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Papers Presented at Fourth Ontario INDUSTRIAL WASTE Conference

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JUNE 9th, 10th, 11th, 12th
1957

Sponsored by
THE WATER AND POLLUTION ADVISORY COMMITTEE
OF THE
ONTARIO WATER RESOURCES COMMISSION

At the
Delawana Inn
Honey Harbour, Ontario

FOURTH ONTARIO INDUSTRIAL WASTE CONFERENCE

This brochure contains the papers presented at the Fourth Industrial Waste Conference held at Delawana Inn, Honey Harbour, Ontario, on June 9th, 10th, 11th and 12th, 1957. This Conference was sponsored by the Water and Pollution Advisory Committee for Ontario. The objective was the same as in previous conferences, namely, to focus attention on Industrial Waste problems and means for treatment of these. The papers are printed in the order in which they appeared on the program.

The Water and Pollution Advisory Committee functions in conjunction with the Ontario Water Resources Commission. This Committee takes the place of the former Pollution Control Board. The Ontario Water Resources Commission is concerned with both industrial pollution and domestic sewage. It is important that each of these sources of pollution be dealt with in an efficient manner if the pollution of streams is to be prevented. At this conference attention was directed to industrial wastes rather than to domestic sewage. The papers are prepared by those who have given much thought to the subjects they discussed. It is hoped that the publication of these papers will aid in the dissemination of knowledge on these subjects, and will prove helpful to those who are faced with the treatment and disposal of wastes.

The Water and Pollution Advisory Committee is grateful to all who contributed papers to this Fourth Industrial Waste Conference, and to those who assisted in any way in making the Conference possible.

For further information write to the Ontario Water Resources Commission, or to the Water and Pollution Advisory Committee, Parliament Buildings, Toronto.

WATER AND POLLUTION ADVISORY COMMITTEE

D.S. Caverly, Secretary.

Dr. A.E. Berry, Chairman

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HANDLING OF PEA STRAW WASTES

- by -

W. J. FORBES

Stokely Van Camp Co. Ltd.,
Whitby, Ont.

It is indeed an honor to be asked to present, at this your fourth Ontario Industrial Waste Conference, a few thoughts on the handling of Pea Straw Waste.

In the processing of peas a great many problems are encountered, but none approach in magnitude the problem of the disposal of the waste pea vines.

At the inception of the canning industry, when the harvesting of a pea crop was a manual or hand operated procedure, when picking out a site for the location of a pea viner, invariably the location desired would be one in the middle of the contracted acreage with a fall away from the ensilage stack, so that the effluent from the stack would seep into the ground or into a fast moving stream, anywhere to get rid of the offensive odor it would create. In those days small stations of one to four viners were the rule, to keep the distance from field to viner at a minimum for horse and wagon or tractor and wagon delivery, since the individual farmer was responsible for the harvesting of his crop. So that the volume of waste vines was small at any one location it did not present a major problem.

However, with the general acceptance of mechanical harvesting, these small viner units have disappeared, and the general trend is to large volume stations in units of fours, so that it is not unusual for stations of 12 to 16 viners to be strategically located in the centre of a much larger growing area. This has increased the waste disposal problem greatly to a point, where a new approach had to be taken to eliminate the unpleasant odors that the effluent created. The high sugar content of this effluent, also made an ideal spot for the breeding place of flies.

People, being what they are, are not inclined to change their method of doing things, especially waste materials, for which there is no financial return, until their hand is forced, either by public opinion or by some law enforcement agency.

So, the first approach to this problem, was to accumulate the effluent in a pit and pump it into a tank truck for distribution on pastures and summer fallow for its fertilizer value. It has been found that the quantity of effluent from a stack varied from 500 gallon to 2000 gallon per viner per 24 hour period, depending upon the season and the succulence of the vines being harvested. The fertilizer value has been computed to be approximately $8.00 per 1000 gallon of effluent, and tests have shown it to contain 4800 p.p.m. organic nitrogen. 3500 p.p.m. potassium and 1650 p.p.m. phosphate. Crop response to the application of this effluent, have been remarkable with increases in the yield of wheat up to 20 bushels per acre. So, what had been a necessary evil, by proper utilization, proved to be of value to our growers.

