizeable fines have helped to ease the situation somewhat. In this example, the IR spectrum of the fuel oil taken from the bilges of the ship in question, matched exactly the sample of oil taken from the Welland Canal Locks. A conviction was obtained.

## 4. Ultraviolet Spectroscopy

The instrument used is the Unicam SP-800B, double beam, recording spectrophotometer with a range of 190 to 450 millimicrons (to 850 mu with the tungsten source and appropriate filter).

Ultraviolet spectra (UV) are not specific as are IR spectra in the positive identification of organic compounds. Instead, UV spectra provide useful information on the functional groups present within a molecule. Therefore, the structural information derived from UV analysis complements other data and aids in arriving at a better picture of the compound.

In the OWRC Laboratory, in lieu of other satisfactory methods of analysis, UV spectra have been used to tentatively identify certain materials and even estimate concentrations in a semi-quantitative fashion.

### a. Low Boiling Petroleum Hydrocarbons

Gasoline contamination of wells and ground water supplies is a more frequent occurrence than is generally expected. This is especially true in the rural areas due to leakages in underground storage tanks and lines of gas stations.

The usual procedure is to obtain samples of gasolines from stations within the area and check the UV spectra against that of the sample extract. The aqueous sample is usually extracted with 25 mls of chloroform ($CHCI_3$) and run against $CHCI_3$. No evaporation of solvent is involved in the procedure, because of the extremely volatile nature of the hydrocarbons.

A series of peaks occur within the 240 to 270 millimicron region. Great care and experience is required in the interpretation of the spectra. Concentrations can also be estimated roughly.

### b. Herbicides

The chlorophenoxyacetic acids (e.g. 2,4-D and 2,4,5-T) and the s-triazines such as Atrazine and Simazine have been estimated by UV methods. Colorimetric analyses are usually performed to confirm the UV results but these procedures are usually more complex and lengthy. The recent acquisition of a gas chromatography has helped in providing additional quick confirmatory evidence of such compounds.

## CHROMATOGRAPHY

### 1. Gas Chromatography

#### a. Instrument

Varian Aerograph (1520 series) with dual columns, temperature programmer, flame ionization detector, electron capture detector, dual pen recorder and sodium thermionic kit for phosphorus determinations.

#### b. Basic Principles

Gas chromatography (GC) is used for qualitative and quantitative analysis of gaseous mixtures. The gaseous sample is separated into its various components in the chromatographic column which is the "heart" of the instrument. The detector responds to a particular physical property of the separated gases which is recorded for quantitative estimation.

#### c. Method of Analysis

The sample to be analyzed (water, mud or fish flesh) is solvent extracted to separate the organic matter. Clean-up of this extract is sometimes required depending on the nature of the extract and the material to be identified. Microlitre quantities of the organic extract in a suitable solvent are injected into the chromatograph and vaporized. The homogeneous mixture is swept through the carefully selected column by an inert carrier gas and separated into its various components. The height of each peak is proportional to the concentration of the compound and can be calculated by comparison with standards of known concentrations.

#### d. Advantages and Limitations

GC is a quick method of analyzing complex mixtures of organics. Very small quantities are required for analysis and detection limits are as low as $10^{-9}$gm/litre to $10^{-12}$gm/litre with certain types of detectors.

The method is non-specific but by varying columns, identifications can be made with reasonable certainty using retention times.

### e. Application at OWRC Laboratories

GC is used in the separation and identification of organics in industrial wastes, especially from the organic chemical industry. Phenolic materials, petroleum hydrocarbons, petrochemicals and other organics are analyzed using the flame ionization detector. Detection limits are in the $10^{-10}$ to $10^{-12}$ gram/litre range. Thus, GC provides an excellent analytical tool for trace analysis.

GC is also being used in the analysis of pesticide residues in the aquatic environment. Since pesticides are powerful poisons, even trace concentrations (in the microgram/litre range) can be very harmful. Water samples, hydrosoils and fish are analyszed in the laboratory particularly for chlorinated hydrocarbons and especially for DDT and its metabolites. The chlorinateds are quite resitant to chemical and biological breakdown within the environment and persist for long periods of time without decomposing. Plant and animals therefore accumulate these materials and concentrations can gradually reach lethal limits or cause other harmful side-effects.

Pesticide analysis is a delicate art and science which requires good instrumentation, excellent skills and experience in the field of interpretation of results. In our laboratory, the electron capture detector is to be complemented in the near future with a microcoulometric detector assembly. This detector is specific and absolute in quantitation for chlorinated hydrocarbons.

Contamination usually arises from agricultural spraying operations and from a number of industries that produce pesticides and herbicides.

## 2. Thin Layer and Paper Chromatography

The Desaga-Brinkman thin layer equipment is used extensively within the laboratory particularly in the field of pesticide residue analysis. The technique is used primarily as a clean-up procedure prior to injection of the sample into the gas chromatograph. TLC is relatively quick (less than 30 minutes for most separations) and simple but is only semi-quantitative in nature.

Paper chromatography is also used for pesticides but only if GC and TLC methods are not available. PC requires a much longer time (of the order of two to three hours) for resolution of spots and is essentially qualitative in nature.

## CARBON ADSORPTION STUDIES

The expansion of the organic chemical industry over the past two decades has led to the appearance of many thousands of new compounds. Many of these compounds find their way into surface waters by a variety of means.

Carbon filters offer a means of sampling river flows and concentrating the organics present in the water for subsequent qualitative and semi-quantitative analysis of the extract. The carbon chloroform extractables (CCE) give an indication of the organic contamination of a river or lake by industrial pollution. All waters contain some CCE, but clean waters usually contain less than 25 microgram/litre (mg/l). Waters contaminated by industrial wastes could contain several hundres or thousands of micrograms per litre.

The OWRC has four carbon filters operating regularly on a monitoring basis on the Great Lakes. Four more filters are being built for special investigations such as taste and odour problems and chemical discharges which have been found to be toxic to aquatic and other forms of life.

The type of filter is similar in principle to that described in the 12th Edition of Standard Methods, but modified somewhat as to its construction by the OWRC laboratories. Operating conditions are ¼ gpm flow rate for a total of 3,000 gallons filtered through a mixture of 10 and 30 mesh charcoal.

The organics adsorbed onto the charcoal are stripped with chloroform ($CHCl_3$) which is evaporated off leaving the crude extract (CCE). The CCE fraction is separated through solubility and pH changes into a number of groups. These are the ether insolubles, water solubles, bases, weak acids, strong acids and neutrals. The neutral fraction is further broken down by column chromatography into aliphatics, aromatics and oxygenated compounds.

Each fraction is subjected to infrared and sometimes ultraviolet examination. Interpretation of these spectra are then attempted. If the spectrum of a particular cut is not clean, then gas chromatographic separation can indicate the number of compounds present in that group.

The aromatic group is of great interest as this usually contains the taste and odour components. Also, pesticides such as the chlorinated hydrocarbons and phenolic materials tend to show up here.

Intensive studies are being carried out on the contribution of organics to the St. Clair River by the industrial complex at Sarnia. CCE levels at Point Edward above Sarnia are approximately 40 to 50 mg/1. At Lambton, about 26 miles below Sarnia and assuming relatively good mixing of the river, the level of CCE is of the order of 100 mg/1, (and has been as high as 150 mg/1) resulting in an additional average concentration of about 50 mg/1. The USPHS recommends a limit of 200 mg/1 CCE in a drinking water supply.

A typical separation of a CCE extract from the St. Clair River into its various groups followed by infrared examination of the extracts, has shown the presence of absorption bonds indicative of aliphatic petroleum hydrocarbons, asphatic material, phenolic compounds, organics with sulphonated groups (similar to detergent bases), fuel oils, rubber compounds, styrene-butadiene polymers, latex, etc. This information is useful in determining the source of the material knowing the industries located on the river.

The CCE gives only the minimum concentration due to the fact that losses occur in the laboratory separations and analysis. Also, the charcoal does not adsorb all organics equally well and thus some species are readily adsorbed while others are not and pass through the filter. In addition, the adsorption process is a dynamic one and desorption also occurs. Thus, the CCE is at best only semi-quantitative and gives an indication as to the nature of some of the compounds present in the river.

## SUMMARY

The paper summarizes briefly the instrumentation available for analysis and characterization of industrial effluents at the OWRC Laboratories. For the immediate future, a carbon analyzer and an emission spectrograph are

slated as desirable requirements. The use of carbon by industry as a parameter for monitoring losses of organics to sewers is becoming increasingly popular. For particular waste streams, correlations can be obtained between BOD or COD and total organic carbon. It is expected that carbon analysis will play an important role in water pollution technology in the future.

BANQUET HEAD TABLE

# "THE APPLICATION OF INSTRUMENTATION IN AUTOMATIC CONTROL AND WATER CONSERVATION"

BY

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## INTRODUCTION

The purpose of this paper is to indicate in general terms the manner in which instrumentation may be applied for the automatic control of effluent treatment processes and for the better utilisation of water in rinsing operations. In a presentation of this type it is only possible to give a general outline of the subject, and for fuller details of instruments reference should be made elsewhere (1-5).

The advantages of instrumentation are several. The extra costs which the installation and maintenance of instruments and automatic control equipment involve are more than offset by the greater efficiency in plant operation, the savings in space from the possibility of smaller treatment systems, and the capital economies which can result with these smaller plants. It is in fact commonly found that the intelligent use of instrumentation can reduce the size of treatment tanks to a point where the savings offset the extra costs of the instrumentation. The other feature is that instrumentation permits the use of continuous treatment, which is nearly always far cheaper than batch treatment.

A side feature often consequent upon the use of automatically controlled effluent treatment is the possibility of water conservation. Savings thus achieved can make a significant contribution towards the installation costs of treatment plants.

## AUTOMATIC pH CONTROL

Of all the various types of instrument employed on treatment plants, pH controllers are amongst the most common. This is primarily because pH is considered an important parameter and also because an upper as well as lower pH limit is usually set for discharge of effluents. Consequently dosing to excess of, for example, acids with alkalis is not technically a sensible approach, quite apart from the wastage which this causes.

### 1. Basic Principles of pH Measurement (1.2)

pH measurements for control of plant operations are nowadays almost exclusively effected through the use of electrochemical measuring systems. These consist of a pH-sensitive electrode, the responsive part of which is constructed in glass, and a reference electrode to complete a measuring circuit. The two electrodes are normally combined into a single system for simple insertion into the vessel or pipeline and the connections are led back to the measuring instrument, known as the pH amplifier. It is of great importance for theoretical reasons to measure the voltage which develops across these two electrodes on open circuit or very low measuring currents ( $< 10^{-9}$ amp.). Since the amplifier is required to measure voltages of the order of millivolts (rather than volts) on open circuit with input resistances deriving from the glass electrode itself of the order of 200 megohms, it is a highly specialized electrometer.

The pH is related to the open circuit potential difference between the glass and reference electrodes by an equation of the following type:

$$E_{pH} = E^{o}_{pH} + 0.2TpH$$

where $E_{pH}$ is the observed voltage, $E^{o}_{pH}$ is a zero term and T is the temperature in degrees Absolute. The significant feature of this equation is that the voltage is linearly related to the pH of the solution in which the electrodes are immersed, although, as is well known, pH is logarithmically rather than directly related to the free acidity of the system (see, e.g. ref 2, Ch.2).

$$pH = f(-\log a_H)$$

where $a_H$ is the hydrogen ion activity.
(note that pH does not necessarily indicate total acidity as determinable by titration; in effluent treatment the quantity of reagent required is the titratable value, and the electrochemical measurement simply provides an indication of the approach to and of the titration endpoint itself.)

A typical pH electrode system and pH amplifier incorporating a meter for direct read-out of pH values is shown in Figure 1. It will be noted that the instrument incorporates adjustable relays which can be employed for automatic control purposes, to be described below. As an alternative the relays may be used for providing alarms either in relation to outfall pH or as a warning of dosing failure.

## 2. Application to Automatic Control

Simple monitoring of pH in the treatment plant is of little value unless the data are used to control the dosing of reagents. The pH amplifiers transmit an electrical signal which is proportional to the pH value, and this may be used to trim the rate of reagent dosing (constituting a form of proportional control) according to the magnitude of the signal, or alternatively, relays incorporated within the amplifiers can be used simply to switch reagent dosing systems on an off around the set values of the relays.

The automatic control arrangement is shown schematically in Figure 2, representing the so-called "closed loop" system. pH disturbances away from the desired value are observed by the pH electrodes, a signal is transmitted to the pH amplifier, and the deviation from the desired value causes the relay system to initiate dosing. This continues automatically until the pH reaches the desired value again, when the signal from the electrode to the amplifier closes the relay and the dosing stops. The term closed loop is applied to indicate the continuous nature of the system as opposed to an open system where external intervention is needed to maintain the continuous control process.

### (a) Two-Step (On-Off) Control

This is the simplest means of automatic control and is by far the commonest in effluent treatment systems. It is usually adequate for all but the most varying of effluents, and its operation has the further advantage of being simple to understand and maintain. Thus if in the amplifier system a control relay is set to a pH value of 8.5, and the effluent is flowing acid, then the electrical circuitry can be arranged so that the dosing system is operating when the pH is below 8.5 but cuts out when it reaches or is above 8.5. In the full operation of a pH-controlled plant, therefore, the actual pH will tend to oscillate around the set value (see Figure 3 (a)), the magnitude of the oscillations depending on the degree of variation in effluent strength, the variation in effluent flow rate, the holding time used in the treatment vessel, the strength of reagent and the rate of reagent dosing. The proper design of a treatment plant takes account of these various factors so as to minimise the degree of oscillation.

One means of minimising oscillation, particularly when the effluent may vary widely in its reagent demand, is by the use of multi-stage on-off control. For example, with an instrument such as that shown in Figure 1(a), the second relay can be set to a point slightly displaced from the first control relay. Thus if in the example above the dosing system cannot cope with a temporary strong acid surge, and the pH drops to a lower value, then the second relay can be used to bring in boost dosing when the pH reaches the second relay set point. Obviously the more relays available the more stages can be used, but generally two-stage control suffices. The circuitry can be arranged so that the boost system does not stop dosing until the pH reaches the first relay (main) pH set point, thereby providing an independent dosing system in the event of main dosing failure (quite apart from the boost feature).

### (b) Proportional Control

A more advanced form of control is achievable by using the output signal from the pH amplifier. Let us consider that we wish to control the pH of an acid effluent stream to a value of 8.5, and that without dosing the pH will tend to fall to a value such as 3.0. If the reagent dosing were made in a haphazard manner then the pH value would vary between 3.0 and 8.5, and the pH amplifier would emit signals proportional to these pH values. Proportional control utilises this variation in a closed loop system by arranging for the reagent to be dosed in quantities proportional to the difference between the observed pH value and the desired pH value. Thus if the pH is 3.0 then the proportional controller will arrange for the dosing to be effected at a rate related to the difference between 3.0 and 8.5, i.e. 5.5, while if the pH is 5.0 then the rate of dosing will be proportional to the difference between 5.0 and 8.5, i.e. 3.5. It can thus be seen that the stronger the acid the greater the rate of dosing, so that a more rapid adjustment to the desired value is possible than with the simple single stage on-off system which does not identify differences in effluent input concentration. Since the pH varies logarithmically with the free acid concentration, in principle it would be necessary to dose at a logarithmically increasing rate to achieve true proportional control with these systems. In fact this is rarely carried out and in any case in practical systems the so-called "rangeability" (the range over which the dosing rate can be varied) of reagent dosing systems rarely exceeds 30:1 for a single dosing stage. This only corresponds to a pH deviation of approximately 1.5 from the desired value, and above this deviation there is no increase in dosing rate. More complicated dosing arrangements can permit much higher rangeabilities, but these are correspondingly more expensive.

The primary value of proportional control is in the speed with which it can adjust the pH to the desired value, provided the variations in effluent concentration are not excessive. The use of proportional control with a simple single stage dosing system will not overcome wide variations in acid concentration, as is sometimes erroneously supposed, for the reasons just given. In fact also proportional control alone will not achieve a return to the desired value, but to a level slightly displaced from this. This displacement is known as "offset". Offset arises from the fact that proportional control systems operate from the difference between a desired value and the actual value, in contrast to on-off systems, which are linked to the desired value itself. To illustrate this point we may take the following example. Suppose an acid effluent is flowing and the dosing value is set up so as to correct for a given flow rate when the pH is two units away from the desired value. If the flow rate increases (corresponding to an increase in the total quantity of acid to be treated) but the pH remains the same, then further alkali is actually needed to achieve the desired value. However since the control system only observes the pH, which will not necessarily vary if the flow rate changes, then the dosing valve will not open any further and the pH will not achieve the desired value. An illustration of this is shown diagramatically in Figure 3 (b).

Offset may be overcome by the use of a further control device known as "integral" or "reset" action, which operates such that the dosing valve or system is caused to move at a rate which is proportional to the deviation. In proportional control the valve position only is simply defined by the deviation, whereas in integral control the valve opening moves at a rate defined by the deviation. Integral action alone is somewhat unstable and the system tends to hunt, so in practice proportional plus integral (p + i) are usually employed together. The ratio of proportional to integral actions is normally set up so that the greatest degree of proportional control can be employed without incurring offset, thereby retaining the advantages of speed of response in proportional systems. A comparison of the effectiveness of correction of a deviation with p + i control as opposed to p control may be gained from inspection of Figures 3(b) and 3(c).

A further control action, known as "derivative", is achieved by causing the valve to move by an amount proportional to the rate of change of deviation. This type of control cannot be used on its own because it does not necessarily return the variable to the desired value, but may be incorporated with p+ i control. It is rarely used in pH control applications, but may be employed where very rapid changes in effluent concentration may occur. Usually, however, this is offset by the use of somewhat larger holding time in the reaction vessels, a procedure which is also a somewhat safer alternative in view of other factors involved in the neutralisation operation (to be discussed below).

An electrically operated type of p + i controller is shown in Figure 4, this instrument being connected to the output from the pH amplifier such as that shown in Figure 1, provides the signals to the dosing system. Commonly used alternative controllers in process control (as opposed to effluent control) are of the pneumatically operated variety.

### (c) Response Lags

The responsive effectiveness of any control system, whether it be automatic or manual, rests on the overall response time of the system. If the rate of correction within the treatment unit is insufficient to meet the changes in effluent concentration then the system will not be effective; dosing inadequacies can also arise from too great a response time on the measuring side with respect to the time available for dosing. In practice this means that the overall response time must be sensibly related to the holding time in the treatment vessel or vessels. The various lags which can occur can be summarised as follows:

#### (i) Electrode and Instrument Lags

Delays from this cause may arise from a sluggish response by the glass electrode, from lags through resistance-capacity effects in the connecting lead between the electrode and the pH amplifier, and to lags due to the pH amplifier system itself. Of these only the first is of any consequence with modern instruments (except where exceptionally long glass electrode leads are employed of the order of 300 ft. or more). The glass electrode is not inherently sluggish but it may become so in the course of plant operation from the formation of coatings on its surface, rendering equilibration of the electrode to new solution conditions a much slower operation than when originally inserted. Overall lags from measurement rarely constitute more than a total of one minute unless the electrode system is particularly contaminated; it is thus obvious that from a control point of view it is essential to maintain the glass electrode surface in a thoroughly clean condition at all times. Poorly maintained electrodes may never achieve the true pH so that good control is then impossible. This point cannot be over-emphasised since the maintenance of the electrode system is probably the most important single feature of good automatic pH control.

### (ii) Transfer Lag

This results when there is a delay between the initiation of the correcting action by the controller and the arrival of the correcting action to the process (excluding distance-velocity lags, considered next). Transfer lags rarely constitute a problem in pH control; they are more commonly found in temperature control where thermal transference may be effected through an intermediate medium.

### (iii) Distance-Velocity Lag

One of the ways in which coatings on glass electrodes can be minimised is by siting the electrode system remotely from the reagent addition point. In effluent treatment precipitation reactions are common and when the precipitate is freshly formed it can form a strongly adherent layer on the glass electrode which is both rapidly formed and difficult to remove. If the electrode system is removed from the immediate precipitating area then the coagulated precipitate shows far less tendency to deposit on the glass electrode. This principle of removing the electrode system from the dosing area can however lead to a different type of lag known as distance-velocity lag. This results when the reagent is added at a significant distance from the point of measurement such that the effects of addition are not seen by the electrode system until a time dependent upon the distance divided by the flow rate has elapsed. In practice a compromise is usually effected between the preference for an electrode system siting to minimise electrode coating and a siting to minimise distance-velocity lags. (A high degree of turbulence around the electrode helps by its cleaning action.) Care in siting the electrode system is essential to control processes and constitutes one of the most important parts of good automatic control.

### (iv) Mixing Lag

If the mixing between the reagent and the effluent is slow then a further delay, known as mixing lag, will occur to a significant extent. Alternatively if the mixing is actually inefficient then of course an incorrect signal will reach the control system and the control will not be effective. It is a mistake to incorporate slow stirrers in automatically controlled continuous treatment systems, because the primary requirement is a thorough and rapid turn-around of the liquors in the reaction vessel, and slow stirrers can induce either significant lags or inadequate control through inefficiency.

(v) Reaction Lag

The effects of dosing may not be immediately apparent, all other lags apart, if there is a significant reaction time. It is normally considered that neutralisation operations are immediate, and this is of course true with homogeneous systems provided the mixing is efficient. However where a phase separation occurs then some effective reaction lag usually arises. Two particular examples of this in effluent treatment are in the use of sodium carbonate for neutralisation involving the liberation of carbon dioxide gas, and in the precipitation of metal hydrated oxides where the precipitate coagulates slowly after being thrown out of solution. In the former case the release of carbon dioxide is accompanied by a slow rise in pH, and if the reaction vessel is not large enough or the mixing system is not adequately designed to ensure good release of the gas, then pH shifts may be observed in the effluent some time after passing through the automatically controlled loop. Where metal hydroxide precipitation is being carried out a more interesting phenomenon is observed, such that pH shifts due to desorption of occluded alkali can occur with eventual pH increase in the effluent. Phenomena of this type have been observed in separate laboratory studies (6,7), and appear to arise from the addition of locally high pH solutions with the local formation of a form of hydrated oxide different from that corresponding to the equilibrium pH value at which the bulk of the liquor is being controlled. These effective reaction lags are minimised by dispersing the reagent as much as possible, during addition, and are of course aided by vigorous agitation.

With the exception of distance-velocity lags, all the above delays in control systems are exponential in character which means that if the response time constant is known the time for 98% response can be approximately calculated by multiplying the time constant by 5. For pH control systems the practical consequence is usually that a reaction vessel holding time of not less than 5 minutes should be employed. The writer has used holding times of as little as 3 minutes but extremely careful control was necessary and even then some slight displacement occurred after treatment. Displacement may not be very important where the pH control is not critical, but it must be remembered that for optimum precipitation of metallic hydroxides, for example, the pH region may be fairly small. The fact that discharges between, for example, 6 and 9 pH may be permitted does not mean that the control system should be allowed to range over the spread of values, since for effective precipitation of any metals present as their hydroxides it is usually necessary to control to within 8.0 and 8.5, (depending on the nature of the metals concerned). Where there are uncertainties and where sudden variations in the effluent may be expected then a holding time of 10-20 minutes is preferable. In these circumstances the value of proportional control of being rapid in action is somewhat lost, and thus, for effluent treatment on-off control is usually adequate if necessary by two-stage dosing.

### (d) Treatment of Intermittent Strong Effluent Discharges

The discharge of effluents is frequently characterised by a relatively dilute running rinse which is occasionally augmented by a very strong discharge, often as much as 10,000 times the acid or other strength of the normal rinse. Bearing in mind the limited rangeability of most dosing systems it is clear that an automatic control system would not be able to cope with this sudden release, and in practice methods must be adopted to avoid over-run of the control. Although in principle it is possible to employ a highly sophisticated multi-dosing proportional control system for this purpose (see, e.g. refs. 8 and 9) it is usually far cheaper to retain the strong liquors for slow discharge over an extended period into the main effluent stream, thereby avoiding a heavy peak in the effluent concentration. For this purpose "balancing" tanks are sometimes employed, the idea being to spread the concentration load by providing a large holding time in the system before treatment takes place. In the author's opinion balancing tanks are of dubious value, since where a strong liquor is discharged an exceedingly large balancing tank is necessary to be at all effective. The strong liquors are better retained in holding tanks from which they are slowly drained into the stream. Even the use of balancing tanks to smooth out variations in rinse concentration is of limited value, and the author considers it is more effective from a control point to employ a suitable fast dosing system with adequate dosing capacity than to employ a large balancing tank. The increase in holding time necessary in the treatment arrangement is far less than the holding time which is necessary for equivalently effective balancing.

### (e) Feedback and Feedforward Control

The closed loop arrangement shown in Figure 2 involves measurement of the effluent pH with transmission of a signal to the dosing system for introduction of reagent at a point preceding measurement. This arrangement is known as a "feedback" one, and is commonly employed in automatic control operations. The alternative of "feedforward" implies that measurement is made before the reagent is introduced, but this has the disadvantage that no corrections can be made after the signal has been transmitted and acted upon. Thus if over - or under-dosing occurs requiring further trim action then this cannot be achieved with a feedforward system. Feedforward control has been used in a few cases where the effluent is entering the system at a very fast rate with widely varying concentration, such that on the normal basis of feedback control inconveniently large systems would result and a high degree of control complexity would be necessary. Chang (9) refers to a complicated problem in which a multiple feedback system was unable to cope with the input variations and consequently a feedforward device was introduced before the feedback to achieve a degree of preliminary control. It should be noted that feedforward demands the use of accurate reagent metering since the signal must be closely followed and the dosing cannot be subsequently corrected. With feedback control metering is not necessary because the loop is self-correcting. Thus for nearly all normal effluent problems feedback control is quite satisfactory and leads to the use of simpler equipment. It may be noted that even where feedforward is used it has to be followed by conventional feedback.

## 3. Alarm Warning Systems

In any automatic control system it is highly desirable to incorporate alarm warnings to indicate if any unusual condition has arisen. Thus in the case of pH control of the addition of alkali to an acid effluent the second relay on the pH amplifier may be used for warning of a significantly lower pH than the control value, taking into account the fact that some degree of oscillation around the desired value will always occur and that consequently the second relay must not be too close to the desired value. Where the amplifier is being used for two-stage on-off control the second relay will be tied to boost dosing; in this case the alarm warning can be introduced via a time delay relay which will operate if the boost standby dosing system does not change the pH from the lower value within a preset time. The value of these alarms is that they can provide warnings during the treatment stage where correcting action can quickly be made manually if necessary. Simple measurement of the pH at the outfall is too late because the effluent is then on its way to the sewer or river. Typical cases where alarm warnings may be given are in the breakdown of the dosing system or where a strong process liquor has been suddenly discharged, and the control system cannot cope with the increase in effluent concentration. The importance of alarm warning systems cannot be overstressed and no effluent treatment plant should be installed without them.

## AUTOMATIC REDOC CONTROL

The general principles of redoc measurement and control so far as instrumentation, control principles and dosing equipment are concerned are essentially the same as for pH control, so repetition is unnecessary. There are however certain special features of redox systems which merit attention.

### 1. Basic Principles of Redox Potential Measurement (10,11)

A redox measurement follows the course of a chemical reaction involving oxidation and reduction. Two examples in effluent treatment are the oxidation of cyanides at high pH, which can be written formally as

$$CN^- + 2OH^- \longrightarrow CNO^- + H_2O + 2 \text{ electrons}$$

and the reduction of chromates in acid conditions to form chromic ions prior to precipitation of the chromium as hydroxide, which can be represented as

$$Cr_2O_7^{2-} + 14H^+ + 6 \text{ electrons} \longrightarrow 2Cr^{3+} + 7H_2O$$

Oxidation-reduction reactions can be followed by means of a platinum or similar inert metal indicator electrode together with a reference electrode, and the voltage developed across these measured an open circuit by an instrument such as a pH amplifier (suitably calibrated in millivolts). The redoc indicating electrode measure the <u>ratio</u> of oxidised to reduced species, and the voltage response of the system is related to this ratio by means of an equation similar to that applying to pH measurements:

$$E_{redox} = Eo_{redox} + \frac{0.2T}{n} \log \frac{a_{ox.}}{a_{red.}}$$

where n is the number of electrons involved in the reaction, $a_{ox.}$ is the activity of the oxidised species and $a_{red.}$ is the activity of the reduced species. Note that with respect to pH systems redox reactions involving more than one electron result in a reduced millivolts sensitivity whereas a pH change of one unit results in 58 mV. change in observed e.m.f. at 20°C., with a 6-electron redox reaction a change in log $\frac{a_{ox.}}{a_{red.}}$ of one unit, corresponding to a ten-fold change in redox ratio, results in only 58/6 mV. = approx. 10 mV. change.

As the oxidation level of the system rises so the platinum electrode becomes more positive with respect to the reference electrode, so that where an odixation reaction is to be followed (as in chlorination of cyanides) the desired value is set higher than in a reduction action. However it should be noted that in the two types of reaction mentioned above it is highly desirable to perform a redoc titration curve for an individual effluent before a control setting is adopted. This is because the desired value cannot be theoretically predicted with any degree of certainty and depends very much on other components within the system.

Titration curves are constructed by adding the reagent to the effluent, which is controlled to the desired pH for the reaction, and by observing the change in redox potential as the reagent is added. A plot of redox mV. against the volume of added reagent can then be drawn. The chosen value for the control should be based on the nature of the reaction. If an oxidation process is to be followed then the control value should be in the region of upper knee of the curve while if reduction is being followed then the control value should be on the lower knee of the curve. A useful indication in cyanide chlorination titrations is to follow the process with starch-iodide papers. When the paper turns blue, free chlorine is present and the titration end point has been reached.

The cyanide chlorination reaction is normally carried out at a controlled pH of between 10 and 11, and the curve should be constructed for the pH applying, since there is a simultaneous measure of pH response in these alkaline conditions by the platinum electrode. Figure 5 shows how the titration curves displace to lower mV. (Less positive platinum electrode potentials) the higher the pH (12).

To illustrate another variation which can occur in cyanide treatment the curves shown in Figure 6 illustrate the effect of iron when it is present in the effluent (12). A depressant effect is noted throughout the entire curve, and if substantial proportions of iron are present it may be impossible to achieve control at all. Indeed the presence of iron will form ferrocyanide so the reaction is complicated anyway (ferrocyanide is not susceptible to breakdown by chlorine), and consequently iron should be excluded from cyanide-containing effluents. The author has observed difficulty in systems where iron is present in water fed to a rinse tank, and in this case it is necessary to perform titration curves at intervals of every few months to check that the characteristics are not changing. The main problem when iron is present is that the control curve is shallower and consequently the system is less sensitive. The result of this is that oscillation may occur in the control system and overdosing may result. It is to be noted that nickel has a similar depressant effect on cyanide titration curves, and this also emphasises the need for excluding nickel, which in any case cannot be treated continuously when it is combined as nickelocyanide.

A further example of how titration curves can vary according to conditions is shown in Figure 7 where the effect of pH on the characteristics of the chromate reduction curve with bisulphite reagent are given. It is customary to control the pH of chromate reduction systems by independent automatic control, but in circumstances where the acidity is relatively high and the pH is therefore fairly low and constant this may not be needed. The chemistry of the reduction must be borne in mind, however, since acid is consumed in the reduction, and if large quantities of chromate are present then some calculation must be made to ensure that sufficient acid will be available and that pH shifts will not occur. If the effluent is not adequately acidic to maintain a pH between 2.5 and 3.0 then automatic pH control of acid addition will be necessary.

In connection with these redox controlled systems involving concurrent pH control it may be mentioned that both redox and pH control should be exercised in the same treatment vessel. This is particularly important for chromate reductions and for cyanide destructions using chlorine gas because in the former case a change in the acidity level will occur as a result of the reaction and in the latter case a change in the alkalinity will occur from alkali consumption by the chlorine itself. If a redox control system is applied after a pH control system then shifts in pH may occur to a region where the treatment reactions do not proceed to completion.

## 2. Application to Automatic Control

The same principles apply to redox control in effluent treatment as to pH control. However in the case of redox electrodes the measurement lags are somewhat greater than in the case of pH electrodes. The effective response time constant of a platinum indicator electrode in the cyanide chlorination reaction is of the order of 2-3 minutes, implying that a holding time for 98% full electrode response should be 10-15 minutes. Similarly with chromate reduction systems the effective response time constant is approximately a minute, implying a minimum holding time of 5 minutes. This greater response time in fact reinforces the need, which also arises from chemical considerations of reaction lags, to have longer holding times in redox systems than in pH ones.* The value of proportional control is therefore again somewhat limited, and particularly in chromate reductions where for theoretical reasons there is insensitivity due to the fact that the process is a 6-electron reduction. Two-stage on-off control is thus adequate where boost dosing is necessary. It is worth noting here that poisoning of platinum electrodes can occur from adsorption of surface-active materials used in plating solutions, which may affect the titration curve, quite apart from the deposition of solids of a kind similar to that found in the use of pH electrodes. Thus in addition to the need for keeping electrode surfaces clean (for example in the case of cyanide treatment systems a weekly or twice weekly cleansing with hydrochloric acid followed by thorough water rinsing is recommended) it may be necessary to carry out periodic cleaning operations to remove adsorbed materials.

* It is inappropriate here to consider the chemical factors in treatment which demand certain minimum holding times. These have been fully discussed elsewhere (3,4) and particularly for cyanide destruction (4,13,14).

One of the best techniques is by cathodic cleaning, whereby the electrode is made the cathode in a very weak acid solution, and 3-6 volts are applied for 5 minutes between the platinum and another metal connection used as anode. This disturbs the electrode for several hours, however, so if cathodic cleaning is to be applied it is wise to have a standby redox system to instal while the cleaning operation is being carried out.

A typical automatic control panel, incorporating pH and redox meter-controllers, alarm warning systems, outfall pH recording, etc., is shown in Figure 8.

## WATER CONSERVATION

There is an increasing motivation towards the conservation of water, and instrument techniques can play a useful role, either by prevention of wastage or by control of treatment of individual effluent streams to permit selective recirculation.

One excellent method of water conservation by recirculation is through the use of ion exchange systems. These produce excellent quality water (in fact usually far better than is actually needed), but the capital and running costs are normally higher than for a conventional chemical treatment arrangement. They are also normally limited to fairly dilute running rinses.

A full discussion on the relative values of the various methods available is inappropriate here, and attention will be confined to the use of instrumentation directly for water control, through electrical conductance measurement for prevention of waste, and through automatic control of individual effluent streams to permit controlled recirculation.

### 1. Conductivity Control of Rinse Waters

#### (a) Basic Principles

The introduction of an electrolyte into water causes an increase in the latter's electrical conductance, which is approximately proportional to the square root of the electrolyte concentration. Rinsing operations are characterised by the periodic introduction of work contaminated with electrolyte from the process tank into water held in a rinse tank. The principle of rinsing is to ensure that these contaminants are washed away, and as a result of this operation the conductance of the rinse water rises, to fall again when the work has passed through. If the conductance is monitored in a rinse tank it should be possible to arrange for the water to be switched on and off via a solenoid valve so as to maintain a constant optimum electrical conductance associated with a contaminant concentration consistent with good rinsing. It is rarely necessary to rinse down to negligible concentrations of contaminant and the problem is therefore to arrive at a conductivity level which is suitable for control corresponding to a given impurity level in the rinse tank, and to identify whether it is sufficiently sensitive to achieve worthwhile control.

The fact that different electrolytes have different specific conductances means that their effects on the solution conductance are different for the same concentration. Conductance is not a specific property but is a function of the concentrations of all dissolved ions, and therefore also covers species present in the rinse water itself. In principle it would be better to monitor specifically the contaminated ion or ions of interest (this has been done (4), but results in relatively expensive instruments), but if the less specific methods of conductance can be applied then relatively simple and cheap equipment can be used.

Commercial equipment for conductance control is available in the form of a kit known as the "Aqualarm", the components of which are illustrated in Figure 9.

### (b) Experimental Study of Solution Conductance*

The question arises as to whether the background conductance of the rinse water is too high with respect to the conductance of the solution including the contaminant electrolytes to permit significant measurements to be made for control purposes. Two series of conductance measurements were therefore carried out to determine the effect of solution on typical electroplating solutions,

* Since this work was completed an independent investigation has been reported by Brace (15). Brace's results show similarly that at the dilutions used for rinsing the conductivity discrimination is adequate for control purposes.

one using London (England) mains water and one using Birmingham (England) mains water, these representing two extremes of high and low dissolved solids content respectively. The types of solution chosen were an alkaline cleaner, a hydrochloric acid dip, a copper-cyanide solution, a bright nickel solution and a chromic acid solution. Some of the results are shown in Table 1; the data for London water solutions only are given because the Birmingham water solutions exhibited fairly consistently lower conductances by an order of 450 micromhos.

If it is considered that an overall discrimination of ± 10% in conductance is achievable in plant practice with these controllers (it may be better in well controlled conditions), then the lowest conductance at which the controller can be set for the conditions covered in Table 1 is approximately 600 micromhos. This means that rinsing dilutions of as great as 3,000 can be achieved for most of the solutions examined; in fact the rinsing level customarily adopted is much stronger than this dilution implies and is often at the 1,000:1 or 500:1 level. In this region the controller can clearly be used to advantage with no discrimination problems.

In practice individual solutions will vary so that it is not possible to predict the exact conductance setting to be applied, and strictly speaking the data should be prepared for each individual solution to verify the feasibility of application. The data also cannot predict the magnitude of the water saving which may be possible: they merely indicate that it is instrumentally feasible to make a significant measurement for control purposes.

### (c) Plant Results

One of the best spheres of application of conductance control is in manually operated process plants, where sporadic use only is made of the rinse tanks and therefore often as much as 50% of the time the rinse water is running unchecked and unused. Even where the plant is fully used water savings of the order 20-35% can be achieved (13) which can offset the initial cost of the equipment. In one case a reduction in water consumption by 60% has been reported (13). On the other hand, with automatic machines the rinse tanks are used on a regular and much more frequent basis. In this case the savings which can be achieved depend primarily on whether the period between work introduction is a sufficient proportion of the total time to result in significant economies. (There is of course also the subsidiary advantage which would apply during start-up and run-down times with automatic machines, which can themselves constitute as much as 10% of a total day shift operation). Investigations are currently being carried out on the use of the Aqualarm system in automatic plating machines, and the indications are that water savings of the order of 20% may be achieved in tank rinses.

## 2. Controlled Recirculation after Automatic Effluent Treatment

Quite apart from the prevention of waste through the use of conductance controllers, which control the actual water input, there is the other and complementary approach of recirculation following chemical treatment. The object of a rinsing operation is to lower the concentration of the associated material from the work surface to a level acceptable for the finish required, and it is this operation which produces the effluent. The effluent contains certain species which may be regarded as toxic or otherwise unacceptable, and other species which are acceptable for a discharge. Removal of the undesirable species is usually achieved by chemical metathesis, e.g. $CN^-$ is replaced by the chemically equivalent quantity of $Cl^-$, $H^+$ (in acids) by $Na^+$, and so on (even ion exchange, it may be noted, is a metathetical process). One of the functions of automatic control is to ensure that this process is stoicheiometrically performed, to give an end product that is relatively harmless for discharge. In the process of effluent treatment the critical species which need to be removed for efficient rinsing are in fact usually removed, and recirculation of treated effluent to the rinsing process may thus be possible.

The feasibility of recirculation rests primarily on whether or not the substituting species and the associated (original) materials are acceptable in rinsing at a concentration level greater than the original rinsing concentrations because the process of recirculation must inevitably involve a build-up in the component concentrations. This applies even in treatment processes where physical removal of effluent contaminants is carried out - e.g. the separation of fibres from paper mill effluent, or of solid matter contributing to an effluent B.O.D. demand, followed by any chemical process such as aeration, or bacteriological oxidation. Manifestly a 100% recirculation of treated effluent will build up dissolved species indefinitely to the point of insolubility, so in practice a partial return only is possible. It is also generally true that the indiscriminate return of a treated effluent deriving from several different types of process can either lead to process difficulties or at least restrict the degree of recirculation possible. It is therefore extremely important to consider recirculation after individual treatment of a given process effluent.

### (a) The Basic Recirculation Equation

To give more specific indication of the factors involved, consider the case where a rinsing process operation is involved producing an effluent containing dissolved salts. An equation correlating the important parameters has been derived (16):

$$S = \frac{R}{W\ (1 - p)} + S_o$$

where $S$ = equilibrium dissolved salts concentration for a recirculation consisting of a proportion of $p$ of the total flow
$W$ = flow rate
$R$ = dragout rate of contaminant feeding into the rinse, expressed in the same units as $S$, per unit time
and $S_o$ = dissolved salts concentration of make-up supply rinse water, expressed in the same units as $S$.

As an example of the application of this equation, consider the simple case where the effluent is an acid, such as sulphuric, where neutralisation is automatically carried out by controlled addition of a sodium alkali to give sodium sulphate. If an average of 1 litre of acid at 100 g./l. concentration is introduced into the rinse water per hour, the equivalent amount of sodium sulphate produced per hour would be 145 g. Assume also that for adequate rinsing it is necessary to reduce the concentration of acid in the rinse tank to 0.1 g./l., i.e. a flow rate of

$$\frac{1 \text{ litre/hr.} \times 100 \text{ g./l.}}{0.1 \text{ g./l.}} = 1000 \text{ litres/hr.}$$

is required. Then if a recirculation of a proportion p of this neutralised stream is carried out, the equilibrium sodium sulphate concentration, S, will be given by

$$S = \frac{145}{1000\ (1-p)} + S_o \text{ g./l.}$$

If the quantity of sodium sulphate in the supply water is negligible, $S_o$ may be neglected. Then if $p = 0.5$, i.e. 50% recirculation is carried out, $S = 0.29$ g./1.; where $p = 0.8$, i.e. 80% recirculation, $S = 0.725$ g./1.

The degree of recirculation which is theoretically achievable depends on the acceptable concentration level of the species formed, and this is decided by reference to the process and the criteria concerned. It is often found, however, that quite high degrees of recirculation are possible in the cases of neutralised acids and alkalis. This is only achievable if automatic control of the treatment is carried out to ensure that undesirable effluent is not returned to the process; thus instrumentation serves here not only to effect efficient effluent treatment but also to conserve water and therefore operating costs through controlled recirculation.

### (b) Application of Recirculation to Counterflow Rinse Systems

Twin counterflow rinsing, where the work to be cleaned moves through two tanks rather than one with the rinsing water moving in the opposite direction (see Figure 10a), offers well known advantages of water conservation with respect to single rinse systems. The equilibrium mass balance equation defining the water flow rate to achieve a given dilution of the dragged-out process solution in the second of twin couterflow rinse tanks is given by

$$\frac{C_2}{C_o} = \frac{D^2}{W_2(W_2+D)}$$

where $C_2$ = average concentration of the dragged out species in the second rinse tank
$C_o$ = concentration of the species in the process solution
$W_2$ = counterflow rate
and $D$ = drag-out rate of process solution into the first rinse rank, expressed in the same units as $W_2$

It is usually desirable or necessary for W to be substantially greater than D, when this equation simplifies to

$$C_2 = C_o \left(\frac{D}{W_2}\right)^2$$

The extent to which this counterflow rinsing can save water with respect to single rinsing is deducible from the above equation through the derived relationship

$$W_2 = (DW)^{\frac{1}{2}}$$

where W = the required flow rate for single tank rinsing.

The proportion of water saved is then given by

$$(1 - \frac{D}{W})^{\frac{1}{2}}$$

Theoretically this can imply very high savings, of the order of 90%, but in practice these are rarely achieved. This is because the equations are equilibrium ones, and take no account of dynamic conditions in the tanks where peaks in work throughput can demand higher flow rates than average ones for efficient rinsing. Thus to maintain rinsing efficiency it is frequently necessary to use much higher flow rates than are theoretically predicted.

This disadvantage can be overcome by partial recirculation at a fast rate of treated effluent from the rinse tanks to the first of these, as illustrated diagrammatically in Figure 10b. In this condition the rinsing in the first tank will be more effective through the use of a higher flow rate through it, and this in turn will permit the use of a lower counterflow rate. It can be shown (16) that the reduction possible is given by

$$\frac{W_2'}{W_2} = (\frac{1}{1 + r})^{\frac{1}{2}}$$

where $W_2'$ is the reduced counterflow with a recirculation rate of $rW_2'$. As an example, if recirculation is effected at three times the new counterflow rate, i.e. r = 3,

$$\frac{W_2'}{W_2} = \frac{1}{2}$$

i.e. the flow rate can be halved. When r = 8, a reduction in input supply water with respect to the normal counterflow condition of 67% can be achieved.

Again, these recirculation systems can only be applied through the use of instrumentation for automatic control of effluent treatment, avoiding both under-dosing and over-dosing of reagents which could be inimical to the rinsing operation.

## MAINTENANCE

In conclusion a note should be made of the need for maintenance of all instrument and control equipment One of the problems that the author has experienced in the application of instrumental methods in effluent treatment is that many companies are loth to carry out the necessary maintenance to ensure satisfactory functioning of the equipment. The fact that a plant is automatic does not remove the need for regular maintenance, and in fact satisfactory operation depends on it. The more intelligent the operator the quicker it is for him to appreciate what is required, but this does not mean to say that other less gifted people cannot carry out the routine operations once they have been trained and have familiarised themselves with the techniques. If effluent treatment plants are placed under the responsibility of the person in charge of the process plant then this usually means that the treatment plant is properly run and maintained, and that sudden discharges of strong liquors which could upset the plant do not occur. It is therefore a good principle to try to locate the treatment plant as close as possible to the process plant for ease of observation by the process operators.

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## TABLE 1. SPECIFIC CONDUCTANCE OF TYPICAL ELECTROPLATING SOLUTIONS AS A FUNCTION OF DILUTION.

Specific conductance of background water - 530 micromhos.

| | Dilution ratio | Specific Conductance in micromhos |
|---|---|---|
| Alkaline Cleaner Solution | 100 | 2,070 |
| | 200 | 1,030 |
| | 400 | 690 |
| | 800 | 600 |
| | 1,600 | 570 |
| | 3,200 | 560 |
| Spent Hydrochloric Acid(50%v/v) Pickle Solution | 100 | 19,800 |
| | 200 | 9,000 |
| | 400 | 3,920 |
| | 800 | 1,690 |
| | 1,600 | 670 |
| | 3,200 | 620 |
| Copper Cyanide Plating Solution | 100 | 3,220 |
| | 200 | 1,850 |
| | 400 | 1,180 |
| | 800 | 850 |
| | 1,600 | 690 |
| | 3,200 | 630 |
| Nickel Plating Solution | 100 | 2,020 |
| | 200 | 1,360 |
| | 400 | 970 |
| | 800 | 770 |
| | 1,600 | 680 |
| | 3,200 | 620 |
| Chromium Plating Solution | 100 | 11,600 |
| | 200 | 5,060 |
| | 400 | 2,130 |
| | 800 | 740 |
| | 1,600 | 610 |
| | 3,200 | 590 |

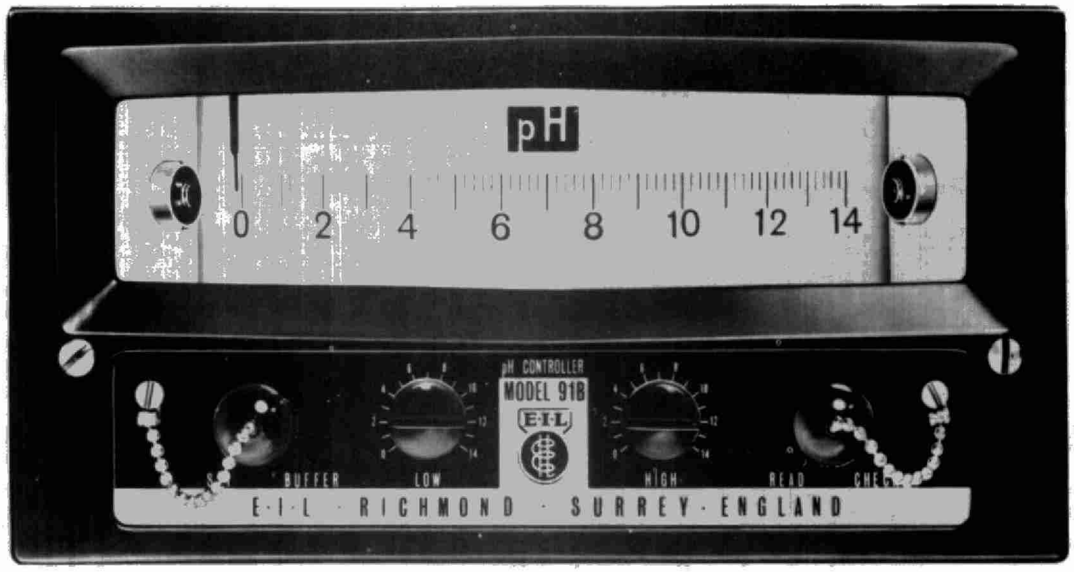
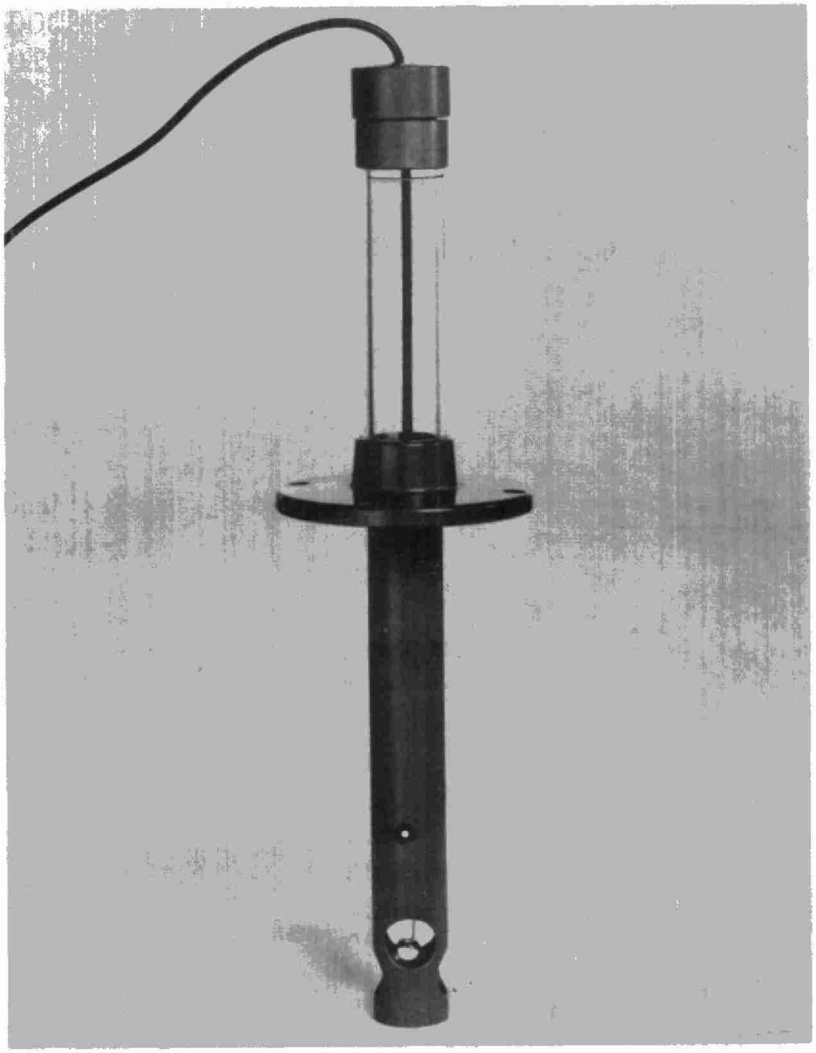


**Figure 1** – *a. Electronic Instruments Ltd. (England) Model 91B panel mounted pH meter-controller. The two control relays are electronically operated, and are adjusted by the controls marked "Low" and "High".*



*b. Electronic Instruments Ltd. (England) B 90 dip pH electrode system, with body constructed in ABS plastic.*

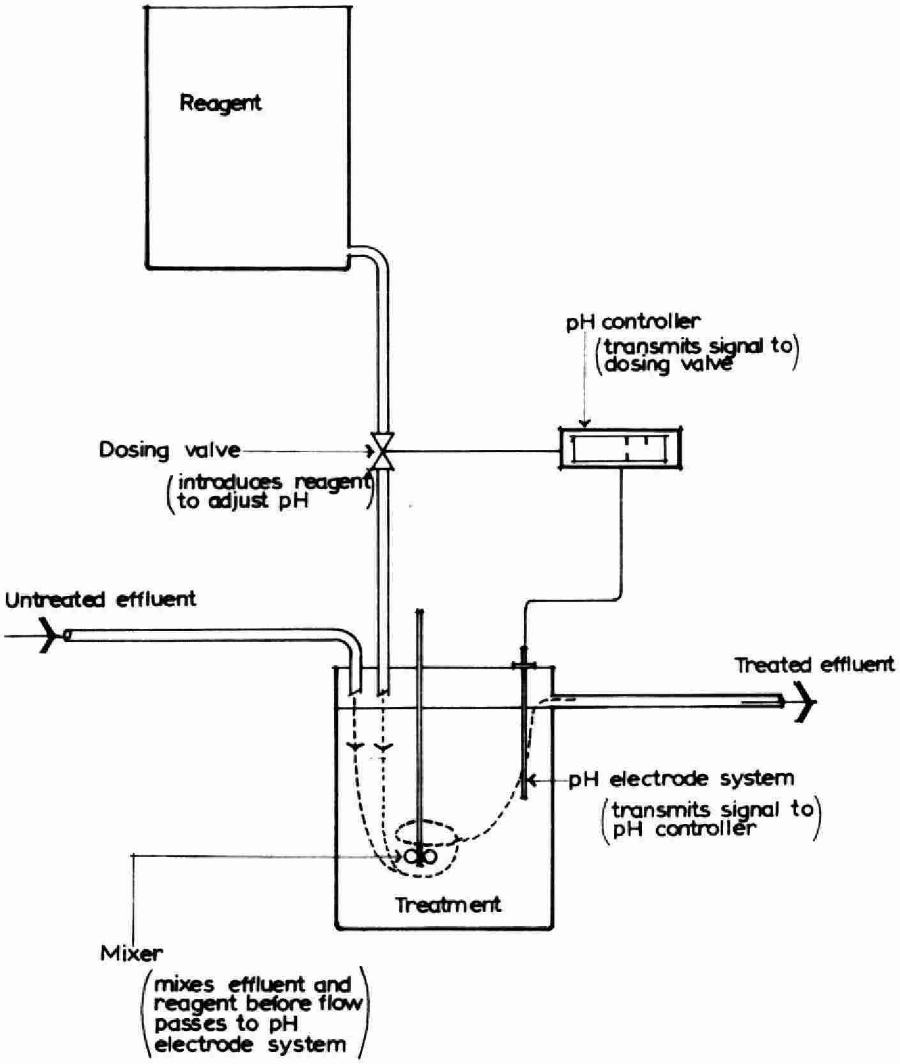


**Figure 2** – *The principle of automatic closed loop control, illustrating the continuous self-correcting action.*

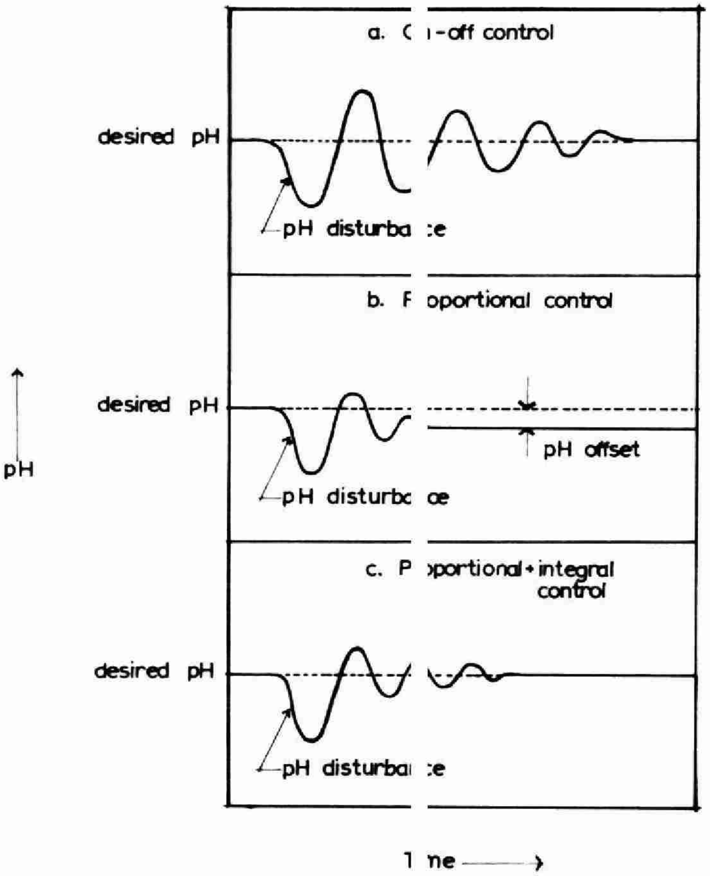


**Figure 3** – *Characteristics o different modes of automatic control, exemplified by a plot of the control variable vs. time after a disturbanc has been introduced into the closed lo p system.*

- *a. Two-step (on- f) control*
- *b. Proportional c ntrol, showing reduced stabilisation t ne offset*
- *c. Proportional + ntegral (reset) control, showing elimi ation of offset and maintenance o short stabilisation time.*

**Figure 4** – *Electronic Instruments Ltd. (England) Model 92C panel-mounted proportional + integral pH controller, showing control adjustments for varying the relative amounts of proportional and integral actions.*

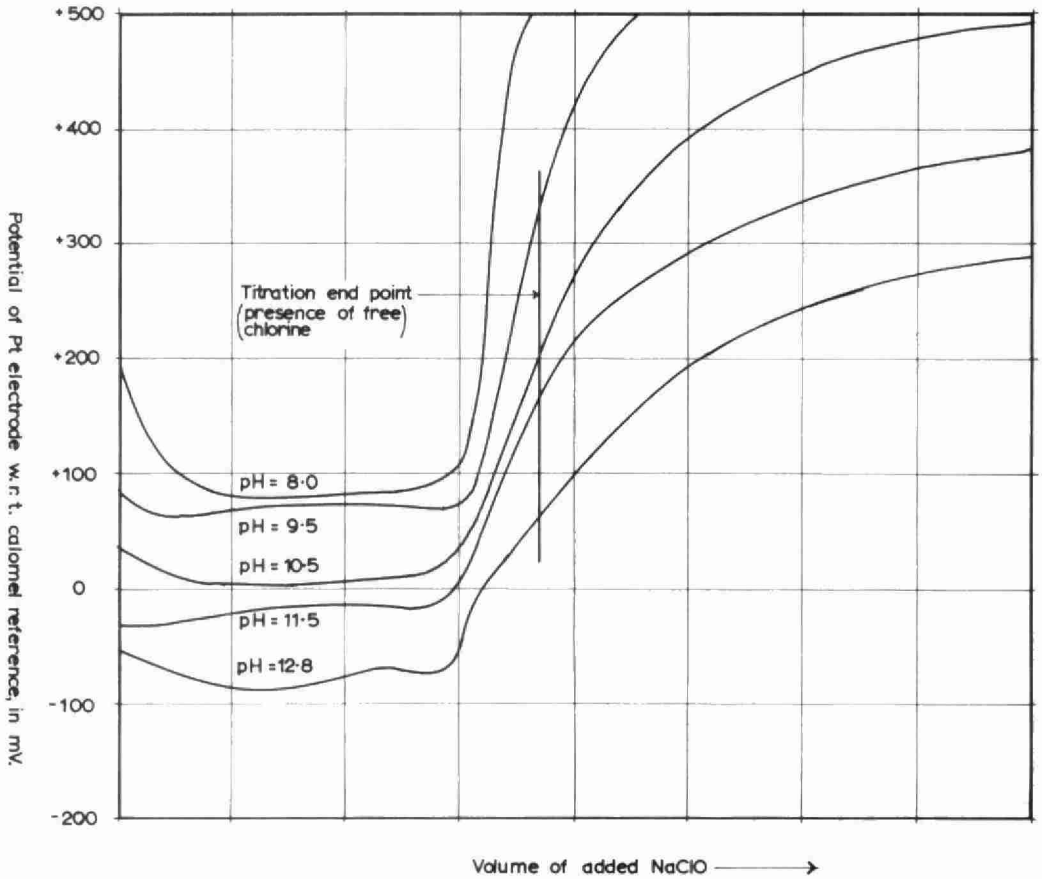


**Figure 5** – *Typical redox titration curves for the chlorination of complex cyanides, with redox millivolts (Pt electrode vs. calomel reference) plotted against units of added hypochlorite. The effect of pH is shown by the different curve positions.*

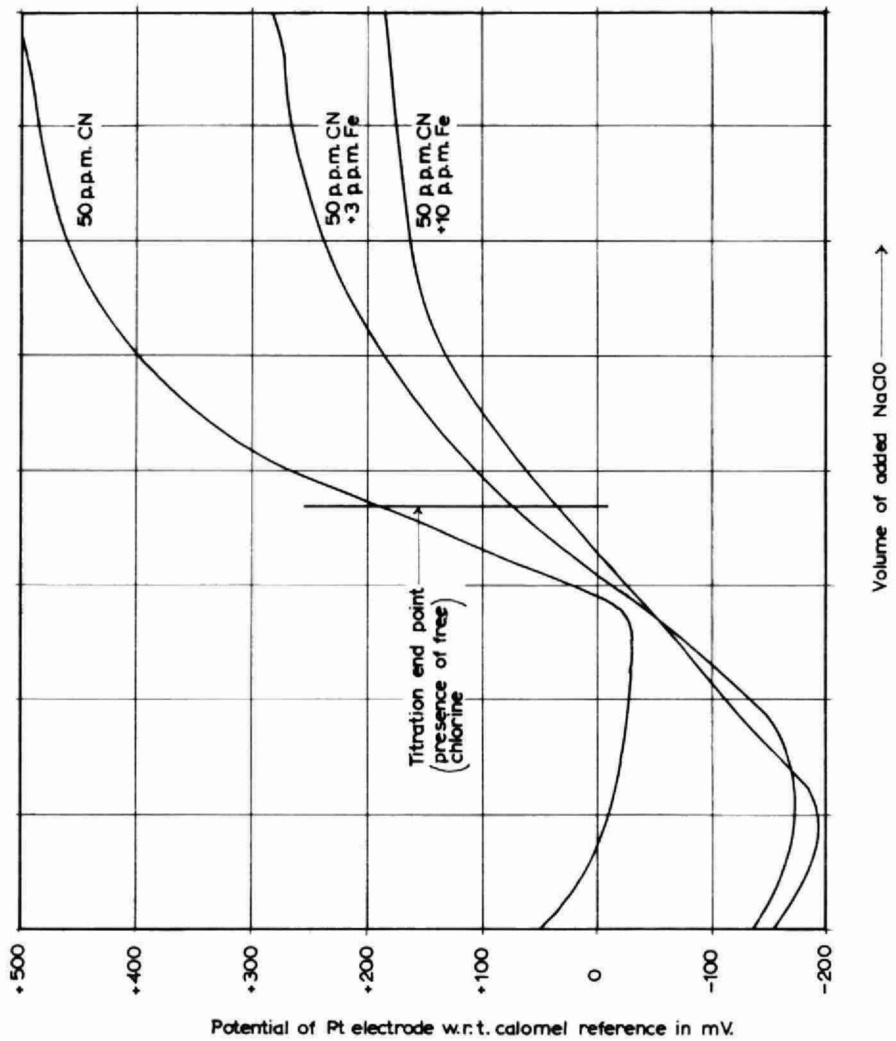


**Figure 6** – *The effect of iron on simple cyanide chlorination titration curves.*

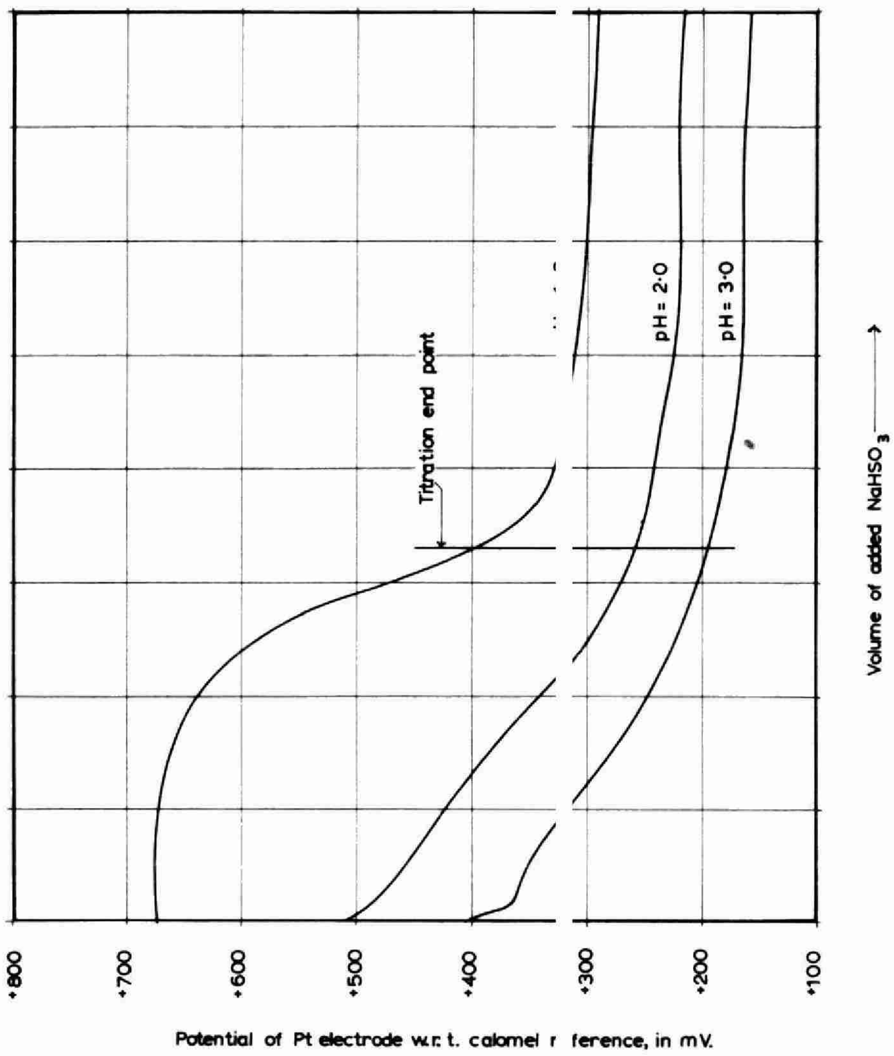


**Figure 7** – *Typical redox titration curves for th reduction of dichromate by bisulphite, with redox nillivolts (Pt electrode vs. calomel reference) ploi ed against units of added bisulphite. The effect of pl is shown by the different curve positions.*

**Figure 9** – *Electronic Switchgear Ltd. (England) "Aqualarm" conductivity rinse control kit.*

*a. Conductivity controller*

*b. Conductivity controller with front cover removed.*

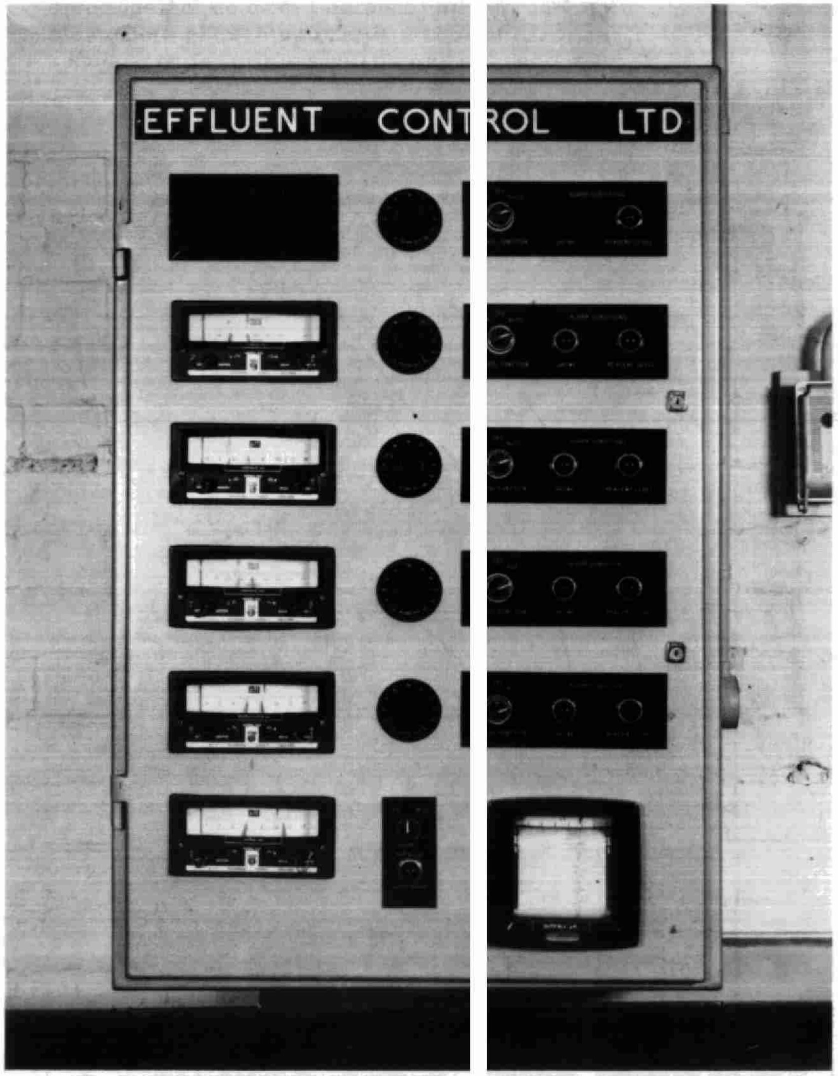
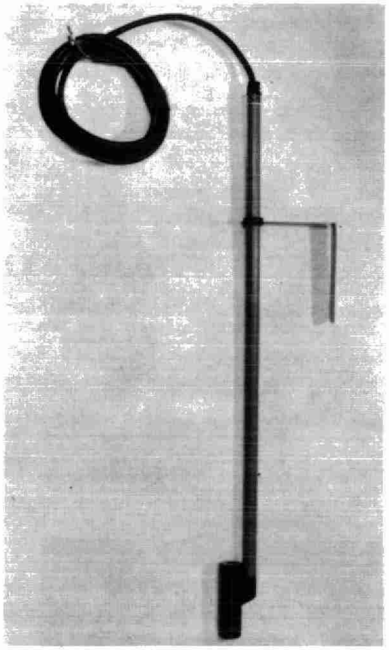


**Figure 8** – *Effluent Control Ltd. (Englan ) instrument control panel, showing pH and redox meter-c ntrollers for cyanide chlorination, chromate reducti n, neutralisation, with outfall pH recording and alarn*



c. *Dip conductivity cell*

d. *Solenoid valve*

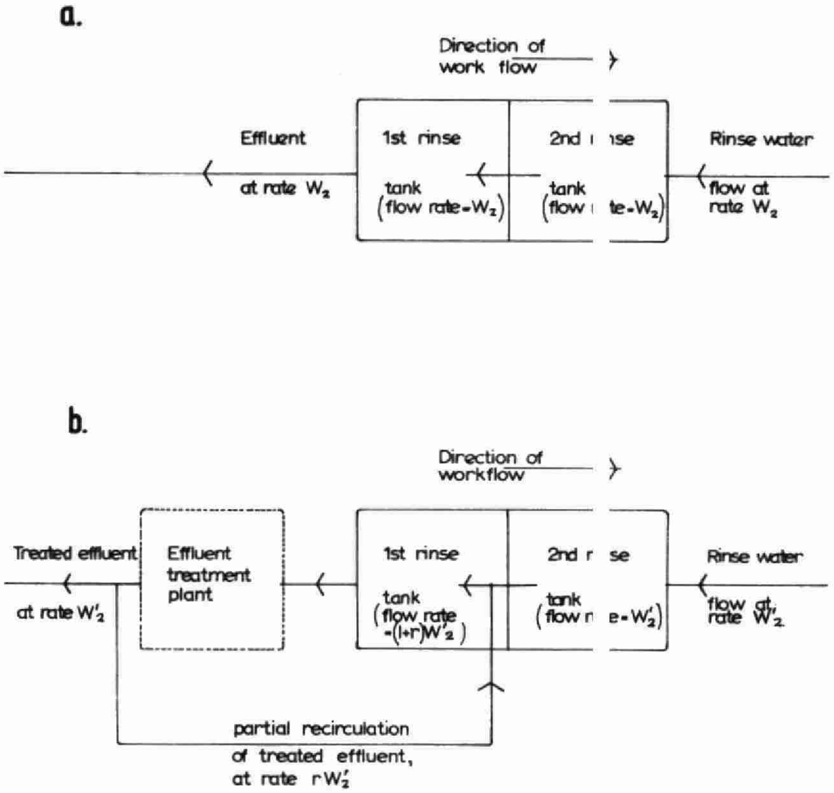


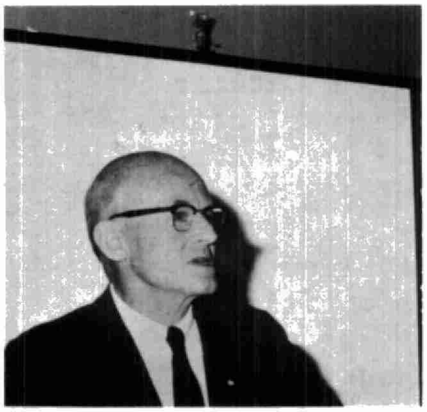
**Figure 10** – *The recirculation of treated effluent in win counter-flow rinse systems to reduce water con umption* ($W'_2$ $W_2$.)

*a. The principle of normal twin tank c unterflow rinsing, with the work moving in the opposite direction to the rinse water.*

*b. Partial recirculation of treated effl nt to the first counterflow rinse tank.*

BANQUET NIGHT

# "LEGAL ASPECTS OF WATER POLLUTION CONTROL IN ONTARIO"



BY

J. P. ERICHSEN-BROWN

SOLICITOR

ONTARIO WATER RESOURCES COMMISSION

When it was suggested to me that I might speak to you on the topic "Legal Aspects of Water Pollution Control in Ontario" I accepted because it was a sort of catch-all which gave me an opportunity to make up my mind as to what I really wanted to talk about. The fact is that the entire operations of the Commission are concerned directly or indirectly with Water Pollution Control, and at almost every point there are legal aspects.

They influence or affect the functions of every officer, both in industry and in public office, who is concerned with pollution, regardless of his own field of administration. The legal aspects of pollution control, in short, are not confined to lawyers. I need only refer to the immense cooperative effort of the Ontario Water Resources Commission and very many municipalities, and many industries, to provide or to perfect treatment works, and to the legal requirements that are relevant. For example; the approvals of The Municipal Board, the questions of title including expropriation procedures, the legal requirements of complex construction contracts, the role of consultants and of engineers under such contracts, the legal consequences of design approval, and such things as the regulation of plumbers and of well drillers, and even of boats.

All of these in a broad sense are legal aspects of pollution control but with the exception of the effect of design approval certificates. I have decided to omit them from this paper. Instead, I intend to concentrate if I can on those aspects of pollution control where there is applied directly or indirectly some pressure upon a person or corporation to stop discharging something because its discharge is impairing or may impair the waters of Ontario. The major force exerting such pressure is The Ontario Water Resources Commission Act itself. However, before discussing the Act I wish to refer briefly to the Criminal Law and the Common Law.

The legal sanctions which are applied to individuals or companies whose activities conflict with those of the public as a matter of theory, should be found in the criminal law. The Government of Canada, which has the constitutional power to create crimes, has not created any crime of "pollution". The public authorities of Ontario, including the Crown Attorneys or other public prosecutors who have jurisdiction to enforce the criminal law, have not seen fit to prosecute for the only crime that might arise under the Criminal Code of Canada from pollution of waters - namely, the indictable offence of committing a "common nuisance". In short - and I say this largely for the benefit of our American friends - the criminal law has not been and is not now employed as an instrument of pollution control in Ontario.

The common law is of diminishing improtance but continues to be relevant to the civil responsibility that may arise between private riparian owners. It is related to the theme of this conference "The Second Century - Clean Water" in that the origins of the pure water policy in which we have taken some pride in Ontario are to be found in the common law. In fact I would say that we owe more to the common law and to the courts than we do to the Legislature in the preservation of this concept.

The obligations of a riparian owner at common law are very strict. I can illustrate this by the famous distillery case which reached the House of Lords in England, in which an upstream owner who pumped pure but hard water from his mine in order to dewater it and put it into a river carrying soft water, was restrained by an injunction at the suit of a downstream manufacturer of whisky. Natural soft water made good whisky but when it was altered by the introduction of hard water it made bad whisky.

injunctions which had been granted against the two municipalities. Instead, it went further and by the same amendment it changed the law in regard to statutory authority.

Prior to 1956 plants had, of course, been operated under statutory authority, but the court said that unless it was "inevitable" that the effluent would pollute the stream, there was a presumption that the Legislature had intended that such plants would operate with due regard to the rights of other riparian owners at common law. To protect municipalities the law was changed so as to make it impossible to sue whenever the construction and operation had been approved by The Department of Health. At the same time the definition of sewage was broadened to include industrial wastes, and at the same time, there was enacted a provision that the discharge of material from a sewage works that had been constructed and was operated with the approval of The Department of Health was not a contravention of the penal provision under which prosecutions were laid for impairment of waters.

The following year (1957) the functions of The Department of Health were transferred to the Ontario Water Resources Commission, which was also given greatly increased powers to deal with pollution in all its aspects.

Thus, a twofold decision was made. Firstly, to do away with the common law liability wherever there was a discharge by a municipality or a corporation of either sanitary sewage or industrial wastes from a sewage works that was "constructed, maintained or operated" with the approval of the Commission. Secondly, to confer broad powers upon the Commission to deal with all discharges of material from works that it had not approved. Thus it was given powers to investigate, and to require that remedial works be undertaken, and there was created a number of new statutory offences under which violators would be liable to prosecution. The net effect was to greatly increase the strength of public authority in Ontario to deal with pollution of waters.

The new offences, and the power to deal with them, are contained in The Ontario Water Resources Commission Act.

This is an extreme case of liability in that there was no pollution in the sense in which we ordinarily understand that word. Thus it has been said that at common law you cannot pollute "to the smallest degree". Alternatively that you cannot "prejudicially affect the condition of the water so as to sensibly injure" other riparian owners.

Decisions of the English courts are not binding in Canada but the judgment in the Distillery case was approved by the Court of Appeal for Ontario in 1956 as a correct statement of the rule of the common law which had been introduced into Ontario in the 18th Century.

The year 1956 was the year when the number of pollution claims that might have gone to the courts was drastically reduced by action of the Ontario Legislature. As soon as the judgment of the Court of Appeal had been delivered affirming the injunction which had been granted by the trial judge against the Village of Richmond Hill, the Legislature immediately adopted an amendment to The Public Health Act which dissolved the injunction. At the same time it dissolved another injunction which had been granted against the City of Woodstock under similar circumstances. Six years previously it had dissolved an injunction obtained by a tourist camp operator against a pulp and paper company.

The Legislature of Ontario, in short, was unwilling to live with the strict rule of the common law. It was responsive to interests other than pollution control. I do not say that this was necessarily wrong. The Legislature must be responsive to economic and social factors in certain situations. It is a proper function of the Legislature to decide whether the collective interests of all the inhabitants of a town in having their sewage treated with an efficiency of less than 100% are more important than interference with the common law rights of a single riparian owner, arising from the fact that sewage treatment was not 100% effective.

I understand that an average sewage treatment plant will remove around 35% BOD with primary treatment; this will be increased to around 95% with secondary treatment; and there are various further refinements described collectively as the so-called tertiary treatment which may boost the BOD removed to around 98%. The size and character of plants varies enormously and none are perfect. It was perhaps for this reason that the Legislature did not consider it was sufficient merely to dissolve the

There are contained within its various sections and subsections at least 32 specific offences, that may result in prosecutions and the imposing of penalties, not including a number of offences which are spelled out in regulations under the Act, such as the plumbing regulations, the well drilling regulations, etc. In addition, there are two sections which give the Commission a statutory power to apply to the courts for injunctions.

I do not wish to lose myself in questions of detail nor lose your attention and your interest. Accordingly, I prefer to deal with the Act from the point of view of certain principles which are to be found in it, and to refer to the text only to illustrate these principles.

However, I think I should point out that the 32 or more offences to which I have referred include a number which are related to pollution control without being directly concerned with pollution. They are designed to put teeth into the regulatory powers of the Commission, whose functions are broadly to control pollution and the use of water. I will cite a single example of the sort of provision to which I refer. The Commission has the power to approve the design and construction of sewage works. There are five possible offences that may arise under the section relating to the construction of sewage works. These are: -

(1) The offence of establishing a sewage works without having secured the prior approval of the Commission;

(2) The offence of changing a sewage works without having secured the prior approval of the Commission;

(3) The offence of failing to provide facilities ordered by the Commission to assist it in its investigation of the sewage works;

(4) The offence of failing to carry out changes in the sewage works when directed by the Commission; and

(5) The offence, after a permit has been issued, of failing to comply with its terms and conditions.

Sewage works is defined to include any works for the collection, transmission, treatment and disposal of sewage and the word "sewage" is defined to include commercial and industrial wastes.

To relieve your minds I would like to repeat my promise not to go into all these offences. However, while on the subject of the approval of sewage works, I would like to refer to the question of the "public interest". As you will have noted, the Commission has power to impose conditions in its permits and the power to impose such conditions has been phrased by the Legislature in terms of an assessment by the Commission of the public interest. The section actually reads:

> "Where, in the opinion of the Commission, it is in the public interest to do so, the Commission may refuse its approval or grant its approval in such terms and conditions as it deems necessary."

If the conditions of a permit are violated, the holder may be liable to a penalty of up to $500.00 per day. Upon such a charge the court is precluded by the words of the section from entering into the question as to whether the imposing of the condition was or was not in the public interest.

> (The Commission was given similar authority to decide what is in the public interest in sections relating to the approval of water works; the prohibition of the taking of water; the reporting to a municipality of its opinion of what the municipality requires in regard to its sewage works and other matters, and in the recently enacted section which gave the Commission the power to designate areas of public water works and public sewer services. There may be prosecutions under all of these sections, with substantial penalties, and in all cases, the court cannot inquire into, nor substitute its own opinion as to what is the public interest.)

At this point I would like to pause and give you an outline of how I propose to handle the rest of this speech. I think it would be most useful to confine it to three specific topics, each of which I would like to bring into rather sharper focus. These are:

(a) The functions of the OWRC and of municipalities in relation to Industrial Wastes.

(b) Prosecutions for impairment of waters.

(c) The use of injunctions against industry to stop pollution.

Prior to the creation of the OWRC there had been included in The Municipal Amendment Act of 1953 a power to pass what was popularly referred to as a "pollution control by-law". Such a by-law could be passed by a "local municipality" which includes a city, town, village and township. There is a wide disparity as between a large city on the one hand, and a rural township on the other. The four types of municipalities have a common character largely when they are in built up areas and municipal sewers of some sort have been installed. This explains the wording of the paragraph in the Municipal Act under which by-laws could be passed:

> "For prohibiting and regulating the discharge of any gaseous, liquid or solid matter into land drainage works, private branch drains and connections to any sewer, sewer system or sewage works for the carrying away of domestic sewage or industrial wastes or both, whether connected to a treatment works or not."

When the Ontario Water Resources Commission was established it was given broad jurisdiction that was superimposed, so to speak, upon the existing municipal powers. Thus, the OWRC Act provides:

> 26(1) "The Commission has the supervision of all surface waters and ground waters in Ontario used as a source of water supply"

> 26(2) "The Commission may examine any surface waters or ground waters in Ontario from time to time to determine what, if any, pollution exists, and the causes thereof."

It will be observed that the Commission's general supervisory powers are restricted to waters "used as a source of water supply", but that where it is a question of pollution there is no restriction: "any surface waters or ground waters in Ontario." The Commission's authority in regard to pollution of such waters reaches into and within every municipality in Ontario.

There is no question as to the Commission's powers in regard to the pollution of surface waters. It is possible that some question may be raised as to a municipality's powers to control by by-law a discharge that goes to a natural watercourse but not to its sewage system. There were two instances where the question arose during the past year. Both cases received some attention in the press. The first involved a prosecution of Lever Brothers Limited in regard to a spillage of vegetable oils that ended up in the Don River. The actual discharge was to a storm sewer and thence to the river. It did not go and could not have gone into any sanitary sewage treatment plant. The relevant section of the by-law was worded in reference to discharge:

> "into a storm sewer, storm sewer connection, storm drain, watercourse or land drainage works which is capable of discharging into any body of water or onto the shore or bank thereof".

By the same by-law "watercourse" was defined to mean"... an open channel, ditch or depression either natural or artificial, in which a flow of storm waters occurs, either continuously or intermittently."

The basic prohibitions of the by-law were in two sections, one covering discharge into either sanitary sewers or combined sewers, and the other discharge under the section and definition I have quoted. The former is solidly grounded upon a municipal function, namely the operation of its sewage treatment plant. The latter is similarly grounded, to the extent that it is a municipal function to control storm water. You will note that the latter stopped short of prohibiting discharge to a natural watercourse of a permanent character. Thus it prohibited discharge into storm sewers, etc. or a "watercourse" (as above defined) that was "capable of discharging into any body of water or onto the shore or bank thereof." The summons in the Lever Brothers case actually charged a discharge to the Don River, but I was informed by our Industrial Wastes Division that it actually went through a storm sewer. I do not believe that a person could be charged under the Metropolitan Toronto by-law (which incidentally is very recent - November, 1965) for a direct discharge to Toronto Bay or Lake Ontario.

The second case concerned two large steel companies at Hamilton. Both have spent large sums on pollution control measures, and have cooperated fully with the Commission. The question which arose did not concern the Commission directly. It did, however, interest me, as a lawyer, who is interested in the question of jurisdiction. It is my understanding that the two steel companies, no doubt on the advice of counsel, refused to give information to the City of Hamilton, on the ground that the City of Hamilton did not have power to control by by-law the discharge of effluent into Lake Ontario.

I have examined the City of Hamilton by-law (which is even more recent, being passed in February, 1966) and my personal opinion for what it is worth is that it resembles the Metropolitan Toronto by-law in that it also stopped short of any prohibition of direct discharge to a natural watercourse of a permanent character. The Hamilton by-law was, in its opening recital, expressed to be "subject to the provisions of The Ontario Water Resources Commission Act."

The point which I would like to emphasize and which is of great importance to those concerned with industrial wastes is that there is concurrent jurisdiction in the pollution control field within large areas in regard to industrial wastes. Insofar as municipalities are concerned this control is in regard to what may be discharged into places or things that are within its territory and under its control. Insofar as the Commission is concerned, it has control in the same general area (subject to an important exception which I will mention), and the Commission's powers extend right into the industrial plant itself.

The important exception arises under subsection 4 of Section 31 of the OWRC Act. This is one section which I won't quote because the language is rather tricky. It will suffice to say that the effect of a double negative in a subparagraph is to make it unnecessary for any person - and that includes a corporation - to secure our approval of any industrial treatment works if the industrial waste is going into a sanitary sewer. I should add a word of caution, under a 1966 amendment, if the industrial waste interferes with the operation of the sewage works, you may be in trouble with both the municipality and with us, regardless of whether the sewage works is operated by the municipality or by the OWRC.

While I am referring to municipal jurisdiction I would like to interject a remark about prosecutions. I am coming to this later. However, at this stage I would point out that the prohibitions in municipal by-laws may be more speedily and more easily enforced by the prosecuting authority for the simple reason that a municipal by-law may be framed in terms of the express prohibition of the discharge of specific substances in specific concentrations, whereas the prohibitions under the OWRC Act are in relation to the impairment of water.

The Commission has a greatly expanded program of construction of sewage treatment plants throughout Ontario. In all of our project agreements by which the Commission agrees to finance the construction of sewage works, to do the construction, and to operate them generally over a 30 year period, our invariable practice is to protect ourselves by the following clauses: -

> "4. Unless otherwise so provided in this Agreement the Commission expressly restricts its responsibility to sanitary sewage and reserves to itself the right to refuse to accept anything else. The Commission may, however, consent in writing to accept land drainage and/or industrial wastes.
>
> 6. No waste contaminated by any chemicals or substances which in the opinion of the Commission may constitute a damage or hindrance to the processes, plant or equipment of the sewage works project shall be emitted or deposited into any sewer connected directly or indirectly to the Commission's said sewage works project."

It is reasonable, in fact essential, that any municipality operating its own sewage treatment plant protect itself in a similar way, and the proper way of doing this is by by-law which controls what all persons, including industrial concerns, can put into municipal sewers.

Last year (1966) there was added to the OWRC Act a provision (section 50a) by which if the Commission was of the opinion that the discharge of sewage into a sewage works was interfering with the operation of the works, it could require any municipality or person by notice "to stop or regulate such discharge or deposit or take such measures in relation thereto in such manner and within such time as the notice may require." The penalty for contravention is up to $200.00 per day.

The section applies to industry, and any industry that discharges toxic substances, for example, that may kill the bacteria in a treatment plant, may be liable to prosecution under this section regardless of whether the plant is operated by the Commission, or by the municipality, and regardless of whether the municipality has, or has not, adopted a pollution control by-law.

So far the emphasis has been on keeping industrial wastes <u>out of</u> sewers, whereas all the experts agree that in the case of many industrial wastes the best pollution control is achieved by requiring the precise opposite, namely that they go <u>into</u> sewers and be treated along with sanitary sewage.

A most important aspect of the treatment of industrial wastes is that the effluent standard which experts - I mean scientific experts - require for discharge to a sewage treatment plant may be quite different, and a more lenient requirement, than for discharge to a natural watercourse.

The answer to the pollution caused by many industrial concerns, whose effluent is now being discharged to a natural watercourse, is therefore to get the industry and the municipality together to negotiate an agreement, by which the municipality will take the wastes in return for special payment by the industry, and where appropriate, the provision by the industry of some form of pretreatment.

The Commission has been given special powers to enable it to put pressure both on an industry and on a municipality to see that this is done. It can issue requirements and directions to an industry under Section 50, with a penalty for up to $200.00 per day for failure to carry them out. It can also report to the clerk of a municipality in writing under section 38:....."that it is of the opinion that it is necessary in the public interest that a water works or sewage works... be established, maintained, operated, improved, extended, enlarged, altered, repaired or replaced...." The municipality is then required by the section to "forthwith do every act and thing in its power to implement the report of the Commission." The penalty for noncompliance is up to $500.00 per day.

When the two sections are used together the report to the municipality may be a very simple one. For example, to afford a connection at a certain manhole in a certain sewer with an effluent pipe from a specified industry. Little or no construction may be involved. By the time the Commission arrives at the point where it is prepared to issue requirements and directions to an industry, and simultaneously, to report to a municipality, it is exremely probable that both the industry and the municipality will be fully aware of the technical problems and costs of treatment in the sewage treatment plant, or of pretreatment on the property of the industry.

I would like to emphasize that when the Commission reports to a municipality under Section 38, it is the Commission which has the statutory power to decide whether or not it is "in the public interest" that sewage works be constructed, etc. If the report states that the public interest requires that the municipality receive the industrial wastes this cannot be effectively challenged by the municipal council. Although a municipal council, upon receiving the application of an industry to discharge its wastes into a municipal sewer, has its normal prerogatives to decide whether or not it will receive them, and therefore is, in a sense, the guardian of local public interests, its powers are related to costs and the safeguarding of the processes of the sewage treatment plant. Accordingly the report of the Commission as to what is required in the public interest cannot be effectively challenged by any municipality as a matter of law, and is unlikely to be challenged, upon the facts, because in practice the Commission is not likely to report to a municipality that a connection ought to be afforded except in situations where all experts would be likely to agree that it was sensible for the industrial wastes to be treated along with sanitary sewage.

I now wish to refer to the special position of industrial concerns which do not hold certificates of approval of their waste disposal facilities. Section 50 to which I have referred is of general application. In other words, while it may be employed, and is frequently best employed, in combination with a report to a municipality, it can also be applied in reference to the construction of treatment facilities (as distinct from pretreatment facilities) for discharge to a natural watercourse. The section reads:

> "(1) If an industrial or commercial enterprise makes arrangements for the collection, transmission, treatment or disposal of sewage that are deemed unsatisfactory by the Commission, or makes no arrangements for the collection, transmission, treatment or disposal of sewage, the Commission with the approval of the Minister, may require such industrial or commercial enterprise,
>
> (a) to make investigations and submit reports to the Commission in respect of the collection, transmission, treatment or disposal of sewage;
>
> (b) to install, construct or arrange such facilities for the collection, transmission, treatment or disposal of sewage; and
>
> (c) to maintain, keep in repair and operate such facilities, as may be directed from time to time by the Commission."

The section says that the Commission "may require" these various things "as may be <u>directed</u> from time to time by the Commission". That is why we speak of "requirements and directions." More informally we speak of a mandatory order to industry. However, it is not an order in the sense of a court order. It does not have the force of a mandatory injunction. It may afford the basis of a prosecution if not carried out, however, and there is in the background the right given to the Commission by Section 54 of the Act to bring an action in court to have the contravention of any order or direction of the Commission restrained by order of a court.

The power of the Commission to require an industrial or commercial enterprise to do something is in the technical field, and accordingly it is of major concern to all engineers, either in private industry or government, who are concerned with the problem of how to treat wastes that will pollute water if not treated. There is a lot of concentrated meaning within the words of the section. The essence of the section is in the power to require that an industry "install, construct, or arrange" facilities. There are some broad implications in these words. To begin with on account of the fact that default may be followed by prosecution and a fine, it is necessary to spell out what is to be installed, constructed, or arranged, with sufficient precision to sustain a conviction. That is a legal point of view. As a matter of legal theory, if the requirement is in vague general language, there may result a compliance by the industry by doing something that is cheap and inadequate, but technically within the requirement.

Our engineers - of our Industrial Wastes Division - in my personal opinion tend to become perfectionists. I do not object to this. It is the mark of a good man in any profession. The point is that they do not like to order an industry to do such and such a thing, unless they know what they are talking about.

Another conclusion I have reached is that the competent engineers and experts in private industry are likely to come up with pretty good answers to those particular pollution problems that arise in the course of their own particular plant processes. If these experts had sufficient funds to spend they could generally solve them. Unfortunately, they are frequently curtailed in what they can spend. In the result they tend to do what they can within the financial limitations. I have reviewed files where action under section 50 has been under consideration where the company experts have had remarkable success in recapturing from industrial wastes materials that can be turned to a profit. We then have the phenomenon: "pollution control as a by-product of increased efficiency as disclosed by profits." I had a dream the other night - the Minister of Finance had announced a revision to the Income Tax Act. Henceforth all companies in Ontario are to have a 100% capital cost allowance for construction of treatment works ordered by the Commission under section 50 of The Ontario Water Resources Commission Act.

That was a digression. Perhaps it was a moment of truth. I was talking of engineers. I have a conviction that the Commission's engineers tend to hold back on recommending a requirement to industry under Section 50 until they have satisfied themselves that the particular thing to be "installed, constructed or arranged" is in fact the best solution. I also have a conviction that if there are good engineers or consultants or waste disposal employed by an industry, the problems can best be solved in consultation and by correspondence.

In our consideration of Section 50 we have, of course, probed the words of the section in depth. I would like to refer to an expedient that has been adopted, where our engineers did not feel they would be justified in prescribing what ought to be done - that is to say: - "installed, constructed, or arranged". This expedient gets around the difficulty. I said that "if th [illegible]

Notwithstanding these factors my view is that a requirement to industry framed in terms of a particular effluent quality adequately defined, and to result from the facilities to be "installed, constructed, or arranged" is a valid legal requirement, and the full sanctions of the law, be it a penalty, or an injunction upon a later application to court, may follow for failure to carry it out.

A further question as to the powers of the Commission arises under subsection (a) which enables the Commission to demand a "report". The words are:

> "to make investigations and submit reports to the Commission in respect of the collection, transmission, treatment or disposal of sewage."