That, however, still left the pea stack, which, while having a high feed value for the winter feeding of livestock, still caused unpleasant odors during the curing period and letting out of the stack in the winter months. Accurate records of the cost of building the stack, removing the effluent and the cost of selling the ensilage in the winter, showed in most cases a net loss. Added to this, the stack is unsightly and a source of annoyance to the surrounding community, due to the unpleasant odors and breeding of flies.

In some locations the complaints assumed the proportions of it being a choice of either moving the viner station to some secluded area or of eliminating the stacking of vines completely. Because of the expense of moving a large station, the latter seemed the most feasible solution to the problem.

Last year, it was decided to experiment on this basis on an eight viner station, located on Highway #7 at Locust Hill. A farmer in the area was contacted and he undertook to remove the vines as it was being produced, to his farm some 18 miles distant for the winter feeding of beef cattle. The following are a few figures of the result of one year:

Acres harvested	375
Tons of ensilage handled	3200
Number of trucks requires	3
Cost of trucking and tractor loading	$4000.
Cost of ensilage del'd to farm per ton	$1.25

This particular farmer operates on a large scale and built 3 bunker silos, 45 feet wide by 70 feet long by 7½ feet high with concrete walls and floor, at an approximate cost of $1500. During the harvesting season, a fork lift tractor loaded the vines onto his trucks, which delivered the vines close to his silos. Another tractor distributed the vines to his silos and packed the vines for better curing. Because of the fact that only the top of the stack and the small ends were exposed to the air, very little wasting took place, only three or four inches in depth.

Cafeteria style self feeding was employed so the cattle would only feed to a width of about four feet at a time. When the first cut had completely been removed by the cattle, the barracade was moved in four feet for the second cut. During the winter months each animal consumed about 550 lbs. of ensilage per week or about 35¢ per week per animal. This feed was supplemented with hay and grain but by far the largest portion of the feed was the pea vine silage.

His experience of last year proved so profitable that he has agreed to increase the number of silos and is removing the vines from another station located at Whitby, where 10 viners are operated, and he has plans on feeding around 800 head of cattle next winter.

It is not always possible to locate a farmer who operates on this scale in every location. So at a 12-viner station at Little Britain this year, five farmers are co-operating on the removal of the vines. To assist all parties we have built accumulating conveyors which discharge directly on the trucks, which eliminate the extra handling of the vines by tractors.

Also, where the individual farmer does not wish to go to the expense of bunker silos, he may excavate pit silos, where the topography of his farm is such that it is practical to do so.

We feel that canners will profit in better public relations and be relieved of a source of complaint, as well as being financially ahead, if pea vines are handled in this manner.

SOME EXPERIENCES WITH SPRAY IRRIGATION

- by -

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Of the many attempts at methods of waste disposal, to date irrigation shows the greatest promise to the seasonal canner. If properly installed it avoids stream pollution and odor nuisance at a fraction of the cost of an adequate disposal plant. However, despite the simplicity of the mechanics of applying water, the concept of the interrelationship of soil type, crop husbandry and water utilization is often difficult to perceive and impossible to determine other than through experience. It is for this reason, therefore, that some provision must be made to gain some knowledge of the potential disposal capabilities of a given location beforehand. Unfortunately, little can be done regarding soil. However, one may alter the cover crop, with the objective of increasing infiltration and water utilization. At the same time the crop should be hardy enough to withstand the effects of the effluent.

FACTORS TO BE CONSIDERED IN IRRIGATION DESIGN

1. Nature of Waste & Source - Effluent & Silage Seepage

   a) Waste or effluent is the resultant water from washing, blanching and conveying of the product. It is non-toxic, containing 20-3500 ppm suspended solids, 240-6000 ppm 5-day BOD, resulting from carbohydrates, fats and proteins. When discharged into streams it undergoes bio-chemical oxidation which depletes oxygen and suffocates aquatic life.

   b) Silage seepage is much stronger waste. It burns vegetation, except at dilutions greater than around 1:40 with wash water or effluent.

   c) It may be desirable to segregate plant effluent to reduce volume, yet provide sufficient dilution to be safe to use on the crop. Silage seepage, unless diluted 1:40 or more, should be disposed of on fallow land.

2. Why Irrigation?

   a) Provides economical method to prevent pollution and eliminates odor nuisance.

   b) Reduction of BOD is often impractical or impossible.

3. Soil Requirements

a) Well drained, with high absorption characteristics, good infiltration, and percolation.

b) Topography - level, to prevent run-off, erosion and ponding, resulting in stagnation and odor.

c) Increasing the land area and use of cover crops will compensate for deficiency under a) and b). Soil encountered at Tecumseh is a heavy, poorly-drained Brookston clay which, although not being ideal, with a good cover crop surprisingly enough has a fair capacity for water disposal.

4. Cover Crop

a) Bare soil absorbs 10-15% of the waste that would be absorbed with a cover crop.

b) Mixture used at Tecumseh as recommended for local conditions of drainage, soil type and fertility:

Kentucky Fescue 31	-	8#
Kentucky Blue	-	3
Red Top	-	2
Orchard	-	5
Empire Birdsfoot	-	5
Ladino	-	1
		24# per acre

5. Disposal Field Capacity

Capacity of the Brookston clay soil with adequate cover varies from .25 to .5 inches per day per acre, based upon temperature, humidity, wind and rainfall: or, approximately 5500 to 11,000 gallons per acre per day. This soil type favors .25" per hour max. precipitation rate, with 1" maximum application per lateral setting. Different soils and state of crop growth will alter the optimum ppt. rate and application per lateral set. Over-application hinders plant functions, thereby reducing water utilization, hence should be avoided.

6. Irrigation System and Operation

Allowable rate of precipitation and amount of application per lateral setting are the limiting factors of design. A low rate of precipitation with a fine spray with sprinklers set at 2 feet above ground encourages evaporation which is desirable. On heavy soils a 40 x 60 spacing has given a little better results than a 60 x 70 or 60 x 60 spacing because of the greater uniformity of coverage when using a finer spray. Another practice which proved effective was the on-2-hour off-2-hour and on-2-hour or interrupted operation of the laterals per a given setting.

It is also desirable to maintain the pumping reservoir at no more than a 1-hour reserve, to prevent stagnation and odors.

An operating log giving the hours of operation by laterals set may be utilized to achieve better water distribution for it serves as a guide to the subsequent operator as to what areas have sufficient moisture and what areas are available for further watering. The use of a Tee-valve hydrant and sub-main for lateral connections is a feature that provides excellent versatility and maneuverability and should be incorporated in the design.

The following is a brief description of the sprinkling system employed at Tecumseh. The components are more or less typical. Size, however, would be dependent upon the designed capacity requirements. The effluent in this case is screened at the plant and then pumped over to the pumping reservoir, where it is handlod through the following component parts:

a) Pumping Reservoir

Pit, dug in the ground with 1:1 slope sides and 1 to 2 hours storage capacity.

b) Pump Suction

1. Steel barrel in bottom of pit in which the foot valve is inserted. Screens are welded into the sides of drum to allow water to enter yet exclude silt.

2. Foot valve to maintain prime.

3. 20-ft. of 3" tubing, with 2' set at 45° for foot valve.

4. 5-ft. of 3" suction hose with dresser coupling connections for flexibility.