There are two possible ways in which this section may be interpreted. First, it may be considered to be an ancillary power, designed to enable the Commission to obtain the facts, upon the basis of which it may proceed to direct the installation, construction, or arrangement of facilities under subsection (b). The second is to regard the section as conferring upon the Commission the power to require that any industry submit to the Commission whatever plans for treatment it has or proposes to employ in the future to treat its wastes, so that they will not impair the quality of water contrary to the other prohibitions affecting the public at large under other provisions of the Act. The Commission has applied the section in both ways, dependent upon the facts, and the prior discussions or correspondence with the industry concerned.

If an industry says they have engaged consultants, but procrastinates, or delays in submitting any plans for treatment of wastes, the section can be effectively employed to bring them to time.

Before concluding this speech I must say something about prosecutions for pollution and the use of the injunction in Ontario to restrain pollution.

I said at the beginning that there was no crime of pollution, and I now wish to add that there is also no offence under the OWRC Act of pollution. It is a question of potentiality to impair the quality of water Section 27(1) reads:

> "Every municipality or person that discharges or deposits or causes or permits the discharge or deposit of any material of any kind into or in any well, lake, river, pond, spring, stream, reservoir or other water or watercourse or on any shore or bank thereof or into or in any place that may impair the quality of the water of any well, lake, river, pond, spring, stream, reservoir or other water or watercourse is guilty of an offence and on summary conviction is liable to a fine of not more than $1,000 or to imprisonment for a term of not more than one year, or to both."

Anyone can lay an Information under this section. To my knowledge it is only officers of the Commission who have laid charges. These have sometimes followed on complaints, and on other occasions as a result of investigations made by officers of the Commission on their own initiative.

The essence of the law is contained in the words "that may impair the quality of the water". This is a question of potentiality to impair rather than of impairment in fact. In other words, the Crown does not have to establish affirmatively in order to obtain a conviction that the water has in fact been impaired. This has now been upheld in a number of decisions in the magistrates' courts.

The practice of the Commission when laying charges under the section is to adduce evidence that the waters have in fact been impaired in all cases when this can be readily proved. For example, in the case of wastes that are discharged to a stream it is frequently possible to demonstrate that its waters have been impaired by chemical analysis of the water of the stream above and below the points of entry of the accused's wastes.

In the case of lakes and particularly large lakes where the dilution factor is great, it may be extremely difficult to establish that the receiving waters have in fact been impaired by the discharge of material from the plant or premises of the accused. I can cite two examples that may be of interest.

Firstly, the discharge of wastes from a plating factory where the toxic character of the wastes, that is to say, their potentiality to impair, was established by expert testimony supported by laboratory tests of the effect on guppies and minnows. In this case it would have been impossible to convict the accused company on the basis of the analysis of the lake waters because of its size.

Another case involved a recent conviction of a canning plant located on the shore of the Great Lakes where the situation was similar.

It might be assumed from what I have said that in Ontario it is now possible to convict on the basis of effluent analysis only. However, I believe that this is too strong a statement. I have in mind certain types of wastes which are high in BOD and suspended solids where factors of time, of distance and of exposure to the atmosphere may be involved. If it is decided to prosecute for discharge of a material that may impair the quality of a watercourse - and, of course, the watercourse has to be named in the Information - it is not sufficient to establish the character of the effluent unless it is also established that this character is maintained down to the point of entry to the watercourse.

Apart altogether from the distinction between potenciality of an effluent to impair the quality of receiving water, and the impairment in fact of the receiving water, I would like to emphasize that the question of whether the discharge of some material does, or does not, have the potentiality to impair, is itself a question of fact. Not only is it a question of fact, but it is a question of fact to be determined by the magistrate.

The opinion of the Commission is not relevant. Its own industrial wastes objectives are not relevant. Its water quality objectives are not relevant. The court must, of course, act upon the basis of evidence and this evidence normally includes the testimony of expert witnesses. Under the law of Ontario the opinion of an expert, once his qualifications have been established, may be received to establish the effect of an effluent upon receiving water. The accused may call his own experts.

The experts may disagree. The court in deciding: "does this material that was discharged have the potentiality to impair the quality of the water of this watercourse" - is at liberty to believe one, and reject the views of another, as in the case of any witness.

The Commission also has the right to apply to the courts for an injunction, and this power is what I would call the "ultimate weapon" of public authority to control pollution of waters in Ontario.

The power has been seldom used, and is frequently misunderstood. The Commission is caught between two fires so to speak. There are those who say without much thought: "they are gross polluters - close them down" and others who go to the other exreme and suggest that the Commission should never apply for an injunction unless there is no other solution. The latter recall the past reluctance of the Legislature to accept injunctions granted by the courts, where economic and social factors were opposed to a plant being closed down, and where the installation of treatment works was not possible before the effective date of the injunction. My own belief is that the Commission, as a pollution control agency established by the Legislature, will be fully aware of the various interests that may be affected by an injunction.

I also believe that the Commission, as an applicant, is in a different position from any private litigant. I put this on the simple ground that it has no private axe to grind, and is concerned solely with the public interest. There are many ways in which a plaintiff asking for an injunction can influence the course of the trial and the ultimate decision.

For example, the Commission does not have to apply for an interlocutory injunction. It may decide to seek a permanent injunction only. It can also exercise some discretion in the timing of the court processes, including the setting of the case down for trial, the adjournment from time to time of the trial, and finally it can influence the court in the conditions, including the coming into force of any permanent injunction that may be granted.

I believe that the injunction which is of value is the permanent injunction, granted after a trial and a full hearing and when the court has had the full opportunity to employ its powers of imposing conditions, such for example as its power to suspend its coming into operation until a future defined date which will be set out in its judgment. When such a hearing has been held, and the process of the court exercised in regard to timing of the coming into effect, there is generally no public opposition left for the simple reason that it is apparent to all that justice has been done.

There is no reference to a "permanent injunction" as such in the OWRC Act. The law is in the Judicature Act, and in the basic inherent jurisdiction of the Supreme Court. It is a civil remedy granted in a civil action, which is started by a writ of summons followed by pleadings (a written statement by the plaintiff of the nature of his claim and the relief sought, and by the defendant of the nature of his defence), by examinations for discovery in advance of the trial, and finally by the trial itself.

Apart altogether from such an action, the Commission has been given a specific power to apply for what is called an "ex parte" injunction by Section 26(3) of the Act. This section is intended to give a speedy remedy in an emergency situation, and the important rule of statutory construction that is applicable is that which says in effect that the Legislature is presumed not to have intended to change the law except to the extent that this is required of necessity by the language employed.

The courts have always been reluctant to grant an injunction against any person, if he has not been notified. An applicant is required to convince the judge that the emergency has arisen so suddenly and the need for its termination so urgent that there isn't sufficient time to notify the party against whom the injunction is sought. It is also the established practice to require that any applicant who applies without notice will be granted the injunction for a limited period only, and that he must give an undertaking in writing to pay any damages that the other party may sustain in case the court should later decide that the defendant has sustained damages that the applicant ought to pay.

Because of the length of time that usually elapses before an action in the Supreme Court is brought to trial, which may be six months or a year, or sometimes even longer, the court is empowered by the Judicature Act to give what is called an interlocutory injunction upon such terms as it considers appropriate. This expression applies to any injunction whether granted on notice, or ex parte, in advance of a trial. I would like to quote what the Chief Justice of the High Court Division said a few years ago:

> "The granting of an interlocutory injunction is a matter of judicial discretion, but it is a discretion to be exercised on judicial principles. I have dealt with this matter at length because I wish to emphasize how important it is that parties should not be restrained by interlocutory injunctions unless some irreparable injury is likely to accrue to the plaintiff, and the Court should be particularly cautious where there is a serious question as to whether the plaintiff would ever succeed in the action. I may put it in a differenct way: If on one hand a fair prima facie case is made out and there will be irreparable damage if the injunction is not granted, it should be granted, but in deciding whether an interlocutory injunction should be granted the defendant's interest must receive the same consideration as the plaintiff's."

It is because of this important background of legal principles that I restate my opinion that it is the permanent injunction after full trial that is the most valuable. It is something that is granted after deliberation, and with care. The special powers such as the Commission has under Section 26(3) to act in emergency situations are of less importance. I say this partly because of my experience with the Commission. The cases which really called for the issue of an injunction are cases where companies have been under investigation for years, have been the subject of inspection, reports and recommendations, and where the Commission will already have exercised a number of its other powers under the Act without having been able to terminate the pollution. Such cases are not emergency cases. They are hard core cases and frequently long standing.

I would like to conclude by saying that the legal aspects of pollution control are complex, and the selection of the best procedure in any situation is frequently a matter of nice judgment. It is also frequently a matter of common sense. I believe that the most effective pollution control in Ontario has resulted from measures voluntarily undertaken by industry in collaboration with the Commission. The role of experts employed in private industry, and of consulting engineers throughout Ontario, has been most important. In the meantime, the sanctions of the law have assisted, for the law "always speaks".

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# "CLEAN WATER - INDUSTRY'S ROLE"

BY

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Man has inherited from his environment certain great natural resources, resources which are being exploited to their detriment and threatened in their usefulness with the advances and concentrations of population, industrial expansion and innovation. Already, by indulging in practices offensive to nature, we are confronted with the possibility of environmental disaster. In the process, we have tended to forget our dependence upon essential life-giving sources. The physical world around us is itself shaped by life processes; the quality of the air, the purity of water, the formation of soil are all crucially related to life and in degree dependant on it. Unless we face this great central fact of existence, environmental pollution will bring disastrous results and the usefulness of this planet for human life will be destroyed.

Nothing is more important to the continuity of existence and the improvement of man's lot than clean water. For too long, the management of our water resources has failed to keep pace with the rapid growth of waste production. The water of our rivers and lakes, if left alone, would be self-perpetuating, renewing and cleansing. This is a great undeniable fact of nature, but man and his processes have stepped into the scene and upset the natural balance. Progressive pollution of our water resources threatens our whole water economy. A return to normalcy and stability is required - adequate conservation and wise use of water will be a decisive factor in the future preservation of our society.

Responsibility for pollution control lies with government, industry, agriculture and to a degree with the public at large. This presentation is an effort to define industry's role and give some indication of industry's philosophy toward the preservation of clean water.

## NATURE OF THE PROBLEM

In this approach to water pollution and its control in industry, the nature of the problem and some of the solutions need to be defined. If economy of method were not involved, controlling water pollution would be a straight-forward, although not always a simple, technical undertaking. But water management can be expensive from initial research to ultimate solution. There is the added complexity of the contributing impact of the total community as well as industry's involvement in the contamination of total water systems. The solutions available to industry may be effected by improved processes, better quality control, and waste treatment or water re-use. Whatever course is taken, however, is almost certainly influenced by the political, economical and sociological conditions that embrace water pollution problems to-day.

Moreover, public awareness of water pollution and its dangers is calling attention to basic causes and offending sources. As a result of this awareness, the sensitivity created, and the pressures developed, combined with industry's own appreciation of its role, major movements are afoot to bring direct control to the besetting problem involved.

Any appreciation of water conservation and acceptance of its importance must bring with it a determined movement toward effluent control and dynamic management of our water resources. Water management occurs when human foresight and ingenuity are applied to the water pollution problem, although hard core solutions are not easily arrived at. Adequate control programs are essential, however, if water of adequate quality and quantity is to remain a way of life.

Industry, in its various phases, is exercised to a major degree and, in developmental measure, is surveying the problems involved, advancing its programs for correction and accelerating its expenditures to effect continuing solutions. However, caution needs to be exercised to avoid costly or precipitant action which contributes little to correction of over-all problems and places undue restrictions or financial burdens on industrial enterprise.

In re-iteration, the situation must be laid at the door of man. The root cause is the population growth and its shift to urban centres. Waste effluent from large cities, compounded by industrial wastes and agricultural run-offs have multiplied enormously in recent years and greatly accelerated the total problem.

Water quality legislation and the formation of water pollution control agencies are forcing the formulation of definite plans to reduce and eventually eliminate serious pollution in rivers, lakes and estuaries. Not only must acceptable standards of water quality be realistically established, and this is no mean feat in itself, but there must be some articulate means of achieving the desired results.

Water quality levels are best defined through a prior and better understanding of the effect of polluted water on humans, animals and aquatic life. In other words, there needs to be a knowledge of the physio-chemical and biological reactions involved. There are equally important considerations of water quality deterioration unfitting it for re-use, odour nuisances and unsightly sludge banks and floating debris. One of our greatest failures has been the fact that too often we have learned to produce and intrude into the environment powerful new physical and chemical forces before we understand the possible harmful effects on the web of life that determines the quality of our water resources.

## ADVANCES TOWARD A SOLUTION

We have long been accustomed to the idea that the solution to almost any physical problem is to be found in our technology. But the present problem and degree of water pollution control confronts us with the basic economic factors affecting every component of the free enterprise system. There are also the social problems involved in urban development, health problems, political factors, legislative responses - and no less importantly, the need for education. There are many important decisions and choices to be made before final solutions come. However, neither the number or complexity of the problems should postpone action where the need for action is both obvious and immediate and can be reasonably defined. Into this context fits the basic philosophy of industry.

In industrial water control, there are two basic areas of concern - the quality of water at the intake and the quality of the discharge or effluent. The former is a factor only as it affects the plant concerned and where good water practice is an imperative. The heart of the control system is controlling the effluent and, as a result, the degree of contamination in a total water system. The total result is the cumulative effect of all invading forces, having their detrimental impact on the system. This means, in most cases, a co-operative approach to correction and control.

### a. Quality of the Intake

Water for industrial uses may be classified as (1) boiler feed water, (2) cooling water, (3) process water and (4) general utility water. Types of water treatment methods for incoming process waters are cation exchange methods, lime-soda softening systems, demineralization, filtration, chemical removal, etc. Other special treatment types are deaeration, odour and taste removal, chlorination and biological treatment.

### b. Controlling the Effluents

Several basic steps can be taken to reduce industrial waste. These, briefly stated are (1) improved process control within the corporate operation, (2) improved equipment design (this involves new installations and the eradication of present problem areas), (3) use of different or better quality raw and process materials, (4) more effective housekeeping, (5) highly organized preventive maintenance, (6) effective treatment of wastes.

Often, completely satisfactory waste water can be achieved by one or more of the methods outlined. Waste treatment is broken down briefly and without elaboration into such basic measures as: (1) thermal processes, including evaporation, incineration, catalytic combustion, etc., (2) physical processes including settling, flotation, centrifuging, screening, filtration, deep-well disposal, irrigation, impoundment and the like, (3) biological processes, such as filtering, activated sludge, aeration, oxidation, lagooning, etc., (4) chemical processes made up of coagulation, neutralization, oxidation, reduction, absorption, ion exchange and other.

Improved process controls have been adopted in many cases to effect economies and efficiencies in operation and reduce the contaminating effect of resulting discharges. The approach is generally toward more precise waste detection devices and more closely controlled systems. Improved equipment designs with higher efficiency ratings, more satisfactory equipment loadings and more meticulous controls make their contribution to discharge control and recovery effectiveness. Preventive maintenance and better balanced systems are necessary contributors to satisfactory effluent containment.

In the case of processes which can use water of lower quality, recirculation offers a solution to pollution problems, and substantially reduces the eventual volume of waste discharge.

Because of the activity generated toward control in the steel industry, the investigation and implementation involved here will first be discussed as illustrative of industry's role.

## POLLUTION ABATEMENT IN THE BASIC STEEL INDUSTRY

The basic steel industry has faced a complex variety of pollution problems. Many solutions have been sought and found-many millions of dollars spent on control measures. Pollution abatement will continue to tax the ingenuity and resources of the industry in the future in the attainment of acceptable control levels.

Both the rapid growth of the industry in terms of production and expansion and the acceleration of technology and metallurgical science have accentuated the water contamination problem. Without describing or elaborating on the size and complexity of the multi-series operation involved in steelmaking, shaping and product processing, some of the common pollution problems and their control will be outlined.

Of the tremendous quantities of water used by the industry, (Stelco's Hilton Works at Hamilton, for example, uses 200 million gallons of water per day), very little is actually consumed. Almost all of it is "borrowed"-used primarily for cooling, quenching, washing, boiler feed and sanitation, or in other steelmaking processes-and then returned to its source.

Treatment and removal facilities are maintained for six main types of waste materials. These are blast furnace flue dust, mill scale, spent pickle liquor, lubricants, coke plant wastes and sanitary wastes.

### a. Removal of Blast Furnace Flue Dust

Fine particles of raw materials, mostly iron oxide, carried out of the top of a blast furnace in the waste gases, are removed for the most part by dry methods. However, the residue is removed by wet scrubbers, clarifiers and thickening basins before returning to the water source. A complex problem, not as yet resolved, is the cyanide compounds contained in the discharge water. As yet, there is no biochemical oxidation or chemical means of removal possible because of volume dilution effect. Recirculation, concentration and treatment is a possible solution for the future. This problem is now under intensive industry research.

### b. Removal of Mill Scale

During the various hot rolling operations, scale formed on the surface of the steel is removed with high-pressure water sprays. Modern methods of containment remove the entrained scale in scale pits equipped with special baffles for maximum removal efficiency before the water used is returned to its origin.

### c. Removal of Spent Pickle Liquor

Steel surfaces which are to be cold rolled and finished by galvanizing and tin-plating must be prepared by acid cleaning, using dilute sulphuric acid. In some cases, the spent acid can be neutralized by the addition of lime; in other cases, this is impractical and costly.

In recent years, however, a new process substituting hydrochloric acid for sulphuric acid has been adopted by some companies, including our own. When spent, the hydrochloric acid and resulting chlorides are recovered by regeneration and there is no effluent contained in the minimal discharge from the system. There is no similar process for regenerating sulphuric acid although concentrating and filtering methods have been tried.

### d. Removal of Libricating Oils

Today, because of more economy of control, less than one-half of one percent of lubricating oils in steelmaking escapes to stream after use. Such equipment as oil skimmers, clarifiers, aeration and chemical devices, and automatic lubrication systems that recirculate the fluids- plus operating attention and skill - have all but eliminated pollution from oil and grease.

### e. Removal of Coke Plant Wastes

Some of the most critical of offending contaminants are ammonia liquor, naphthalene, phenol and cyanides contained in coke plant wastes. Methods of removal vary from acid treatment for ammonia, tar absorption systems for naphthalene, "dephenolizing" processes, and the use of contaminating water in the coke quenching process, embodying the recirculation re-use principle.

### f. Control of Sanitary Wastes

Progress made in primary sanitary waste treatment in conjunction with steelmaking facilities is gradually overcoming this basic problem.

Lagooning is another method widely used to contain steel plant effluent and provide for separation and control. Deep well disposal of acid wastes is also a means of control.

### Recirculation of Waste Waters

Many processes in the steel industry can use water of much lower quality than that required by control agencies. For this reason, recirculation of process water is more and more solving basic pollution problems. As a result, sewer volumes and tertiary treatment equipment can be reduced to a fraction of the cost necessary for once-through operations. Hot strip mills, continuous casting machines, basic oxygen furnaces and many other processes are being constructed with total recirculating water systems. Where necessary, water treatment plants are being built into these processes.

## 5. CONTROL FACTORS IN OTHER INDUSTRIES

There is no evidence of indifference toward the problem of pollution on the part of those industries whose nature it is to contaminate water. The case for the steel industry has been stated. But in the chemical, electric utility, oil refining, paper and other metal industries, substantial work has been done and the financial outlay to minimize pollution has been high. Most of this investment does not produce a financial return. Anti-pollution regulations and control in many areas have done much to effect improvement in attitude and action.

There is much yet to be learned about abatement techniques. Technology has not yet been developed to meet all the problems, some of which are basically economic. Many important decisions and choices must be made before water pollution is under control. Concern must be exercised toward the undue financial burden which may be caused by pressures being exerted toward solutions. In fact, government action to reduce the burden by tax concessions is well merited.

Action by all of the industries cited or plans for the future have to do with correction of pollution where problems now exist and construction of facilities to prevent future pollution in new plants and installations. In Ontario, the effort toward a co-operative approach exercised by the Ontario Water Resources Commission has been outstanding. Encouragement has been given to voluntary programs and to a systematic approach to the goal of eventual correction and control.

Illustrations of effective action taken by the oil refining industry, the chemical industry and others aiming toward eventual control could be used. There is more need for co-operative action between industries and municipalities to correct conditions affecting communities and water resource systems. There are possibilities for expanded waste treatment facilities where municipal and industrial offenders share cost of sewage disposal plants, corrective and control measures.

## 6. FOR THE FUTURE

If we were to list the main challenges before us, the most important named would be: economics, knowledge of the scope of pollution problems, awareness of conservation practices, and realistic goals and effective remedial action. Not the least of these is the matter of economics.

Another fact to be faced is that water pollution control must begin with the concept of an entire water system. Pollution problems can only be solved through a directed and co-operative effort between industry, community and government.

Not only is water conservation a problem of our total environment, but it is, and I repeat, also an economic problem directly affecting every industry and every consumer or user of the products of industry and agriculture. It is a social problem affecting the development of our cities and the pattern and practices of our daily lives. It is a political problem a legislative problem, a health problem - and of no less importance, it is an education problem.

There is need also for a co-operative program of research toward methods of treatment, development of chemicals, water recycling, quality control, new approaches to ultimate waste disposal and water augmentation. Here we could cite the action of the Federal Government through the Department of Energy, Mines and Resources to construct the Great Lakes Water Pollution Research Centre on Hamilton Bay. In many geographic areas, we are close to having used up the capacity of the environment for absorbing the ordinary waste products of man and the contributing pollutants from industry and agriculture. We must, in the future, construct control facilities, build the missing treatment plants, and reduce the load of natural and industrial wastes to levels that the biology of our surface water will tolerate. Industry is faced with substantial capital outlays to effect their contribution to over-all environmental control.

Consideration should be given to the minimal introduction of new synthetic pollutants to our water systems, detergents, insecticides, herbicides, chemicals and the like. We must endeavour to rectify the scientific imbalance which is the source of so many of our pollution troubles - the imbalance between the rapid application of physical and chemical innovations and our lagging knowledge of the world of life which they powerfully affect. There is a need for a linking of the physical and biological services as effective partners to technology and industry. A lack of comprehension of the intricate interplay of forces prevailing in nature which, when disturbed, bring about pollution, may frustrate our attempt at solutions.

## 7. A WATER CONSERVATION POLICY

Perhaps, what has been stated in this report can best be summed up in a suggested water conservation policy for industry. This is presented in the following terms:

a. Vigorously promote the conservation of water resources in all corporate facilities and operations.

b. Encourage and support with technical ability, time, facilities and money, needed research in the solution of related technological problems.

c. Co-operate with and assist departments and levels of government in the continued establishment of sound laws, codes, rules and regulations based on adequate scientific assessment and realistic determination of need.

d. Promote, assist and encourage the enforcement of water conservation and pollution control with the agencies and levels of government assigned this area of jurisdiction and equipped to deal with the problems involved.

e. Support with technical competence and financial resources corrective programs necessary for control of waste emissions and conservation of water sources.

f. Assign specific responsibilities to designated persons within the corporation to assure co-ordinated, active, and continuing programs of abatement, control and correction.

Certainly, the crisis of environmental pollution demands an all-out effort, in which the benefits of modern industry will play its full part and the competence of modern technology will be placed fully at the service of human welfare.

## 8. CONCLUSION

In conclusion, we would emphasize again the fact that clean water is a critically important resource and that adequate conservation and wise use of water will be a decisive factor in the future well-being of mankind.

There is an urgent and increasing need for a high degree of rational management of our water based on detailed and authentic knowledge and well programmed action. Industry, in co-operation with other segments of the community, has a vital role to fulfil in minimizing the adverse consequences of waste disposal, pollution and degradation of our lakes and rivers.

Indeed, there is no alternative to gaining knowledge concerning our environment and its preservation, in developing technology to meet the demands of effective and economic correction and control and in doing something with them.

# "WATER MANAGEMENT PROBLEMS IN THE CHEMICAL INDUSTRY"

BY

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The conference theme "The Second Century, Clean Water" is to my mind a very excellent one for clean water is the very lifeblood of our existence. The thought should not be allowed to drop after the meeting is over. It should be the guiding light for all to see and heed as the years pass. If we all strive for this objective we can and will have the water resources for maximum development of both industry and municipality. Such a condition will not be cheap to obtain because waste water control is expensive. However, with imagination, sensible application and the further development of technology, it certainly can be achieved at the minimum of cost.

It is only in the last few years that we in the United States have become painfully aware of the pollution problem and are now making the maximum effort to correct the situation. It will not be done overnight, nor will the cost be small, but with the programs now being instituted and further studies in development, we will achieve our goal. This will not be done by any one segment but will be the combined efforts of industry and municipality working closely with the regulatory agencies to achieve the water quality necessary.

Basically, pollution control has been centered in the several states. This is where it belongs and it should be left there. However, due to many factors - politics, finances, proper agency setup - it has not always kept pace with our industrial and urban growth. True, some of the states have been actively concerned over the years and have accomplished much, but there remains more. In some states, only flagrant pollution has been controlled due to an aroused public.

Federal law was virtually nonexistent until 1946 when the first water pollution control bill was passed by the Congress which brought the Federal Government into the picture through the U. S. Public Health Service in the Department of Health, Education and Welfare. This legislation has been modified and expanded through the years, and in 1965 President Johnson signed into law the most far-reaching of water pollution control legislation enacted in the United States. A Federal Water Pollution Control Administration was set up for the first time to administer the law and was to be directed by an assistant secretary.

The most pertinent provisions of the act were those requiring each state to classify its streams according to best usage on the basis of all factors: public water supply, recreation, fish propagation, agriculture, industrial water supply and navigation. Thus, depending on local conditions, there could be several use classifications on a single water course. Having classified for usage, water quality criteria were to be established to achieve the usage classification. Criteria include dissolved oxygen, pH, temperature, chlorides, total solids, nutrients, organisms of the coliform group, together with the so-called "four freedoms."

1. Free from substances attributable to municipal or industrial waste, or other waste, that will settle to form sludge deposits that are unsightly, putrescent or odorous to such a degree as to create a nuisance or to interfere directly or indirectly with specified uses of waters;

2. Free from floating debris, oil, grease, scum, and other floating materials attributable to municipal or industrial waste, or other waste that are unsightly to such a degree as to create a nuisance or to interfere directly or indirectly with specified uses of waters;

3. Free from materials attributable to municipal or industrial waste, or other waste which produce odour, or appreciably change the existing colour or other conditions to such a degree as to create a nuisance or interfere directly or indirectly with specified uses of waters; and

4. Free from high-temperature, toxic or other deleterious substances attributable to municipal or industrial waste, or other waste in concentrations or combinations which interfere directly or indirectly with specified uses of such waters.

With the criteria set, it was necessary that a plan of implementation be prepared for obtaining the river quality goals. This whole program is to be completed by June 30, 1967, and all of the information is to be submitted to the Federal Water Pollution Control Administration. When accepted by the Federal Water Pollution Control Administration, they will become Federal Standards enforceable by the Federal Government should a state not enforce, or is unable to enforce them.

Setting usage and criteria will not in itself solve the problem. It is the implementation which must be developed by the state agency and industry and municipality in the time required which will bring about the changes desired. This is where the full impact will be felt since this will require funds for engineering studies as well as treatment works. A five-year program has been proposed in the law beginning July 1, 1967. Funds to defray engineering studies and a good portion of the cost of construction are available to municipalities from the Federal Government. Industry must finance its own work. Some states now allow a fast tax write-off, or they exempt the cost of waste treatment facilities from local taxation. It is expected that some similar legislation will be passed by the Congress with reference to Federal taxation. This will be most helpful.

In establishing the criteria for a river area, one of the arguments has been that without a satisfactory cost benefit picture it would be impossible to develop economically sound requirements. With this in mind, such a study was instituted on the Delaware River estuary below Trenton, New Jersey. It is in this reach of river that the maximum concentration of industry and municipality occurs. In this area are the cities of Trenton, New Jersey; Philadelphia, Pennsylvania; Camden, New Jersey; Chester, Pennsylvania; and Wilmington, Delaware.

Five objective sets were developed for river quality. Objective Set I was the highest, Objective Set V, the lowest, and this represented existing conditions.

The final evaluation narrowed to Objective Sets II and III. The main difference between them was the dissolved oxygen concentration; 3.0 mg/l for Set III and 4.0 mg/l for Set II. The cost to industry and municipality to improve the river to Objective Set III was estimated at 155 million dollars and the benefits obtained, at 90 million dollars. To reach the next higher goal, Objective Set II, the increase in cost was 120 million dollars making the total 275 million dollars. The benefits increased only 5 million dollars for a total of 95 million dollars. The increase in benefit is due to an increase in fishing area and a 10% higher predicted survival rate of anadromous fish, principally shad, from 80% to 90%. There would be no significant change in appearance, colour and odour and no upgrading of the quality to help recreational use or public water supply. The Delaware River Basin Commission voted to choose a program which is substantially the same as called for under Objective Set II.

The question arises, is it worth spending another 120 million dollars to lift the shad survival rate 10% when little else is likely to be gained? Or, might these funds be more wisely used for education and other necessary services by the municipalities and in the kind of investment which means new products and new jobs by industry. Only the future will provide this answer.

I believe there is much which we in the states are doing in our struggle for clean water that can be helpful in making the conference theme a reality.

Industry is not lily white, but neither is it all black. Enlightened management has realised that unless there is clean water available, it cannot operate or expand. Therefore it must clean up its waste water discharges and it must accept the cost of so doing. In this light I should like to quote from a speech by Mr. H.D. Doan, president of Dow Chemical Company at the 39th Annual Conference of the Water Pollution Control Federation held in Kansas City in 1966.

"But pollution control in the long run does make economic as well as aesthetic sense. And Whether it does or not, pollution is an undesired but direct by-product of our great technology and our growing population. It is clearly one of the problems of a developed nation that must and will be solved regardless of economics.

"Industry, in brief, must be an active, even an aggressive participant in the clean water program. This is the first part ahead for industry."

I think this characterizes both the problem and industry's duty.

The chemical industry has been concerned about pollution and I feel that they have done something about it. A survey made in 1962 by the Manufacturing Chemists' Association of its member plants both in the United States and Canada showed that of the 875 U. S. plants reporting, representing some 81% of the total chemical manufacturing installations of M.C.A. member companies, 711 or 87% were in compliance with stream requirements. In Canada, 24 plants reported. Of these, 20 or 83% were in compliance. More has been accomplished since this survey.

With the new standards being established by the states we will find that many existing plant effluents will not meet these criteria. Factors such as temperature, colour and suspended solids, not rigidly enforced before must now be seriously considered. In addition, nitrogen, phosphorous, total dissolved solids, organisms of the coliform group and radio activity must also be reconciled. Dissolved oxygen levels are being upgraded from 3 to 4 to sometimes 5 mg/l. With all of this, we must face up to a new life and new costs which must be absorbed in our manufacturing operations.

The problem of temperature can affect many of us either from spent cooling water or from industrial effluent.

Water temperature criteria vary somewhat from state to state and greatly from south to north. The maximum in the south is generally 93-95$^{\circ}$F. In the north it is 83-85$^{\circ}$F, except for trout waters where it is lower. To these maximum are added the rate of change and allowable increase over ambient. This latter is usually 10$^{\circ}$F. Usually the rate of change is limited to not over 2$^{\circ}$F per hour.

Some industrial wastes will run as high as 104$^{\circ}$F and effective biological treatment obtained. Uncontaminated cooling waters may reach 120$^{\circ}$F. Where there are high ambient stream temperatures there will be little heat absorptive capacity and problems will be experienced in maintaining the stream criteria.

Hercules had one plant where the spent cooling water was 120$^{\circ}$. The receiving stream was small and temperatures over 100$^{\circ}$F were developed below. A cooling tower was necessary for this stream and with its installation the problem was solved.

High colour values can be troublesome. The wastes resulting from chemical cotton purification at a Hercules plant have a colour of about 6000 mg/l. After biological purification this value is about 9000 mg/l. When discharged into the river, they produce a noticeable change until thoroughly mixed and diluted. Because of the economics of colour removal, reduction was not required. The pH of the raw waste water is about 11.5+. To remove colour, the pH must be lowered to between 2.5 and 3.0. Acid resistant equipment is required. At this pH the colour is precipitated and excellent removals obtained. It must then be neutralized back to pH &.0+ for biological purification. Acid and alkali costs are prohibitive, and the sludge handling problem is difficult. We must now develop an economical solution to this problem because colour removal will become mandatory. This is only one of many such problems in the chemical industry that will require resolution.

While suspended solids have always been given consideration, the need for adhering to low standards has not always been rigidly enforced. As a result, waste effluents contained as much as 100 mg/l or more of suspended solids. Such conditions will not be allowed in the future. Under the new criteria we can well find our treatment facilities requiring enlargement or the need for coagulant aids.

Ammonia is no newcomer to the sanitary field. The nitrogen, in small quantities, is used as nutrient by the bacteria in biological treatment facilities and it is added if not present in the industrial waste. However, in larger concentrations, it can be detrimental, even lethal, to fish life. Generally 2 mg/l at a pH of 9 has been accepted as non-lethal. This may not seem unreasonable to obtain in effluent streams but in an anhydrous ammonia plant it is difficult to eliminate all traces of leakage of free ammonia into the air. As a result, cooling tower installations will concentrate ammonia in the circulating water by scrubbing it out of the air. We have found values of over 30 mg/l of $NH_3$ in the tower circulating water in cooling systems where there was no ammonia process equipment involved in the cooling system.

Phosphorous is one of the basic nutrients for algae growth. In certain areas, however, high phosphorous values have become detrimental. The Detroit River - Lake Erie area is one such section. Phosphorous removal is now being required by industry and municipality and reductions of 80% and higher are stipulated.

Organisms of the coliform group may be a problem in biological treatment plant effluents that are not chlorinated. The wide range of bacterial population in the activated sludge or trickling filter system includes organisms from the coliform group even though sanitary sewage is absent. They can enter the system from the plant operating areas and once present will be hard to kill. We have found high coliform count in industrial waste waters in our plants along with fecal coliform although the sanitary sewerage system was entirely divorced from the industrial system and proven so. In one instance the waste water as checked showed an MPN count over 1,000,000 per 100 ml. Fecal coliform were also found. Chlorination was necessary prior to discharge.

The MPN values specified in the interstate receiving waters for recreation or total body contact vary from 1000 in some of the states to 2400 organisms per 100 ml in others. Municipal water supplies are higher varying from 2000 to 5000 organisms per 100 ml. If the same zone is designated for recreation and water supply then the lower value would govern. Each plant installation will now require a thorough study before a definite decision is made, but by and large, chlorination will become necessary.

Hercules has a plant on Lake Huron where edible and commercial starches are produced. The waste effluent contains about 300+ mg/1 of phosphorous as $PO_4$ and is discharged into the lake. Due initially to algae problems, the plant was required to reduce the phosphate as much as possible. A value of 0.02 mg/1 P in the lake after dilution was the goal.

Laboratory and pilot plant studies were carried out, and it was found that by using high calcium lime the $PO_4$ value could be reduced to between 5 and 10 mg/1 and the 0.02 mg/1 P maintained in the area. A pH above 9.5 was necessary. High clarity supernatant was a problem without coagulant aids. A large amount of sludge was produced and the handling was very difficult. Vacuum filtration at high cost or centrifugation at lower cost produced an acceptable cake. Total operating costs were high. The economic value of the dewatered sludge with 85% moisture was exceedingly poor. It was a problem to even give it away. Disposal by land fill in a selected area several miles from the plant was the only answer. This points up again that sludge handling and disposal can be the most difficult part of the overall purification problem.

One of the comparatively little used methods of waste water disposal is the use of injection wells for discharge into the ground. The oil companies have been using this method for years to get rid of their salt water into subsurface formations. It was not until the early 1950's that it began to be used by industry for the disposal of their contaminated waste waters. Since then it has expanded quite rapidly. It is a method that has been accepted by a number of states and as time passes more will allow its use. Texas probably has the greatest number of disposal wells, there being 31 now in operation, at least 90% of which are chemical plants. These must be approved by the state agency and a permit issued before construction and operation. Properly constructed, they have proven very successful. They are applicable to acids, alkalis, brines, plating liquors, organics from chemical, paper and pharmaceutical operations.

The conditions applicable for deepwell disposal are a porous strata which must be completely isolated from any usable ground water or other natural resource. The injected wastes must be completely contained within the formation. They must be completely restricted from migrating to the surface. Such formations are found at depths ranging from 1,000 to 12,000 feet.

Usually the porous materials are sandstones, limestones, and dolomite. There are locations where sands and gravels are found deep below the surface which are completely isolated. Well capacities will vary from under 50 GPM to as high as 1000 GPM. Injection pressures will range from 50 psi to 5,000 psi.

The liquid to be injected must be free of suspended solids, somewhat near the temperature of the liquid in the formation and must be compatible with it. This usually requires temperature control, pretreatment and filtering before injection with the ground. It may be necessary to partially neutralize the acids to obtain compatibility with the underground liquid.

The cost for such an installation is usually not low. Compared to the cost of treatment facilities to allow disposal into surface streams, it can prove to be the most economical. It is an excellent solution where toxic materials are involved. Operating costs are usually less than conventional treatment costs. There is no question that as time passes this method of disposal will become increasingly popular when subsurface conditions are satisfactory.

The products of the chemical industry are extremely diverse. An industrial waste may contain one or several types of materials, depending upon the magnitude and complexity of the operations. Thus, the answer to the pollution problem can be relatively simple or extremely complex. Whichever it is, it can be reduced to proper limits at a <u>cost</u> through effective treatment and control. Whether that cost will be reasonable in regard to the overall economics of a new plant may well determine whether it will be built at the proposed site location, moved to another, or dropped entirely. It, therefore, behooves us to look critically at the waste water effluent and also at the process operations that produce it.

Industry has not been looking squarely at the problem of recovery or development of by-product materials from its process waste waters. It has in the past been content with somewhat lower operating efficiencies because the cost of obtaining the last few percent of efficiency was not justified by the economics of the losses. By-product materials produced from operations are not always recovered because the cost of doing so has been un-economical. As a result, these discharges have been accepted for treatment.

Today the picture has changed and the cost of treatment may well over-shadow the increased process costs. It is essential that proper research be applied to these problems on a full scale basis to either upgrade the process or develop recoverable products or both. The day has long gone when we can afford to throw away recoverable dollars. This program can be just as important to the overall company economics as cost reduction programs, which it actually is under another name.

We must also know more about the ultimate fate of the constituents in our waste water. Are they completely degraded in the treatment works or are they changed in character so we do not detect them? What happens when they are discharged into the Stream? We have never been too concerned about these in the past but questions are now being asked. We must find out. The Manufacturing Chemists' Association has instituted a research program to determine the fate of a number of chemical compounds. Each industry will have to carry out similar programs on its products.

Building a waste water treatment facility does not of itself solve the disposal problem. It must be operated efficiently every day of the year. It is not something to be built and left alone. Well trained operators are necessary and they must have and maintain an interest in their work. They must be provided with the necessary analytical tools so they will be able to determine whether the equipment is operating properly and, if not, be able to find out why.

It is their duty to see that the operation of the facility produces an effluent that will meet the river standards at all times. It is assumed that the plant has been properly designed to meet the requirements. If they find problems are occurring, it is their responsibility to make sure their supervisor is informed so steps can be taken to correct the problem. Too often delay increases the magnitude of the correction.

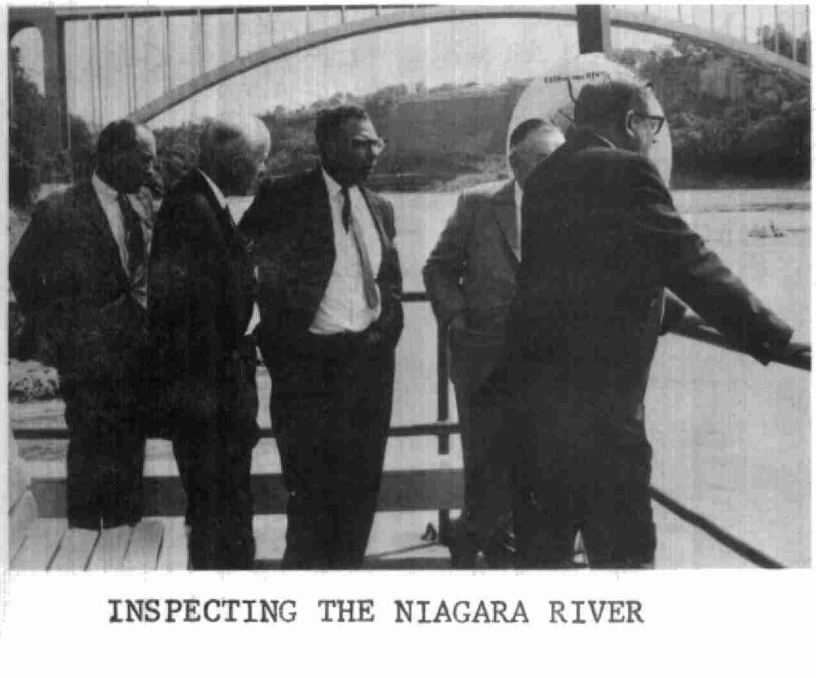
Complete operating reports should be submitted each day by the waste plant operators. These should be directed to the individual on the plant staff who is responsible for the operation of the facility. This individual should be technically trained and have an understanding of the functioning of the waste facility. His authority should be such that when a process operation has become sloppy because of poor housekeeping or maintenance, and losses to the sewer are high, his voice will be heard and corrections will be instituted. If his authority is limited, his effectiveness may be zero.

There should be someone at the corporate level, preferably a vice president, who is kept fully informed of waste water control at all plant operations. A short memorandum once a month to keep him informed should be sufficient. If there is trouble it should be stated. His authority should be such that he can require a plant manager to see that the river standards are being met. In this way, trouble can be stopped early and plant shortcuts, and so-called economies which reduce operating efficiency, can be stopped. He will be able to ascertain when the treatment plant will be overloaded and can ensure that proper steps be taken to provide the additional capacity necessary in adequate time. Too often plant personnel wait until the facilities are overloaded before requesting funds for enlargement. Then it is too late.

The need for educational programs among all employees to show that waste is costly and must be held to a minimum is absolutely essential and must be a continuing thing. It is a part of their job to see to it that spills and leaks are stopped. Dumping a bad batch down the sewer to get it out of sight can no longer be tolerated.

Waste water control was complicated enough before the new criteria were established. Now it will be more so. We will have another face to look at if we do not do a good job, and that is the face of the Federal Government. We will be faced with greater costs for investment and operation and we cannot afford to overlook a single detail for these must be kept to a minimum if we are to stay competitive. With thorough study and planning we will meet the challenge.

INFORMAL MEETINGS



INSPECTING THE NIAGARA RIVER

SESSION CHAIRMAN
R. R. PARKER

# "THE DESIGN OF WASTE TREATMENT FACILITIES FOR THE AUTOMOTIVE INDUSTRY"

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## 1. Introduction

This paper is intended to present the Consulting Engineer's viewpoint of the design of treatment facilities for automotive wastes.

As in the provision of engineering services to any other type of client, the Consultant's role in this field can vary, from a "rent-a-draftsman" proposition to the other extreme, where the consultant turns over a complete operating facility to the client whose only function is to sign the cheques.

We have been fortunate in that the projects with which our Company has been associated have fallen between these extremes. Working with waste treatment Engineers from the automobile manufacturers, we have been privileged to share in the vast amount of knowledge that has accumulated over the years on this type of waste. At the same time we have had considerable scope in the development of our own ideas. Over all, we feel that a true team effort has resulted.

I have personally found contact with the industry's waste treatment Engineers extremely rewarding and gratifying.

## 2. Sources and Types of Wastes in the Automotive Industry

The automotive industry is vast, complex and almost all embracing in the scope of its operations. It encompasses such industries as steel making, stamping, casting and forming, plastics, trim, glass, electroplating, anodizing, and a host of others.

This paper, however, is confined to two types of facilities that are fairly specific to this industry. They are:

(a) Automotive Assembly Plants

(b) Automotive Engine and Transmission Plants.

Let us examine the source of liquid wastes in plants of these types.

An automotive assembly plant can be likened to a boy producing a constant stream of completed plastic models from a pile of the loose components. The modern assembly plant is a marvel of logistic control where thousands of parts are delivered from a multitude of different sources and assembled into the 20th Century chariot. The tendency to-day is to divorce the assembly plant from manufacturing functions. Thus, facilities such as electroplating, which once could be found in assembly plants, are gone.

Liquid wastes may originate at many points along the assembly line, such as:

- Drawing compounds used in sheet metal forming are removed with alkaline detergents.
- Welding gun cooling water may be chemically treated and recycled but is periodically discharged.
- The "bonderizing" process or preparation of the car bodies for painting gives rise to a variety of continuous or intermittent wastes. Bonderizing usually consists of alkali cleaning, phosphating, chromic acid rinses. In between these dip or spray treatments the bodies are given cleaning rinses.
- Water dispersible paints are applied to unitized bodies by some manufacturers. The excess paint on exterior surface is rinsed off.
- Priming and finish spray painting of exterior surfaces is carried out in paint booths where water curtains catch the overspray. The water for the curtain contains an additive to coagulate the paint particles and hence facilitate their removal in flotation tanks. The water is recirculated but

overflows and batch dumping give rise to waste discharge.

- As part of the painting operation, bodies are wet sanded manually under water sprays.
- Gasoline, glycol and crankcase oil may be spilled.
- Paint is stripped from the chains, carts, racks, hangers and other conveyors with caustic cleaners.
- Completed cars are tested for rain leaks under intense water sprays.

Turning to an engine or transmission plant, operations are found to be similar to other machining type industries. Rough castings of blocks, cylinder heads, crankshafts and other parts are machined, ground, drilled, tapped, bored, honed, polished, etc., and then mated with other components such as carburetors and fuel pumps.

In machining operations a liquid is usually required at the tool-to-metal surface in order to provide lubrication, remove machined particles, and provide cooling. A straight cutting oil may be used for this, but where high cooling capacity is required, water is used. To provide lubrication and also prevent corrosion of the part, a soluble oil is added to the water. This oil-in-water emulsion is cleaned by filtering and sometimes centrifuging and is recycled. Eventually, however, these so-called "central coolant systems" must be discharged to the sewer. Often a cause of this, is bacterial contamination and hence biological decomposition of the soluble oil. In a word, it goes rancid.

The close tolerances required for modern engines necessitate clean parts both for accurate gauging and for final assembly. The many washers required to accomplish this, spew a variety of cleaning compounds, soaps and synthetic detergents in solution, and are other sources of liquid wastes in a plant of this type. Before proceeding to some specific projects, I would like to mention two contaminants that occur in the automotive industry which even in small concentrations can quickly induce a visit from the regulatory Authority.

The first is phenol. Short of treatment by a complete biological system, coupled possibly with expensive chemical oxidation, there is only one thing to do with phenols--eliminate them at source. They can and have been eliminated from soluble oil, paint, paint strippers and cleaners by "writing them out" of the purchase specifications for these materials. However, certain other sources of phenols, such as phenolic resins in foundries, are not as easy to control.

The second contaminant is chromium. In the assembly plants the source of chromium is usually the chromic acid final rinse of the bonderizing operation. Some plants treat this waste on-line by reducing the hexavalent chromium to the insoluble trivalent state for later precipitation in the treatment facilities. Sodium metabisulfite is the common reducing agent. Other plants have found that the concentration of hexavalent chromium is low and that reduction is accomplished in the mixed waste streams by the variety of other chemicals present.

### 3. Specific Projects

Some specific projects will illustrate design approaches.

### (a) Ford Motor Company - St. Thomas

The Ford Motor Company's 1.5 million square foot assembly plant at St. Thomas, Ontario, is indicative of current practice for both plant design and industrial waste control in a new facility. Figure 1 shows an aerial view of the entire area. The waste treatment facilities are in the lower right foreground.

In these enlightened times full segregation of wastes is built-in from the start. The separated streams are storm water, sanitary wastes, industrial wastes, and uncontaminated process water. As a result of this segregation, the industrial wastes to be treated amount to only 200,000 U.S. gallons per day. As land is available for sedimentation lagoons, the treatment at St. Thomas simply consists of chemical treatment in batches followed by discharge to the lagoons. The exact volume and composition of the wastes is highly variable and unpredictable and thus batch treatment is utilized. Batch treatment, or at least equalization prior to treatment, is common in the automotive industry for this very reason.