c) Pump

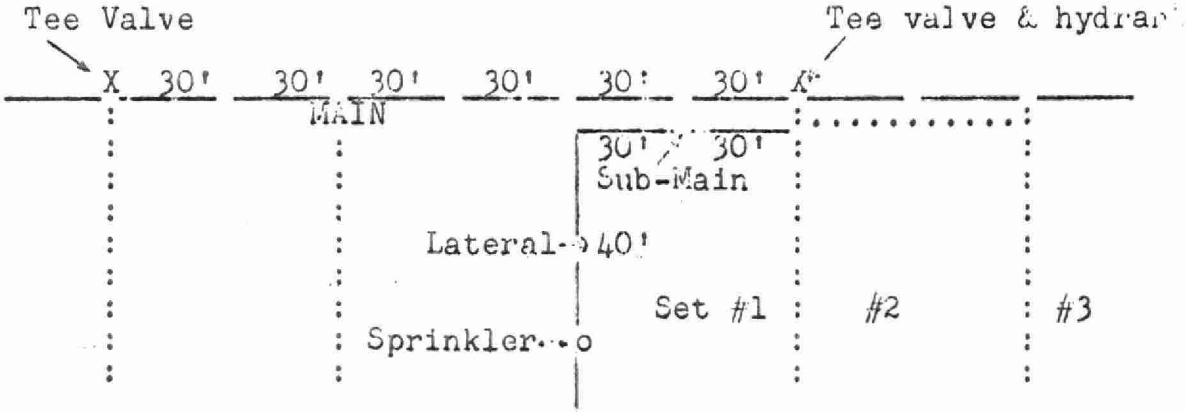
160 GPM @ 50 psi, with automatic primer. Also a drum of water connected to pump to facilitate priming.

d) Mains

4" x 30' main, with T-valves at 180'.

e) Sub-Main

Consisting of a hydrant, 2 only 4" x 30' tubing, 90° x 4" elbow, 4 x 3 reducer to connect to 3" lateral. This provides 3 lateral settings at each T-valve, or 180 ft.



f) Laterals

3" x 40' with 24" x 1" riser, a 1" x 3/4 PT reducer and 3/4 male rainbow sprinklers with 8 GPM orifices.

In conclusion, it is essential thattwo things be stressed in considering irrigation as a means of plant effluent disposal, namely the soil type and cover crop. These two factors are the very foundation upon which an irrigation program must be designed ., therein rests success or failure.

CURRENT TRENDS IN PLATING WASTE ABATEMENT

- by -

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The electroplating industry, particularly in Canada and the United States, England, and Germany, has long been aware of the necessity for waste abatement. The highly toxic nature of many plating-room effluents causes troubles that are almost unique among industrial waste problems. This has been recognized within the industry, and practical or applied research was initiated about fifty years ago (1, 2). Organized attacks on fundamental or basic problems of plating waste abatement are more recent. The program of the American Electroplaters' Society is ten years old this year, and other groups such as the British Water Pollution Research Laboratory have been conducting research in this field for about as long.

Reduction of Waste

The most conspicuous trend or emphasis in plating-room waste abatement, in recent years, has been the reduction or elimination of waste within the plating room itself, This trend is not confined to the metal-finishing industry, but is generally typical of all process industries. In my opinion, this emphasis on waste reduction will not only continue into the future, but will increase. The elimination of a waste at its source, it removes the necessity of treating or otherwise processing the waste for disposal.

This present-day trend toward waste reduction ties in closely with the great need for water conservation. Available water supplies in most regions are probably not actually dwindling, but they appear to be because of the ever increasing demands for water by industry, municipalities, agriculture, and recreational interests. The elimination of an industrial waste frequently implies the conservation of an equivalent volume of water, hence these two desirable policies directly complement each other,

The electroplating industry, like many other wet-process industries, must use considerable quantities of water; yet no part of this water is sold in the final product. All water purchased or pumped by the industry, or by any single plating shop in the industry, must be disposed of as waste.

If metal-finishing procees water can be utilized twice instead of once in its passage through the plant, the raw water purchase cost is halved and the cost of disposal is also reduced.

Similarly, if smaller quantities of water can be employed for a given job, economies in both purchase and disposal are realized. These accomplishments must, of course, be obtained without significant sacrifice in product quality. This limitation makes the achievement difficult, but far from impossible. Other possibilities for water and chemical conservation will occur to an engineer studying electroplating wastes; these techniques for in-plant waste reduction will comprise the principal portion of my discussion.

Engineering Design -- Waste Disposal

Of four broad approaches to plating-room waste abatement, my first topic is engineering design. The factors I shall discuss here are best built into a plating plant in its original layout, design, and construction. They can be added to an existing plant, although usually at greater cost than if provided originally. Even if this greater cost is necessary, the engineering improvements may be well worth while.