Figure 2 shows the St. Thomas waste treatment facilities schematically. Wastes gravitate to the plant and are pumped into one of two 60,000 gallon batch tanks which are used alternatively. In the batch tanks, the wastes are treated with ferric chloride and/or calcium chloride. These chemicals act both as emulsion breakers and coagulants. The pH is adjusted with sulphuric acid and caustic soda; the operator examines the waste to ensure that a healthy floc has formed and then the entire batch is discharged to the lagoons for precipitation. The two 1,000,000 U.S. gallon lagoons are used alternatively, thus providing a 5-day detention period for the design flow. This method of batch and lagoon is used by several of the automobile manufacturers at many assembly plants.

As shown on the schematic Fig. 2, the effluent from the sedimentation lagoons is discharged to a storm water pond. This pond is necessary due to the topography and it also provides a surge tank function for storm flow. Treated effluent from the sanitary waste treatment plant (100,000 U.S. gallons per day) as well as uncontaminated process water (450,000 U.S. gallons per day) blend with the treated industrial wastes in the storm water pond prior to being pumped to the receiving watercourse. Storm water when available also discharges to the pond and is subsequently pumped to the stream. The uncontaminated process water, (largely welding gun cooling water which is not recirculated in this plant), is quite significant. Objectives for effluent standards are expected to be met without this flow; however, dilution IS achieved. While dilution has been spoken of as "no solution to pollution", the dilution water in this case is imported from Lake Erie and not abstracted from local surface waters. This imported dilution water, therefore, is of significant benefit to the small streams which carry the entire assembly plant liquid discharge to Lake Erie.

Figures 3 and 4 show the completed waste treatment plant.

## (b) Investigation of Existing Manufacturing Facilities:

Compared to the new assembly plant just described, an existing manufacturing facility presents an entirely different problem of waste treatment design. Theories, estimates and predictions are superfluous. The buildings, equipment, sewers and above all the liquid wastes themselves are in existence and must be investigated in person.

The first phase in an in-plant investigation of an existing manufacturing facility is to establish the origin, volume and characteristics of the wastes. The objective of this phase is to determine:

- where the introduction into the sewers of contaminants may be reduced by improved housekeeping or modifications to procedures.
- where economies may be effected by segregation of wastes.

The second phase is to obtain an accurate assessment of the volume and characteristics of the flow which actually must be treated.

## (c) Ford Motor Co. - Windsor:

An example of an in-plant study is one undertaken at the Ford complex in Windsor of which an aerial view is shown in Fig. 5. This complex comprises several divisional operations as shown schematically in Fig. 6. The project is still in the report stage but segregation is a likely solution because of the high flows. Certainly batch treatment of a 49 MGD flow cannot be lightly contemplated!

Flow measurement in a 60" sewer flowing $2\frac{1}{2}$ feet deep is not the simplest of assignments but good results were obtained on this project using an Ott propeller type velocity meter as shown in Figures 7 and 8. Stream gauging techniques were utilized. Vee-notch weirs with a portable recorder were only used for flow measurement. This equipment is shown in Figures 9 and 10.

(d) Chrysler of Canada - Windsor:

Another in-plant study which resulted in the design of treatment facilities was at the Chrysler complex in Windsor. The manufacturing facilities there consist of an assembly plant plus an engine plant, together employing upwards of 10,000 people.

Both the process wastes and storm water were conveyed in a combined sewer system to the receiving watercourse, and therefore the possibility of segregation was given prime consideration in the study. The multitude of existing interconnections within the manufacturing plants, however, made segregation economically unfeasible. Efforts were then devoted to the determination of the volume and characteristics of the wastes being discharged at the two discharge points, a 60" diameter and a 27" diameter sewer. At these locations conditions permitted the construction of rectangular weirs for flow measurement as shown in Figures 11 and 12. Flow measurement on this Chrysler project took place over a three-week period, and sampling and analysis took place over two weeks.

Sampling techniques on an oily waste can give rise to significant discrepancies. For sampling of this type of waste on inaccessible sewers, we have used a vertically sliding tube which produces a sample of the entire cross-section of flow. However, for accessible sewers, as in this case, a reasonably intelligent member of the species Homo sapiens is preferable. Oil appears in the sewer in slugs, and with manual sampling, considerable judgment in sample collection can be exercised. Some of the results of the sampling and analysis at Chrysler are shown in Figures 13 and 14. From the results of this in-plant study and the flow measurement sampling and analysis program, design parameters were established and design concepts formulated for the Chrysler Waste Treatment Plant.

Because of the low flows in the receiving stream it was deemed inadvisable to bypass the storm flow directly to this watercourse. As this storm flow would contain all the industrial wastes discharged including the free oils, some form of treatment was considered necessary. The method adopted was "ponding" of the storm water for later reclamation through the process wastes treatment plant, as spare capacity became available. Spare capacity in this context means capacity not in use due to the intermittent batch nature of the flows through the treatment plant. A pond was designed to give total retention to 1½" of rainfall assuming 100% run-off from the entire contributing area. Even on the rare occasions when overflow from the pond does occur, surface baffles coupled with sufficient retention time will prevent the discharge of most of the free oils.

An investigation was carried out of the pond hydraulics based upon a theoretical storm. This is shown in Figure 15. The design flow of the process wastes (i.e., Dry Weather Flow), was determined as 2.2 MIGD. The treatment method adopted will consist of a three-stage treatment system as shown schematically in Figure 16. Process wastes enter the wet well and are pumped automatically to four 550,000 gallon batch clarifiers. Stormwater is diverted automatically to a stormwater well from where it is pumped to the pond. Site conditions do not permit gravity diversion of the stormwater. The stormwater pump is a vertical propeller pump rated at 50,000 gallons per minute and direct driven by a 300 HP diesel engine only. No electric motor is provided. The batch clarifiers are equipped with bottom scrapers, surface skimmers and chemical feed equipment. Settled solids are removed as in a conventional sedimentation tank. The batch is treated with sulphuric acid to lower the pH to about 3 to 3.5 which by itself will affect the emulsion stabilizing agents sufficiently to permit an emulsion break. Some batches, however, may require the addition of an aluminum salt or other chemical as an emulsion breaker. Soluble oils, emulsion cleaners and emulsified paints may usually be broken in this way. After a quiescent settling period, free oils together with the free floating materials which have been broken out of emulsion are skimmed from the tank surface. The entire batch is then discharged to the second stage air flotation clarifiers by pumps which control the flow rate at 2100 g.p.m.

Air flotation clarification is a subject unto itself and there are many avenues to follow. Controversial points include:

| | | |
|---|---|---|
| Round Units | Versus | Rectangular Units |
| Total Pressurization | Versus | Recycle Pressurization |
| Float skimmed in direction of flow | Versus | Float skimmed against direction of flow |
| Flocculation | Versus | No Flocculation |

The units in this plant represent what we consider to be the highest form of the art at present. Two flotation units are provided, each unit being preceded by flash mixing and flocculation. A portion of the unit effluent (up to 50% of throughput) is pressurized and recycled. Coagulants provided are alum and a coagulant aid which can be activated silica, bentonite, or one of the more exotic polyelectrolytes. The pH is raised with caustic soda to the optimum level for coagulation. Emulsions remaining after the batch clarifiers as well as suspended solids are considerably reduced in the air flotation clarification stage. The effluent from this stage, however, while fairly healthy, still will contain up to about 50 ppm of ether solubles and suspended solids.

It was decided to provide tertiary treatment in the form of chemical coagulation to soak up most of these remaining contaminants with aluminum hydroxide floc. While in specifications for the process equipment specific requirements were laid down for the batch and flotation clarifiers, this was not the case for the tertiary stage. Instead, equipment suppliers were invited to submit tenders for any type of unit for this third stage which employed chemical coagulation and which could do the job. Acceptance of any proposal was thus conditional upon a guarantee of performance. The units finally selected were two "Accelator" solids-contact units supplied by the Infilco Company. Subsequent to the award of the equipment supply contract to the Infilco Company, bench scale tests were conducted on split samples, concurrently by Chrysler Corporation and Infilco laboratories. The aim of these bench scale tests was to verify the treatment methods selected and also to establish effluent acceptance limits for the full scale plant. Performance guarantees for the equipment were then related to the laboratory tests.

The final effluent from this Chrysler plant is expected to meet OWRC objectives. Quality of this effluent will be monitored by continuous measurement and recording of pH and turbidity. Should either the pH or turbidity exceed pre-set limits, the total effluent will be automatically bypassed to the stormwater pond until quality improves to the required standards. The plant has been squeezed into a small piece of otherwise useless ground that was once a dump site. A perspective of the layout is shown in Fig. 17.

In most waste treatment plants, the problem of the disposal of the sludges removed from the liquid wastes is formidable. Often this facet of the design poses a greater challenge than the treatment of the raw liquid waste. In brief, at Chrysler the following are the proposed methods for disposal of the sludges. Batch tank bottom sludge will be dewatered on a Delpark type filter with disposable media. An incinerator of a simple burner type, with atomizing nozzles on the feed systems, will dispose of most of the other sludges. Batch tank skim oil will be dewatered by gravity separation and then will be fed to the incinerator as a primary fuel. The major, and most voluminous material to be disposed of, is the aluminum hydroxide floc from the second and third treatment stages which includes the absorbed oil and particulate matter. This floc will be violently agitated with sulphuric acid to dissolve the aluminum hydroxide and release the oil. This oily sludge will be skimmed off and although still containing a high proportion of water will be fed to the incinerator as a secondary fuel. The dissolved aluminum salt will be reclaimed for use on a coagulant thus reducing the amount of purchased aluminum sulphate.

Originally, it was intended to handle water based paint sludges trucked in from the assembly plant in the same incinerator installation, and for this dual purpose, fluidized bed incinerators were investigated. Tenders were actually called but the cost of the fluidized bed units was so high that they could not be justified economically. The water based paint sludges will be trucked to dump as at present. They are considered to be too viscous to be handled by the atomizing nozzles.

## 4. Conclusion

What is the future for automotive plants in Ontario with regard to the treatment of industrial liquid wastes? Existing plants either have this problem reasonably under control with pretreatment on Municipal Systems, as in the case of General Motors at Oshawa and American Motors at Brampton, or they are actively working toward pollution control, as in the case of the plants I have mentioned and also McKinnon Industries who produce GM engines and transmissions. Within a few years this type of industry will be absent from the OWRC's black list.

The automotive industry plays a vital role in the well-being of the North American economy. The industry is to be commended for realizing that it has a vital role to play in the well-being of North American surface water. Fortunately for our children and our grandchildren, more and more industries are also adopting this attitude. They have come to accept pollution control as part of the cost of doing business.

Figure 1 – *Ford Motor Co. – St. Thomas Assembly Plant-Waste Treatment Plant in right foreground.*

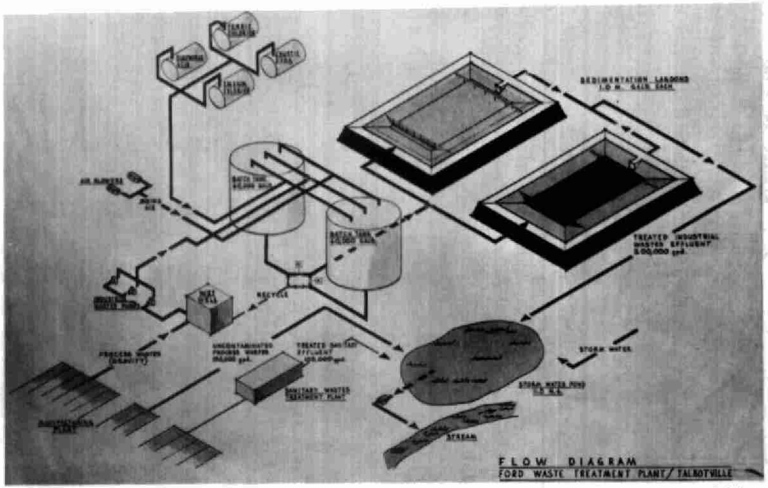

Figure 2 – *Ford Motor Co. – St. Thomas Assembly Plant-Flow Diagram of Waste Treatment.*

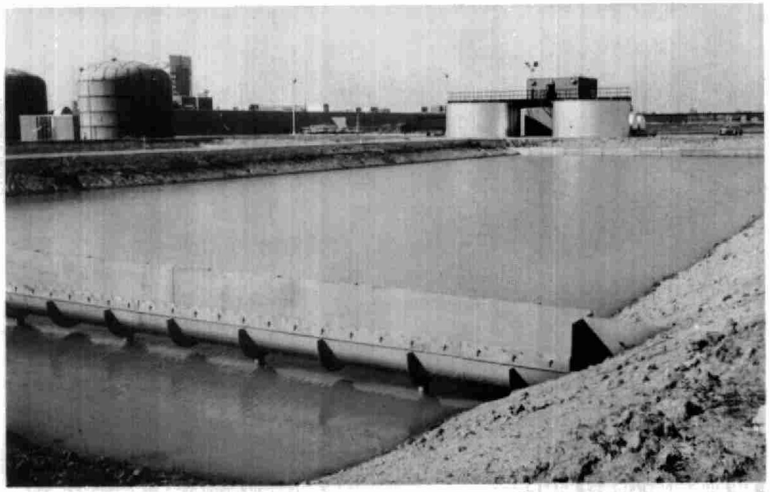

Figure 3 – *Ford Motor Co. – St. Thomas Assembly Plant-Sedimentation Lagoons*

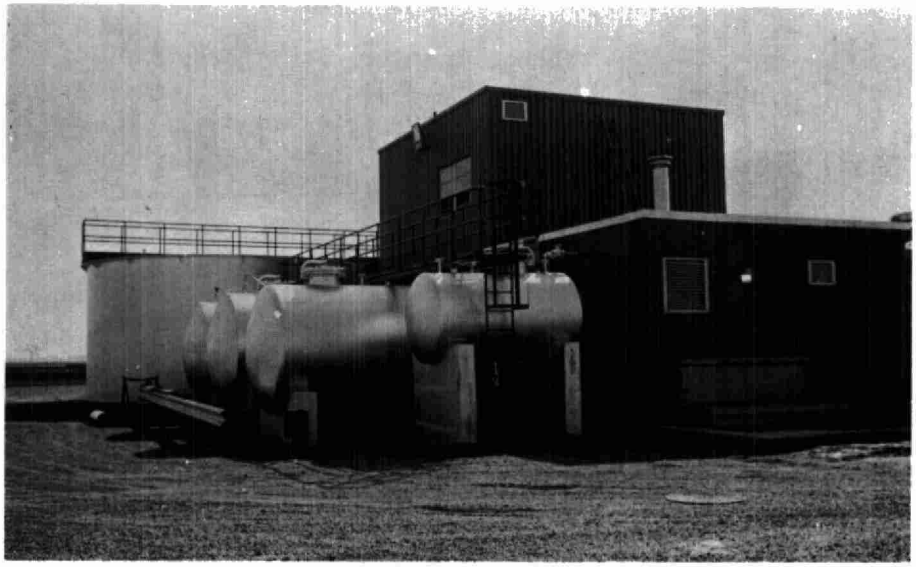

**Figure 4** – *Ford Motor Co. – St. Thomas Assembly Plant-Chemical Storage Tanks and Control Building*

**Figure 5** – *Ford Motor Co. – Windsor Complex*

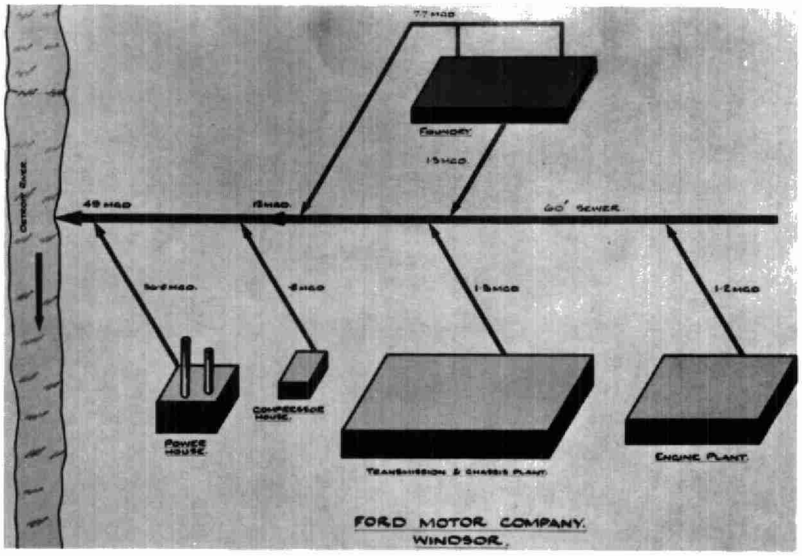

**Figure 6** – *Ford Motor Co. – Windsor Flow Diagram*

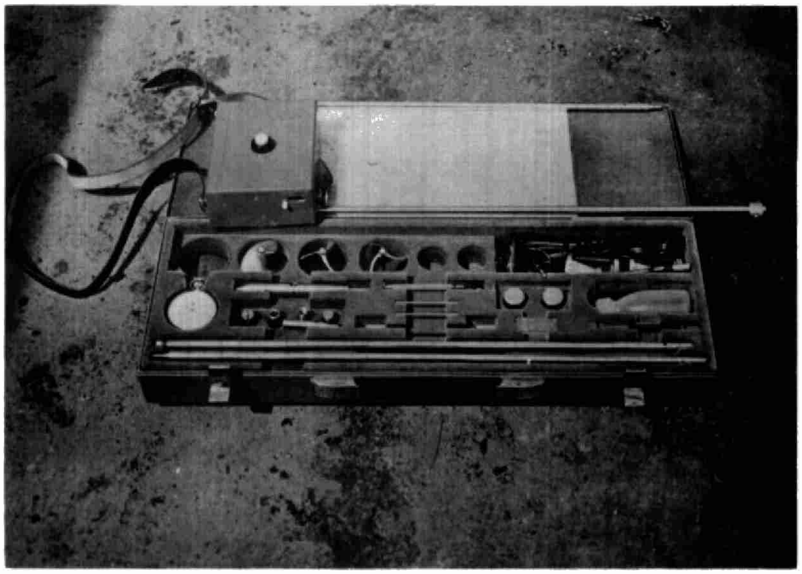

**Figure 7** – *Flow Measurement in Sewers with Ott Velocity Meter*

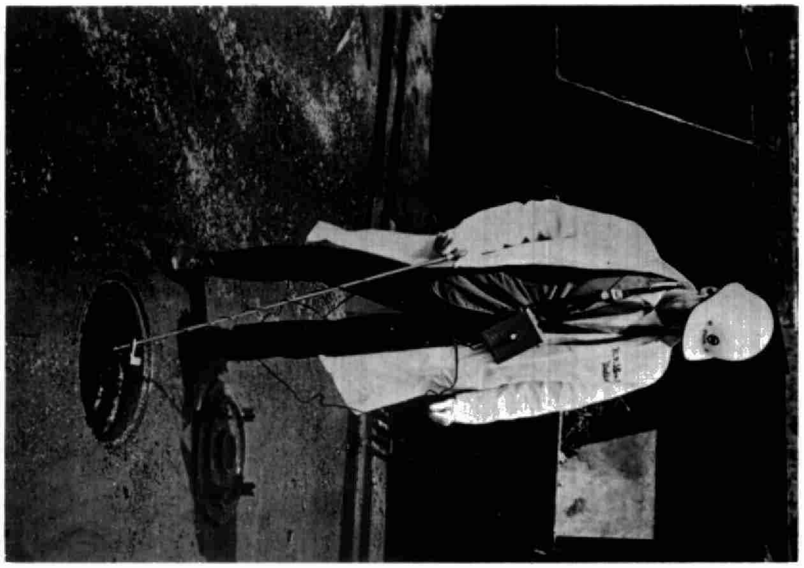

**Figure 8** – *Flow Measurement in Sewers with Ott Velocity Meter*

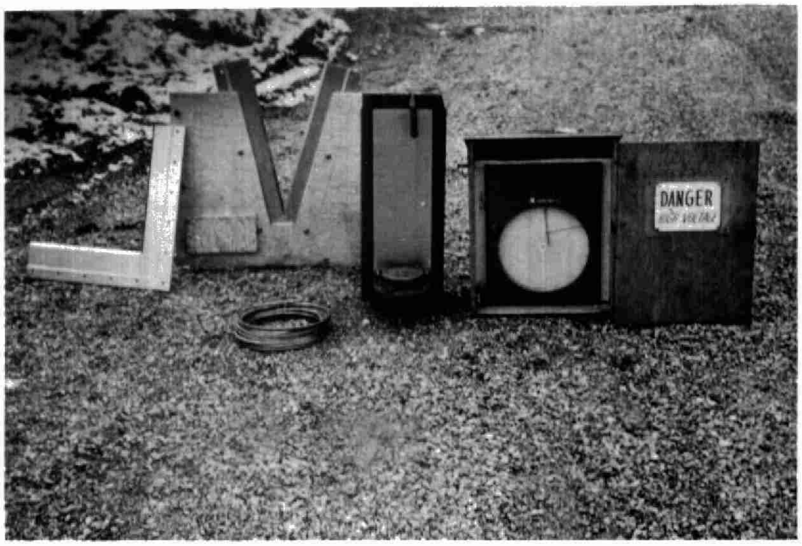

**Figure 9** – *Vee-Notches and Recorder for Flow Measurement*

**Figure 10** – *Vee-Notches and Recorder for Flow Measurement*

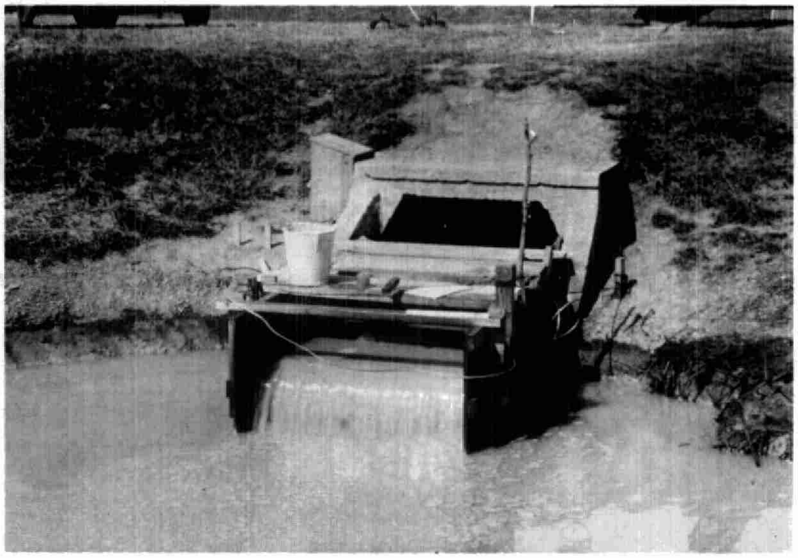

**Figure 11** – *Chrysler Canada Ltd. – Windsor*

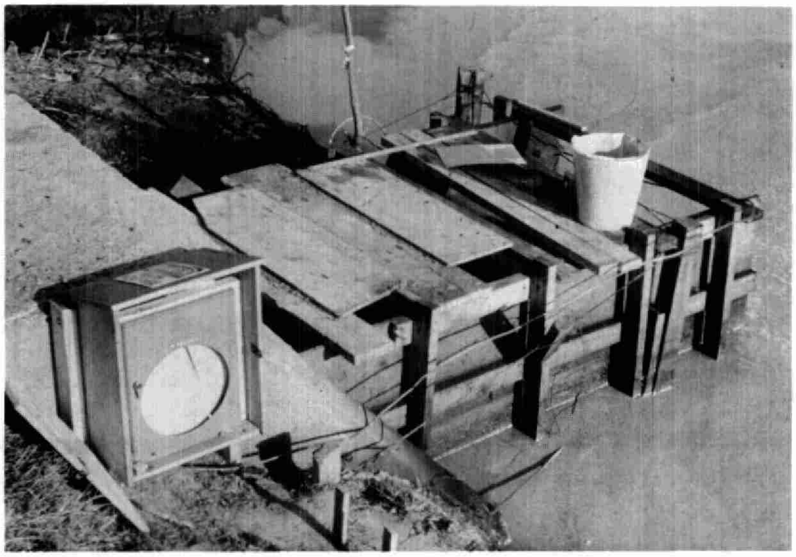

**Figure 12** – *Flow Measurement with Rectangular Weir*

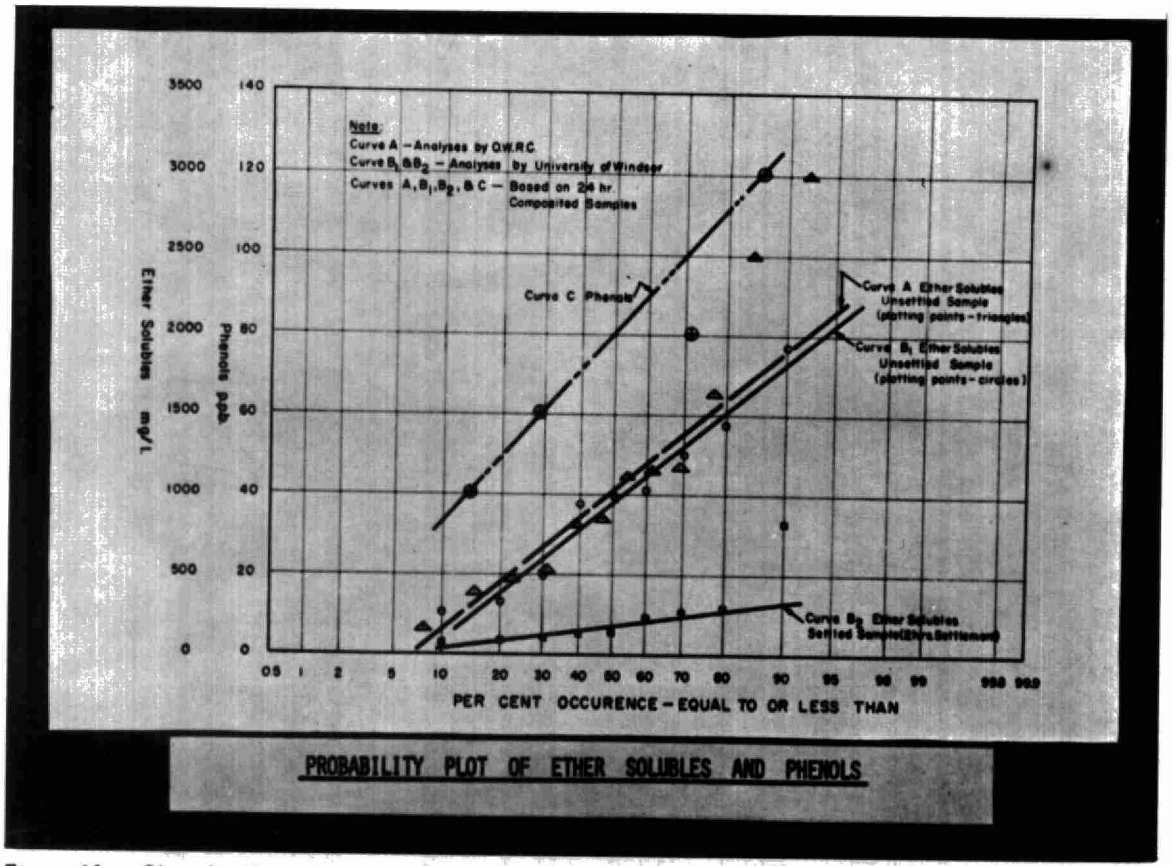

Figure 13 – *Chrysler Canada Ltd. – Results of Sampling and Analysis Programme*

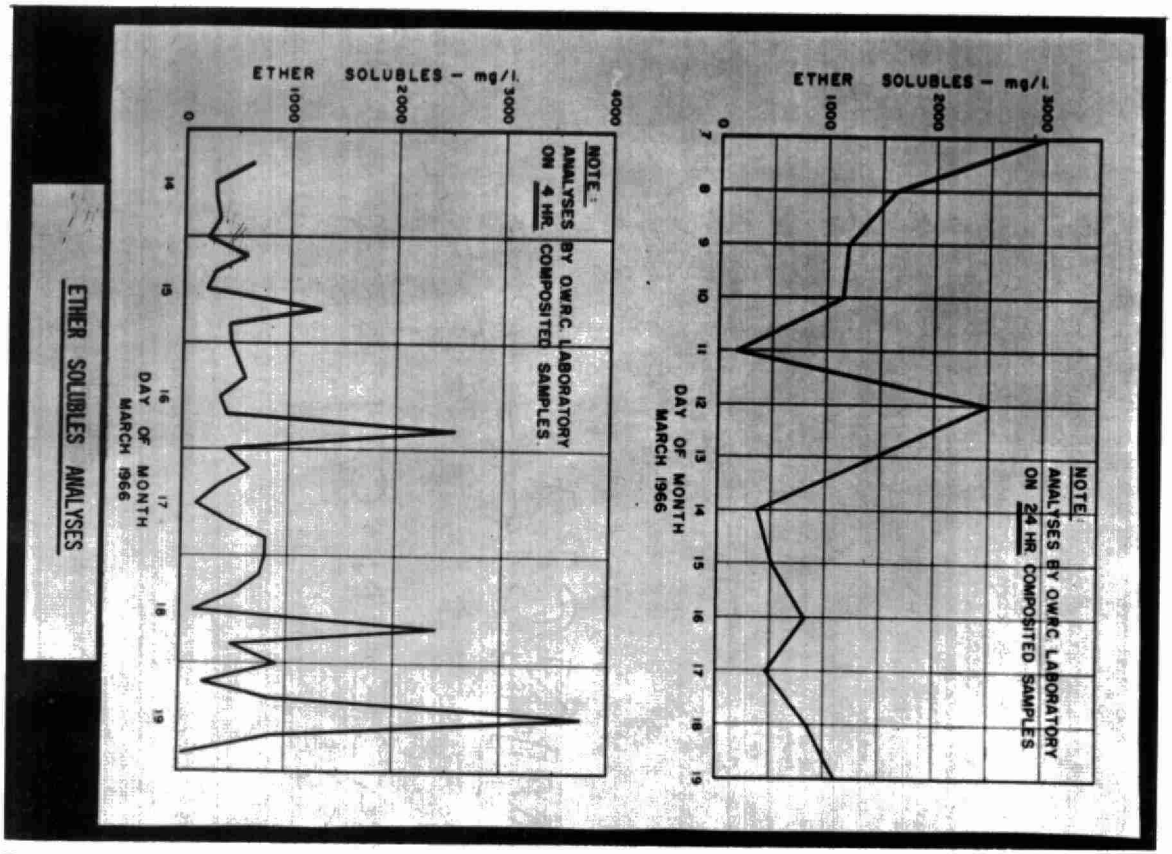

Figure 14 – *Chrysler Canada Ltd. – Results of Sampling and Analysis Programme*

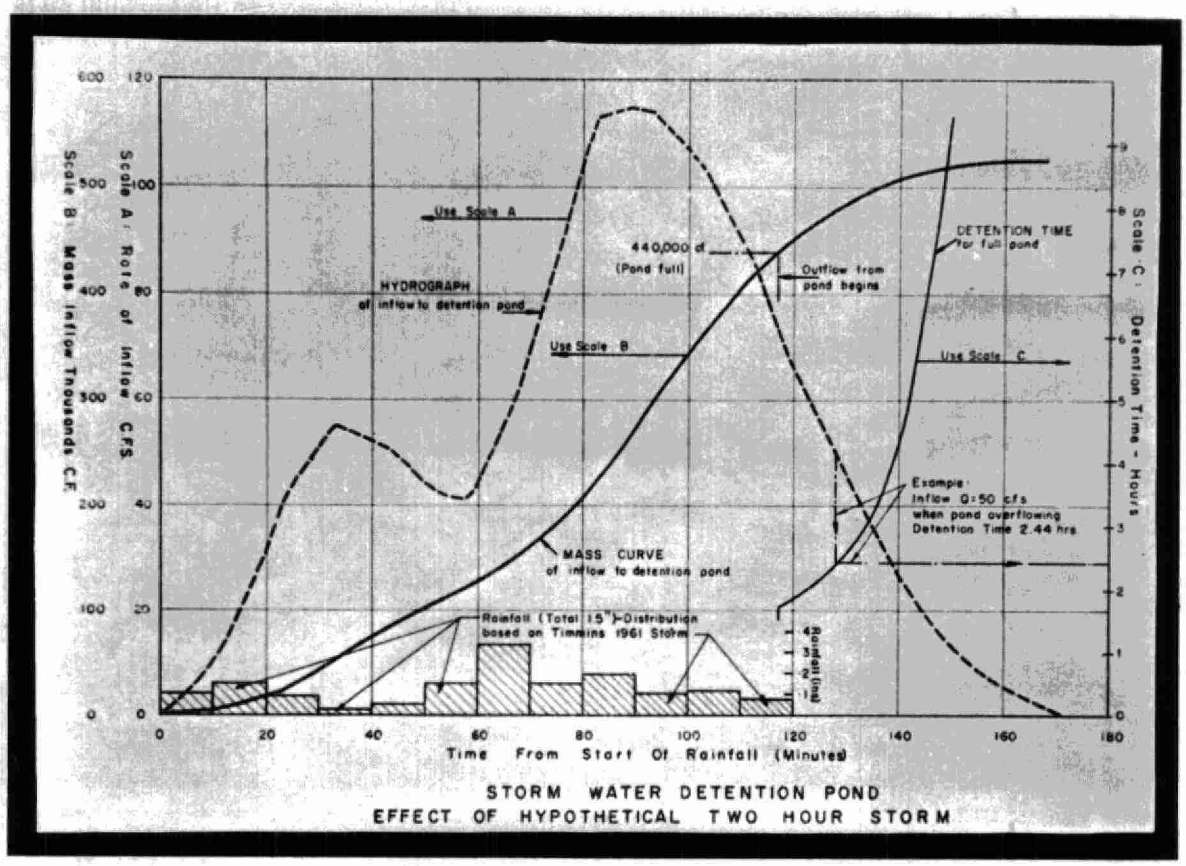

Figure 15 – *Chrysler Canada Ltd. – Windsor-Hydraulic Investigation of Stormwater Pond*

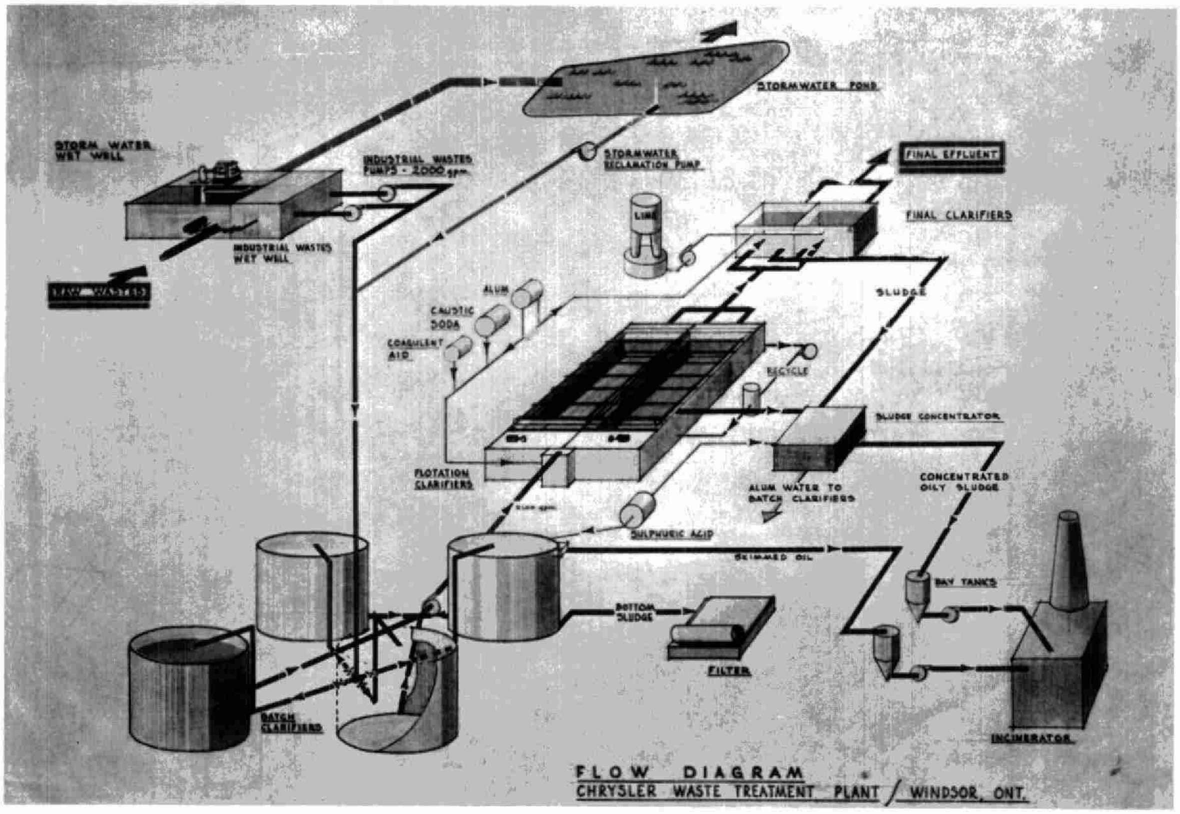

Figure 16 – *Chrysler Canada Ltd. – Windsor-Flow Diagram of Waste Treatment*

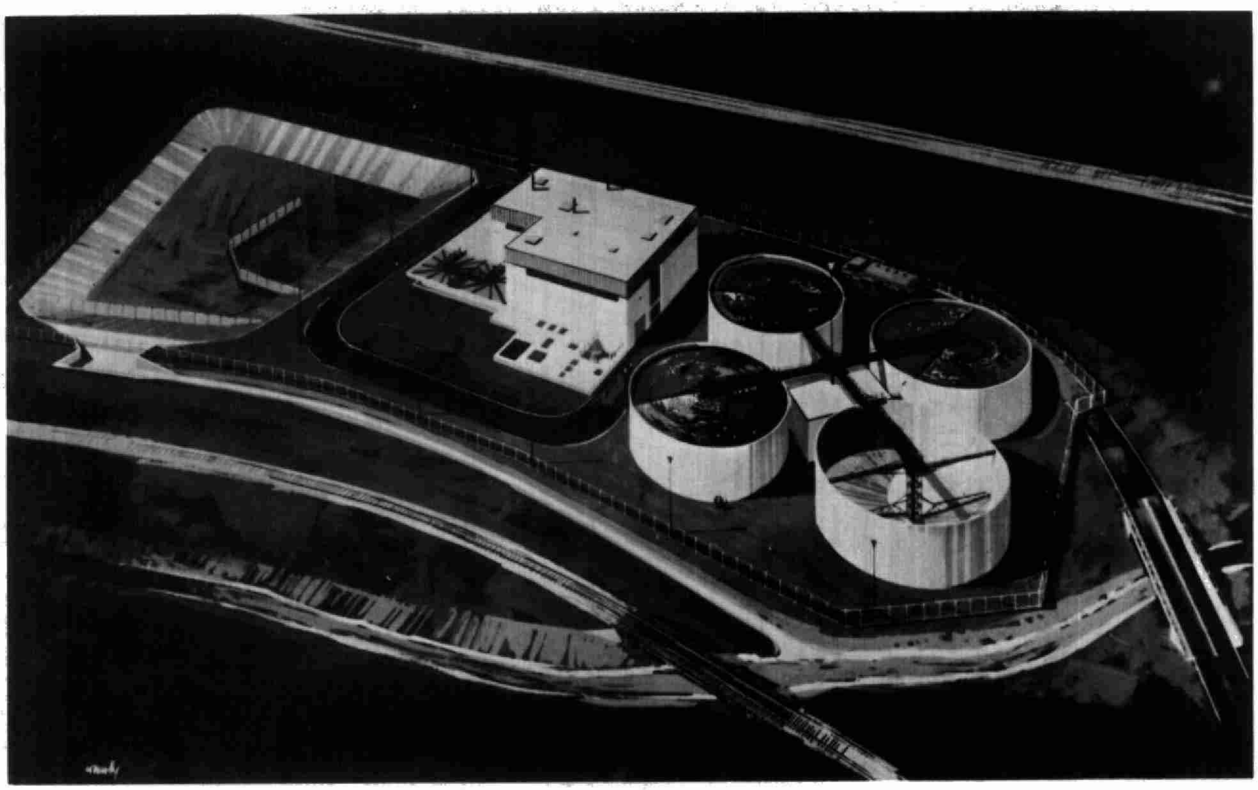

Figure 17 – *Chrysler Canada Ltd. – Windsor-Proposed Waste Treatment Plant*

# "CENTRIFUGES FOR CONCENTRATION AND DEWATERING OF WASTE STREAM SOLIDS"

BY

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In treating waste streams, two well-recognized trends are producing changes in the type of equipment used. Stricter regulatory specifications require more efficient treatment; higher flow rates and increased loadings of suspended and dissolved solids require more efficient equipment. Centrifuging, flotation, and biological treatment are frequently needed to complement or replace simple gravity systems. Centrifuges are generally applied to clarification of a main waste stream only when that stream is relatively small, perhaps up to several hundred GPM; where the waste stream is larger, which is the more usual case, the economic approach is to concentrate the solids by gravity settling or flotation with subsequent dewatering of the concentrate centrifugally. Centrifuging must be considered, therefore, from two points of view: one role is clarification of a stream to produce a good quality of effluent with less emphasis on the concentration of the underflow; the other role is dewatering the concentrate or sludge after a high volume preconcentrator so that underflow concentration is of primary concern, with effluent clarity of secondary interest. Associatedwith the latter type of operation is that of emulsion-breaking in a liquid-liquid separation which may also include concentration of attendant solids. In order to illustrate the use of the two types of centrifuges most often applied to waste treatment and the type of operation to be expected of them, examples are drawn from the pulp and paper industry, petroleum refining, municipal sewage treatment, and electrochemical machining.

With the increasing use of centrifuging as a unit operation in processes, many engineers and operators are now familiar with the principles of centrifugation. For those who are not, some discussion of the designs might be helpful, as an understanding of the operation of the centrifuges increases appreciation of the process and mechanical variables. A scroll or conveyor centrifuge as shown in Figure 1 is most often used for separation of suspended solids from a liquid, particularly when high concentration cakes are desirable or the solids loading is high. It is basically an imperforate cylindrical bowl, supported between bearings, with one end conical to provide a drainage zone for solids during removal from the bowl. The other end of the bowl has effluent ports whose distance from the bowl wall can be varied to provide different pond depths in the bowl. Inside the bowl is a helical screw conveyor or scroll which rotates in the same direction as the bowl but at a slightly slower speed. An external planetary gear assembly determines the basic differential speed between the bowl and the scroll, while auxiliary drive equipment permits increase or decrease of the differential from the base value. Feed, introduced through a stationary tube at one end of the centrifuge, enters a central compartment of the conveyor where it is accelerated through ports into the pond of the bowl. Under centrifugal acceleration in the pond, solids are deposited against the wall of the bowl; the conveyor plows the settled solids to the conical end of the bowl while progressively finer particles are sedimented from the liquid as a function of the time in the centrifugal field. Solids that are not settled within the bowl discharge with the effluent. One important characteristic of any type of solid matter is the operating line showing the relation between throughput rate and proportion of the feed solids sedimented or recovered in the bowl. The other important feature of waste material is the dryness that can be achieved in the discharged cake. Aside from the nature of the sludge, there are both mechanical and process variables that can be controlled to combine satisfactory clarity and solids dryness.

The design or mechanical variables that affect clarification are bowl speed, bowl length and diameter, pond depth, and conveyor differential speed. The capacity of a given bowl is generally proportional to the square of the bowl speed so that higher speeds greatly enhance the capability of the centrifuge. Lengthening the bowl is the most effective way to improve clarification at a particular diameter bowl. Bowls for scroll centrifuges are therefore made in length-to-diameter ratios ranging from 2 to 4. Larger diameter centrifuges should, of course, be used for higher flow rates as the area of the pond and consequently the useful pond volume increases in the larger sizes. Unfortunately, mechanical design parameters limit bowl and gear box stresses so that the allowable maximum bowl speed decreases faster than bowl diameter increases. Larger bowls thus operate at lower centrifugal forces than do smaller bowls. In theory, the liquid layer in a bowl should be very thin for maximum effectiveness, but, in practice, disturbances due to feed, conveyor movement, and fluid flow turbulence require operation with deeper ponds to optimize clarification. Increasing the depth of the pond in a given size bowl, however, also increases the distance that a particle must settle to reach the bowl wall so this factor alone has limitations and pond depths of 2" or 3" often given optimum performance. A high conveyor speed relative to the bowl increases the rate of removal of settled solids from the clarification zone but at the same time creates disturbance and redispersion of the cake; consequently, a medium to low differential speed such as 10-25 rpm often is optimum.

The dryness of the cake discharged by the centrifuge is of particular importance where trucking, land fill, or incineration may be involved. The design variables of the centrifuge, however, affect cake dryness differently than in clarification. For example, the shallower the pond in the centrifuge, the longer the drainage time for solids on the beach above the pond and generally the drier the cake becomes. Very fine particles, however, compact to a limiting dryness at the bowl wall under the pond and capillary forces may prevent appreciable drainage of liquid from such solids on the beach; in this case, a deep pond improves conveying and the removal of this type of cake. Lower conveyor differential speeds increase retention time either for compaction under the pond or for drainage on the beach so that dryness is improved. The tendency of a solid to compact or to drain is increased by increasing bowl speed so that higher centrifuge speeds generally mean drier discharges. It will be noted that some of the factors improving dryness are the antithesis of those for good clarification. A compromise in design and operating characteristics of the centrifuge bowl is frequently necessary to balance the requirements for clarity of effluent and dryness of cake.

Feed rate or capacity is the most important process variable as its relationship to the process determines the number of centrifuges necessary for the desired effluent clarity and cake dryness. Higher feed rates clearly mean less retention time in the bowl with less recovery of the finer fraction of solids. Larger volumes of cake also mean less retention time and usually thicker cakes with less efficient drainage so that cakes increase in wetness.

Until recently, there was little that could be done to improve the sedimenting characteristics of solids. Now, however, the introduction of floccing aids, particularly the polyelectrolytes, has tremendously increased the range of materials that can be satisfactorily handled in centrifuges. In general, it is not necessary to use floc aid where the particles to be settled are relatively coarse or the degree of clarification need not be high. At the other extreme, however, are certain types of soft or floccy solids which cannot be conveyed from the bowl at all without being conditioned by the addition of a polyelectrolyte.

Before reviewing the design of a disc type centrifuge, consider some of the applications of the scroll centrifuge. Among the more readily sedimented materials fed to the latter are the underflow sludges from primary clarifiers such as in paper mills. Figure 2 shows a capacity and recovery plot for primary sludges from several types of mills differing appreciably in characteristic. The ordinate shows the proportion of suspended feed solids recovered during centrifugation; the abscissa is a generalized correlation for the flow rate Q in the centrifuge. The data are from 6", 14", and 25" bowls of various lengths operating at various speeds; to compare them it is necessary to calculate a theoretical centrifuge capacity factor* indicated by $\Sigma$ and to divide the flow rates for a given set of data by the pertinent $\Sigma$ value. This produces a generalized correlation parameter, $Q/\Sigma$ for the capacity data for all the different centrifuging conditions. Such a $Q/\Sigma$ plot is conveniently used for scaling from one size of centrifuge to another by simply multiplying the $Q/\Sigma$ at the required recovery by the appropriate $\Sigma$ of the machine under consideration. In Figure 2, clearly the recoveries can be good but depend markedly on the type of mill.

Data are shown for six sludges from mills differing appreciably in characteristics. The operating line to the left is for primary sludge from a converter mill producing coated paper from wet lap; fiber content of the feed solids was about 51%. Another line is for sludge at 50% fiber from a soda pulp mill producing coated papers. Relatively high capacities at low loss are found for sludges from three other mills, one at 70% fiber from a Kraft mill producing board, another at 33% fiber from a Kraft mill producing coated papers, and a third at 78% fiber from a groundwood mill producing newsprint. While the data are insufficient to be definitive, it appears that sludges from mills with a pulping operation show relatively good recoveries at fairly high flow rates regardless of the fiber/ash ratio. The single example for a converter shows relatively lower rates although good recovery can be achieved. It might be noted that fibers are generally easier to sediment than the ash material, so that solids in the overflow have a lower fiber/ash ratio than the feed whereas the underflow has a higher ratio. Flow rates for pulp and paper mill primary sludges are generally 200-300 GPM in the larger scroll centrifuges.