In any wet-process industry -- and electroplating is no exception -- multiple sewer systems present many advantages. Cost is, however, an opposing factor, and must be balanced carefully against the merits of separate sewers. Each plant is different, and must be studied as an individual problem. Let us consider the hypothetical -- and very unrealistic -- plant where cost is not an object. What sewer lines are desirable under these Utopian conditions? I shall answer this question, and then relinquish the problem to you, as design engineers for your particular plants, to decide how much my idealized layout must be modified to meet the demands of practical economics.

I would like to have one sewer for the sole purpose of collecting and transporting clean water, used but not polluted. This line will carry storm water from the plant area, plus uncontaminated cooling waters. Cooling systems are needed in several types of plating process, and the used cooling water is warm but not otherwise polluted. These wastes can be discharged freely to a drain or stream or sewer. I would prefer to recover them for re-use in the plant, but this topic comes later in my talk.

My idealized plant (in which cost is not being considered) will have a second sewer line to carry contaminated process wastes. These will include used rinse waters; discarded solutions like cleaning solutions, pickles, bright dips, and occasionally (but rarely, I hope) a spoiled plating bath; spills; drippings; floor washings; and tank wash waters from plant cleaning operations. In a plating plant, this sewer might have to be constructed in duplicate; one line for acid wastes and one for alkaline. Cyanide wastes should not be permitted to mix with acids, for obvious reasons; hence the necessary duplication of process-waste sewers.

The third type of sewer line in my ideal plant will carry sanitary wastes, from toilets, wash rooms, drinking fountains, and the like. Obviously these should not enter the clean-water line. They should be segregated also from the process wastes, since each interferes with treatment and disposal of the other.

In addition to these three -- or four -- main types of sewers, I would like to add a number of special-purpose waste lines. This multiplicity of pipes may sound ridiculous to the old-time plater, who was accustomed to dumping all waste liquids into a common sewer with no regard for stream pollution or the operation of his municipal sewage treatment plant. Under certain conditions, of course, it would be ridiculous; a small, carefully operated plating shop in a large industrial community may often be permitted to discharge all its wastes into the city sewer. In large plants, however, and in rural areas, the more complicated sewer layout is not only necessary but is often justified economically. Several such plants have been built during the past few years.

These special-purpose waste lines that I speak of should preferably be called "recovery" lines. A number of plants find it desirable to collect separately such effluents as rinses from copper, nickel, and chromium plating, and to salvage the metal and water content of these wastes, by ion exchange, evaporation, or other techniques. It is essential, for such recovery, that the rinses be kept separate, and not contaminated by the addition of other wastes. Metal recovery from a mixed plant waste is practically impossible, and certainly not economical. Transport lines for these individual liquids are not usually gravity-flow sewers; instead, the spent rinses are picked up by pumps from small sumps located close to the plating tanks, and are conveyed through pipes, often overhead, to the recovery area.

I have listed for you a considerable number of sewer lines that I would like to see installed in an ideal plating plant. Several large plants actually use as many as I have suggested, and find it definitely advantageous to them. In other plating shops, especially in small plants, several of these can be omitted because the economic factors are different. In any new plant or plant undergoing modification, all should be considered and the decisions should be based on practical economics.

Another factor of engineering design that directly affects waste disposal is the process of waste equalization. Stream pollution problems and problems of sewage plant operation are more often caused by uneven or peak flows than by the uniform discharge of plating wastes. Acclimatization of stream life or of treatment-plant microorganisms may be possible if toxic wastes are discharged slowly and steadily, but the "slugging" of wastes can upset the entire biological system, often for a long period of time. The plater has both types of discharge: relatively weak and uniform wastes in his continuously flowing rinses, and slugs of concentrated wastes in his periodic or irregular dumpings of spent or spoiled solutions, and during clean-up periods. Good engineering design, even in a plant already built, can reduce the suddenness and the severity of shock discharges. Proper plant operation is even more important (and will be discussed later), but plant design is also a major factor. The technique of equalization is simple, although there is opportunity for many modifications in its application. Basically, a holding tank is incorporated into the waste line, in order to provide time for the dilution of peak concentrations by the weaker wastes which precede and follow them. Mixing is essential, and may be caused by proper baffling of the natural flow, or by mechanical means. The time of detention is a matter of engineering calculation and judgment. A 24-hour lagoon should provide adequate equalization for any situation; space for this, however, is rarely available, and the designer must be content with far less. Even a 15-minute equalization period, in wastes as subject to fluctuation as plating-room effluents, is worthy of consideration, and the designer should take advantage of whatever facilities he can find or invent.