In discussing centrifuge variables, it was seen that both cake dryness and effluent clarity must be considered and that what is good for one is not necessarily good for the other; thus the clarity and capacity relation is not the whole story. The relationship between solids dryness and suspended solids recovery in the centrifuge is shown in Figure 3 for six sludges. Clearly for primary sludges, solids dryness increases as recovery increases. This is a fortunate and unique trend; most materials show an inverse trend because the presence of finer solids from higher recoveries generally produces softer and wetter cakes. The response for pulp and paper mill primary sludges reflects the good packing characteristic of ash material in the fiber matrix and the effect of squeezing action when handling larger quantities of solids.

* Fully discussed under "Centrifugal Separation" in Volume 4 of Kirk and Othmer "Encyclopedia of Chemical Technology", 2nd edition, or in Perry "Chemical Engineer's Handbook", 4th edition.

There seems to be a trend also with fiber/ash ratio where higher ash content material gives a drier discharge. The very fine fibers of the flotation scum with no ash content give a relatively wet cake and also show the more usual increase in wetness with increasing recovery.

The effects of pond depth and of bowl speed are shown in Figure 4; the latter is expressed by the multiple of gravity to which the sludge is exposed. Recoveries for the three conditions shown are approximately the same; comparison of the corresponding flow rates shows the expected response of rate proportional to the square of the speed, but little effect of pool depth. For cake dryness, however, a much drier cake results from a shallow pool than from a deep pool at the same level of centrifugal force. Also, reducing the centrifugal force from 3200 G's to 2100 G's with the same pool decreases the dryness of the cake as would be expected. These responses to the centrifugal acceleration show the marked importance of operating at as high a bowl speed as is feasible.

In this regard, the factor limiting bowl speed to something other than design maximum is usually the problem of abrasion. Scroll centrifuges are designed to take considerable abrasion with hard-surfacing alloys applied to the edge and face of the scroll, hard-surfacing or ceramic inserts at the solids discharge ports, ceramic inserts in the feed and effluent ports, rubber or ceramic liners in the feed chamber of the scroll, and other abrasion resistant materials as needed in the bowl and covers. Nonetheless, where sludges contain relatively large amounts of coarse particles, it is sometimes desirable to reduce the bowl speed in order to reduce the rate of abrasion. On oil refinery waste, it is even occasionally necessary to insert a cyclone in frontof the scroll centrifuge in order to knock out a few percent of very coarse solids and thereby decrease abrasion rates by as much as three-fold. A cyclone is also used ahead of a large Super-D-Canter at one pulp and paper mill to remove grit and pebbles picked up by the waste stream during flow in an open drainage ditch.

Many pulp and paper mills are now operating primary settling systems on their wastes and most of the others will soon do likewise. Secondary treatment systems are not yet common although a number are in use; the limited removal of suspended solids in the primary clarifiers, however, and the relatively small reduction in BOD in primary treatment indicates strongly that most primary systems will have to be followed by a secondary treat. As the characteristics of sludges and centrifuges on primary and secondary treat are somewhat different, they are better considered separately.

Since a disc centrifuge is considered in connection with activated sludges, it would be well to digress briefly on the design and operating features of this type of centrifuge. A disc centrifuge is usually more suitable than a scroll centrifuge for handling finer sized particles; it can apply a higher centrifugal force to sediment and compact the solids and is not subject to the problem of scrolling solids out of the bowl. Figure 5 is a schematic drawing of a nozzle-discharge disc centrifuge bowl. The speed is relatively high so that the centrifugal acceleration at the wall is two or three times that common in scroll centrifuges.

Feed, introduced at the center of the bowl, moves outward to a zone outside of the discs which are represented by the closely spaced parallel lines. These discs are actually a nest of cones with spacers between to keep them from 0.025" to 0.100" apart. As feed enters these narrow spaces, solids settle radially outward under centrifugal acceleration. There is such a short distance to travel, however, that relatively fine particles can be readily captured. The settled solids slide down the undersurface of each disc and out to the bowl wall where they compact before discharge through orifices in the periphery of the bowl. Clarified effluent emerges from the inner edges of the cones and is discharged separately. In order to build up the concentration of the sludge discharged, a portion of the nozzle discharge is commonly returned to the bowl as a concentrated recycle stream equivalent in volume to a considerable part of the total nozzle discharge. The advantage of the disc centrifuge is that it has a very high $\Sigma$ or theoretical capacity factor and the flow rates handled are often much higher than in a scroll or other type of centrifuge of comparable size and cost. Such a centrifuge is frequently used not only for oil separation from emulsions as in petroleum refinery or fish plant wastes but also for removal and concentration of fine solids from these waste streams.

One of the strong trends of the times is the growth in secondary treatment plants for all types of industrial and municipal wastes. These most frequently take the form of aeration to produce an activated sludge at about 1% concentration. Gravity thickening can normally raise this to not more than 3 or 4% while flotation may achieve 5%; centrifugation in a disc centrifuge can give 5 to 10% concentration on most activated sludges. These materials are characteristically soft and flocculant, not a type of material which is easily scrolled in the conveyor centrifuge. Figure 6 is a recovery and capacity plot for several types of activated sludges in scroll centrifuges. A waste activated sludge from a chemical complex at a feed concentration of about 1% is shown with floc aid addition. Another curve shows a difficult waste activated sludge from a paper mill secondary treatment plant for operation with no floc aid and also with about 20 lbs/ton of polyelectrolyte addition. Waste activated sewage sludge is also shown with and without floc aid addition. In practice, it is found that the individual particles of activated sludges from different sources do not sediment too differently, but their aggregate conveying characteristics may vary markedly, even from hour to hour within a given plant. Recoveries at reasonable flow rates generally do not exceed 40 to 60% without the use of coagulants. With the latter, recoveries to better than 90% can be achieved with polymer dosage at 25 lbs/ton or less. Feed rates for such activated sludges in large scroll centrifuges would normally be 50-150 GPM. The concentration of underflow solids may vary appreciably ranging from 7% on some domestic sewage to 20% or so on industrial activated.

In contrast to the spread in scroll centrifuge data on activated sludges due to the conveying problem, operating curves for disc centrifuges on activated sludges show considerable consistency. Data are shown on Figure 7 for two municipal activated sludges, one activated sludge from a chemical plant, and another from a paper mill. These curves are for operation without floc aid addition and it is seen that relatively high recoveries can be obtained in this type of centrifuge. In large disc centrifuges, these operating curves correspond to 100-200 GPM of sludge feed for recoveries of 80-90%. Underflow concentrations of 5-10% are readily obtained while recycling on some sludges which do not contain too much grit or fibrous material can produce underflow concentrations up to 12% by weight.

For a small municipal sewage plant where a scroll centrifuge may run for only a few hours a day to concentrate all the activated sludge available, a scroll centrifuge would probably be more advantageous. For larger municipal sewage plants and particularly for large industrial secondary treatment systems where flow rates range from a few hundred to several thousand gallons per minute of waste activated sludge, continuous dewatering in a disc centrifuge offers considerable economic advantage.

A number of solid-liquid separations have been reviewed in terms of the clarification involved and the solids concentrations that must be obtained for waste disposal. In general, the soft type of sludges considered is the most difficult to handle in centrifuges; flow rates for feeds with coarser and more particulate solids may range up to more than several hundred GPM in the larger centrifuges now available. Applications involving three phases such as oil, water, and a solid are not as common but often represent more of a treating problem. Separate specifications often exist for the quantity of oily matter that can be discharged in a plant effluent. Moreover, an appreciable discharge of oily matter is usually clearly visible in the effluent and receiving streams.

A particularly important application for centrifuges is treating petroleum refinery waste streams. A schematic flow sheet for most of the wastes in an oil refinery is shown in Figure 8. The streams consist of large quantities of water, lesser quantities of oil, and a smaller portion of suspended solids. The solids are usually sand and silt, catalyst fines, filtering or bleaching clays, and various carbon or degradation products from refinery operations. Preliminary gravity separation in an API separator produces overflow emulsion fairly high in oil, water that may still contain appreciable dispersed oil and fine suspended solids, and bottom sludge at 10-40% solids with some oil. Past practice has been to lagoon the water, but the present trend is to flotation units with the flotation scum being added to the API separator overflow emulsion which it closely resembles in composition. Settlings from field tanks, water treatment, and perhaps bio-treatment are generally high in solids. These are conveniently combined with the API separator bottoms and treated in a scroll centrifuge to rough out 60 or 70% of the coarser solids. The cake discharged from the centrifuge is low in oil content and is frequently suitable for land fill. Emulsion overflowing from the conveyor centrifuge is similar to the flotation scum and the API overflow emulsion. These streams are frequently combined, heated to about 190° F if the light-ends content permits, and fed to a disc centrifuge for resolution of the emulsion into clarified oil of 1-5% BS&W,

clarified water, and oil-free water stream containing the fine solids. Disposal of the last depends on the refinery situation. The stream may be lost in the main refinery effluent or may be recycled to the API separator. In the latter case, no buildup of fines has been observed. If buildup did occur, occasional addition of floc aid to the scroll centrifuge would knock down the fines and permit maintenance of a controlled fines content in the waste stream.

This application illustrates the value of sequential centrifuging operations. A rougher centrifuge, well protected against abrasion, handles the bulk of the coarse solids. It is followed by a second higher speed centrifuge making the important oil-water split but also handling the finer solids without excessive abrasion. Despite differences in refinery operation, crudes, range of products, and designs of API separators, the nature of the solids and quality of the emulsion are suprisingly consistent from one refinery to another. A sufficient number of installations has been made to show that test work need not be conducted in order to estimate results for centrifugal waste treating equipment for new refinery installations.

Despite the presence of oil as an emulsion, the operating curves for solids removal in the scroll centrifuges are similar to those for other simple solid-liquid separations.

Figure 9 shows operating curves for the separation of the Super-D-Canter emulsion overflow in a DH-3 Nozljector disc centrifuge. BS&W of the clarified oil is given as a function of the clarified oil flow rate. The light oil emulsion contained relatively large quantities of light ends; the middle curve is for higher viscosity oil and is more representative of the average refinery emulsion; the upper curve was for an extremely stiff emulsion, totally depleted in light ends, from an emulsion disposal pond that had been aging outdoors for 20 years or more.

Sewage treatment is a field in which the potential of centrifuges is just starting to be realized. Most of the centrifuges have so far been applied to assist existing equipment to accept an appreciable overload and forestall a plant expansion. It is common practice to treat primary and secondary sludges in digesters in order to reduce the odour problem and permit eventual disposal of the solids on drying beds. The flow sheet in Figure 10 makes no attempt to show all the variations that are found in sewage plants but does indicate several points where centrifuges can advantageously be applied. For example, waste secondary sludge may be further concentrated before addition to primary sludge so as to increase the digester solids loading. Digester sludges may also be dewatered before disposal on drying beds with consequent reduction in drying space and time.

Limitations on drying space and odour problems from the proximity of even digested sludges to residential areas, however, are reducing reliance on drying beds with replacement by incineration. In order that incinerators be self-sustaining in combustion, the volatile solids content of the feed must be 18-20%, considerably higher than obtainable by simple gravity processes. Centrifuges, occasionally in combination with presses, are important in preparing both primary and secondary sludges for incineration. Where digesters exist, digested sludges may be dewatered before the incinerator, but trends in sewage treatment indicate feeding of dewatered primary and secondary sludges directly to the incinerator. In treating sludges that are predominantly primary with its usual large particle size, conveyor centrifuges are the most satisfactory.

One of the newest and fastest growing metal working processes is electrochemical machining. In this process metal is removed by dissolving it into an electrolyte by electrochemical decomposition with both tool and work piece immersed in the solution. A direct current is passed through the electrolyte between the tool as the cathode and the work piece as the anode. Metal from the work piece ionizes and goes into solution in the aqueous medium where the metal ions combine with hydroxyl ions present to form insoluble hydroxide sludges. If the sludge content of the electrolyte increases beyond a certain point, the conductivity decreases rapidly and production rates decrease. The fine flocculant solids have very slow settling characteristics and, even when settled, do not compact to facilitate disposal. Filters have been and are used for clarification, but they are largely unsatisfactory, particularly in the bigger machine installations. Cartridge type filters give good clarity but are quickly plugged by the sludge; backwashing them has not been successful. Scroll, disc, and basket centrifuges have been used on these sludges. A recovery and capacity plot is shown in Figure 11 for ECM sludges from several different sources handled in these centrifuges. Since the sludges do vary, the relationship of the operating curves in this plot reflects characteristics of the centrifuges as well as variations of the feed material.

The relatively high rotational speed of the disc centrifuge tends to shear the weak hydroxide flocs so that the $Q/\Sigma$ range for this type of centrifuge is relatively low although very high recoveries can be achieved. In the scroll centrifuge, rotational speeds are lower and the floccy solids of the feed are less degraded during accelration. The scroll centrifuge, however, has a problem in conveying the peanut-butter-like solids that are deposited at the bowl wall. While the basket centrifuge has some tendency to break flocs, its slower speed dampens this effect. Solids are removed from the basket by a scooping device at intervals of one-half to several hours depending on the rate of solids loading.

It is of interest to use these three operating curves to study some of the factors entering into selection of the proper centrifuge for a particular job. Since flow rates for ECM installations may range from 25 to several hundred GPM, it is important to consider first the range of centrifuge sizes available in each of the types indicated. Both disc and scroll centrifuges are available in many sizes up to those handling about 500 GPM per centrifuge. Basket centrifuges are also available in sizes from 1ft. diameter to about 5 ft. By way of example, assume that centrifuges are needed for about 90% recovery of solids. From the operating curves, an approximate value of $Q/\Sigma$ can be found at 90% recovery for each type of centrifuge. Also needed are the relative $\Sigma$ factors of suitably large units and the relative costs of these units. These values are shown in Table 1.

TABLE 1

Centrifuge Selection for Handling ECM sludge

| Type of Centrifuge | Disc | Scroll | Basket |
|---|---|---|---|
| $Q_F/\Sigma$ at 90% Recover | 1 | 3.7 | 35 |
| Ratio of $\Sigma$ Values | 90 | 13 | 1 |
| Ratio of Capacities ($\Sigma x Q/\Sigma$) | 90 | 48 | 35 |
| Ratio of Centrifuge Costs | 4.1 | 6.1 | 1 |
| Ratio of Cost/Unit Capacity | 1.6 | 4.5 | 1 |
| Solids Content of Underflow (% W/W) | 4-7 | 8-12 | 18-22 |

The table reflects the data of Figure 11 showing a high relative $Q/\Sigma$ factor for the basket. On the other hand the relative $\Sigma$ value for the disc is much higher than for the basket while the scroll is intermediate. The product of and $Q/\Sigma$ determines the capacity per unit for the type and size of centrifuge selected. The capacity ratio of the disc is almost three times that of the basket while the scroll is one-third higher than the latter. The table next shows the low cost ratio of the basket compared to either the disc centrifuge or the scroll. The ratio of cost per unit capacity is finally shown for each type of centrifuge. The basket is the lowest in this case with the disc 60% higher and the scroll several-fold higher. This obviously is one of the important parameters in selecting a centrifuge for a particular job.

Where waste streams are concerned, disposal of the cake or underflow solids is often a problem. In general, the more concentrated the cake, the easier it is to dispose of it. Consequently, Table 1 also lists the solids content of the ECM cakes from the three types of centrifuge. Disc centrifuges inherently produce a less concentrated cake than either of the others. On ECM cake, no drainage of the solids is possible due to their fineness so the scroll centrifuge yields a wetter cake than the basket. The combination of cost per unit capacity and the underflow concentration in this case very clearly favours the basket centrifuge.

The results of this comparison are by no means general. If the solids loading were higher, if continuous discharge of solids were required, or if the solids were more readily scrolled and were capable of draining to achieve better dryness, the scroll centrifuge would probably be the best type. Again, if flow rates were very high or excellent clarities were required, the disc centrifuge might be the choice. The latter might even be followed by a scroll or basket centrifuge to concentrate the underflow to a further degree for disposal. This example points up the importance of comparing the several types of centrifuge that might handle an application. The first type offered or the kind used on another job may not be the best one for the job at hand.

This survey of centrifuges treating industrial waste has necessarily touched on only a few applications. Extrapolating the trends apparent today, what changes can be foreseen in the application of centrifuges to waste handling in the future? Certainly centrifuges with larger capacities will become available as the need becomes apparent. This does not mean that centrifuge power requirements will be so reduced as to warrant their application to large main flows, but capacities double those of the larger units available today are well within reason. At present, only municipal sewage treatment requires a sufficient number of centrifuges in a multiple unit installation as to warrant producing centrifuges of such higher capacities. Another development of importance will be the improvement in use of coagulants. This will involve development of new coagulants, reduction in prices of available coagulants, and improved methods of treating with coagulants, particularly with respect to centrifuge operation. Such improvements can bring into the range of reasonable centrifugal handling some sludges which now show too great a loss or insufficient concentration. Another trend will certainly be that of incinerating of wastes to produce the minimum quantity of ultimate solids. For autogenous operation, incinerators generally require feed concentrations that can sometimes be achieved on filters but more generally are available only by centrifugation. The trend towards secondary treatment will certainly be accelerated under the urging of both federal and local government for both municipal sewage plants and industrial waste treatment systems. Centrifuges can be expected to play a large part in handling the rather difficult solids produced by all types of activated treatment.

Many engineers have already discovered the value of applying centrifugal force as a complement to gravity settling operations in order to reduce treatment costs through reduction in space, manpower, and associated equipment. It is hoped that these brief indications of the capabilities of centrifugal equipment may be helpful in solving your specific waste treatment problems.

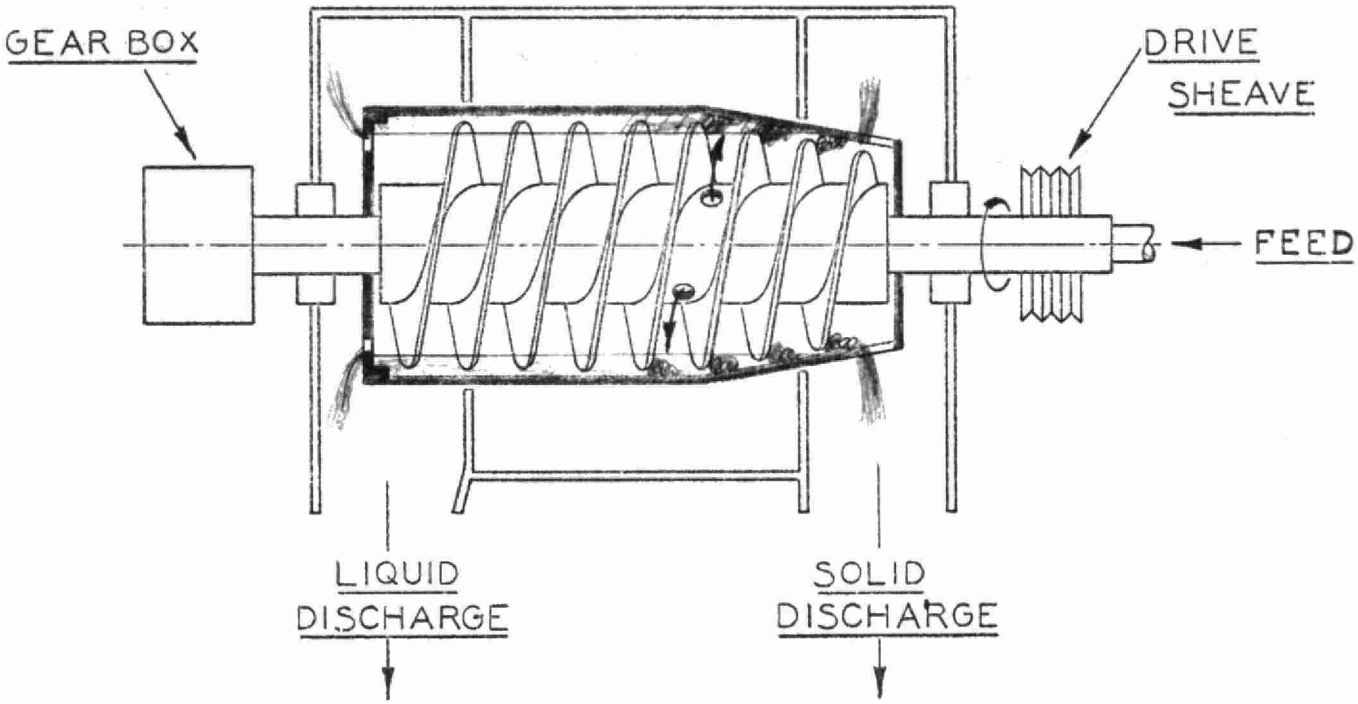


Figure 1 – *Imperforate Bowl Conveyor Discharge Centrifuge*

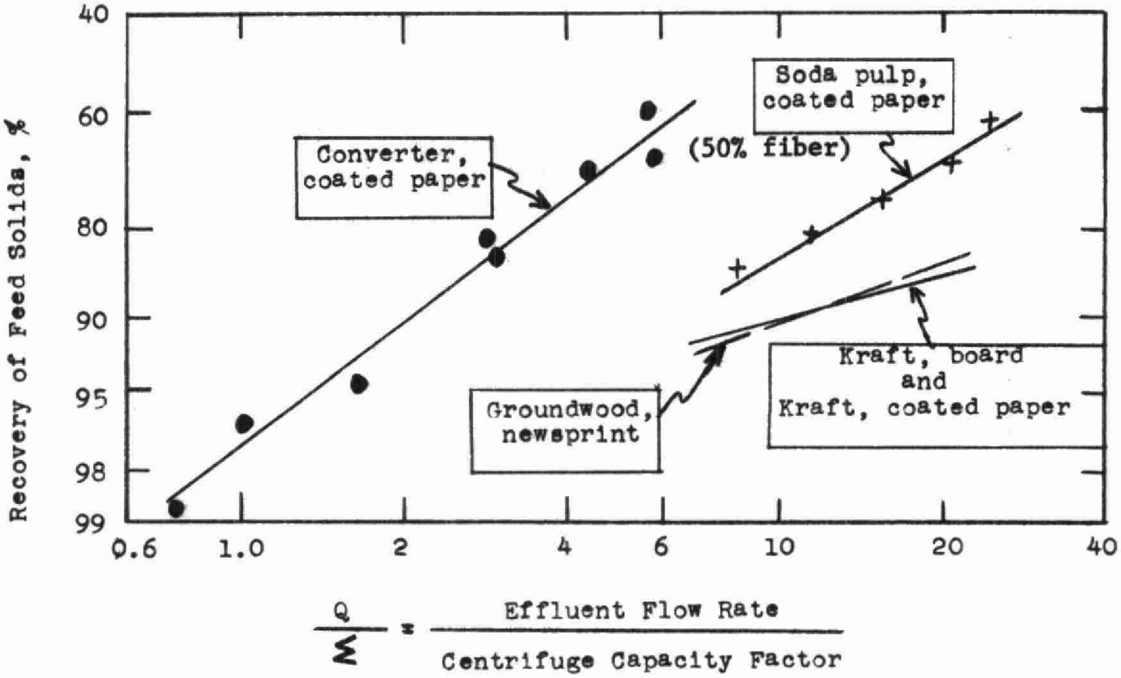


Figure 2 – *Centrifuge Capacity and Recovery on Pulp and Paper Mill Primary Clarifier Sludges*

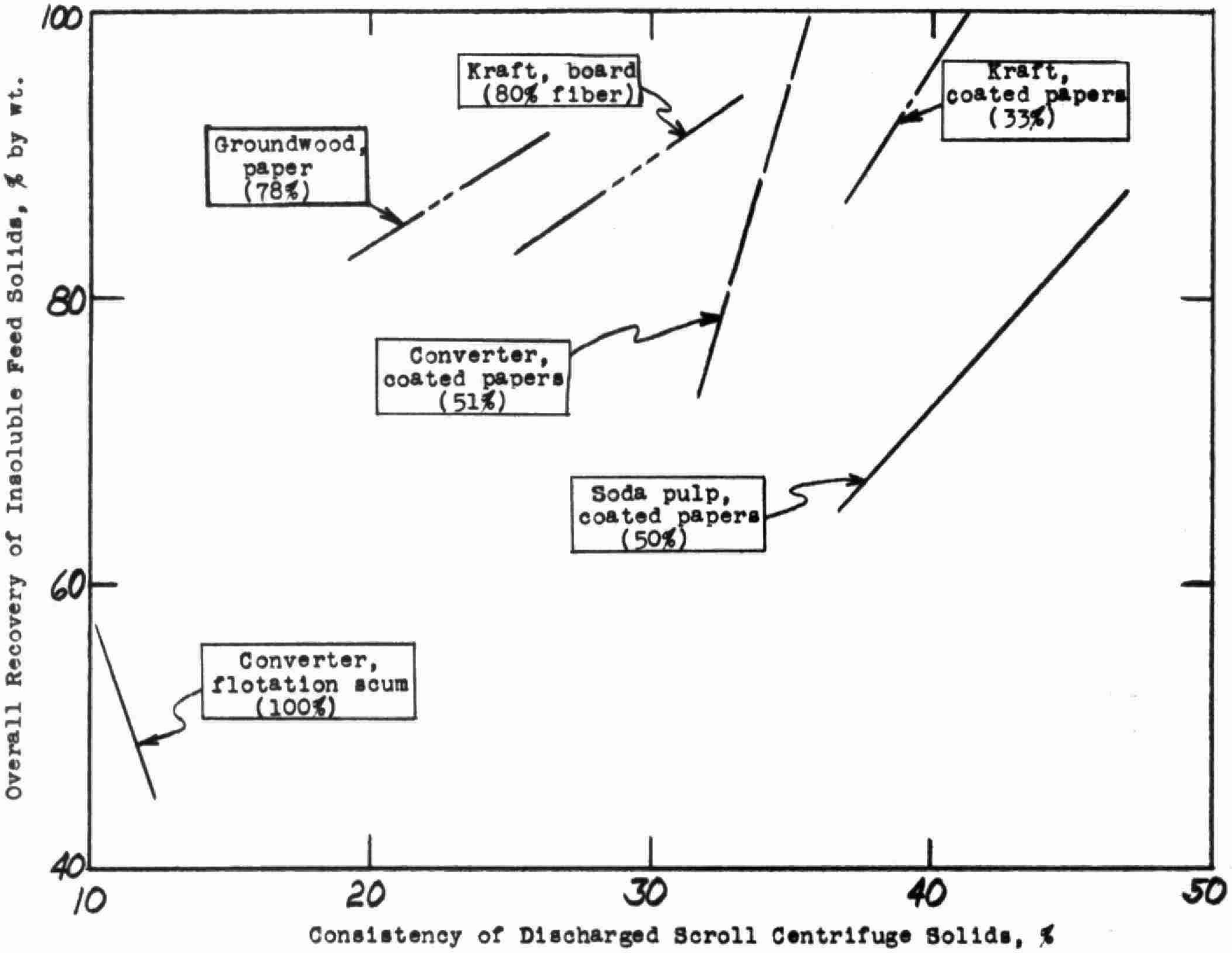


Figure 3 – *Effect of Recovery on Scroll Discharge Solids*

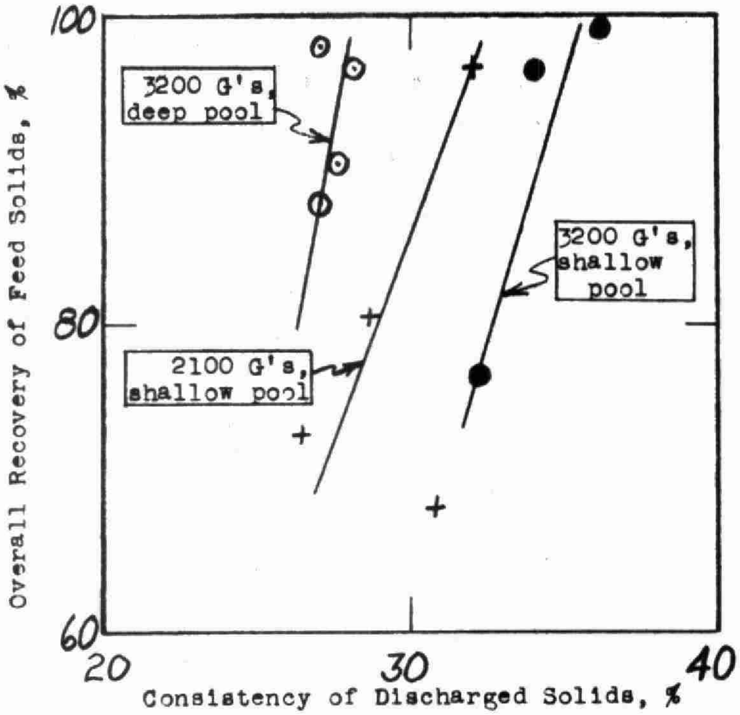


Figure 4 – *Effect of Centrifugal Force and Pool Depth on Consistency of Discharge*

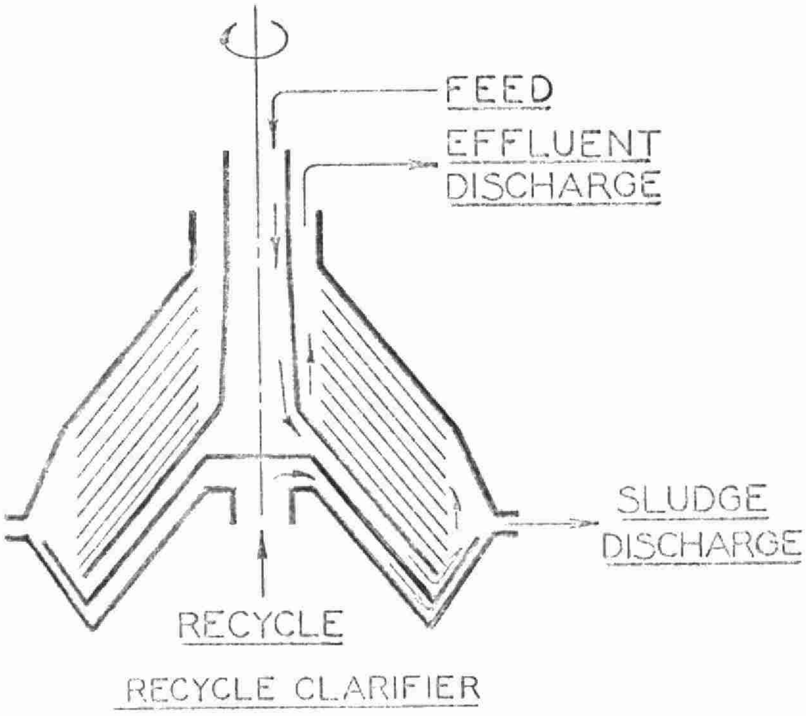


**Figure 5** – *Disc Centrifuge Bowl*

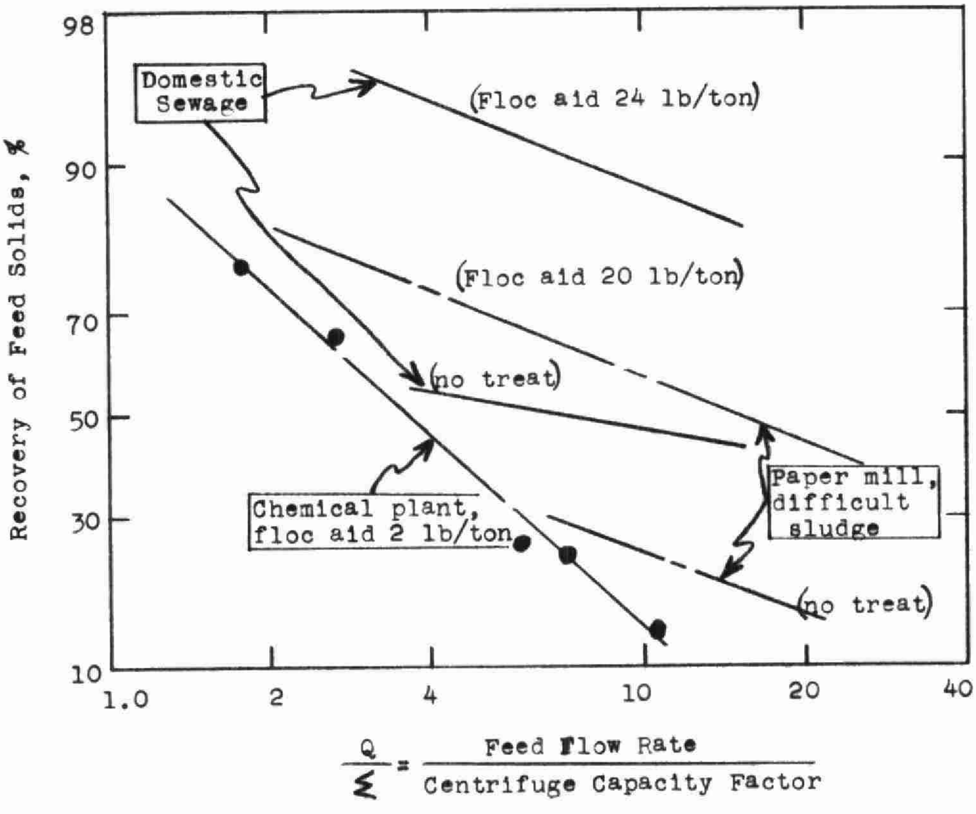


**Figure 6** – *Scroll Centrifuges on Activated Sludges*

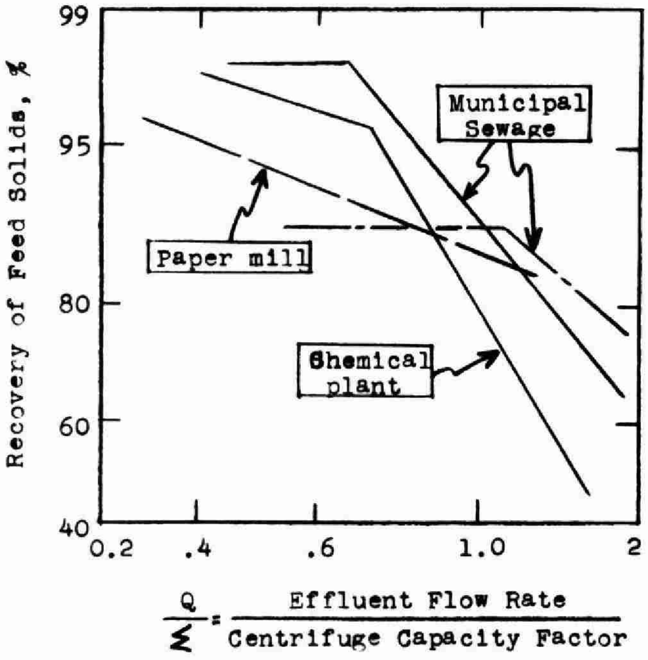


Figure 7 – *Disc Centrifuges on Activated Sludges*

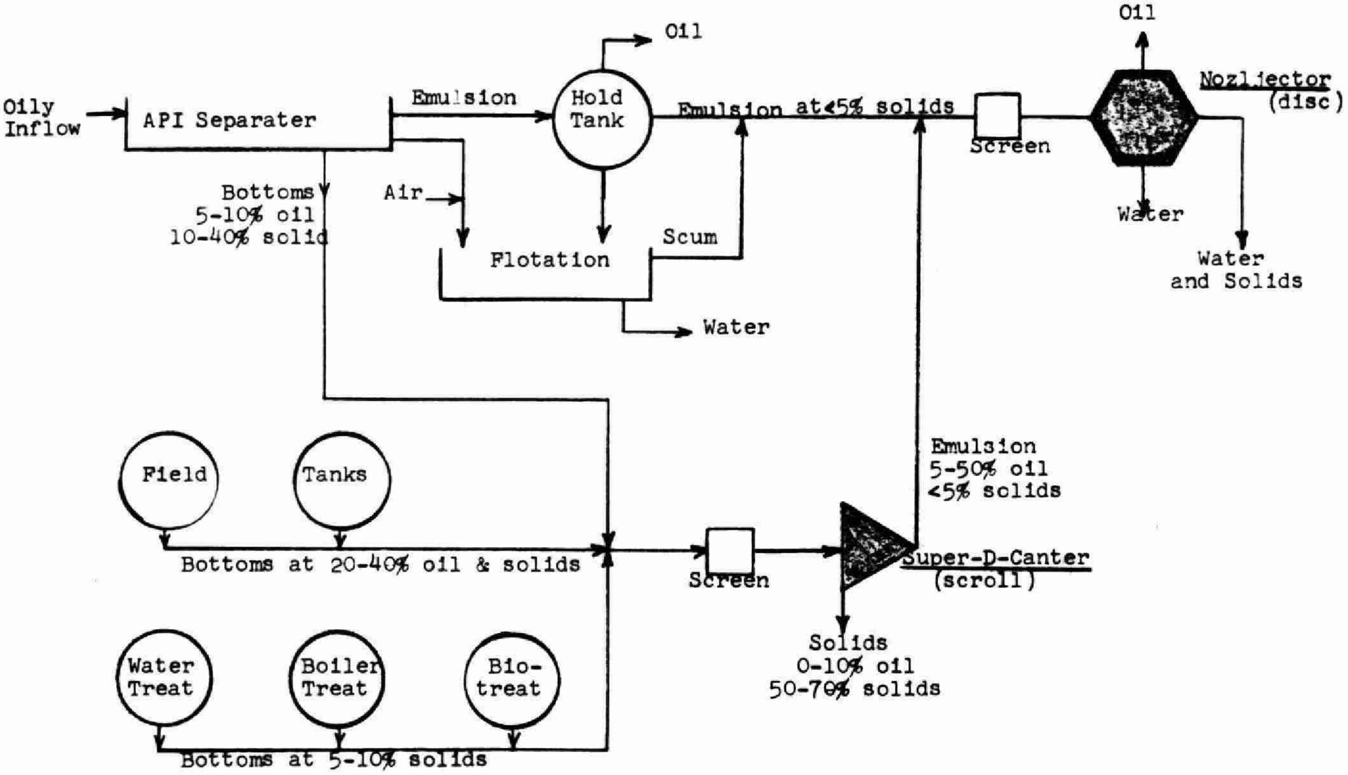


Figure 8 – *Petroleum Refinery Wastes in Centrifuges*

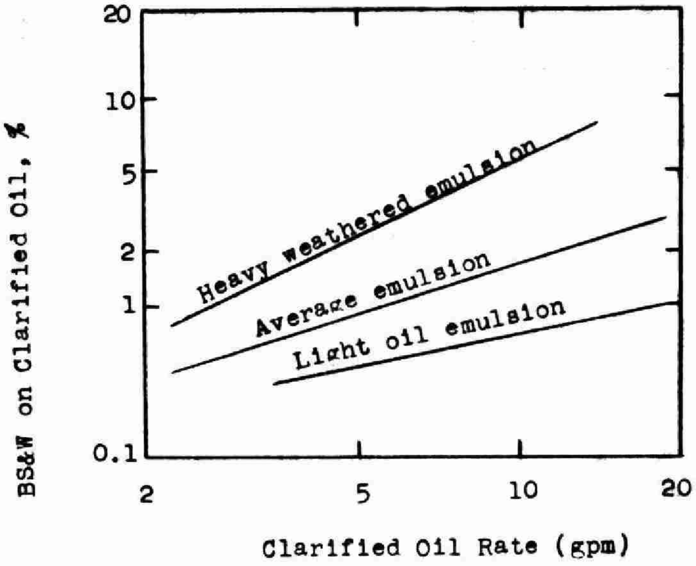
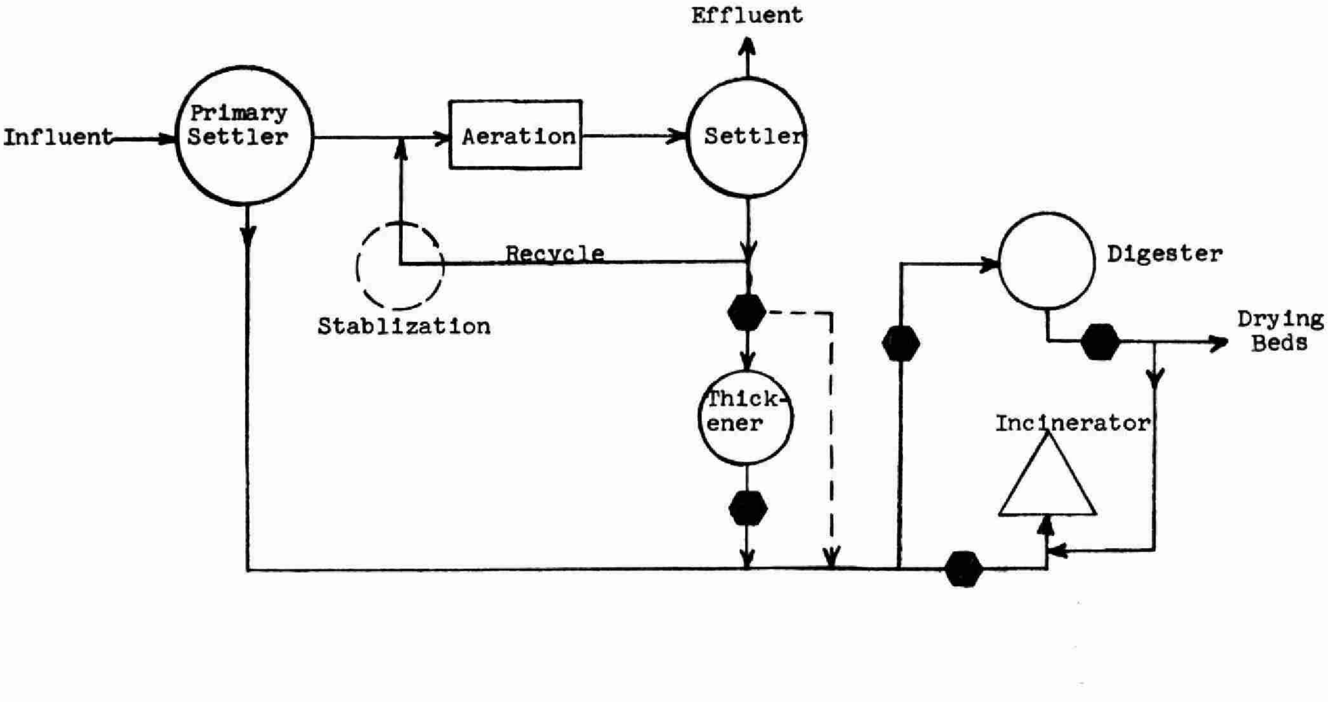


**Figure 9** – *DH3 Nozljector Separating Oil From Petroleum Refinery Waste Emulsion*



⬢ = Effective locations for centrifuges.

**Figure 10** – *Centrifuges on Sewage*

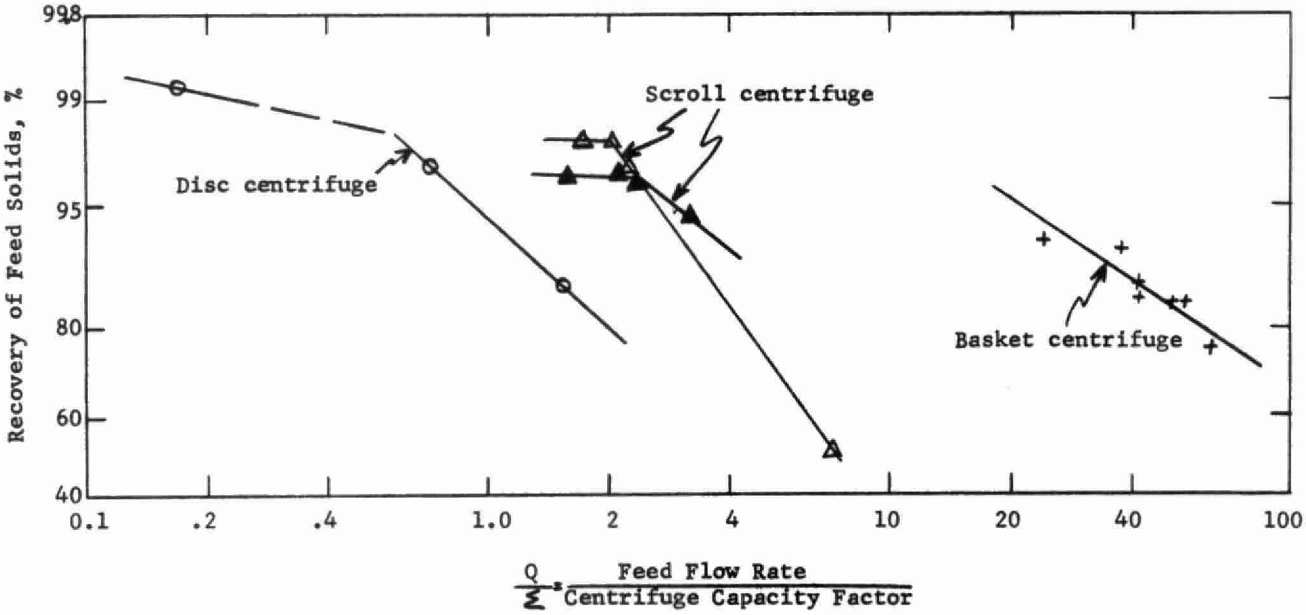


Figure 11 – *Centrifuges on ECM Sludges*

# "SOME NEW CONCEPTS IN APPLICATION OF AEROBIC BIOLOGICAL METHODS TO WASTE TREATMENT"

BY

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## A. Introduction

This paper will be primarily concerned with the intrinsic aerobic biological phenomena that control the oxidation and metabolism of the organic material in a liquid waste. It will not involve itself to any extent into the various methods of transferring oxygen to liquid wastes; however, studies during the past decade have shown that the two phenomena, one physical and the other biological, cannot be dealt with completely independently of each other. In fact, our ability to have the aerobic organisms perform at their maximum efficiency is greatly dependent on the methods we utilize to get $O_2$ and food to them. Therefore, I will, of necessity, have to discuss certain general aspects of oxygenation and mixing, but only as they influence and relate to the functioning of the organisms.

There is fairly definite evidence, both from field experience, theoretical analyses, and controlled laboratory studies, that the rate of removal of BOD, (or COD, if you wish) in any aerobic biological system is dependent on three basic physical and biological phenomena, which it would be worthwhile, to set forth:

(1) Rate of dissolving $O_2$ into the liquid.
(2) Ability to get the $O_2$ <u>and</u> the <u>food</u> to the surface of the organisms.
(3) The maximum rate at which any weight of organisms can oxidize and metabolize food when food is made <u>properly</u> available to them.

We have developed various methods and techniques for measuring the performance and the ability of various types of aeration equipment to obtain usable data so far as (1) above is concerned. Though, as I will mention later, we still have a great deal to learn about the factors that influence the performance of such aeration equipment which are closely related to the maximizing of items (2) and (3) above.

Item (2) appears to me to be the one that we know the least about, and so far we have not done sufficient enough study in evaluating the performance and true efficiency of the activated sludge process and related systems of treatment. This item includes such physical factors as the diffusion by turbulence of the dissolved oxygen from the main body of the liquid to the liquid film surrounding the organisms. The "scale" and "intensity" of such turbulence is all-important. Conceivably, the intensity could be so great, and the scale so small, (high velocity gradients), that agglomeration and flocculation of the organisms, in order to facilitate their removal by gravity settling, could be impaired, or even prevented.

However, it certainly must be true that high intensity and small scale turbulence can greatly influence the transfer of dissolved $O_2$ and food to the surfaces of the organisms, and before that is accomplished the organism is "helpless", so-to-speak. The diffusion of the $O_2$ and food through the liquid film surrounding the organism must be molecular in nature, and, therefore, anything we can do to decrease the thickness of this "laminar" film would increase the "diffusion" rate. Intense, micro-turbulence would accomplish such decrease in liquid film thickness.

In accomplishing transfer of the oxygen through the film surrounding the organism, it would appear that the rate would be dependent on the "driving force" across the film. Therefore, it is my opinion, and there is some experimental substantiating evidence, that until we are supplying $O_2$ at the maximum rate possible for the organisms to utilize it, the concentration of the D.O. in the main body of the liquid should control the transfer rate across the film to the surface of the organism. This, of course, is counter to the generally accepted, though not completely proved theory, that values of D.O. above about 1 or 2 mg/1 are of no value so far as increasing the rate of biological oxidation is concerned. There is some evidence, which I will cite later, that the D.O. concentration above 1 or 2 mg/1 does have an influence on the rate of organism oxygen utilization, and it could be that this general "rule", that we all have more or less accepted, is merely the outward evidence of the fact that other factors are more important in the $O_2$ transfer across the liquid film surrounding the organism than the D.O. concentration in the body of the liquid after such concentration reaches, say 2 mg/1.

Now regarding item (3) above. There is ample evidence, which I plan to cite, that our present biological systems have not reached the maximum limit mentioned in Item (3). Thus we find in the literature that $O_2$ utilization rates of 500 mg/1/hr (this is equivalent to over 20 times our "conventional" BOD loading of, say, 35 lbs. per 1,000 $ft^3$ per day) are possible.

With the above generalizations let us now discuss some pertinent specifics:

## B. The Completely - Mixed Activated Sludge System

Probably one of the most significant developments during the past decade in regard to utilization of the activated sludge process has been the so-called "completely - mixed" system. Since this has been so adequately described in the literature by such writers as McKinney, the author, and others (1), (2), (3), (4), (5), (6), I will devote very little space in this paper to its description.

The completely - mixed system essentially maintains a uniform concentration of D.O., food and type of organisms uniform throughout the entire aeration basin volume. The incoming waste and return solids are quickly and intimately mixed with the entire aeration tank contents. This is the most distinctive feature of the process. The liquid separated from the mixed liquor suspension in any part of the basins is essentially the effluent. So-called "short-circuiting" of the raw waste has no meaning in this process. All the organisms are functioning at their optimum for the conditions in the aeration basin. It should be kept in mind that this system is applicable to any of the various modifications of the activated sludge process; such as the so-called "high-rate" process, "extended aeration", or any of the processes involving aerobic oxidation of organic matter by a suspension of organisms.

McKinney (1) has presented an excellent mathematical analyses of the process in a most elegant fashion. The author first described the essentials of the process in 1950, (4) and built a pilot plant incorporating the basic principles with the additional feature of incorporating so-called "internal recirculation" or "integral" sludge return so that no separate pumping or piping was necessary in order to return the solids from the clarification zone to the aeration compartment. This latter design feature makes the operation of the C-M process simple and inherently incorporates all the necessary process requirements. Such a combination aeration and clarification unit eliminates the problems associated with providing for, and properly controlling sludge recycle irrespective of the settling characteristics (SVI) of the aerated mixed liquor. Many such units of various designs have since been built in the U.S. and Europe especially for treating industrial wastes.

One other feature which is extremely desirable for optimizing the C-M process is the use of some sort of mechanical mixer which can be used as an air disperser at the same time. Diffused air systems are difficult to design in order to attain all the necessary and desirable features of the C-M process. Such mechanical mixers can be submerged turbines with air sparjers located below them, or they can be the presently widely used surface entrainment mechanical aerators.

The outstanding advantage of a properly designed C-M system is the ability it provides to attain much higher BOD removal rates in smaller aeration basins. In fact, it is the only system we now have that permits us to approach the tremendous oxidizing and assimilating ability that apparently aerobic organisms possess, as will be discussed later on and for which we only recently have designed plants to apply and achieve the enormous economic and technical advantages. As will be pointed out later, it appears that it took some 40-50 years for the engineering profession to finally realize the potentialities of the activated sludge process since its original development in England in the early part of the 20th century.

In 1948 and 1949 the author operated a pilot plant, designed as described above, at the sewage treatment plant at Elmhurst, Illinois and some of the typical data obtained are shown in Table I.

The pilot plant had about 100 $ft^3$ of aeration volume, so those interested can calculate the BOD loading per 1,000 $ft^3$. The indicated retention time includes that in the clarification compartment. It will be noted that the volumetric loading was of the order of 300 lbs. of applied BOD per 1,000 $ft^3$ of aeration volume. It will be noted that the loadings are of the order of ten times those conventionally used. However, they still are not equal to those that Pasveer (7) and others have predicted are possible. In a recent paper, Pasveer, (8) who has always claimed, correctly or not, that our ability to get oxygen to the organisms has been the limitation in utilizing the full capabilities of the activated sludge process, presented data showing treatment of a sewage having a BOD of 220 mg/1, with 95% removal, at a loading of 1,500 lbs/1,000 $ft^3$ of aeration capacity. This is 50 times "normal" loading. Von der Emde (9) has presented data showing 90% BOD removal in a total retention time of one hour. Our "conventional" plants use six hours.

Recently we have made some studies on the treatability of a variety of industrial wastes using the C-M process principles. For example, using a pilot plant not too different from the one described above and acetic acid waste from a furfural manufacturing process having a BOD of about 10,000 mg/1 was treated successfully producing an effluent of about 100 mg/1 of BOD. The MLSS were 6,700 mg/1 and the loadings were 1.5 lbs. of BOD per lb or MLSS/day and 600 lbs. of BOD per 1,000 $ft^3$ per day.

A plasticizer (diester) waste having a BOD of 25,000 mg/l and a ph of 12 was treated with 95% removal. The pollutant was entirely soluble, and the effluent obtained permitted its discharge into the municipal sewer. The MLSS were 4,000 mg/l and a design loading of 0.5 lbs. of BOD/lb of MLSS/day was recommended due to the fact that the waste was oxidized relatively slowly. Peculiarly, though neutralization was attempted, it was not found necessary as once the MLSS were developed the ph remained at 8.5 - 9.0 irrespective of any attempts to alter it.

Another unusual waste was that consisting of homopolymers, copolymers, and methocel, the latter a detergent. The BOD was 350 mg/l and the ph was 5.7. Biological treatment produced a BOD of 66 mg/l but the organisms were relatively non-flocculant probably due to the methocel. Chemical coagulation with alum, lime, and Separan, gave an effluent having a BOD and S.S. of 10 mg/l which met the regulatory agency requirements.

Some data were obtained using a small C-M unit employing an "integral" aeration and clarification compartments as previously described on canning wastes. A summary of typical data are given in Table II. The MLSS for the pea and carrot wastes was about 3,000, giving an average loading of about 4.8 lbs. of BOD/lb MLSS/day, or 300-400 lbs. of BOD/1,000 $ft^3$. For the beet canning wastes the loading averaged about 650 lbs. of BOD/1,000 $ft^3$ of aeration volume. It is apparent these wastes had a high rate of treatability.

By the way, it shouldbe mentioned that in dealing with industrial wastes, it is quite essential that acclimatized organisms be developed before a BOD is determined. Failure to do this can give BOD values too low by a factor of five to ten sometimes.

## C. Biological - Chemical Treatment Processes

During the past five years or so we have been studying the activated sludge process more intrinsically and more fundamentally. As Garrett (10) has so effectively stated, "we have not spent time studying the physical aspects of how $O_2$ and food are gotten to the organisms as much as we have been concerned with what occurs after the $O_2$ and food reach the organism.

We have neglected the very fruitful field of trying to establish what are the maximum rates of organism oxidation and metabolism if we provided optimum conditions". It is fortunate that such studies are now being intensively pursued.

Processes are now in use which involve utilizing the very high rate of oxidation and metabolism of which organisms are capable and then following (or combining in some cases) with chemical flocculation in order to settle out the dispersed organisms. Such processes have been widely used in Europe (Lurgi's "Bio-Floc" Process) and are now being applied in industrial waste treatment in the U.S.A. Many have referred to such a process as a "Bio-Chem Process".

Detailed studies relating to this general idea of separating the steps of biological metabolism and "bio-flocculation" have been reported by Tenney, Johnson, and Symons (11), Tenney and Stumm (12) and others. Benedek (13) gives an excellent summary of the thinking that has been going on in Europe in regard to advantages of the separation of these two basically unrelated steps in the activated sludge process. In fact, mechanical flocculation, without chemicals as an intermediate step between a highly-loaded biological unit and the final clarifier, shows promise both technially and economically.

In Switzerland, a modified two-step activated sludge process, known as the Attisholz (14) system, has been put into operation, which offers some distinct advantages. Briefly, the theory on which the process is based is that the biological stage can be loaded quite high and its operation is not sensitive to waste changes etc. if good flocculation is not desired in this stage. In the second stage, which in this process is also biological but lightly loaded, the D.O. is kept high, and the mixing is gentle in order to obtain good growth of protozoa and good flocculation. After the first settling step where no attempt is made to obtain good suspended solids removal, the second stage can have incorporated in it coagulation with alum or iron salts in order to eliminate the phosphates while accomplishing coagulation at the same time.

These so-called "Bio-Chem" processes have much to recommend them and are being studied intensively. A recent excellent report of controlled experiments was presented by Eberhardt and Nesbitt (15) which indicated the possibility of combining the biological and chemical flocculation, (with alum), steps in order to get a high quality effluent in respect to BOD, suspended solids, and phosphates. In addition, a waste sludge is obtained that has good dewatering properties.

I am sure we will be hearing a great deal about, and also using to economic and technical advantage, this so-called two stage process which takes advantage of the high-rate of organic material destruction and assimilation, if proper mixing and D.O. conditions are provided and chemical flocculation for obtaining settleable organisms and, if necessary, elimination of the soluble phosphates. As we all know, just getting a low BOD is not going to be the only requirement frequently any more.

In this connection, it should also be mentioned that treatment in the second stage with lime, in order to remove phosphates and obtain a high ph for air stripping of the ammonia, so as to remove the nitrogen in our effluents, is also definitely in the picture. Culp and Slechta (16) have proved fairly definitely that air stripping of $NH_3$ appears to be the most economical of the various processes considered to date for nitrogen removal from waste effluents.

### D. New Theories Relating to Aeration and Mixing of Activated Sludge

Some basic work has recently been reported, and hopefully it is continuing, relating to the energy considerations in regard to flocculation of activated sludge by Fair, Gemmell, and Myrick (17).

In line with the separation of the biological and physical stages of the activated sludge process discussed previously, these authors have analyzed the basic theory of biological flocculation. In order to understand the fundamentals of this analysis one must refer to the basic physical considerations and analyses of flocculation in general as presented by Camp (18).

Briefly, this theory involves the calculation of the mean velocity gradient term, G, and the dimensionless factor, Gt, (where t is the retention time in the flocculation basin). Fair and his associates showed that the factor G in activated sludge aeration basins is about 2-3 times that in normal water flocculation basins and the more basic factor, (Gt), is as much as 50 times as great. Obviously, energy is being put into aeration basins which is many times greater than that needed for flocculation. It is required for getting the $O_2$ and food to the organisms. But since experimental data have shown that the biological process itself can be accomplished very rapidly, it would appear that we are wasting a great deal of energy when we attempt to accomplish both the biological and the physical process of flocculation in the same basin. Again we note that there appears to be good scientific basis for separating the two process steps.

Jenkins and Garrison (19) in a recent paper demonstrate, in a very precise manner, that the activated sludge process is capable of high organic loadings so far as removal of soluble, degradable COD is concerned. This study has considerable significance since the authors conclusively demonstrate that one cannot obtain precise, meaningful and scientifically reproducible data relating to the biological aspects of activated sludge organisms, or the process generally, by BOD measurements. One must use COD data. This fact alone, I am sure, explains the numerous contradictory, anamolous and misleading data that have appeared in hundreds of papers relating to studying the behavior, and the end results in laboratory and field studies, of the activated sludge process as it is used in practice.

It is my opinion that the activated sludge process can be practiced most efficiently by the use of so-called "intense" mixing and aeration in the biological stage. The physical problems associated with getting $O_2$ and food, present in the substrate, to the surface of bacteria where it must be transferred, is a problem that has not been properly appreciated. We have been too concerned with possible "destruction of the floc" without considering the requirements of the physical process so far as providing conditions for optimum functioning of the organisms are concerned. This problem is of basic importance in adapting the activated sludge process to the multitude of organic waste treatment problems if we are to utilize its potentialities to their fullest economic and technical extent.

Recently, we have been making laboratory studies using continuously fed systems to determine what is the maximum biological loading possible if we increase the intensity of mixing in the aeration compartment to a very high degree. We have recently obtained values of G of about 600 (ten times that in normal flocculation basins) and Gt of $8 \times 10^6$. The value of Gt was not as much relatively greater as G since we were interested in establishing (by turbine type air dispersers) very high shear (velocity gradients) values in order to bring O2 and food to the surfaces of the bacteria and to establish fine-scale turbulence so as to decrease as much as possible the thickness of the laminar film surrounding each bacteria through which $O_2$ and food must diffuse molecularly. Much to our surprise, under the above conditions, we obtained a "healthy" looking and good settling floc with a resultant BOD reduction from about 350 to 30 mg/l. The SVI averaged about 125. The MLSS were about 1,500 mg/l. The "loading" was varied from 0.7 to 2.0 lbs. of BOD/lb or MLSS/day.

We have since increased the value of G (average velocity gradient) by a factor of 3 (nine times more power) and are now adding alum to assist in flocculating the organisms. The MLSS are 1,000 mg/l, the loading is 2-4 lbs. BOD/lb MLSS/day, the SVI is about 150 and the BOD reduction is about $90^{+}\%$. By the way, the value of Gt is $25 \times 10^6$, about ten times that which is normally used in activated sludge aeration basins.

I cannot, at present, give you what our final conclusions will be as a result of these studies, but we can be sure of one item: the activated sludge process, and associated organisms, have capabilities for treating organic wastes far beyond anything we have ever imagined. For this we can all be grateful, considering the enormity of our waste treatment problems of the future.

## E. Oxygen Transfer to Activated Sludge

Our traditional concepts regarding how $O_2$ gets to organisms in activated sludge suspensions are rapidly changing. Wuhrman (20) in discussing the role of $O_2$ concentration in purification performance back in 1960 said the subject is "controversial"so far as activated sludge plants are concerned. Since that time there has been some very significant experimental work which definitely indicated that the exact physical phenomena of how $O_2$ is transferred to organisms, and what factors can influence such transfer, have been largely erroneous to say the least.

The basic studies which have shed new light on exactly how $O_2$ reaches the individual organisms were those of Bennett and Kempe (21) who demonstrated in a very elegant manner that $O_2$ can be transferred directly to organisms without having to first dissolve into the liquid. This is of enormous significance so far as oxygenation of activated sludge suspensions are concerned. It means, basically, that tests on aeration devices made in clean water are only qualitative and are not an absolute measure of their $O_2$ transfer capabilities.

The second finding, of even greater significance, is that the old accepted concept that $O_2$ uptake rate in an activated sludge suspension can be measured by merely saturating the suspension and then measuring the rate of $O_2$ depletion, while gently stirring the suspension, gives entirely erroneous results. Such uptake measurements are very important for design purposes and also for determining the rate at which $O_2$ is supplied to activated sludge mixed liquor by various aeration devices. Bennett and Kempe showed that not only does stirring speed influemce the uptake rate significantly, (which many of us have suspected), but also, that the uptake rate can be as much as three times greater when the suspension is being aerated. The importance of this finding cannot be overemphasized as it has profound significance in regard to very basic concepts relating to the obtaining of very important data relating to activated sludge suspensions. In a word, we apparently have not really understood how activated sludge mixed liquor suspensions behaved so far as $O_2$ transfer is concerned.

Not only does the uptake rate vary with magnitude of agitation and aeration, but also, Drehwing and Nemerow (22) have shown that the uptake rate can vary with the D.O. concentration, in the range 2-7 mg/1. This latter upsets some very basic concepts which we now must revise. In other words, though apparently we have felt, and certain data have confirmed it, that D.O. values above, say 2 mg/1, have no influence on rate of oxidation, this is <u>not</u> a fact. Our observations were probably "masked" by the fact that our aeration basins had limited agitation, which certainly is true with diffused air systems. Oxygen uptake measurements are presently obtained with so-called D.O. probes which give an electrical signal; however, some of these devices have lags of at least 30 seconds and greater. It would appear that such devices are not capable of giving correct "rate" data in rapidly respiring systems.

A recent paper by Zahradka (23) on the role of aeration in the activated sludge process emphasizes the importance of considering the "activity" of the mixed liquor in the aeration tank under operating conditions which includes the "mixing factor". The latter is, of course, dependent on the power input into the tank and the manner of the power input. He presents data which conclusively demonstrate that BOD removal is basically dependent on the ratio of loading and aeration intensity. This ratio correlates his data better than any other factor. In fact he says that the so-called "mixing factor" is of greater significance than sludge loading.

A discussion on $O_2$ transfer to activated sludge would not be complete without at least some brief comments relating to the influence of the physical design criteria of aeration equipment and of liquid characteristics on $O_2$ input in activated sludge suspensions and liquids in general. We have all heard about the influence of various surface active agents that may be present in wastes which can either hinder or increase the rate of $O_2$ transfer from aeration equipment, as compared to such transfer into "clean water". We have designated this influence by measuring under certain prescribed conditions, a factor we call "alpha", which supposedly compares the $O_2$ transfer characteristics of the waste to those of clean water, whose "alpha" factor we designate 1.0.

The transfer of $O_2$ through air-liquid interfacial areas is profoundly influenced by the presence of certain surface-active compounds, present even in minute quantities, which tend to accumulate in such interfacial areas or they may have a very great affect on the total interfacial area created under any particular hydraulic and pneumatic condition. In one instance they can hinder the transfer of $O_2$ while in the other they can greatly increase it.

The entire phenomenon is further complicated by the fact that both influences are affected by the method used for introducing the air into the liquid and the attendant mixing intensity. It thus becomes apparent that the measurement of these influences under artificial laboratory conditions, becomes, at best, only a rough estimate. The most important factor that must be adhered to in such laboratory tests is that the aeration method must be at least qualitatively similar to the full scale system.

The author (24) pointed out that surface active agents can have entirely different and frequently opposite affects, depending on whether the air is introduced through porous diffusers or mechanical surface entrainment aerators. This has been confirmed by others.

The adverse affect of any compound in hindering the transfer of $O_2$ can be significantly greater in a diffused air system than when $O_2$ is transferred to the liquid by surface aerators. The physics of this are readily explainable.

This so-called "alpha" factor is of such great significance that basic research work is needed in order that we can understand the physical principles more completely and perhaps be able to do some predicting, instead of depending on questionable measurements.

It was satisfying to see a recent study reporting on the fundamentals of this phenomenon based on some basic studies (25) in which data were obtained on the influence of various soluble compounds in water on the diffusion coefficient $K_L$, and the total bubble area, the combination of which is our famous "combined" factor ($K_La$).

Some brief remarks are in order regarding so-called surface entrainment aerators which are so widely used at present for supplying $O_2$ to all types of aerobic biological treatment systems. The subject is very complex, but engineers and users of this equipment should be cognizant of certain basic fundamental facts regarding their selection and operation:

1. In general, such aerators will supply a given rate of $O_2$ at a power cost between 1/2 to 2/3 of that of compressed air. Also, installation costs are usually substantially less. Industry has almost standardized on this type of aeration equipment for their waste treatment plants.

2. The extrapolation of data from small sizes to large sizes for this equipment is an extremely complex procedure. Do not believe anything different. The laws of hydraulic similtude must be combined with empirical measurements, and there are no straightforward model laws that apply for the complex hydraulic and pneumatic phenomena created by these devices.

3. In general, the small size units give substantially better $O_2$ input efficiency (defined as lbs. of $O_2$ input per HP per hour under standard conditions) than larger units. We have small geometric models which give efficiencies three times as great as similar units, say, ten times as large. Obviously, some painstaking care and analyses must be resorted to in making extrapolations.

4. Any specific design of these units will usually be less efficient at a high tip speed of the turbine or whatever rotating machine is used. Our data on dozens of designs of such units are very definite in this regard. There is no optimum speed. One must compromise between having a good efficiency and an unwieldy, expensive, slowly rotating machine.

5. The pumping capacity for liquid of these units is of extreme importance and it must be optimized so as to provide sufficient agitation to keep the desired solids in suspension, distribute the input $O_2$ adequately and still not consume excessive power in pumping instead of creating intense turbulence and localized interfacial air-liquid areas for facilitating $O_2$ input. This is always a matter of selecting an optimum tip speed of the rotating element.

6. Basin geometry has some influence on the $O_2$ input of these devices, though precise data do not indicate that the influence is as great as one might suspect from purely geometric considerations.

7. The evaluation of these devices by use of the so-called non-steady state technique in "clean" water is far from simple and is subject to many factors which can greatly influence the results. The basin must be "completely-mixed" and there are criteria for establishing if such a condition exists; otherwise the data are worthless.

## F. Some New Ideas Relating To Application of the Activated Sludge Process

Before I conclude this review of new concepts that are making a relatively old process (40-50 years) infinitely more useful, more applicable and more efficient than it has ever been in the past, there are some fairly definite new ideas that have been brought forth regarding this process, and some that are just creeping up over the horizon, which warrant comment:

(1) The most significant of these ideas and the one that has created the greatest interest during the past year or two is the idea that an activated sludge plant can be operated so it can "take-up" much more phosphate than the normal metabolism of the organisms require. This has been referred to as "luxury' uptake of phosphate". This is of considerable significance, if true, since we are presently very much concerned about the phosphates that are discharged with our effluents. Its removal, except for about 20% of the total amount present in sewage which is metabolized in the sludge, has been usually accomplished by chemical precipitation with lime or alum. Such "luxury uptake" is counter to basic ideas of biological metabolism, and has been seriously questioned by many, including the author. Laboratory studies by Levin and Shapiro (26) appear to confirm such increased uptakes.
Also, a study of several plants in San Antonio, Texas have indicated that certain operating procedures can greatly increase the phosphate removal above that normally expected (27). However, tests by the author relating to chemical and biological removal of phosphates points out very definitely that there are many factors that can lead one to false conclusions. The numerous "stumbling blocks" and techniques that must be watched, if meaningful data are to be obtained regarding such biological phenomena, cannot be discussed in this paper. However, a very careful study of this problem has been carried out recently by Jenkins and Menar of the Sanitary Engineering Research Laboratory of the University of California in Berkeley and their data very conclusively show that over a 30 to one range of substrate COD removal rates, the phosphorus removed remained at 20% and that there was no so-called "luxury" uptake. I am afraid that these data must be given very serious consideration and that we cannot expect biological processes to remove phosphates beyond their normal metabolism (28). This is further confirmed by Hall and Engelbrecht (29).

(2) Studies have been going on using extremely high MLSS concentrations (30), up to 25,000 mg/1. Though such concentrations may seem impractical, offhand, there are applications where such high values of MLSS could have useful application in the treatment of very concentrated wastes. Obviously, liquid-solids separation would have to be accomplished by means other than gravity, perhaps by centrifuging or by use of the rapidly developing technology relating to use of membrane ultra-filtration (31).

(3) Throughout the years many of us have been intrigued about the possibilities of thermophilic, ($140^{\circ}$ - $160^{\circ}$ F.), activated sludge. The aerobic organisms would be similar to those present in composting. Conceivably the oxidation rates of such an activated sludge system could be extremely high, if composting criteria are any indication. Recently, the possible usefulness of such a process was mentioned in connection with waste disposal in space craft (32). Other applications of such a process could be possible if the technical problems of liquid-solids separation and $O_2$ input can be solved.

## G. Conclusions

I will not attempt to summarize the wide range of subjects covered in this paper. The important observation one must make is that it is difficult to understand why a process such as that of "activated sludge" and its various modifications, should have remained practically unchanged and used by engineers in the same manner for some 30-40 years. Of course, the answer is obvious: no attempt was made to <u>really</u> understand the process fundamentally, except during the past ten years and mostly during the past five years.

One cannot desist from concluding that it was the realization of the possibilities of the process for the treatment of industrial wastes that was the basic reason why the process began to be studied more than superficially. Industry enlisted the services and interest of chemical engineers, biologists and bacteriologists, so that technically sound and economically justified design criteria for the process could be obtained and applied.

For reasons that need not be mentioned herein, it would appear that the "public works" consultant, and regulatory agency officials, had no real interest in promoting the investigation of this all important waste treatment process, so long as they were concerned only with domestic sewage. Rule of thumb design criteria were good enough. However, that is not the way true progress in any science or technology occurs.

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# TABLE I

## SUMMARY OF PILOT PLANT OPERATIONS

(ALL SAMPLES ARE 24-HR COMPOSITES)

| Flow GPM | Total Retention Time, Hours | Raw Sewage | | Effluent | | D.O. in Aerator | Sewage Temp °C | MLSS mg/1 | SVI | Loading: lbs BOD/lb MLSS/day |
|---|---|---|---|---|---|---|---|---|---|---|
| | | BOD | S.S. | BOD | S.S. | | | | | |
| 10.4 | 3.7 | 162 | 170 | 23 | 30 | 2.0 | 12 | 700 | 170 | 4.5 |
| 13.6 | 2.8 | 210 | 200 | 27 | 21 | 3.5 | 8 | 1970 | 81 | 2.7 |
| 13.6 | 2.8 | 213 | 320 | 9 | 24 | 6.0 | 9 | 1890 | 118 | 3.0 |
| 13.6 | 2.8 | 190 | 260 | 22 | 28 | 6.8 | 9 | 1000 | 90 | 4.9 |
| 13.6 | 2.8 | 167 | 194 | 13 | 17 | 4.0 | 9 | 2800 | 110 | 1.5 |
| 19.7 | 1.95 | 335 | 576 | 22 | 19 | 1.0 | 11 | 3100 | 164 | 4.1 |

All units, unless indicated, are in mg/1. Raw, screened, unsettled sewage used in tests.

## TABLE II

## PEA AND CARROT CANNING WASTES

| Flow GPM | BOD Raw | BOD Effluent | ph Raw | ph Effluent | Aeration D.O. | % BOD Removal |
|---|---|---|---|---|---|---|
| 0.1 | 2330 | 150 | 6.8 | 7.9 | 2.0 | 94 |
| 0.1 | 1750 | 125 | 6.9 | 8.5 | 1.0 | 93 |
| 0.1 | 2254 | 102 | 6.5 | 8.0 | 0.8 | 96 |
| 0.1 | 1190 | 40 | 5.8 | 7.8 | 1.3 | 97 |
| 0.1 | 1140 | 83 | 6.2 | 7.6 | 1.2 | 93 |
| | | | **Beet Canning Wastes** | | | |
| 0.033 | 4970 | 130 | 9.9 | 7.5 | 0.5 | 97 |
| 0.033 | 4845 | 224 | 9.8 | 7.4 | 1.0 | 95 |
| 0.0165 | 5360 | 92 | 9.8 | 7.5 | 1.3 | 98 |
| 0.0165 | 5185 | 96 | 9.7 | 7.4 | 1.0 | 98 |

Note: All figures in mg/l unless otherwise noted (Wastes were not neutralized: Nutrients added).

# BANQUET ADDRESS

## "ON BECOMING AN UNCOMMON PERSON"

BY

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The 20th Century began with the writing of a book entitled "The Century of the Common Man". In it the author set forth his belief that this century would see the common man come into his own to a degree never known before in history.

At least in our part of the world, his prediction has proven to be correct. The growth of the trade union movement has placed in the hands of the ordinary labouring man the power to stop the wheels of industry. During the days of the Second World War, we were reminded time and time again that the winning of the war would depend not solely upon the ability and dedication of a few in the upper echelons of military command, but upon the pooling of the best efforts of every man and woman at home, in the factory and on the farm, and, when the war was over, no less a figure than Sir Winston Churchill declared that this victory was "a victory of the common man!".

Now in essence this recognition of the contribution ordinary people make to life is one that has been long overdue. It is quite appropriate that we should remember, to use a phrase credited to Abraham Lincoln, that "the Lord must love the common man, because He made so many of them". However, having said this, let us note with equal conviction that there is a grave danger in glorifying commonness to the place where we make almost a religion about the business of being ordinary and being proud of it! There is little virtue in seeking to reduce, others, or in allowing ourselves to be reduced, to the same low level of mediocrity! The problems of our day are so immense, so complex, so universal, that it is going to take some unusually gifted and dedicated people to bring us safely through the next few years. More and more I find myself cherishing the words of another former President of the United States, the late Herbert Hoover, who is reported to have declared that "the future of America depends upon the number of UNCOMMON MEN AND WOMEN whom we can produce in our generation". It seems to me that throughout history it has been the UNCOMMON men and women who have led the common people to their promised land, in every realm of human thought and endeavour, all the way from Socrates to Moses to Lincoln to Ghandi to Christ!

What are some of the marks of the uncommon kind of person whom I believe our generation sorely needs?

One is that he is a person who DOES SOME THINKING FOR HIMSELF!

At least once each week, a professor of mine at Queen's University used to look sadly at his class and remark "It is not in the nature of man to think with any profundity". Sometimes I got the uncomfortable feeling that he was looking at me as he said it! Certainly it is not difficult these days for us to allow others to do our thinking for us! There are plenty who are willing to try! One newspaper columnist is read by fifty million people every day! We scan the morning paper and get our mood for the day! The headline shouts "Hate!", and we hate! "Peace!" and we relax! "War", and we are thrown into a mood of despair. I am not suggesting that we should not listen to, and read, what others are saying. But I am suggesting that in addition to this, we should do some serious thinking for ourselves, about life, the world, business, our nation, and the issues of war and peace. I like the definition given by a little girl in school one day, when, in response to her teacher's invitation for someone to come up with a definition of the difference between a "student", and a "scholar", she replied, "a student is somebody who memorizes other people's thinks, but a scholar is somebody who thinks his own thinks!". Not very grammatical, but very true!

I urge you to seek to be uncommon enough, in an age when so many of us become intellectually lazy, in an age when what passes for "thinking" is, as someone has remarked, "merely rearranging our prejudices", that you will honestly seek to do some honest-to-goodness thinking for yourselves!

And the second mark of the uncommon person of whom I am thinking is that is is DEPENDABLE!

I speak to many business and other organizations in the course of a year, and almost upon each occasion, I hear someone saying what we all suspect, that it is difficult to find people upon whom you can always and entirely depend!

A famous minister of an earlier day, Dr. Henry Ward Beecher, likedto go horse back riding, but he was not an accomplished horseman. He went one day to a livery stable to rent a horse, explaining to the liveryman that he wanted a kind, patient horse, one that wouldn't throw him! The keeper of the stable led out this particular horse, described its many virtues to the clergyman, and concluded by saying "here is a horse that is thoroughly dependable!". Dr. Beecher walked over to the animal, patted it, and said feelingly, "Old Horse, how I wish YOU were a member of my congregation!" Many ministers long for more dependable church members - and many churches, no doubt, long for more dependable ministers!

Dependability may be a lost art, but it is still a necessary virtue! It is one of the qualities without which we cannot get along, whether one thinks of political, business, religious, or social life. Whatever else you are in life, do not be less than this - be Dependable!

Be Uncommon enough to learn to use ALL THE POWERS you possess!

Few of us do this. William James, the father of modern psychology, has said that few people use more than a fraction - perhaps ten or fifteen percent - of their possible brain power! I fear it is true!

A minister conducting a funeral service declared "this corpse has been a member of this church for the past twenty years!" More than one corpse has been a member of more than one church. In the church we speak of inactive members as "dead wood!" The term is very apt. The President of a large university was asked "How many students have you in your college?" He promptly replied "About 25% of the total enrollment!"

A popular book of a little while ago was entitled "Man Alive-You're Half Dead!" All of us have powers - physical, mental, moral and spiritual, that we never develop and rarely use!

One night, a man who had spent the evening in his favorite pub, made his way unsteadily home, taking a short cut through a cemetery on the way. He had the misfortune to step into an open grave! When he realised where he was, he started jumping, and jumping, trying to jump out of the grave into which he had fallen. He was unable to do so. The earth at the top kept breaking away under his clutching fingers, and finally, exhausted, he gave up, and settled down in a corner of the grave, to wait for someone to rescue him in the morning. He had just settled down, and started to doze off, when he heard a loud thud, and, looking up, discovered that a friend who had reamined a little while longer in the same pub, had fallen into the same grave. In silence the first man watched his newly arrived friend going through the same motions - trying to jump out of the grave. Finally, when the second man too was exhausted, the first got up quietly, tip toed up behind him and putting one hand heavily on his shoulder, he said in a sepulchral voice, "You can't jump out of this grave!" But HE COULD AND HE DID..AND THEY HAVENT SEEN HIM SINCE!!"

The fact of the matter is that we all have physical powers that are greater than we dream - it only takes the proper situation and the proper motivation to release them! And this is true equally in every realm of life.

Learn to use the great potential with which God has entrusted you. You will find that you can be greater than you think!

Be uncommon enough to FIND SOMETHING BIG FOR WHICH TO LIVE - some cause greater than yourself. And then see your powers unfold!

It has been said that when a man gets all wrapped up in himself, he makes a mighty small parcel! Just so! We were meant to lose ourselves in something bigger than ourselves. This is the road to true greatness.

An ingrained attitude that asks of life only "what will I get out of it?" leads ultimately to a blind alley of disillusionment and bitterness, to frustration and failure. When we ask instead "what can I give? We find that life takes on new zest and has new meaning. We do become alive!

Perhaps this is one of the weakest points in our democratic armour today - as Dr. Will Durant puts it: "Once democracy was a CAUSE TO BE SERVED; now, for may, it has become only A PICNIC TO ATTEND!"

And now, lest it might not have been noted, you will see that what I have been speaking about as the marks of an uncommon person belongs to our Judeo-Christian concept of life, which declares that we have all come from God and that we all one day return to Him and that having both origin and destiny in God, it is in serving others that we best fulfill the will of God for us, and that it is in tolerance and love and understanding and goodwill that we come closest to the most uncommon Person of all time, Jesus Christ.

And, I am convinced that the future does depend upon the number of ordinary people who are so motivated that they become extra-ordinary; the future depends not upon mediocrity but upon greatness; it depends upon the number of uncommon men and women whom we have in our day and generation - and here is the most exciting news of all - you and I can be among them if we want to!

SESSION CHAIRMAN
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ONTARIO WATER RESOURCES COMMISSION

# "PLASTIC BIOLOGICAL OXIDATION MEDIA FOR INDUSTRIAL WASTE TREATMENT NEEDS"

BY

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Industry has as one of its broad definitions, "all forms of business and manufacturing." From this we realize that the term industrial waste describes discarded materials from any one of these businesses or manufacturing operations. As each of these produces its own particular product(s), so also they must discharge their own characteristic waste.

Wastes from industry usually originate from raw material washing, intermediate products, spilled product or spilled raw materials and clean-up. These wastes can be distinguished between organic and inorganic wastes. Of these, organic wastes are generally regarded as the most common and difficult to treat. To treat these organic wastes, many of which contain large amounts of soluble organic matter, the biological waste treatment systems such as activated sludge and trickling filters have proven to be the most popular. Often several biological processes have been used in series. Generally in such cases a trickling filter acts as a roughing unit ahead of the polishing second unit.

## ADVANTAGES OF TRICKLING FILTERS

Trickling filters have some very distinct advantages over the other major biologically centered waste treatment schemes. Microorganisms, which are the heart of any biological process, are very tempermental and sensitive to changes in their environmental conditions. Change in temperature, pH, type or concentration of a waste can lead to major upsets in operation. The activated sludge processes in many cases have been upset in that anyone of these mentioned environmental changes can cause death to the active organisms or produce, very rapidly, a specific species of organism that will eventually cause loss of the activated sludge. In order to cope with this, many industrial waste treatment facilities have constructed large stabilization ponds or holding tanks to equalize the flow going to the biological process. Other industries have constructed roughing units which have been quite successful in smoothing out rapid fluctuations.

Standard rock trickling filters or high rate rock trickling filters have been quite successful in treating wastes which have rapid changes in one or several environmental conditions. The environmental change affects the organism on the surface of the slime layer. However, since most of the biological slime does not have a chance to come in direct contact with the unfavourable condition, the trickling filter system can recover quickly from the shock loading.

In addition to withstand these changed conditions in an industrial waste stream, trickling filters traditionally have been noted for their ease and economics of operation. Generally, very little supervision is required of a trickling filter waste treatment plant.

In order to make use of the advantages of trickling filters, many designers have constructed them prior to activated sludge systems. The function of the trickling filter is to rough (decrease the applied BOD concentration by up to 50%) the waste stream before it reaches the polishing or the second stage biological process. In so doing, the roughing filter takes the brunt of any shock loads. Then the secondary biological process can cope with the softened shock.

Rock trickling filters in themselves have several disadvantages which often prevent their use in industrial waste application. Where strong organic wastes are involved, the limiting organic loading to the filter is very low, and therefore, large areas of land are required to treat the waste. Also, rock trickling filters because of the kinetics of the biology involved, are not able to produce an effluent as polished as that produced by aerated systems. Finally, in many industrial wastes, the biological growth on the supporting rock media is of such magnitude that plugging and clogging can occur with resulting odor problems and complete breakdown in waste treatment.

## NEW MEDIA - PLASTICS

Over the last 15 years, great strides have been made in the development of new supports for biological growth. Of particular importance have been those supports constructed of new and modern plastic materials. The following discussion and data is based on Surfpac® biological oxidation media*. This media is currently being made of PVC and Saran.

The plastic media is used in a fashion quite similar to that of standard rock or high-rate rock trickling filters. The plastic material acts as a support for microorganisms which stabilize the organic matter in the waste stream. This media was designed to take advantage of the inherent good points of rock trickling filters for industrial waste treatment and, at the same time, solve some of the disadvantages. Figure 1 shows one module assembled from corrugated sheets. The media represents more than double the square footage of surface area per cubic foot than that of available 3 inch rock. This surface area is even more important when one considers that often, because of the random orientation of rock in a trickling filter, much of the surface area is unavailable because the inner-connecting passageways have become clogged with slime. The predominantly vertical nature of the supporting walls and lack of small crevices allows the hydraulic flow to shear off excessive growth and permits an unhindered removal of slough-off material. The media stays clear of excessive build-up even when subjected to concentrated industrial wastes. It is also very apparent from the figure that the majority of the packing is void space. This high rate ratio of void space insures excellent oxygen transfer.

The modules themselves are self-supporting. Therefore, the surrounding wall can be constructed of many different structurally light materials. The basic strength of the bundle is derived from the strength of the plastic itself. This strength and critical shape allow the assembled modules to support over 850 pounds per square foot. Because of this, and the already mentioned factor of high void space, these trickling filter systems have been built upward rather than outward and thereby have saved valuable land for many industries. As a result of this vertical construction the hydraulic and organic loading rates applied to these trickling filters are much greater than possible with any rock or high-rate rock trickling filters.

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* Product of The Dow Chemical Company

## REVOLUTION IN CONSTRUCTION

Since the development of plastic media for trickling filters, industry has been the leading user. This was due largely to ease of operation and land savings. Currently, out of 24 full-scale installations now using this particular media, 16 are strictly for industrial waste treatment. Recently many consulting engineers have been designing plastic media for application in domestic waste treatment. The switch in acceptance of plastic media for domestic treatment has been caused by development of new ideas in construction revolving around the use of plastic media. Improved structural designs made specifically for plastic media have brought the cost of full-scale installations to levels in direct competition with any other type of waste treatment system.

Most units now in operation contain over 21 feet of media. Figure 2 shows a 21.5' deep installation at an oil refinery. In this case the supporting structure was steel grating and the enclosing wall was 1/4" steel plate. Other firms have chosen to construct the supporting towers in unusual shapes. Figure 3 shows a Surfpac unit treating a hot textile waste. The more recent milestones in plastic media construction have been initiated by municipalities. Figure 4 shows a small municipal plant with a supporting wall constructed out of decorative shadowblock. This structure as is contains only 9 feet of media. Its contribution to advancing technology is that its foundation and base work is made in such a way that as the flow to the plant increases, the rotary distributor can simply be removed from the top of the filter and the depth of the filter can be more than doubled. This then will supply this small community with almost instant plant expansion at a relatively small cost. The newest and possibly the most revolutionary of all plastic media installations now in operation is one just completed in midwestern United States. Figure 5 shows two 250,000 cu. ft. plastic media trickling filters. These trickling filters were designed to treat a combination of domestic and industrial wastes. The main point of interest here is that the surrounding wall is nothing more than reinforced fiberglas. The walls support or restrict no load other than that which can be obtained from outside wind pressures. The colour of the wall is a blue-green and is surely a first step in making waste treatment plants attractive as well as functional. This unit is also the least expensive system that could be constructed to do the desired job.

## PILOT PLANT STUDIES

The development of a new concept or idea necessitates a large amount of pilot plant information. Over the last ten years, well over 80 pilot plant studies have been conducted using this particular plastic media. Most of these studies have been carried out with the co-operation of the media manufacturer. However, several studies have been made independently by universities, cities, and industrial associations.

Currently there are over 18 pilot plant studies being conducted in various parts of the United States. All of these pilot units look quite similar to the one seen in Figure 6. The unit itself contains 21.5' of plastic media and the diameter is about 3 feet. Pumps are mounted on the system to provide a raw waste flow of anywhere between 0.1 and 3.0 gpm/sq. ft. A special pump is also provided to recycle wastes in any ratio reasonable for a meaningful study.

The results of previous pilot plant studies have been used to assemble an equation by which full-scale unit volumes can be calculated(1). The formula is as follows:

$$\left[ Q = \frac{K\,D}{2.3 \log_{10} \frac{1}{P}} \right]^{2*} \qquad (1)$$

where P is percent of BOD remaining after secondary clarification

K = a rate of coefficient, called a treatability factor (differs for various type wastes)

D = depth of filter media, ft.

Q = the hydraulic dosage rate of liquid on filter without recirculation, $gpm/ft^2$

*Exponent of 2 has been experimentally determined for Surfpac.

(1) Germain, J. E. "Economical Treatment of Domestic Wastes Using Plastic Media Trickling Filter," 38th WPCF Conference, October 13, 1965.

As a result of the great volume of pilot planting, treatability factors have been established for a great number of industrial wastes. We know, for example, that most domestic wastes have a K of 0.088. This value has been confirmed on full-scale installations. In the case where we are faced with a waste on which we have not previously pilot planted, it is often possible to estimate a design K based on the various organics contained within the waste. However, there are times when pilot planting is necessary to determine the treatability of that waste and, therefore, the amount of media needed to get a desired degree of treatment.

Equation (1) points out the importance of depth when using plastic media. By increasing the depth of media, it is possible to do a required job of treatment with less media volume than would be required using a shallower unit. As a result, most of these filters have been constructed using 21.5' of media depth. This depth is convenient because the media can be stacked to this depth without intermediate supports. If a deeper filter were required, an intermediate deck would have to be constructed to support the next layers of plastic media. However, this added depth brings with it additional operating costs that most municipalities and some industries do not want to maintain.

## SPECIFIC INDUSTRIAL WASTE TREATMENT APPLICATIONS

Numerous industries have pilot planted and have constructed full-scale units containing Surfpac as both roughing filters and complete treatment systems. It would be meaningless to discuss each and every one of these pilot plant and full-scale units in the time we have available. However, I have chosen several industries which traditionally have problems treating their waste on biological systems. In each case, I am including specific treatment parameters so that you will be able to examine the loadings possible with this type of waste treatment system.

### Refinery Wastes

A full-scale, 15,000 cu. ft. plastic media unit has been operating at a refinery in Robinson, Illinois (2)

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(2) Davis, R. W., Biehl, J. A., and Smith, R. M., "Pollution Control and Waste Treatment at an Inland Refinery," Proceedings 19th Industrial Waste Conference, 126-138, Purdue University, January 1965.

for over five years. The waste applied to the trickling filter first passes through oil separators. It is then applied to the filter through standard rotary distributor arm systems. The tank used to house media was a surplus oil storage tank, Figure 2. Internal support members and grating support deck were added and the plastic media was then installed and put in operation. The normal flow to this unit is approximately 800 gpm. The lift pumps have a capacity to provide 50% recycle, however, recycle is seldom used. Loading to the plastic trickling filter media is approximately 75# of BOD/1000 cu. ft./day. The hydraulic loading is about 1.04 gpm/sq. ft. Table 2 gives a brief summary of the operating data on this waste. In reviewing this data, it should also be emphasized that this particular system has operated without pH control on the feedwater. The pH of this waste is often outside the normal range of 6.0 to 8.5 considered optimum for biological oxidation. In addition, it has been found that even with sudden changes in pH and waste concentration that the system recovers quickly when more normal wastewater application is resumed.

This particular trickling filter is followed by a holding pond for polishing. The last column in Table 2 gives the over all plant removals based on phenols, COD, and sulfites. In this first example, the trickling filter was used to accomplish most of the treating job.

At another refinery, it was decided to use a combination of waste treatment processes. This oil refinery is located in Michigan and produces straight-run gasoline and kerosene which are then used as feed stocks for an ethylene plant. The raw wastes to the waste treatment unit consists of 150 gpm of excess quench water and polyethylene plant wastes, with an initial COD of about 2000 ppm, phenol about 50 ppm, and an odour threshold of over 4,000,000 dilutions. Some of the specific compounds in the waste are benzene, toluene, xylene, and methanol. The waste stream from the polyethylene plant contains hexane, catalyst, and alcohols(3).

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(3) Shannon, E.S., "Experiences in Handling and Treating Petrochemical Plant Wastes," 14th Oklahoma Industrial Waste Conference, Oklahoma State University, November 20, 1964.

Figure 7 shows a flow diagram of this particular waste treatment plant. As can be seen, two plastic biological oxidation towers are used in this scheme. The first of which contains 6200 cu. ft. of media is used as a roughing tower ahead of the activated sludge unit. The second tower contains 9000 cu. ft. of Surfpac and is normally used as a polishing filter in series with and following the activated sludge step. The mixed liquor from the activated sludge tank is pumped over this second filter where the sludge is further oxidized. It has been reported that the plant has run as long as five months without wasting excess sludge. As can be seen, the first stage tower removes about 50% of the BOD and COD, and almost 95% of the phenol. About 90% of the remaining BOD and 60% of the remaining COD, and essentially all of the remaining phenol are removed in the activated sludge unit. By the time the waste stream reaches the final settling tank, the odour threshold has been reduced to less than 25,000 dilutions. After chlorination of the final effluent, the average COD is less than 75 ppm, BOD less than 10 ppm, and phenol less than 0.01 ppm, the odour threshold level below 1000 dilutions and usually less than 350 dilutions. Specific performance of the first oxidation tower, containing 6200 cu. ft. of media is shown in Table 3. Of particular importance is the organic loading on this trickling filter system. COD removals of up to 50% are being maintained even at COD loadings of 290#/1000 cu.ft. /day.

## Pharmaceutical Wastes

Several years ago a pilot plant study was conducted at a pharmaceutical manufacturer in the eastern United States. The waste at this plant is quite similar to conventional domestic waste but it has a much higher biological oxygen demand with occasional complicating variables. Among the usual and troublesome pollutants in the waste stream are sanitizing and disinfecting agents, small quantities of solvents, red blood cells, and acid cleaning solutions. In addition, there is also an imbalance in inorganic nutrients, primarily nitrogen and phosphorus.

When it was decided to double the manufacturing capacity of this pharmaceutical plant, it was also necessary to double the size of the waste treatment facilities. The previous waste treatment plant consisted of two rock trickling filters, settling tanks, and sand filter beds. To double the plant's capacity with similar equipment would have required considerable investment and even more important, space. The results of a pilot plant study indicated that a plastic media trickling filter, acting as a roughing unit ahead of the existing rock filters could give them the most economical plant expansion(4). The results of the pilot plant studies can be seen in the first row of Table 4. In addition to pilot plant results is a summary of data taken from the now-operating full-scale installation. Even though the concentration of the waste going over the trickling filter is somewhat higher now than it was during pilot planting, the roughing unit is doing its job in taking out a great percentage of the BOD. The organic loading to the trickling filter is over 300# of BOD/1000 cu. ft. /day. The current practice is to add approximately 100 pounds of anhydrous ammonia to the main waste stream each day to supply the necessary nutrients.

The use of high rate trickling filters in this situation has permitted this plant to maintain an average BOD reduction of 99% across the entire plant, despite doubling the plant load. Labour, material, and space requirement were only a fraction of those which would have been necessary for extension of the rock bed system(4).