Engineering Design -- Water Use

The waste disposal system itself is not the only opportunity for pollution abatement by the design engineer. He can also contribute by a study of water usage. In this study, the waste abatement engineer may appear to conflict with the plater, because the latter will not hesitate to demand large quantities of high-purity water in order to ensure the quality of his plated product. There should be no compromise on product quality, but the water requirements to achieve quality can often be greatly reduced. Let us consider what the design engineer can do toward this end; and why he should be concerned.

Except for their final discharge to a receiving stream or to a sewer, all wastes should be kept in as concentrated a form as possible at all times. At the ultimate plant outfall, dilution is desirable; but at any prior point, as long as there is any prospect of salvage or any plan for treatment of the waste, the maximum possible concentration should be maintained. Both salvage and treatment are more effective and more economical with high-strength wastes. This implies that waste cooling waters and other diluents should not be mixed with a waste stream that is to undergo processing; it means, further, that the waste itself should originate, within the manufacturing process, in as concentrated a form as possible. The economical use of process water is an important factor in attaining the latter goal.

Most plating-machine operators, and even some plating-room foremen, cannot tolerate a partly open valve. Rinse tanks, therefore, run at full flow and full overflow, even though a few gallons per minute might do just as satisfactory a job of rinsing. This practice results in an expensive loss of water and, of greater importance to our discussion, it makes more difficult the task of waste recovery or waste treatment. It is not sufficient to tell the plant people that wasteful usage of water is undesirable.

It is possible, however, for the plant engineer to insert restrictions in the water line to prevent flows greater than the necessary rate. I recommend this practice, but I caution you on two counts: do not make the orifice or other restriction so small that it clogs and diminishes the flow too far; and do make provision for rapid filling of the tank after clean-outs and other dumpings.

Some plating plants have solved the problem of keeping rinse flows to a minimum by using a control valve on the input line, and regulating this valve by conductivity or similar measurements on the rinse water. This technique, when it can be employed, provides a controlled-volume rinse that is fully automatic.

Another engineering technique that serves to minimize rinse flows is the use of spray rinses directed at the plated work. As the work is lifted from the rinse tank, it passes through a fine jet or fog of fresh rinse water. This provides countercurrent rinsing, and is far more effective than simple dip-rinsing in a tank of water. The spray serves also to maintain the tank full of water, and does so more efficiently than a large-volume input pipe or hose. A further refinement of spray or fog rinsing is timing the spray so it operates only when plated work is being lifted through the spray zone. This permits really effective rinsing with minimum water volume. Such rinses have even been employed directly over plating tanks, provided that evaporation of liquid from the tank is sufficient to prevent overflow.

One further example of engineering design as a means of reducing waste, and also of salvaging valuable plating chemicals, is the provision of adequate drainage time for plated parts or parts in process. As much time as possible should be allowed for drainage and dripping back into the process tank, in order that this liquid may be salvaged instead of being transferred to the rinse water and to waste. The time required for drainage depends principally on the shape and size of the plated work, and is affected by solution viscosity. A minimum drainage time of 15 seconds has been suggested; a longer period is often desirable.

Some plants have installed air blasts or air "wipers" to remove excess liquid from plated parts as they are drawn up out of the process solutions. This is not such a powerful blast that it scatters solution all over the surrounding area, but is a gentle blowing that serves to dislodge and recover hanging droplets. The air blast technique is not adaptable to some shapes and sizes of plated ware, but performs an excellent job on others. I have seen it used in the continuous plating of wire, which is perhaps an ideal set-up for this operation.