Textile Wastes

Currently 16,500 cu. ft. of plastic media is being used as a basic waste treatment scheme for a textile plant located in southeastern United States. This plant is a textile dyeing and finishing unit producing finished corduroys, velvets and velveteens. Because textile wastes as a group are considered one of the most difficult to treat, a pilot plant study was carried out in 1962. This pilot plant was constructed by the mill engineering staff. During operation, heavy strings of slime developed causing slight ponding on the media(5). This condition was attributed to nitrogen deficiency and immediately a nitrogen feed pump was installed. For the remainder of this study period, diammonium phosphate was added to the raw wastewater to insure proper balance between phosphorus, ammonia, and carbon. The addition of nutrients immediately eliminated the ponding, and the slime took on a more normal characteristic.

(4) Wett, T. W., Hartshorne, D., "Single Tower Doubles Capacity of Waste Treatment Plant," Chemical Processing Magazine, April 1965.

(5) Snyder, D. W., "Surfpac Pilot Study on Textile Waste," Proceedings 18th Purdue Industrial Waste Conference, April 30, 1963.

Results of the pilot plant study are presented in Figure 8. It was also noted(5) that the pilot plant study was not operated with true equalized flow and consequently, shock loadings to the unit were quite severe. Even under these conditions the unit recovered rapidly. Rapid recovery also occurred during resumption of manufacturing after weekend shutdowns. This pilot plant data has been used to construct a full-scale treatment plant. The plant is somewhat unique in that it is designed so that 20% additional media can be added to the tower if future demands require additional treatment.

## Paper and Paper Products Wastes

More so than most other industrial wastes, paper waste can mean any one of many types of waste depending on the type of plant and process used. Recently, Gehm and Gellman(6) wrote up the results of a two-year study program on various biological processes for treating paper and pulp wastes. The main systems discussed and observed were activated sludge alone and activated sludge preceded by a roughing unit containing plastic media.

Financing of this study was done by a group of mills and plants faced with industrial waste problems. The pilot plant system used a 10' deep plastic media tower constructed directly over an activated sludge tank. The pilot plant was operated on the settled effluents from a fine paper mill, a boxboard and a paper mill employing deinking. The BOD average of these three wastes was about 250 mg/l. Diammonium phosphate was added to supply the necessary nutrients.

Results of this study indicated that the activated sludge unit alone could not perform well over a wide range of BOD loadings. The combined system, roughing filter ahead of activated sludge, allowed much higher organic loadings to the entire system. In addition the quality of the sludge from the activated sludge unit was much better when the roughing unit was used. This is illustrated in Figure 9. This figure is based on the results obtained from the fine paper waste

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(6) Gehm, H. W., Gellman, I., "Practice, Research and Development in Biological Oxidation of Pulp and Paper Mill Effluents," Jour. Water Pollution Control Federation, pages 1392-1398, October 1965.

since it produced the most difficult to settle sludge. Figure 9 shows that the sludge volume ratio for combined treatment was generally below 200 and most of the time below 150. For activated sludge alone, the sludge volume ratio never dropped below 100 and usually exceeded 150.

In addition to operating benefits, the authors made a cost estimate based on construction costs involved with the combined system vs. activated sludge alone to remove a given poundage of BOD. The results indicated that the combined treatment could be from 5 to 25% less than the cost of building activated sludge alone. Additional savings could also be made if the filter were constructed directly over the activated sludge unit as was done in the pilot plant study. This cost comparison was based on the cost of the plastic media at $100/cu. yd. However, since that time the average price for plastic media has come down to approximately $68/cu. yd. At the same time, costs for concrete, steel, and piping have risen so that the current difference in price between the two systems is somewhat more than what was illustrated several years ago.

Data is also available on kraft mill wastes. A pilot plant study was carried out on such a waste containing screened white water and black liquor from pulp mill wash-up. The study used two 20' deep towers in series with no intermediate clarification. This simulated a tower of 40' in depth. The pilot unit was run on many combinations of raw feed and recycle. Results of three of these combinations are seen in Table 5. As expected the percent BOD removal decreases with increased hydraulic and organic application. However, even at these high figures, there is no evidence of limitations in this system's ability to treat the waste.

A final chart, Table 6, is presented showing results of pilot plant work done on a boxboard waste. This waste, from the repulping of kraft corrugated boxes, contained starches and glues as the main pollutants. Once again the data shows the ability of the system to remove large poundages of BOD and still maintain good percent removals.

## Fruit Canning Wastes and Beet Sugar Wastes

Over the last year or so, the National Canners Association has been investigating various methods of treating high strength wastes resulting from the canning and processing of peaches and pears. In addition wastes from the caustic solution used in the peeling process are also applied to the biological processes under investigation. Thus far Surfpac has been used successfully to remove a large amount of the BOD from the cannery waste before it is applied to the city sewer system. Influent and effluent samples are settled for 15 minutes before analysis to simulate primary and secondary clarification. The raw waste at pH 10.5 needs pH adjustment only occasionally. Table 7 summarizes some of the data collected over this pilot unit. The unit was operated at BOD loadings in excess of 300# BOD/1000 cu. ft./day and up to 1500#/1000 cu. ft./day. The object of these studies has been to determine BOD ranges to get the waste strength down to a level where it can be added to the city sewer system without putting an excessive load on the municipal waste treatment plant. It can also be seen in Table 7 that the addition of nutrients had a positive effect on removals, especially at the very high organic loadings.

Results of these studies in California have shown that a large poundage of BOD can be removed very economically using the plastic media filters. The units are virtually maintenance-free and can be activated in a relatively short period of time prior to the beginning of the canning season. However, the biggest advantage to the canneries on the west coast is that of being able to build the towers vertically, thereby greatly reducing the need for very expensive acreage of land for waste treatment.

Another pilot study of interest was that conducted on a beet sugar waste also in the California area. The waste going to the trickling filter system consisted essentially of beet fluming water, and therefore had a somewhat lower BOD than effluents from plants which sewer other waste streams. The plastic media trickling filter was placed in parallel with an activated sludge pilot unit to determine the roughing advantages of each system. Results of the tests indicated that overfeeding of the activated sludge unit quickly produced an imbalance in the aeration system and that many times only one group of bacteria, Sphaerotilus, could be found(7). Based on these

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(7)Norman, L. W., et al. "Waste Water Treatment Studies at Tracy, California," Jour. of the American Society of Sugar Beet Technologists, Vol. 13, No. 5, April 1965.

studies, it was concluded that the activated sludge unit as such would not serve as a roughing unit in the normal sense in that overloading to obtain just 50% removal caused the development of filamentous forms of bacteria and then the sludge would not settle in the clarifier. The plastic media trickling filter, however, had BOD reductions of between 33 and 50% on once through passes involving organic loadings of 750 to 350 pounds of COD/day. This is equivalent to approximately 395 to 234 pounds of BOD/1000 cu. ft./day. This study also included a brief cost comparison for construction. Based on pretreating a waste having 650 mg/l of BOD influent so that at least one-third of the sugar is removed, it was determined that the trickling filter would cost about $45,000/million gpd and that the activated sludge system would cost about $30,000/million gpd. These figures are based on media costs of several years ago and since that time, these costs have come down to a point that, keeping everything else constant, capital costs for each system would be approximately equal. However, it was also concluded that in the case of annual operating costs, trickling filter systems would be about $1500 where activated sludge would be about $4500.

## General Chemical Wastes

Many industries produce a waste that contains numerous biodegradable byproducts. Some of these wastes can be extremely high in COD and contain materials that are normally very difficult to remove. One such plant, located in Vancouver, British Columbia, treats the chemical waste from the manufacture of phenol. The waste itself contains benzoic, acetic, and formic acid, as well as phenolics. The trickling filter here has been used as a pretreatment ahead of activated sludge. This waste treatment plant was constructed in the early 1960's and data from its operation was later reported by Smith(8). The data collected at that time is represented in Figure 10. It is very obvious that well over 50% of the phenolics and COD are removed across the Surfpac tower. The loadings on the trickling filter are approximately 44# phenol/day/1000 cu. ft. and 236# COD/day/1000 cu. ft. The hydraulic application rate over the unit is generally maintained at about 2 gpm/sq. ft. The entire waste treatment plant is removing over 99.9% of the phenols and about 95% of the COD.

(8) Smith, R. M., "Some Systems for the Biological Oxidation of Phenol Bearing Waste Waters," Biotechnology and Bioengineering, Vol. 5, pages 275-286, 1963.

Within the last several months a pilot plant installation has been established at an aircraft manufacturer in central United States. Waste from this plant consists of phenols, chromes, cyanides, detergents, and miscellaneous industrial wastes. Phenol content can vary anywhere between 10 and 200 mg/l and the COD is normally over 200 ppm. Based on approximately 35 sets of data, the plastic media filter is removing 90%+ of the phenols and over 50% of the COD at hydraulic application rates of 1 gpm/sq. ft. raw and 1 gpm/sq. ft. recycle. This is equivalent to approximately 50# and 111#/1000 cu. ft./day of phenol and COD respectively. As a result of this encouraging data, the consulting engineer involved with this plant is designing a full-scale unit using plastic media.

Because data such as this has been gathered from other industrial locations, plastic media trickling filters are now being designed without pilot planting. A full-scale unit is now under construction at the Trans World Airlines Overhaul Base in Kansas City, Missouri(9). The waste going to this trickling filter contains phenols, free oils, solvents, degreasers and other miscellaneous industrial waste fractions. This unit, which represents the secondary treatment facilities at this plant, will be followed by tertiary treatment which consists of two lagoons, which will perform a polishing job on the effluent before it goes to the receiving water body.

## Slaughterhouse Wastes

Some work has also been done with slaughterhouse wastes. One such evaluation, on a waste from the processing of hogs, cattle, and sheep, has shown plastic media filters to be effective in removing 71% of the BOD at hydraulic loadings of up to 64 mgad and BOD loadings of 616#/1000 cu. ft./day(10). Optimum recirculation was about 2:1. Maximum organic loading during the test period was 1260#/1000 cu. ft./day. In general, the waste concentration to the filter was about 2000 mg/l BOD and about 3500 mg/l COD.

(9) Higgins, G.C., "Industrial Waste Treatment Trans World Airlines Overhaul Base," presented at 22nd Annual Purdue Industrial Waste Conference, May 2 - 4, 1967, Lafayette, Indiana.

(10) Garrison, K.M., Geppert, R.J., "Packinghouse Waste Processing Applied Improvement of Conventional Methods," proceedings 15th Annual Purdue Industrial Waste Conference, May 3 - 5, 1960.

In still another study on packing house wastes, removals of 43% BOD were accomplished with BOD loadings in excess of 3000#/1000 cu. ft./day. Again the BOD in the raw wastewater was about 2000 mg/l.

A full-scale plastic media filter has just been completed and is treating a combination domestic waste and waste from a poultry processor. The average strength of the waste, BOD, is about 600 mg/l. The single stage unit containing Surfpac makes up the entire secondary treatment facilities of the plant. With loadings of 75# BOD/1000 cu. ft./day, removals in excess of 90% are being obtained. This 90% is being obtained across the filter and the following clarifier. The entire waste treatment plant including primary clarifiers is getting an excess of 95% BOD removal.

## General Installation Costs

For many years the use of plastic media in industry has generally been confined to roughing. Large poundages of BOD could be removed quite inexpensively and a secondary system could polish to the desired final effluent. However, within the last several years, the cost of plastic media has been decreasing steadily. In addition to this, new and improved construction techniques based upon plastic media is saving industry and municipalities great sums of money.

It is almost impossible to set general costs for media and construction since these values will vary considerably with the volume of the unit to be constructed, the type of waste and the degree of treatment to be accomplished. Based on past experience and on some of the units now being constructed, the enclosing structure which includes foundation, concrete work, rotary distributor, steel supporting grating, can be constructed and put into operation for approximately $1.00/cu. ft. of filter volume. This number can go as low as $0.60 to $0.70/cu. ft. for larger installations. The cost of plastic media trickling filters complete, media and supporting structure, can be made for around $3.00/cu. ft. These numbers are all "ball park" estimates and, of course, each situation should be investigated on its own problems and economics.

The operating expense involved with plastic media filters basically is one of pumping liquid over a tower of usually 21' in height. Based on pumping over such a unit and recycling 1:1, pumping costs come out to approximately $3.00/million gallons. Since this is about the only operational cost and maintenance on any type of trickling filter is traditionally very little, it can be seen that there are great advantages to using this type of system if it can adequately meet the needs of a particular plant.

## Future Potential and Development for Plastic Media

Currently there are about 25 installations in various stages of design by numerous consulting firms. The general usage and acceptance of plastic media is just beginning. Part of our continuing work with this particular product will be in promoting its general acceptance by consulting engineers, regulatory agencies and municipalities. In addition, we will be investigating new, better, and less expensive methods of constructing the supporting shell for the plastic media. This information will be passed on to the consulting engineers so that they can use the knowledge we have assembled.

In addition to making available the technical benefits of the current product, it is also our intention and our current objective to develop new ways of utilizing plastic media. In the near future, we hope to establish a process by which plastic media can be used as part of a phosphate removal scheme. In addition to this, we are currently studying ways of optimizing combined treatment of roughing with trickling filters followed by activated sludge. Our immediate goal, however, is to make you aware of the availability of plastic media and how it might economically fit in with your waste treatment needs.

## TABLE 1

### BULK PROPERTIES OF SURFPAC MEDIA VS. ROCK MEDIA

| PACKING | PACKING DIMENSIONS | UNIT WT. lbs./ft.$^3$ | SURFPAC AREA ft.$^3$/ft.$^3$ | VOID SPACE % | AVERAGE PACKING DEPTH |
|---|---|---|---|---|---|
| SURFPAC | 39"x21"x19" | 2.60* | 27 | 94 | 21.5' |
| ROCK | 1" - 3" | 90.5 | 14** | 40 | 7.0' |

* BASED ON SURFPAC MADE OF PVC

** BASED ON 1.5" ROCK

## TABLE 2

## PERFORMANCE DATA ON TREATING REFINERY WASTES

| | RAW | FILTER EFFL. | FINAL EFFL. |
|---|---|---|---|
| PHENOL, mg/l | 11.0 | 0.5 | 0.1 |
| BOD, mg/l | 115 | 48 | - |
| $H_2S$, mg/l | 78 | 20 | 0 |
| COD, mg/l | 250 | 125 | 90 |
| BOD LOADING, lb/1000 ft.$^3$/day | 75 | - | - |
| HYDRAULIC LOADING, gpm/ft.$^2$ | 1.04 | | |

TABLE 3

| | INFL. mg/l | EFFL. mg/l | LOADING lbs.BOD/1000 ft.$^3$/day | % BOD REMOVAL |
|---|---|---|---|---|
| PHENOL | 30 | 1 | 18 | 95 |
| COD | 500 | 250 | 290 | 50 |
| BOD | 250 | 125 | 145 | 50 |

PERFORMANCE DATA ON ROUGHING TREATMENT
FOR REFINERY WASTE

## TABLE 4

| | BOD, mg/l | | HYDRAULIC LOADING gpm/ft.$^2$ (RAW) | % BOD REMOVAL |
|---|---|---|---|---|
| | INF. | EFFL. | | |
| PILOT PLANT | 285 | 1.43 | 1.75 | 50 |
| FULL SCALE UNIT | 428 | 1.87 | 1.80 | 56 |

COMPARISON OF PILOT PLANT AND FULL SCALE DATA

ON A PHARMACEUTICAL WASTE

## TABLE 5

| TOTAL FLOW gpm/ft.$^2$ | FEED TO RECYCLE RATIO | AVERAGE BOD, mg/l | | BOD LOADING lbs./1000 ft.$^3$/day | % BOD REDUCTION |
|---|---|---|---|---|---|
| | | RAW | SETTLED EFFLUENT | | |
| 1.0 | 1:2 | 251 | 47 | 25 | 81 |
| 1.5 | 2:1 | 296 | 66 | 86 | 78 |
| 3.0 | 2:1 | 320 | 110 | 190 | 65 |

PERFORMANCE DATA ON 40' DEEP
TRICKLING FILTER TREATING KRAFT MILL WASTES

## TABLE 6

| FLOW, gpm/ft.$^2$ | FEED TO RECYCLE RATIO | AVERAGE BOD, mg/l | | BOD LOADING lbs./1000 ft $^3$/day | % BOD REDUCTION |
|---|---|---|---|---|---|
| | | RAW | SETTLED EFFLUENT | | |
| 1.0 | 1:6 | 1240 | 346 | 97 | 73 |
| 2.0 | 1:2.5 | 1260 | 514 | 395 | 59 |
| 2.0 | 1:1 | 1240 | 780 | 683 | 37 |

SINGLE STAGE TRICKLING FILTER
DATA ON BOXBOARD WASTES

TABLE 7

| FLOW, gpm/ft.$^2$ | | BOD, mg/l | | BOD LOADING | % BOD |
|---|---|---|---|---|---|
| RAW | RECYCLE | INFLUENT | EFFLUENT | lbs.BOD/1000 ft.$^3$/day | REMOVAL |
| 0.14 | 2.0 | 4033 | 580 | 316 | 86 |
| 0.42 | 2.0 | 3200 | 1395 | 730 | 56 |
| 1.0 | 1.0 | 3210 | 2040 | 1760 | 36 |
| 1.0 | 1.0 | 2750 | 1515 | 1510 | 45* |

PILOT PLANT DATA ON FRUIT CANNING WASTES

* SUPPLEMENTAL NUTRIENTS ADDED

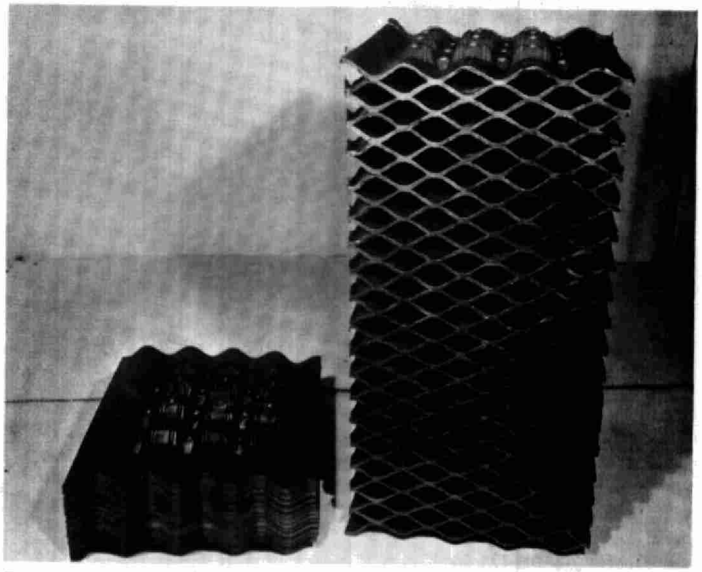


Figure 1

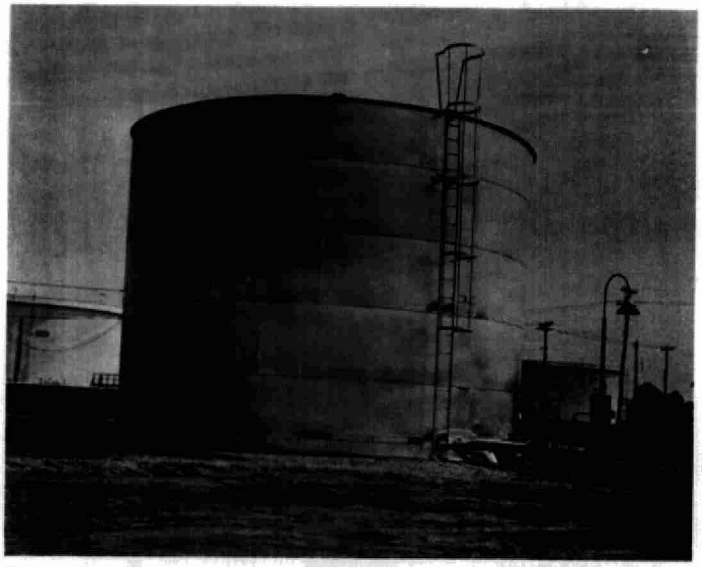


Figure 2

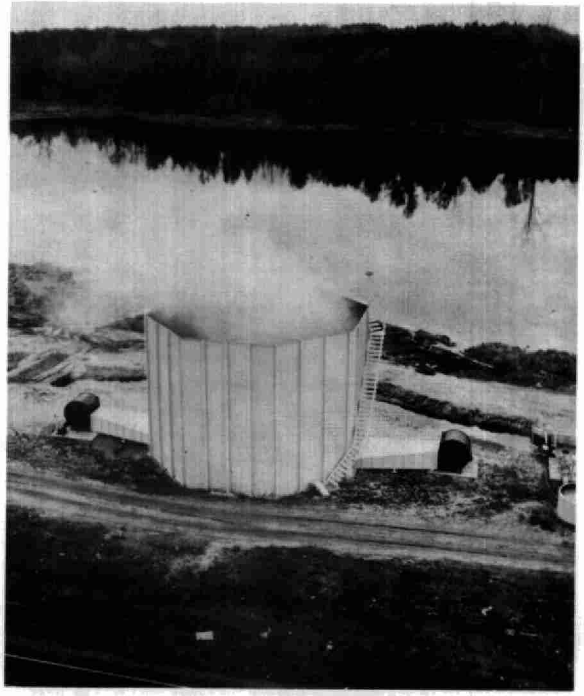


Figure 3

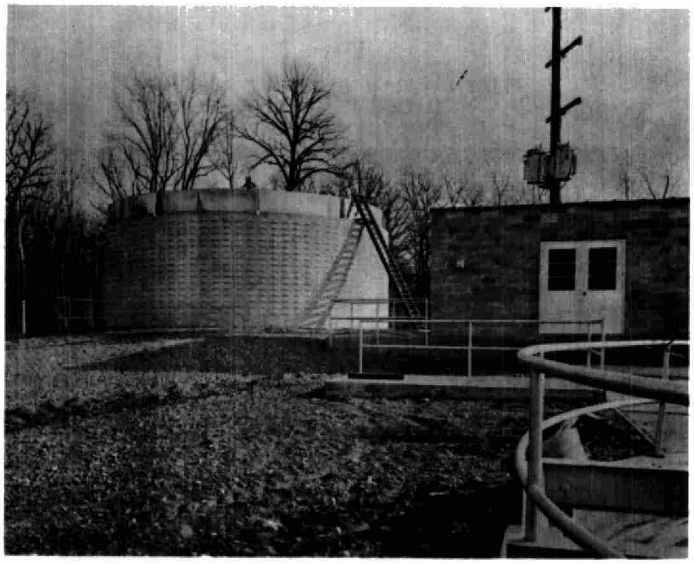


Figure 4

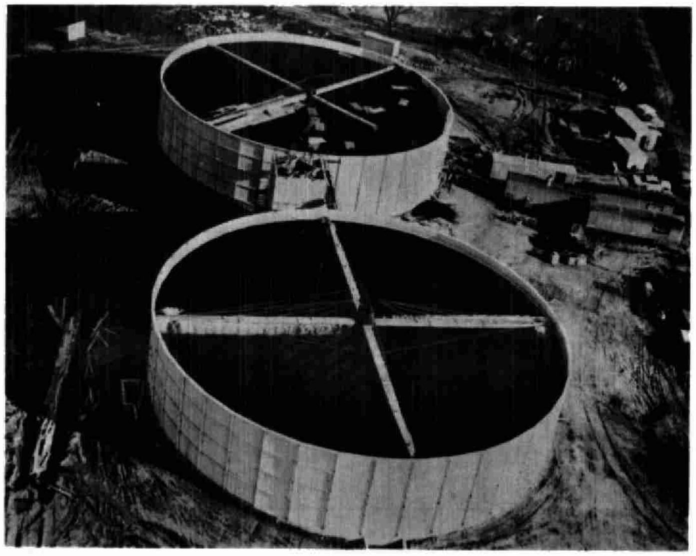


Figure 5

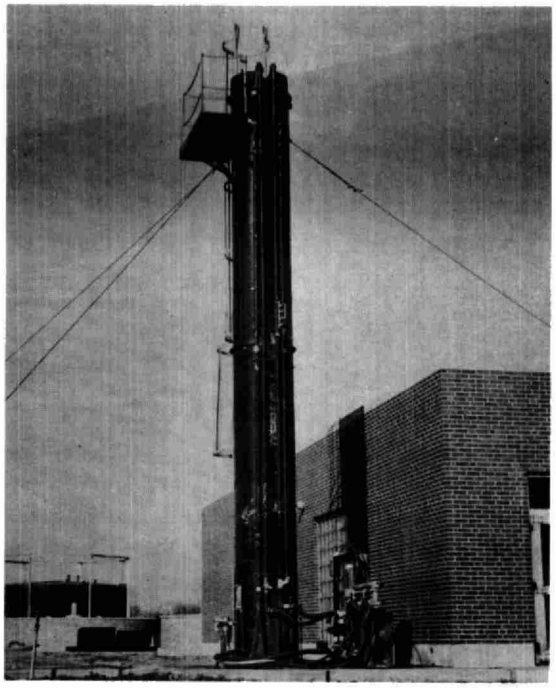
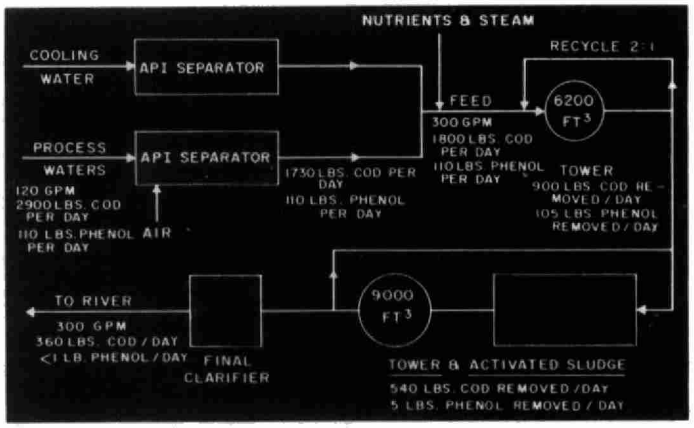


Figure 6

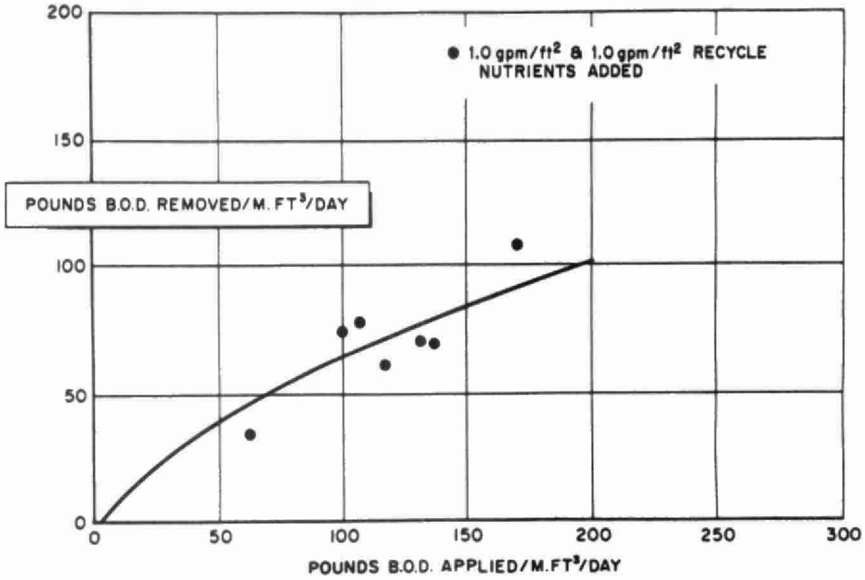
## Figure 7

FLOW DIAGRAM OF WASTE TREATMENT
FACILITIES AT OIL REFINERY



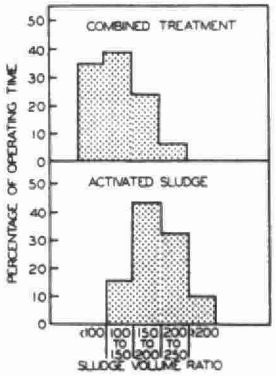
## Figure 8

RESULTS OF PILOT PLANT EVALUATION ON
TEXTILE WASTES (4)



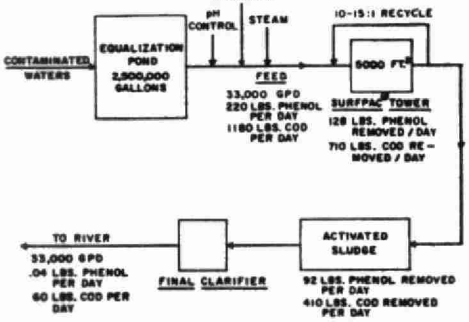
## Figure 9

EFFECT OF COMBINED
TREATMENT ON THE
SETTLEABILITY OF MIXED
LIQUOR SOLIDS (5)



## Figure 10

PHENOL WASTE TREATMENT PLANT
FLOW DIAGRAM (7)



REGISTRATION

AND

RELAXATION

WIND-UP OF LADIES' PROGRAM

# "A RATIONAL PROCEDURE IN THE DESIGN OF BIOLOGICAL OXIDATION PLANTS"

BY

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There has been considerable research and development over the past ten years which has increased understanding of the mechanisms involved in the biological treatment of organic industrial wastes. In the past, extensive pilot plant study has been employed to establish design parameters. Extra polation to conditions other than those employed in the experimental study was hazardous and in many cases led to process failure or inadequate performance.

A greater understanding of the mechanisms and principles involved in the various biological processes in use today has permitted the engineer to design a process with reasonable assurance of success and with a minimum of experimental data. It is expected that in the near future optimization and computer techniques will vastly improve both the efficiency and economics of industrial waste treatment.

This paper presents, in outline form, a procedure which may be employed to develop design criteria for various biological systems.

It is understood, of course, that for many wastewaters the necessary coefficients are not available, and would have to be developed from experimental investigations.

PROCEDURE FOR THE DESIGN OF A BIOLOGICAL OXIDATION PLANT*

Data to be obtained from the industrial plant:

1. <u>Waste Flow</u>
    - a. Average daily waste flow, (MGD) - present
      Average daily waste flow, (MGD) - future design
    - b. Maximum average 4-hour waste flow - present
      Maximum average 4-hour waste flow - future design
    - c. Peak flow at any time - future design

2. <u>Waste Strength*</u>
    - a. Average daily $BOD_5$ (24 hour composite), mg/1
    - b. Maximum 4-hour composite BOD, mg/1
    - c. Maximum 4-hour $BOD_5$ loading, (lbs/day)

3. <u>Other Waste Characteristics</u>
    - a. Suspended solids and volatile suspended solids (24 hour composite), mg/1
    - b. COD or TOC, (24 hour composite), mg/1
    - c. Nitrogen ($NH_3$-N and total organic) and phosphorus (24 hour composite), mg/1
    - d. pH - instantaneous values
    - e. Alkalinity or acidity (if pH is less than 5.5 or greater than 9.0) - instantaneous values
    - f. Presence of heavy metals, oils, toxics, etc.

* In some cases waste strength is reported in terms of COD or TOC. The non-biodegradable fraction must be substracted to get an equivalent BOD. A further adjustment must be made to get $BOD_5$. For example, in a waste the COD is 1,000 mg/1 and the estimated non-biodegradable portion is 200 mg/1. The ultimate BOD would be approximately 800 mg/1 and the $BOD_5$ approximately 800 x 0.8 = 640 mg/1. (The $BOD_5$ will be approximately 80% of the ultimate BOD for most readily degradable organic wastes). If the results are reported as TOC (Total Organic Carbon), they may be converted to COD by multiplying by $O_2/C$ (32/12) and then by 0.8 to get the $BOD_5$. The same precautions for non-biodegradables must be considered when using TOC.

## DESIGN PROCEDURE

### a. Pre or Primary Treatment

1. If suspended solids are present in excess of approximately 125 mg/1, solids separation by lagooning, sedimentation, or flotation should be considered. For estimating purposes only, a sedimentation tank would have an overflow rate of about 1000 gpd/ft$^2$.

2. If oil, grease or floatables exceed 50 mg/1 a skimming tank or separator should be provided.

3. Heavy metals (Cu, Zn, Ni, etc.) should be removed prior to biological treatment.

4. a. If the pH exceeds pH 9.0, neutralization should be provided if the ratio of caustic alkalinity (expressed as $CaCO_3$) to COD removed exceeds 0.7 lbs. $CaCO_3$/lb COD or 0.56 lbs. $CaCO_3$/lb $BOD_5$ removed. Neutralization need only reduce the alkalinity to the aforementioned levels.
   b. In some cases where a wide variation in alkalinity is encountered during the day or plant operating schedule, the aforementioned levels can be achieved by providing an equalization tank or pond.

5. If the waste contains organic acids, bio-oxidation will convert these acids to $CO_2$ and bicarbonate salts provided the process design reduces these to $<$ 25 mg/1 as $BOD_5$.

6. When mineral acids are present, neutralization or equalization should be provided if the pH is less than pH 5.5.

7. Sulfide should be pre-stripped or otherwise removed if their concentration exceeds 250 mg/1.

8. If the influent BOD loading, in lbs/day, based on four-hour composites exceeds a 3:1 ratio an equalization tank should be considered to bring the variation within this range.

### b. Biological Treatment

It is first necessary to select the process or processes applicable to the solution of the particular problem. The options for biological treatment are as follows:

1. Activated sludge
2. Extended aeration or total oxidation
3. Contact stabilization
4. Aerobic lagoon
5. Aerated lagoon
6. Trickling filter
7. Anaerobic and facultative ponds.

General considerations in process selection are as follows:

1. Activated sludge should provide an effluent with a soluble $BOD_5$ of less than 10-15 mg/l and a total $BOD_5$ including carryover suspended solids of less than 20 mg/l. The process requires treatment and disposal of excess sludge and would generally be considered where high effluent quality is required, where available land area is limited, and where waste flows exceed 0.1 MGD.

2. Extended aeration or total oxidation will provide an effluent with a soluble $BOD_5$ of less than 10-15 mg/l and a total $BOD_5$ of less than 40 mg/l. The suspended solids carryover may run as high as 50 mg/l. [High clarity (low solids) effluent will usually require a post-treatment by filtration, coagulation, etc.] This process is usually considered for waste flows less than 0.25 MGD.

3. Contact stabilization is applicable where a major portion of the BOD is present in colloidal or suspended form. As a general rule the process should be considered when 85% of the $BOD_5$ is removed after 15 minutes contact with aerated activated sludge. The effluent suspended solids are of the same order as that obtained from activated sludge.

4. The aerobic lagoon is only applicable where partial treatment (~50-60% $BOD_5$ reduction) and a high effluent suspended solids are permissable. This process should be considered as a stage development, which can be converted into an extended aeration plant at some future date by the addition of a clarifier, return sludge pump and additional aeration equipment.

5. The aerated lagoon will provide effluent soluble $BOD_5$ of less than 25 mg/l with a total $BOD_5$ of less than 50 mg/l depending on the operating temperature. The effluent suspended solids may exceed 100 mg/l.

The system is temperature sensitive and treatment efficiencies will decrease during winter operation. A post-treatment is necessary if a highly clarified effluent is desired. Large land areas are required for the process.

6. Anaerobic and facultative ponds for industrial waste treatment should only be considered where odours will not cause a nuisance. If high degree treatment is required, these ponds must be followed up by aerobic treatment (i.e., aerated lagoons, activated sludge, etc).

## Biological Treatment Design

After selection of the possible process considerations from (2), the preliminary design calculations should be developed as follows: (This procedure presumes that no pilot plant or laboratory treatment study data is available. If such data is available, the appropriate coefficients and factors should be used).

### 1. General

a. Select the appropriate $K^1$, a, $a^1$, b and $b^1$ from Tables 1 and 2. It should be recognized that at this time there is limited data on the treatment of many industrial wastes so that some of the coefficients are necessarily estimations. As more data is accumulated these coefficients will be refined.

b. Each of the processes are designed using the equations shown in Table 3. It is important to remember that the coefficients as shown in Tables 1 and 2 generally apply to all systems, and that the principle differences between systems is the change in concentration of biological solids and retention time.

### 2. The Aerobic Lagoon

a. The required retention period for a specified effluent soluble BOD is estimated by combining Equations (1) and (3).

$$t\text{, days} = \frac{1}{(24aKs_e - b)}$$

## TABLE 1

Reaction Rate Constants for Completely Mixed Aerobic Biological Systems

| Waste | K | Reference |
|---|---|---|
| Sewage | 0.00108 | Von Der Emde (Flensburg) |
| Sewage | 0.00137 | Von Der Emde (Hamburg) |
| Sewage | 0.00177 | Von Der Emde (Kassel) |
| Sewage | 0.0007 | Manchester |
| Sewage | 0.00097 | Von Der Emde (Detmold) |
| Synthetic Rubber | 0.0028 | Busch |
| Sewage | 0.00122 | Wuhrmann (Zurich) |
| Chemical | 0.00006 | Busch |
| Rendering | 0.0015 | Mancini and Barnhart |
| Petrochemical | 0.00028 | Ford |

## TABLE 2

| Waste | a | a' |
|---|---|---|
| Spent sulfite liquor | 0.55 | 0.40 |
| Waste paper repulping and semichemical | 0.76 | 0.38 |
| Mixed pulp and paper |  | 0.48 |
| Kraft pulping and bleaching | 0.5 | 0.65-0.8 |
| Board mill |  | 0.33-0.40 |
| Wallboard | 0.7-0.78 | 0.37-0.48 |
| Synthetic fiber | 0.38 | 0.55 |
| Refinery | 0.70 | 0.56 |
| Brewery | 0.93 | 0.44 |
| Pharmaceutical | 0.77 | 0.35 |
| Domestic Sewage | 0.49-0.64 | 0.52 |

b. The equilibrium volatile solids in the lagoon is computed from Equation (3)

$$X_v = \frac{S_o + as_r}{(1 + b\ t)}$$

and the total suspended solids is

$$X_a = \frac{X_v}{\text{volatile fraction}}$$

For soluble organic waste the volatile fraction can be assumed as 80%. Where suspended solids are present in the waste, this estimate should be revised depending on the volatile fraction of the influent suspended solids.

c. The effluent BOD will be composed of the soluble BOD plus that contributed by the concentration of suspended solids in the basin which will be approximately the same as in the effluent for a completely mixed system.

$$\text{Effluent BOD} = s_e + fX_a$$

when f is the BOD contributed per unit of effluent suspended solids. This is selected from Figure 1.

d. The oxygen requirements are calculated from Equation (5) and include the oxygen used by the organisms for growth and that used for endogenous respiration.

The Aerated Lagoon

a. Since the relatively low power level in the system permits the major portion of the suspended solids to settle to the bottom of the basin, the solids level in suspension will be low. An estimate of biological (volatile) solids in suspension is 50 mg/1. The effluent soluble BOD is selected and the required retention period calculated from Equation (1)

$$t= \frac{S_r}{24\ KX_v S_e}$$

b. The total effluent BOD is computed as in 2(c) using an effluent volatile suspended solids of 50 mg/1.

## TABLE 3

## SUMMARY OF DESIGN RELATIONSHIPS

The basic relationships applicable to the design of biological waste treatment facilities are summerized below:

(1) BOD or COD Removal is a Completely Mixed Basin; Aerobic or Anaerobic

$$\frac{S_a - S_e}{X_a t} = Ks_e \quad (1)$$

(2) Sludge Yield

$$\Delta X_v = S_o + as_r - bX_v \text{ (conventional systems; aerobic or anerobic) } (2)$$

$$\Delta X_v = S_o + as_r - bX_d \text{ (total oxidation system; aerobic) } (2a)$$

(3) Equilibrium Solids in an Aerobic Lagoon or Anaerobic Flow-through system

$$\frac{S_o + as_r}{(1 + bt)} = X_a \quad (3)$$

(4) Sludge Age

$$G = \frac{X_v}{\Delta X_v} = \frac{X_v}{as_r - bX_v} \quad (4)$$

(5) Oxygen Requirements (Aerobic Systems)

$$0_2 = a's_r + b'X_v \text{ (conventional systems) } (5)$$

$$0_2 = a's_r + b'X_d \text{ (total oxidation systems) } (5a)$$

(6) Nutrient Requirements

$$\text{Nitrogen (N)} = 0.12\, \Delta X_v + 1.0 \text{ mg/l} \quad (6)$$

$$\text{Phosphorus (P)} = 0.02\, \Delta X_v + 0.5 \text{ mg/l} \quad (6a)$$

c. The oxygen requirements are computed from Equation (5).

d. It is important to check that enough power is supplied to maintain uniform distribution of oxygen throughout the basin particularly when the waste is low in BOD.

The Activated Sludge Process

In the activated sludge process, a primary requirement for effective operation is rapid settling and compaction of the sludge. This means that the sludge loading, lbs BOD/day/lbs. MLSS must fall within the flocculation ranges and below the level conducive to the growth of filamentous organisms (see Figure 2). The activated sludge process is schematically shown in Figure 3, which includes all ranges of operation. The design relationships for the various processes are summarized below:

1. Conventional Activated Sludge

a. Required basin volume:

$$F = \frac{24\ s_a}{X_a t}$$

F must fall in flocculation range (usually 0.3-0.7 lbs. BOD/day/lb MLSS);
$X_a$ is selected based on sludge settling properties; usually between 2,000 and 4,000 mg/l; will usually yield optimum removal.

$$V = Q/24 \cdot t$$

where Q is the waste flow in (mgd) and V, the basin volume in (MG).

b. Oxygen requirements -- Equation 5
c. Sludge yield -- Equation 2
d. Nutrient requirements -- Equation 6

2. Conventional Activated Sludge With Nitrification

a. Required basin volume -- Equation 4, with sludge age selected from Figure 4.
b. Oxygen requirements -- Equation 5 plus N oxidized · 4.5
c. Sludge yield -- Equation 2.

3. Extended Aeration

a. Required basin volume

$$X_a = \frac{a_o s_r}{fb\ (\text{col. fract})}$$

where

$a_o$ = fraction of BOD converted to degradable solids
$f$ = fraction of degradable solids in system
$v$ = fraction of volatiles

$$V = \frac{X_a\ (\text{lbs})}{X_a\ (\text{mg/l}) \cdot 8.34}$$

in which V = MG of basin volume

b. Oxygen requirements -- Equation 5a

Design

a. It is first necessary to assume a mixed liquor suspended solids concentration of solids in the return sludge and on the return sludge rate. In general good settling flocculated sludge can be expected to concentrate to 10-12,000 mg/l; in the final settling tank return sludge rates of 20-50% of the average waste flow are common. This would indicate a selection of 3000 mg/1 as a conservative operating level.

b. Since a well-flocculated good settling sludge is essential to effective process operation, the loading level must be in the proper range (see Figure 3). For most wastes a value 0.5 based on average waste loadings will yield a conservative design.

Extended Aeration

a. In the extended aeration process, the retention time or basin volume required is that required to oxidize all of the degradable sludge produced in the system by synthesis. For a soluble waste, the quantity of sludge which must be maintained under aeration to accomplish this oxidation is:

$$X_{av} = \frac{a_o s_r}{fb}$$

in which $a_o$ is the fraction of BOD converted to degradable sludge and can be assumed to be equal to $(a - 0.11)$.

The total solids under aeration is then:

$$\frac{X_{av}}{\text{Fraction volatile}}$$

The volatile fraction for soluble wastes in an extended aeration process will probably average 70%.

Assuming 3500 mg/l mixed liquor suspended solids, the required aeration volume is:

$$V = \frac{X_a \text{ (lbs)}}{3500 \times 8.34} \text{ (MG)}$$

b. The aeration requirements are calculated from Equation (5a).

c. The excess sludge will be the non-biodegradable residue and will be approximately equal to

$$\Delta X = 0.23\, as_r - \text{effluent loss}$$

The biological oxidation design parameters are summarized in Table 4.

## Summary

This paper has presented a procedure which can be employed for the preliminary design of biological treatment facilities for industrial wastes. In many cases, additional experimental work will be desirable to verify the coefficients used in the design.

Continuing research and development will improve and sophisticate these procedures and eventually lead to optimization and computer technique.

## TABLE 4

## SUMMARY OF BIOLOGICAL OXIDATION DESIGN PARAMETERS

| Process | Activated Sludge | Extended Aeration | Aerobic Lagoon | Aerobic-Facultative Lagoon |
|---|---|---|---|---|
| Loading Range<br>lbs BOD/day/lb MLSS | 0.3-0.6 (1) | 0.1-0.25 | ≃ 2.0 | ≃ 2.0 |
| Aeration Solids<br>mg/l | 2000-5000 (2) | 3500-5000 (2) | 1/2 $BOD_{REM}$ | 50-100 (3) |
| BOD Removal Eff. (4)<br>% (overall) | 90-95 | 85-90 | 50-60 | 80-90 |
| Effluent |  |  | (5) | (5) |
| Soluble BOD, mg/l | 10-20 | 10-20 | - | - |
| Total BOD, mg/l | 15-25 | 20-40 | - (5) | - (5) |
| Suspended Solids mg/l | <20 | <70 |  | 50-100 |
| Sludge Yield<br>lbs/lb BOD removed | ≃ 0.30 | ≃ 0.10 | ≃ 0.50 | - |
| $O_2$ Requirement<br>% of BOD removed | 90-95 | 120 | 75 | ≃ 100-120 |
| Minimum Aeration Power Level | ≃ 0.4 ft/sec (6) | ≃ 0.4 ft/sec (6) | ≃ 0.4 ft/sec (6) | ≃ 8 HP/MG |
| Temperature Coefficient θ | ≃ 1.0 | ≃ 1.0 | ≃ 1.035 | ≃ 1.065-1.085 |

(1) Higher loadings will frequently result in filamentous and non-flocculent sludge growth.

(2) Upper level limited by concentration and rate of return sludge.

(3) Related to influent BOD and suspended solids and to aeration power level and mixing intensity.

(4) Includes both soluble and suspended BOD.

(5) Depends on design retention period

(6) Bottom velocity in aeration basin

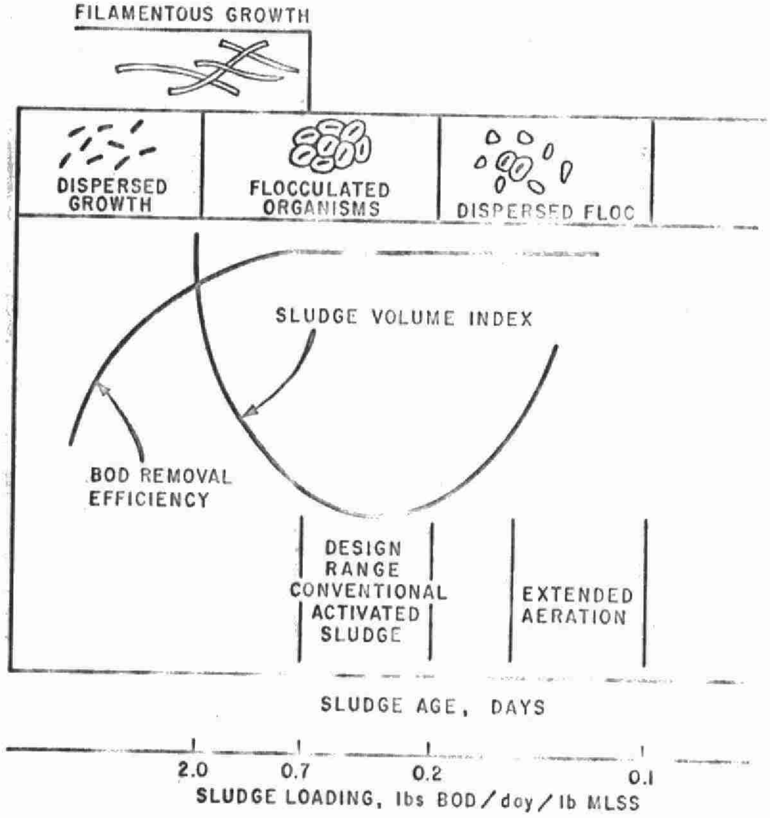


Figure 1 – *Sludge Loading, lbs Bod/day/lb MLSS*

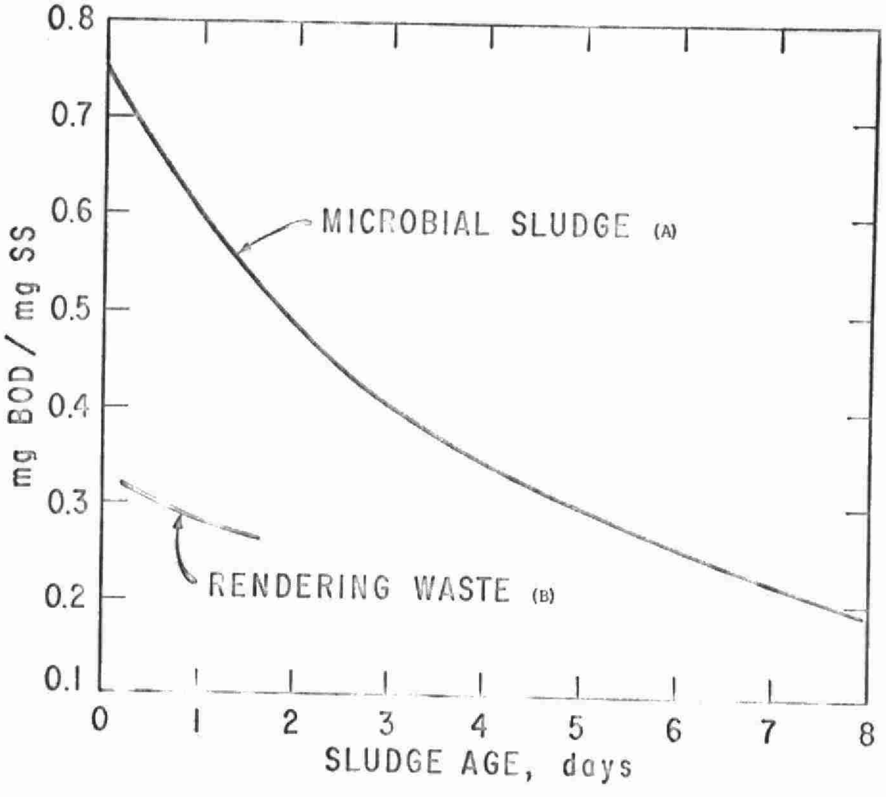


Figure 2 – *Sludge Age, days*

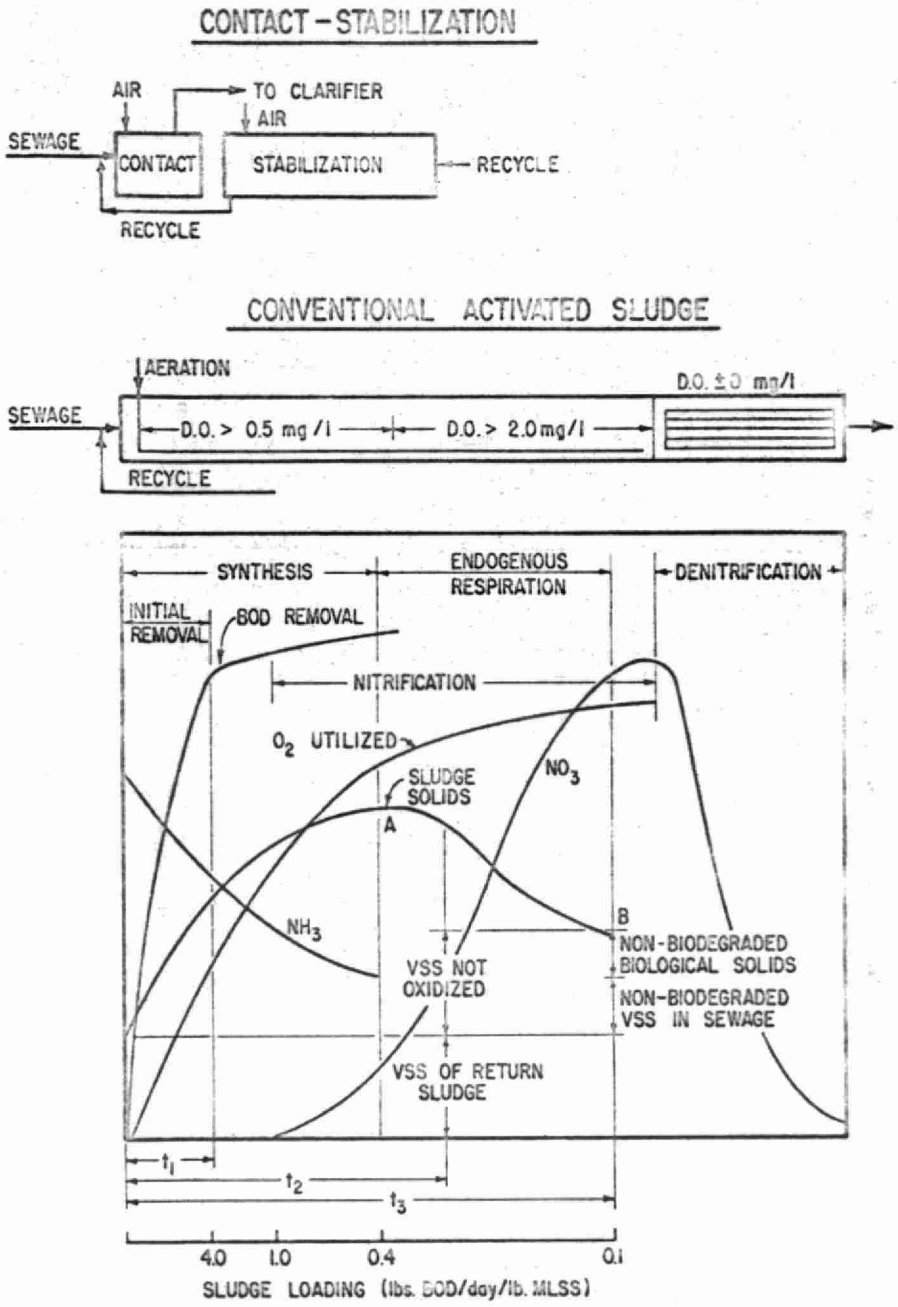
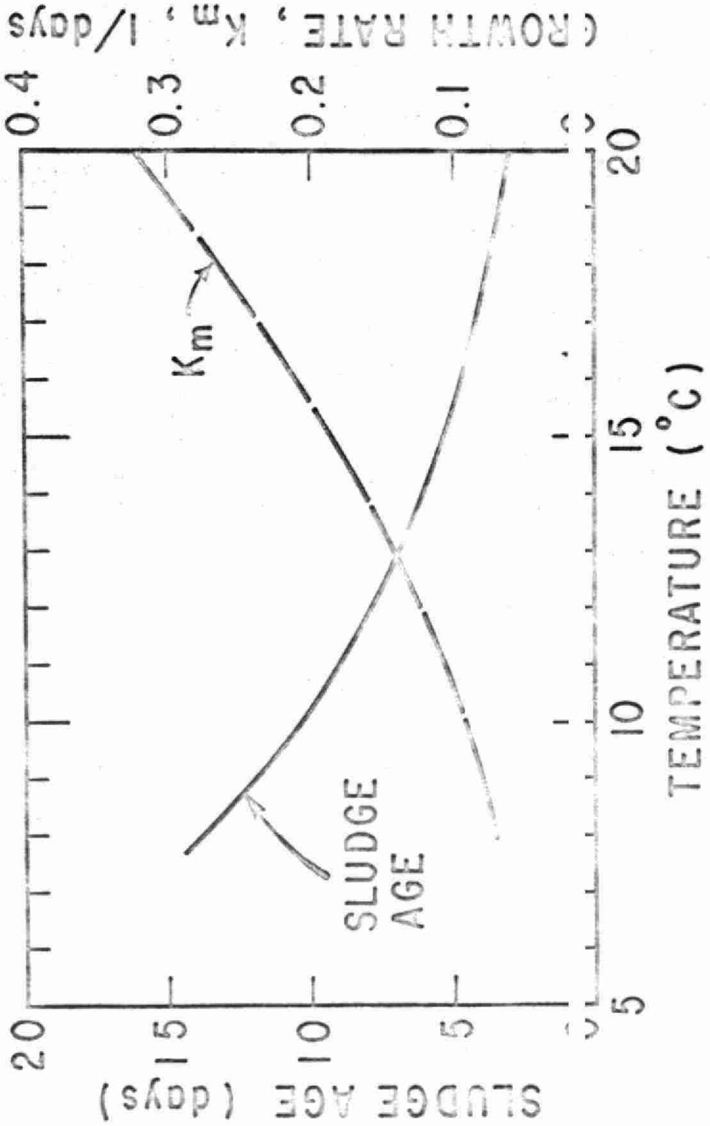


**Figure 3** – *Schematic Representation of the Activated Sludge Process*



GROWTH RATE OF NITROSOMMONAS
(After Downing)

**Figure 4**

# "CONTACT STABILIZATION"

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## LITERATURE REVIEW

Since biological waste water treatment, in the form of activated sludge, was introduced by Arden and Lockett in April 1914 (1) many engineers and investigators have attempted to improve and modify the process so as to increase efficiency and reduce cost. Other important considerations are that a waste water treatment plant receiving domestic sewage, with or without industrial wastes, was very subject to swift and unannounced changes in the complex material being treated. Thus an inexpensive process, which will produce continuously, a high degree of treatment with a minimum of plant control and adjustment, is desirable.

When a sewage treatment plant becomes continuously overloaded due to municipal expansion there is a quick reaction on the part of those responsible to seek additional capital for the purpose of building extended facilities. In 1947 in Austin Texas the treatment plant superintendent and his assistant took the somewhat unusual step of trying to alter the plant operation to accommodate considerably greater flow without the sacrifice of treatment efficiency. Ullrich and Smith (2) undertook a pilot study at the municipal plant designed to take better advantage of the well known, albeit poorly understood, adsorptive properties of activated sludge.

In 1957 Ullrich and Smith reported the results of two years of operation and validated their conclusions drawn ten years previously. The conclusions drawn were:

1. Due to the brief mixing time, the elimination of primary settling tanks and the high concentration of sludge being reaerated, the tank capacity required to accommodate this process is extremely low and as a result the capital cost is reduced.
2. A minimum of "in plant" operating adjustments are required to deal successfully with a wide range of sewage flows and strengths.
3. The elimination of primary settling facilities removed the problem of primary sludge and all its attendant treatment, disposal and odour problems.

In addition to this the settleability of the sludge improved and the sludge bulking or rising problem, experienced regularly in the Austin plant, was eliminated. Thus the plant designed for 6 MGD was operated at up to 9 MGD with BOD removal of over 90%. The true design capacity was raised to 14-16 MGD without addition of any aeration capacity. The average 1955 BOD loading was 144 lbs/day/1000 CF as compared with the average listed by Sawyer (3) of 35 lbs/day/1000 CF. Air required for the stabilization of 1 lb. $BOD_5$ was 665 cubic feet.

In 1959 Zablatzky, Cornish and Adams (4) experimented with the activated sludge plant at Little Ferry, Bergen County, New Jersey. In this case they made use of the Biosorption technique but left primary settling in the system. These investigators chose to call the process contact stabilization. Loadings on this plant were increased to over 100 lbs. BOD/day/1000 CF of aeration capacity and 300 lbs BOD/day/1000 CF of mixed liquor. The air requirements to satisfy 1 lb $BOD_5$ was between 900 and 1500 CF. The operators of this plant, were able to double its capacity to 56 MGD using largely process modifications.

In 1957 the name Biosorption had become a registered trade mark of the Infilco Co. and thus this process became known by a series of further names. As Weston (5) points out in 1961, the first process employing sludge reaeration and brief sewage sludge contact time that was developed in England in 1921 was known as bioflocculation and was protected by patent. Such a plant went into service in 1930. So biosorption, Bioflocculation, Contact Stabilization, Sludge reaeration and undoubtedly other names such as the Hatfield and Kraus processes, are all either the same or very subtle modifications of the same process. The latter two do have slightly more obvious differences but these still tend to be operating, rather than functional differences.

Table 1 is a summary (6) of Haseltine's data on a number of activated sludge plants utilizing a variety of process and design modifications. The figure which is most striking in the table, in the context of this paper, is the relationship between BOD loading and BOD removal. The contact stabilization (Extended Aeration in Haseltine's table) loading of 158 lbs BOD/day/1000 CF aeration tank volume indicates very small tanks and yet this same loading has a BOD removal of 93.4% associated with it. Also of significance is the fact that the air applied per lb. BOD removed is by far the lowest on the table.

Table 11 (6) shows a summary of the operating data of a large number of plants using different process modifications recorded over a number of years. Many sewage treatment plants have utilized sludge reaeration (7) as a step in their activated sludge modifications from 1917 onwards, and the percentage of the total aeration tank volume used for this purpose has ranged from 10% to 67%.

It can thus be seen that a very wide spectrum of possible modifications can be obtained by varying the operating parameters. The various names of the treatment processes are validated only by placing design limits on these variables. As described by Sawyer (8), there is a "Biological Piano" at our disposal for the treatment of waste water.

In order to more clearly lead in to the significant operating and design parameters it would first of all be pertinent to describe the contact stabilization process as it appears to the writer and thus how it relates to the remainder of this paper.

## PROCESS AND MECHANISMS

The contact stabilization process provides for a brief contact or mixing period between the incoming raw sewage and the activated sludge. The period of contact may vary operationally from 15 mins. to 1 hour without too significant a change in performance. The raw sewage should, prior to the contact tank, pass through screening, degritting and comminution processes.

The mixed liquor passes from the contact tank to the final settling tank where it is detained for a period of 1-2 hours. At this point the supernatant is of a sufficient degree of purity that it may be released for chlorination before subsequent discharge to the receiving body of water.

The sludge collected at the bottom of the final settling tank is pumped back to a sludge reaeration tank where this reduced quantity is aerated for a period of 4-6 hours. During this period the organisms release proteolytic enzymes to hydrolise the particulate nutrient matter adsorbed in the contact tank. The hydrolised matter is then synthesised to new cells and at the higher aeration periods quoted (6 hrs.) these cells enter the endogenous respiration phase and in fact reduce in mass of organic carbon. At the lower aeration period (4 hrs.) the syntheses is completed but no mass reduction is accomplished before the sludge is ready for renewed contact with the nutrient source (raw sewage).

It can readily be seen that the 15 minutes to 1 hour contact period provides insufficient time for the organisms to absorb and synthesise a large quantity of soluble material. It may thus be implied that a considerable amount of BOD must be removed in particulate form. This matter will be discussed in greater depth in the section following, dealing with parameters of operation and design.

If one were to take domestic sewage and mix it with activated sludge in an aerated vessel, then remove aliquots at intervals, allow it to settle and measure the BOD in the supernatant the resulting curve would approximate the one shown in Figure 1.

The very rapid drop taking place within a short period of time is due to the adsorption of particulates and the absorption of readily assimilable solubles. (x mg/l). The curve rises again to a peak a distance of z mg/l which simulates the solution of hydrolised particulates. The balance y mg/l represents the initial soluble BOD which was absorbed and synthesised in the early part of the process. The entire process may be visualised as three simultaneously occurring reactions indicated in Figure 2.

The reactions shown in figure 2 are postulated to agree with the net effect observed experimentally. It is known that the absorption phenomenon is considerably slower than adsorption but both reactions are likely to simulate a first order equation, such as $C/Co=e^{-kt}$, where C and Co are the concentrations at time t and at time zero, respectively of the material being absorbed and adsorbed. The hydrolysis reaction is dependant upon the adsorbed material and thus will be a second order or more probably a hybrid system. The arithmetic sum of these reactions produces the familiar sag curve.

It can be seen that if the adsorbed material is minimum or there is little particulate material in the waste then the reaction will follow the absorption curve. It should thus be evident that if we select a time of reaction of 1/2 hour then the percentage BOD removed will be less if the absorption reaction is dominant than if adsorption is the primary mechanism. This all leads to a conclusion that the ratio BOD soluble/BOD total is significant in the design of a contact stabilization process.

It is also important that the concentration of the sludge be considered. Regardless of which mechanism is dominant the larger the number of sites of reaction the more rapidly the reaction will proceed. So the mixed liquor suspended solids is as important parameter here as it is in all activated sludge processes.

Since the sludge is reaerated after separation to hydrolise, synthesise and stablize the removed BOD, the period of time required for aeration is also of great significance.

In summary we may therefore conclude that the parameters of operation and design requiring further study are as follows:

1. The effect of solubility of waste material upon treatment efficiency.

2. Optimum concentration of sludge.

3. Optimum time of reaeration.

4. BOD loading parameters.

5. Air requirements /lb. BOD stabilized.

   (a) Mixing air.
   (b) Sludge reaeration air.

6. Optimum time of contact related to solids concentration of return sludge.

There are without question other parameters of significance but it is felt that the above are the more important variables peculiar to the process of contact stabilization.

## EXPERIMENTAL PROCEDURES AND RESULTS

A series of batch studies were undertaken to determine a few of the optima referred to in the preceding section.

### (A) EFFECT OF SOLUBILITY

Synthetic waste water was made up consisting of standard BOD dilution water with mixtures of glucose and washed fish meal. These two carbon sources were added in such proportions as to maintain the same total $BOD_5$ but varied the ratio of BOD soluble to BOD total.

Activated sludge obtained from a municipal sewage treatment plant was concentrated by settling and siphoning the supernatant. This thickened sludge was aerated for 30 minutes then used to simulate the return sludge at a concentration of approximately 12,000 mg/l MLSS. In this section of the study an attempt was made to fix all possible variables with the exception of the one under study, thus varying the solubility index and holding constant the BOD, total air rate, mixing time, settling time, MLSS and "return sludge rate" (total mass of organisms).

Approximately 1500 Ml of thickened "return sludge" was aerated with 1500 ml of waste water for 30 minutes. It was then settled for 30 minutes and the supernatant was sampled for BOD remaining. Table III gives the results.

Figure 3 shows graphically the results of this brief study and indicates a significant trend increasing the reduction of BOD with a reducing solubility index. Further work utilizing a continuous reactor was reported on by Jones and Brown (7) substantiating these findings and extending on them.

### (B) OPTIMUM SOLIDS CONCENTRATION

A 10 litre sample of activated sludge was obtained from the Humber sewage treatment plant and concentrated four times by settling and removing the supernatant. The supernatant was stored in a refrigerator as was 10 litres of raw sewage. The 2.5 litres of thickened sludge were aerated to prevent septic conditions while the experiment proceeded. The sludge was then partitioned into four aliquots of 500 ml each. To the first aliquot was added 1.5 litres of supernatant (previously stored), to the second 1 litre, to the third 0.5 litre and to the fourth nothing. These sludges now represented a range of MLSS from the original value up to four times that concentration. From each sample was taken 500 ml of liquor and to this was added in each case 500 ml of raw sewage. These mixtures were then aerated for 30 minutes, allowed to settle for 30 minutes and their supernatant was sampled for BOD and solids. Figure 4 shows the results of this experiment and may be compared with the findings of the Austin Texas pilot study (2). A small side study accompanied this one and a 10 ml sample of Sabin polio vaccine was added to the raw sewage to determine if such viruses may be removed by the contact stabilization process. The results were evaluated by Dr. Donald MacLean at the Toronto Hospital for Sick Children and no decrease in viable viral units was observed as a result of this sewage treatment process.

### (C) FULL SCALE OPERATION

During this period of time a full scale contact stabilization plant was started up in Penetanguishene, Ontario. Results of performance have not been taken frequently, and the start up period is not a steady state condition on which to base conclusions. Table lV indicates the data gathered to date by the Ontario Water Resources Commission. One fact becomes quite obvious that during the start up period, normally fraught with all kinds of misadventure, this process showed itself to be very smooth and not subject to upset. It can be further seen from the data that the combined sewer system in the town produces a seasonal hydraulic overload to the plant which does not appear to have any serious detrimental effect upon its performance. Furthermore it can be seen from the data that inexperienced operation as evidenced by the widely fluctuating solids level, has had no serious effect upon performance. So far this process appears to be performing in the manner predicted by its proponents. In the coming year a more detailed study is proposed as this installation becomes a part of a National Sanitation Foundation full scale study on this process to fully evaluate all its advantages, disadvantages and relationship between design and operating parameters.

## GENERAL CONCLUSIONS

The evidence has existed for some time and is increasing daily to indicate that the contact stabilization modification of the activated sludge process lends itself well to the treatment of most municipal waste waters. It has considerable advantages in reducing the capital costs by eliminating primary settling tanks and also reduces the necessary aeration tank volumes by permitting a short detention period of the bulk of the sewage flow.

With these advantages we must also consider the disadvantages. The primary limitation which must be placed on this process is that it has a very limited ability to treat soluble organic matter. Thus the determination of soluble BOD is of considerable importance in evaluating the contact stabilization process for any given situation. A further difficulty which may prove limiting is the fact that some high strength carbohydrate (usually soluble also) wastes may generate a light fluffy floc which is difficult to settle. It has been shown here that an optimum MLSS concentration is 3500 mg/l or a little more. This concentration is somewhat higher than the 2000-2500 mg/l normally employed at conventional activated sludge plants. With this higher value a far more settleable sludge is required to quickly and efficiently separate solids from liquids in the final clarifier.

A very large proportion of the municipal waste waters generated in Canada and the U.S.A. are undoubtedly quite amenable to this form of treatment. With the current prospects of billions of dollars of capital outlay to solve the pollution problem, a more widespread use of this process, where applicable, would prove to be a significant saving of tax payers' money. There are a large number of municipal plants in Southern Ontario which are presently overloaded and furthermore not completely paid for. Under these circumstances the Municipality's industrial growth is prevented, thus cutting off the source of tax revenue necessary for the accelerated payment for the existing or enlarged sewage treatment facilities.

The contact stabilization process has demonstrated repeatedly that it can withstand shock loads both hydraulic and organic without becoming operationally upset. One further advantage which may be obtained from this process modication is that no primary sludge is generated. Primary sludge being comprised largely of putrescible organic solids is a constant source of problem both in its dewatering and in its disposal. The activated sludge which is generated in the contact stabilization process is easily digested under aerobic conditions and if care is exercised in the design, a minimum of sludge disposal is required. The aerobic sludge digester becomes a natural part of the contact stabilization process and provides a point in the system to take maximum advantage of the biological concentration of nutrients as described by Leven and Shapiro. As more and more attention is paid to the removal of inorganic nutrients, so we will have to seek suitable points in the process to remove these nutrients.

The aerobic digester forming a part of the contact stabilization process provides such a suitable tapping point. The nitrogen is oxidized to $NO_3^-$ and by operating controls the nitrate may be reduced to nitrogen gas. At the same time the phosphates concentrated in the cells will be released to the hydraulically small supernatant stream from which it can readily be precipitated as tri-calcium phosphate.

In summary we could say that the Contact Stabilization Process offers economy of first cost, economy and flexibility of operation and a minimum of skilled attention. However, it must be remembered that this process is not suitable for all waste waters.

## SPECIFIC RECOMMENDATIONS

1. To determine if a waste is amenable to treatment in this manner, the first steps of a biodegradability study (9) should be undertaken to ensure that adsorption removes a significant proportion of the BOD. A significant clue may be obtained by making soluble and total BOD determinations before the biodegradability study. This simple step will not, however, give the same assurance of success as will the study because a great deal depends upon material which comprises the soluble fraction of the BOD and how rapidly it is assimilated by the microbial cells.

2. The biological air requirements of this process amount to less than 1000 SCF per lb BOD destroyed. To determine how much less would require studies of a greater complexity than the savings might warrant. So it is suggested that blower and distribution capacity be provided for 1000 SCF per lb. BOD.

3. The concentration of MLSS should be maintained in excess of 3500 mg/l. The maximum concentration to which this may be allowed to go will depend upon the physical settling properties of the sludge generated and should be the subject of an operational study subsequently.

4. The optimum time of contact between the re-aerated sludge and the incoming waste varies considerably depending upon the waste to be treated. Results however may be expected to deteriorate if the time falls below 15 minutes or rises much above 45 minutes.

5. The sludge re-circulation rate will of course vary to provide the desirable concentration of MLSS. The sludge, however, should be re-aerated for a period of 4 to 6 hours at a concentration of 12-15,000 mg/l to permit proteolysis and synthesis to occur prior to contact.

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TABLE 1 - SUMMARY OF AERATION TANK OPERATION AT ACTIVATED SLUDGE PLANTS UTILIZ NG SLUDGE REAERATION

From: Haseltine (6)

| Time of Record | Sewage to Aerators | | | | Mixed Liquor to Clarifiers | | Return Sldg. | | BOD Applied (lb/day) | | Air Used (cf) | | Aera ion Per od (h ) | | Remove (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Mo | Quant (mgd) | SS (mg/l) | 5-Day BOD (mg/l) | SS (mg/l) | Sludge Density Index | Solids (%) | %Sewage Flow | Per 1,000 cf Aer Tank Vol. | Per 100# Sol Under Aer. | Per Gal | Per lb BOD Removed | M x L q | Sldg Reaeration | SS | BOD | $NO_3$-N in Ef (mg/l) |
| (a) HISTORICAL PLANTS | | | | | | | | | | | | | | | | | |
| Houston Tex. S. Side | | | | | | | | | | | | | | | | | |
| 31 | 9 | 4.47 | 235 | 178 | 1820 | 1.05 | 0.37 | 104. | 45.0 | 30.1 | 2.05 | 1760 | 2. 0 | 1.79 | 77.5 | 78.5 | 2.8 |
| Topeka, Kans. | | | | | | | | | | | | | | | | | |
| 37-38 | 11 | 5.6 | 106 | 176 | 1250 | 0.45 | 0.69 | 30.9 | 29.3 | 29.7 | 1.32 | 1050 | 5. | 4.2 | 78.3 | 85.7 | - |
| (b) EXTENDED REAERATION | | | | | | | | | | | | | | | | | |
| Austin Tex., A | | | | | | | | | | | | | | | | | |
| 55 | 12 | 7.70 | 226 | 307 | 1900 | 0.87 | 0.69 | 41.3 | 158 | 41.6 | 1.59 | 675 | 0. 2 | 5.70 | 92.1 | 93.4 | - |
| Salem, Ill. | | | | | | | | | | | | | | | | | |
| 58-59 | 13 | 0.75 | 96 | 166 | 5090 | 1.45 | 1.00 | 104 | 46.5 | 9.0 | 1.34 | 1000 | 0. 5 | 2.88 | 94.6 | 95.5 | - |
| (c) HATFIELD PROCESS | | | | | | | | | | | | | | | | | |
| Decatur Ill. | | | | | | | | | | | | | | | | | |
| 55 | 12 | 5.24 | 95 | 166 | 2410 | 1.82 | 1.51 | 17.6 | 43.5 | 11.0 | 0.98 | 878 | 3. 6 | 10.9 | 41.1 | 80.1 | - |
| Decatur, Ill. | | | | | | | | | | | | | | | | | |
| 58 | 11 | 5.73 | 120 | 169 | 2750 | - | 1.67 | 18.9 | 46.3 | 10.6 | 0.87 | 700 | 3. 8 | 9.76 | 77.8 | 88.5 | - |

TABLE I - SUMMARY OF AERATION TANK OPERATION AT ACTIVATED SLUDGE PLANTS UTILIZING SLUDGE REAERATION

From: Haseltine (6)

| Time of Record | | Sewage to Aerators | | | Mix Liquor to Clarifiers | | Return Sldg. | | BOD Applied (lb/day) | | Air Used (cf) | | Aeration Period (hr) | | Remove (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Mo | Quant (mgd) | SS (mg/l) | 5-Day BOD (mg/l) | SS (mg/l) | Sludge Density Index | Solids (%) | %Sewage Flow | Per 1,000 cf Aer Tank Vol. | Per 100# Sol Under Aer. | Per Gal | Per lb BOD Removed | Mix Liq | Sldg Reaeration | SS | BOD | $NO_3$-N in Ef (mg/l) |
| (d) <u>KRAUS PROCESS</u> | | | | | | | | | | | | | | | | | |
| Bellevile, Ill. | | | | | | | | | | | | | | | | | |
| 56 | 8 | 3.15 | 155 | 184 | 3500 | 1.47 | 0.97 | 68.1 | 32.2 | 10.3 | 2.19 | 1540 | 4.38 | 1.59* | 93.1 | 92.9 | - |
| Peoria, Ill. | | | | | | | | | | | | | | | | | |
| 56 | 12 | 19.1 | - | 200 | 4400 | 2.22 | 1.20 | 52.3 | 82.0 | 19.7 | 1.20 | 850 | 1.20 | 24.0* | - | 82.5 | - |
| (e) <u>STEP AERATION</u> | | | | | | | | | | | | | | | | | |
| Indianapolis, Ind. B | | | | | | | | | | | | | | | | | |
| 57-59 | 11 | 12.8 | 92 | 124 | 2120 | 0.88 | 0.49 | 91.9 | 33.4 | 18.9 | 1.13 | 1240 | ‡ | ‡ | 88.0 | 88.8 | 2.1 |
| N. Y. City Hunts Pk. | | | | | | | | | | | | | | | | | |
| 59 | 12 | 1100 | 76 | 74 | 730 | 0.00 | 0.29 | 24.0 | 35.8 | 49.1 | 0.47 | 910 | ‡ | ‡ | 80.5 | 83.8 | - |

* Period applies to only part of return sludge, balance receives no separate reaeration

‡ Periods indeterminate in step aeration plants.

TABLE II COMPARISON OF VARIOUS SLUDGE REAERATION PROCEDURES

From Haseltine (6)

| ITEM | OPERATION PROCESS | AVG | MEDIAN | HIGH QUARTILE | L W QUA TILE | MAX | MIN |
|---|---|---|---|---|---|---|---|
| Bod loading (lb/day/1,000 cu ft aer. tank vol.) | Ext. reaer. | 83.8 | 104 | 114 | 1.1 | 158 | 34.5 |
| | Hatfield | 45.7 | 46.3 | 46.4 | 4.2 | 49.9 | 42.5 |
| | Kraus | 59.5 | 57.1 | 86.2 | 5.2 | 90.4 | 32.2 |
| | Step aer. | 33.7 | 33.4 | 37.0 | 9.5 | 45.1 | 22.7 |
| BOD red. by act. sl. process alone (%) | Ext. Reaer. | 89.4 | 88.7 | 92.6 | 6.0 | 96.5 | 84.6 |
| | Hatfield | 84.0 | 84.4 | 84.1 | 2.6 | 88.5 | 80.1 |
| | Kraus | 87.2 | 86.2 | 92.2 | 3.3 | 92.9 | 82.5 |
| | Step aer. | 88.8 | 88.8 | 89.6 | 7.2 | 94.2 | 83.8 |
| BOD loading (lb/day/100 lb sol. under aeration) | Ext. reaer. | 28.3 | 30.2 | 35.5 | 2.5 | 41.6 | 9.0 |
| | Hatfield | 11.3 | 11.0 | 12.4 | 0.7 | 13.2 | 8.7 |
| | Kraus | 16.6 | 15.0 | 23.2 | 1.7 | 26.5 | 10.3 |
| | Step aer. | 25.7 | 21.5 | 26.5 | 8.5 | 49.1 | 10.2 |
| Air used (cu ft/lb BOD removed) | Ext. reaer. | 989 | 955 | 1010 | 23 | 1,430 | 675 |
| | Hatfield | 781 | 779 | 807 | 44 | 817 | 700 |
| | Kraus | 1160 | 1110 | 1200 | 040 | 1540 | 850 |
| | Step aer. | 1010 | 933 | 1080 | 11 | 1240 | 910 |
| Sludge density index | Ext. reaer. | 0.97 | 0.01 | 1.21 | 0.87 | 1.45 | 0.60 |
| | Hatfield | 1.61 | 1.61 | 1.76 | 1.49 | 1.82 | 1.43 |
| | Kraus | 1.56 | 1.64 | 1.89 | 1.47 | 2.22 | 1.05 |
| | Step aer. | 0.95 | 0.93 | 1.02 | 0.89 | 1.10 | 0.88 |
| Mixed liq. aeration period (hr) | Ext. reaer. | 1.04 | 0.65 | 1.94 | 0.52 | 2.18 | 0.42 |
| | Hatfield | 3.21 | 3.26 | 3.30 | 3.11 | 3.49 | 2.93 |
| | Kraus | 2.94 | 3.88 | 3.98 | 2.57 | 4.33 | 1.20 |
| Sludge reaeration period (hr) | Ext. reaer. | 4.20 | 4.35 | 5.27 | 4.73 | 5.70 | 1.60 |
| | Hatfield | 12.0 | 11.2 | 13.2 | 1 .0 | 14.4 | 9.76 |
| | Kraus | 18.0 | 17.5 | 21.9 | 1 .3 | 24.0 | 9.35 |

## TABLE III-EFFECT OF SOLUBILITY ON TREATMENT EFFICIENCY

| RUN NO | WASTE NO | INFL. Tot | BOD Sol | AVE Tot | * BOD Sol | BOD Sol. BOD Tot. | EFF. BOD Tot. | REDUCTION $BOD_T$ (mg/l) | % BOD REDUCTION |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 533 | 137 | 295 | 89 | .30 | 138 | 157 | 53.2 |
| | 2 | 535 | 232 | 296 | 136 | .46 | 171 | 125 | 42.2 |
| | 3 | 536 | 326 | 297 | 184 | .62 | 225 | 72 | 24.2 |
| 2 | 1 | 533 | 137 | 295 | 89 | .30 | 110 | 185 | 62.7 |
| | 2 | 535 | 232 | 296 | 136 | .46 | 154 | 142 | 48.0 |
| | 3 | 536 | 326 | 297 | 184 | .62 | 189 | 108 | 36.4 |
| | 4 | 538 | 421 | 298 | 231 | .78 | 227 | 71 | 23.8 |

* Ave BOD is calculated by averaging the sludge supernatant and the influent BOD thus allowing for dilution effect.

## TABLE IV OPERATING DATA FROM CONTACT STABILIZATION PLANT AT PENETANGUISHENE ONTARIO

**Design Capacity** 350,000 GPD  Max. rate of flow treated 1.01 MGD.
Average Cost of Operation $500/month

| Date | $\text{BOD}_5$ mg/l Influent | $\text{BOD}_5$ mg/l Effluent | SUSPENDED SOLIDS mg/l Influent | SUSPENDED SOLIDS mg/l Effluent | MLSS mg/l | REAERATION Susp. Solids mg/l | AV. FLOW MGD | HIGH FLOW MGD | LOW FLOW MGD |
|---|---|---|---|---|---|---|---|---|---|
| 9/19/66 | 140 | 17.0 | 162 | 17 | 4582 | 104 | 266 | .500 | .170 |
| 9/27/66 | 116 | 12.0 | 156 | 15 | - | 7786 | 346 | .500 | .200 |
| 10/5/66 | 72 | 13.0 | 74 | 12 | 5354 | 47 | 371 | .600 | .230 |
| 10/12/66 | 42 | 2.0 | 96 | 20 | 5608 | 126 | 569 | .780 | .330 |
| 10/24/66 | 275. | 2.8 | 382 | 12 | 7832 | 7822 | 350 | .550 | .220 |
| 10/31/66 | 140 | 1.6 | 516 | 13 | 6216 | 244 | 344 | .760 | .230 |
| 11/14/66 | 54. | 12.0 | 86 | 15 | 4752 | 12472 | 399 | .640 | .260 |
| 11/23/66 | 66. | 9.2 | 102 | 30 | 8516 | 11804 | 349 | .590 | .280 |
| 12/1/66 | 103 | 3.0 | 90 | 11 | 4970 | 16456 | 604 | .610 | .330 |
| 12/13/66 | 84. | - | 120 | - | 5454 | 14176 | 588 | .690 | .380 |
| 12/20/66 | 128. | 1.5 | 110 | 12 | 13922 | 7170 | 623 | .560 | .270 |
| 1/3/67 | 120. | 11.0 | 155 | 10 | 7370 | 14020 | 369 | .500 | .250 |
| 1/3/67 | 50. | 4.8 | 82 | 13 | 9458 | 19038 | 381 | .480 | .240 |
| 1/16/67 | 148. | 14.0 | 268 | 2 | 8498 | 14368 | 348 | .470 | .200 |
| 1/28/67 | 52. | 15.0 | 85 | 6 | 5880 | 13236 | 558 | .550 | .380 |
| 2/2/67 | 108. | 8.8 | 144 | 11 | 8396 | 13196 | 441 | .550 | .320 |
| 2/9/67 | 108. | 10.0 | 88 | 9 | 8194 | 15416 | 313 | .480 | .240 |
| 2/16/67 | 130 | 16.0 | 168 | 15 | 7214 | 10564 | 350 | .450 | .210 |
| 2/23/67 | 92 | 14.0 | 196 | 10 | 6024 | 11606 | 339 | .470 | .220 |
| 3/2/67 | 115. | 12.0 | 260 | 3 | 7964 | 12420 | 310 | .450 | .200 |
| 3/9/67 | 140 | 10.0 | 230 | 12 | 6300 | 12568 | 416 | .490 | .210 |
| 3/28/67 | 37 | 11.0 | 75 | 36 | 5846 | 9708 | 601 | .650 | .600 |

## TABLE V - COMPARISON OF LONG-PERIOD AVERAGE DATA FOR CONVENTIONAL AND SLUDGE REAERATION PLANTS

|  | PLANT TYPE | AVG | MEDIAN | HIGH QUARTILE | LOW QUARTILE | MAX | MIN |
|---|---|---|---|---|---|---|---|
| BOD Loading (lb/day/1,000 cu ft aer. tank vol) | Conv. (Table 1) | 26.7 | 24.9 | 34.0 | 1[illegible].2 | 52.0 | 13.7 |
|  | Reaer.(Table 11) | 57.0 | 43.0 | 77.3 | 3[illegible].7 | 158 | 22.7 |
| Mixed Liq. aeration period (hr) | Conv. (Table 1) | 6.36 | 6.1 | 7.79 | [illegible].05 | 9.27 | 3.3 |
|  | Reaer.(Table 11) | 2.49 | 2.152 | 3.68 | [illegible].66 | 5.79 | 0.42 |
| BOD red. by act. sl. process alone (%) | Conv. (Table 1) | 87.2 | 91.0 | 93.7 | 8[illegible].4 | 95.0 | 77.1 |
|  | Reaer.(Table 11) | 87.1 | 88.6 | 90.8 | 8[illegible].8 | 96.5 | 73.7 |
| BODloading (lb/day/100 lb sol. under aeration) | Conv. (Table 1) | 22.1 | 18.0 | 32.1 | 1[illegible].1 | 49.9 | 10.1 |
|  | Reaer.(Table 11) | 20.7 | 18.8 | 30.5 | 1[illegible].8 | 49.1 | 8.7 |
| Air used (cu ft/lb BOD removed) | Conv. (Table 1) | 812 | 773 | 905 | 7[illegible]0 | 1600 | 435 |
|  | Reaer.(Table 11) | 1010 | 955 | 1240 | 8[illegible]3 | 1540 | 675 |

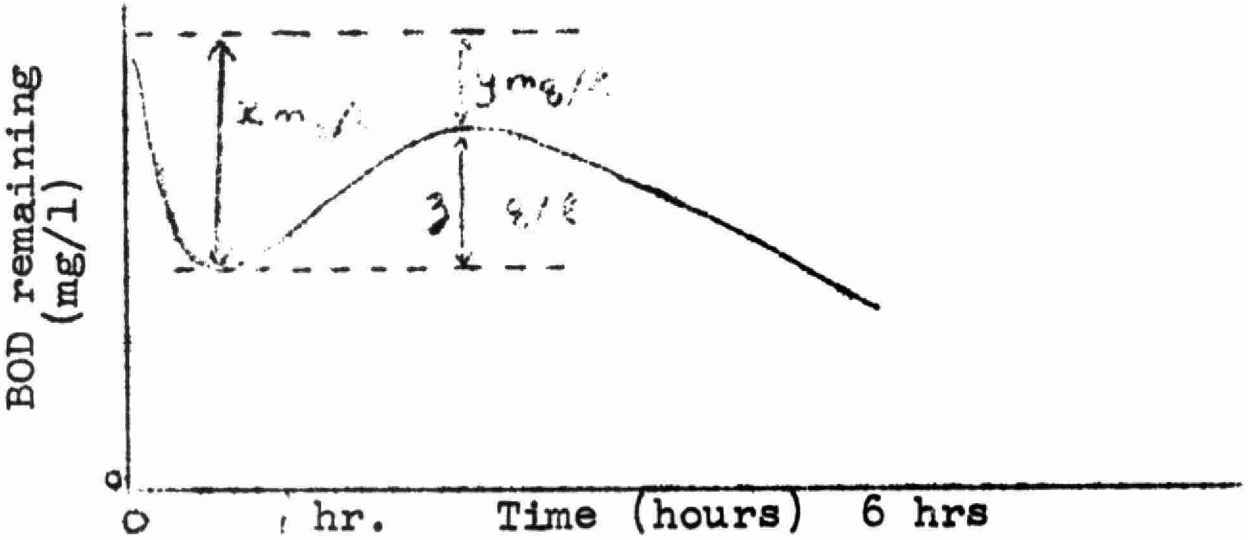

Figure 1 – *Bod Vs Time Response Curve.*

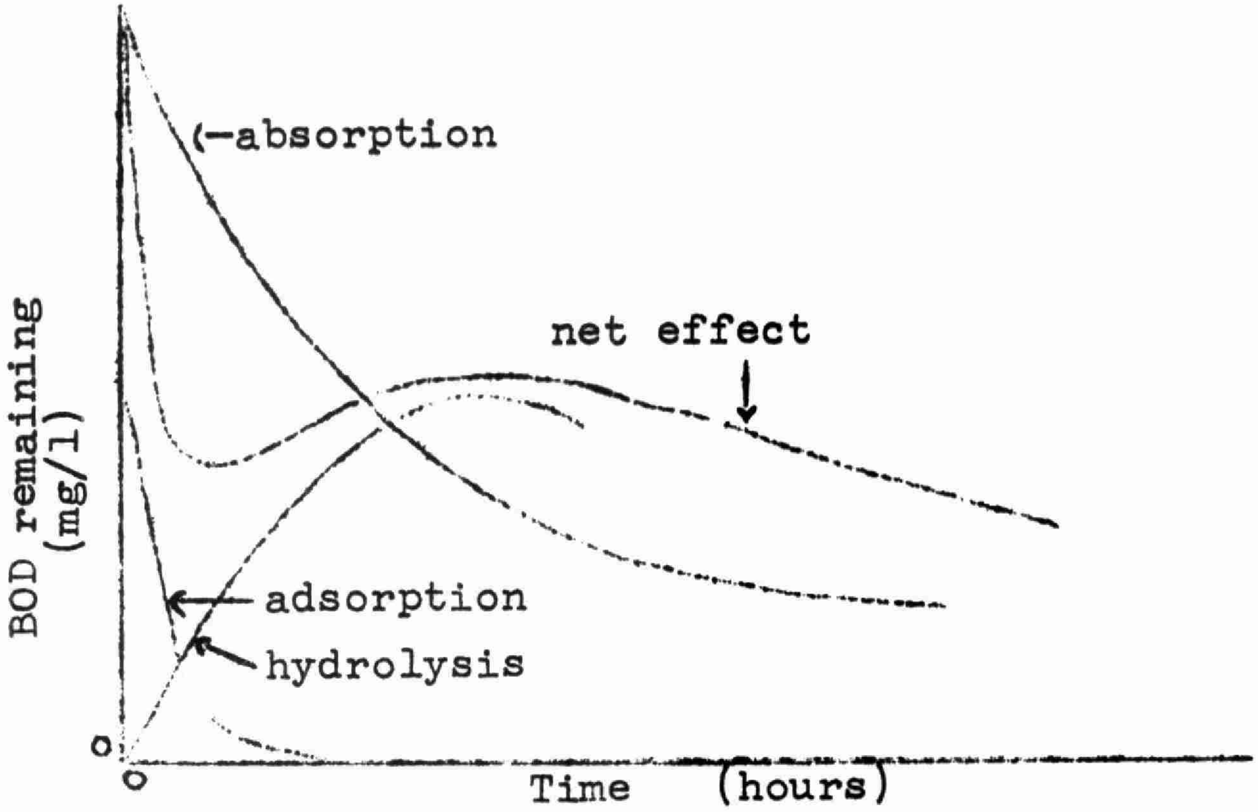

Figure 2 – *Postulated Construction of Bod Removal Mechanism.*

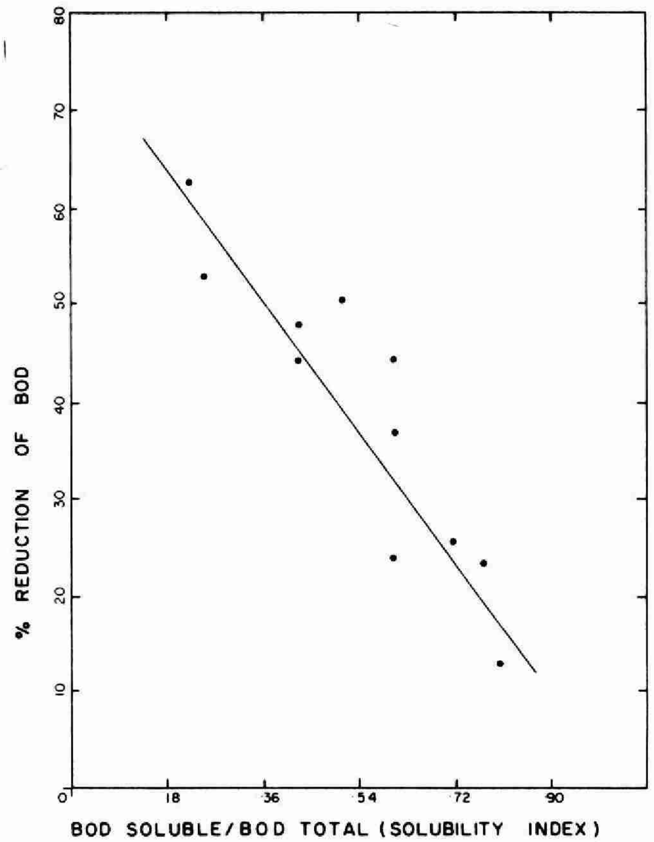

Figure 3 – *Effect of solubility on Bod Removal in contact stabilization process*

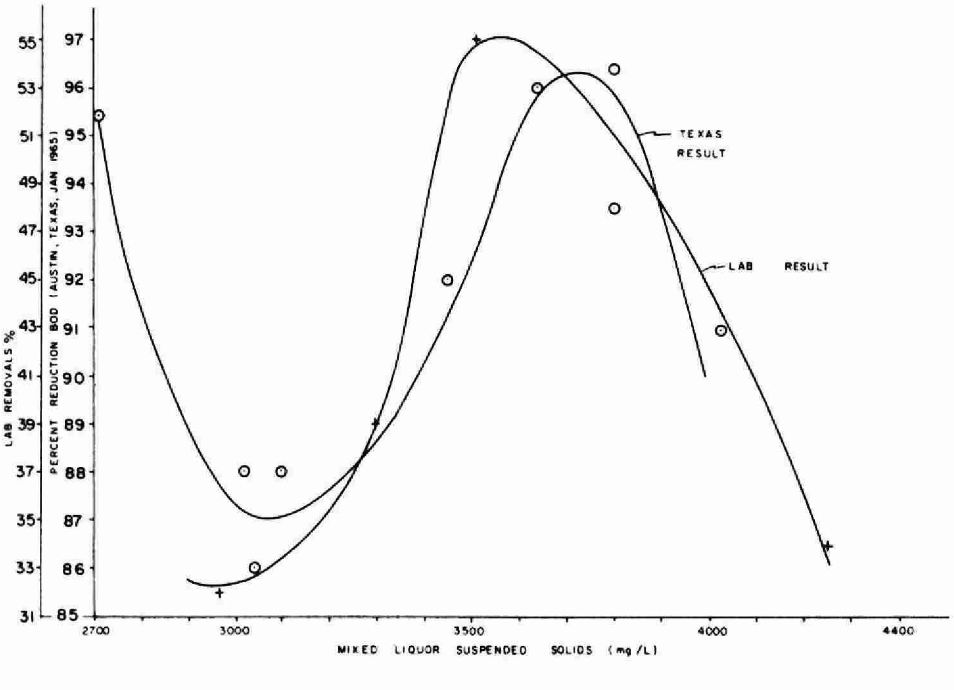

**Figure 4** – *Effect of MLSS on Bod Removal in contact stabilization process*

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