Process Changes

I have spent a large portion of my allotted time on engineering design as a factor in plating waste abatement because it offers many opportunities for large benefits. This is particularly true when the design precedes plant construction, although several of the principles listed are applicable also in an existing plant. However, there are other factors, in addition to design, that can contribute much to in-process reduction of wastes. Many of these changes can be adapted to plating shops after construction, and even during operation. First, I would like to consider modifications in the actual plating processes.

Platers have continuously sought, through their research organizations, for new types of plating solutions and new techniques or processes of electrodeposition. The usual goals have been an improved plated product or a more economical production procedure. Another goal, lesser but nevertheless recognized, is curtailment of water pollution. Some researches have been directed specifically toward that end.

A major contention between platers and those whose principal thought is anti-pollution has long been the cyanide question. The very toxic cyanide chemicals have always been essential to some of our most important plating processes. The plater would like to stop using cyanides, just as all of us would like to have him do so, but he cannot. There is no effective replacement.

You may tell me that copper, for example, which is commonly deposited from a cyanide solution, can also be plated from a copper sulfate bath that contains no cyanide. This is true, and large tonnages of sulfate-electroplated copper (as well as electrorefined copper) are produced commercially. But the two types of copper plate, sulfate versus cyanide, are vastly different in their metallurgy, their physical properties, and their uses. It is a rare application that can utilize the two types of copper deposit without distinction. Accordingly, sulfate copper is not often a replacement for cyanide copper, and the cyanide waste problem cannot be appreciably reduced by this means.

Other copper solutions than the sulfate hold more promise for a decrease in cyanide usage. Phosphates, organic amines, and many other copper compounds are currently being studied, and some have reached full-scale application. Most of these have been developed by individual companies, including suppliers, and so are either secret or proprietory in nature; this, in addition to higher material expense, increases the cost of such processes for the general user. For this reason, together with technical difficulties, we do not expect that the substitution of another type of solution will solve the cyanide problem in the near future. I am sure, however, that some platers, probably in small rural shops, have adopted non-cyanide plating solutions with the principal purpose of eliminating stream pollution.

As far as the metal ions are concerned, there is little hope of relieving the waste problem by process change. Many of the commonly plated metals are about equally toxic, so there is little gain in substituting one for another. Furthermore, each metal is used by the plater because it performs a specific duty and is the best for that purpose when all factors are considered. Substitutions were in use during the war, because of metal shortages, but no one was happy with them, and I do not recall that the waste problem was alleviated in any instance. All in all, I can offer little hope for progress through this type of process change. I would have devoted less time to it, except that in earlier talks and papers, referring to other industries, I have emphasized process change as a possible technique for waste abatement.

In non-plating processes used by the plating industry, such as metal cleaning prior to plating, substitute processes occasionally have merit. In the closely related iron and steel industry, for example, waste abatement benefits as well as product improvements have resulted from sodium hydride descaling as an alternate technique for acid pickling. The hydride process has been adopted by several mills, and largely eliminates the waste problem of spent pickle liquor. This process can also be used in the cleaning of metal parts prior to electroplating.

The plating industry uses a number of finishing treatments, such as bright dips, that may cause pollution troubles from acids and other constituents. Occasionally in this field there is room for improvement by substituting less objectionable chemicals for those usually employed.

A different type of process change involves redesign of the part being plated, or of the method of racking the parts for plating. Consideration should be given to possible changes in shape or position, to permit better drainage of solutions after processing, and correspondingly reduced carryover of process solutions into the rinse tanks. Sometimes very minor design changes can result in great improvements, both in waste reduction and in process economy. A classical example of this was the redesign of an automobile bumper, locating a bolt hole so it served also as a drainage hole, which permitted recovery of about a pint of full-strength plating solution per bumper plated.

Salvage and Recovery

In the plating of precious metals, like platinum, gold and silver, waste recovery has been practised for years. With the more common metals, which are plated in much larger volume, this has not been true. Recently, however, for a number of different reasons, a definite trend toward the salvage of materials has been evident. These reasons include: increased knowledge of recovery processes, savings due to metals and metal salts salvaged, improved economy in water consumption, and, of very real and practical importance, abatement of pollution.

I have already pointed out that wastes which are to be processed for salvage and recovery should be kept separate from all other wastes. Let me re-emphasize this fact. It is practically impossible, and certainly not economical, to salvage nickel, for example, from a mixed waste of nickel, copper, and chromium. The further incorporation of floor sweepings and sanitary sewage complicates the picture even further.

By proper design and operation of the rinsing step, most of the chemicals lost from plating tanks by drag-out on the plated work can be salvaged and re-used. A still rinse or standing rinse should be provided for the first dip after each plating step; for example, after chromium plating. In theory, this rinse will gradually increase in concentration until (at infinite time) it is equal to the plating solution. In practice, this standing rinse water is transferred into the plating tank as rapidly as possible, to make up for evaporation and other losses. The chromic acid or other plating chemicals are thereby salvaged, with an obvious economic advantage as well as the benefit that they are kept out of the waste stream. As liquid is removed from these save-rinse tanks, it is replaced with fresh water or, better, with overflow water from the rinse tank next in series.

Evaporation techniques are being employed at a number of plants for the concentration and recovery of plating rinse waters. This is particularly desirable when vaporization losses from the plating solution are not large, and only small quantities of make-up water can be used. Multiple rinse tanks with countercurrent flow provide an overflow liquor of reasonable concentration for charging to an evaporator. The partially evaporated or concentrated product can be returned to the plating tanks, to furnish make-up of both water and plating chemicals. Some plants have encountered opposition from their plating foremen to such returned liquors, but the fact that no difficulties were experienced, plus the obvious economic advantages, soon overcame this dissent.

Chromium rinses were probably the first type of plating waste to be reclaimed by evaporation. Glass-lined equipment is generally used; this is expensive, but the salvaged materials rapidly amortize the original investment. More recently, evaporation has been used to concentrate rinses from nickel plating and from the cyanide plating of copper, zinc, and cadmium. Vacuum evaporators are commonly used and multiple-effect evaporation is often important economically, because it needs no softening or other treatment before re-use. Condensate from chromium rinse evaporation may contain a small content of chromate ion, resulting from carry-over in the evaporator; this is not high enough to interfere with its re-use for rinsing. In at least one plant, such condensate has been utilized for boiler make-up, where the chromate serves as corrosion inhibitor.

Use of ion-exchange techniques for the recovery of plating chemicals from rinses is becoming wide-spread in the United States. Copper and nickel salts are salvaged by this method in many plants. Ion exchange was formerly not suitable for treating chromate solutions because these oxidized and destroyed the ion-exchange resins. Recent research has resulted in chromate-resistant resins, so chromate recovery and concentration is now possible. Furthermore, such resins can be used to remove unwanted contaminating ions from chromate solutions, permitting longer use of the chromates, as in anodizing. Ion exchange has been investigated for cyanide recovery, but this is not yet successful on a commercial scale. The principal problems are poisoning and clogging of the resin bed, precipitation of metals within the bed from metallocyanide complexes, and the fundamental fact that hydrocyanic acid is a weakly ionized material.

It is only fair to point out that the capital investment required for plating waste recovery may be greater than the corresponding cost of a plant for treatment by destruction of the waste. However, it is equally important to mention the financial benefits that are realized in operating costs, due to credit for re-usable plating chemicals and water. In many installations, the original cost has been paid off rapidly by these savings.

Occasionally some constituent of a waste stream can be recovered as a by-product, even though it cannot be salvaged for re-use in the process. Contamination by mixed wastes may prohibit re-use, but need not prevent reclamation in some other form. For example, several companies have considered treating chromate wastes with barium hydroxide or other barium salt to precipitate barium chromate. This material is a valuable yellow pigment, used in the paint and ink industries. I do not believe that sales to pigment companies have been accomplished, but this is the type of by-product recovery that merits further study.

Other industries sometimes reduce their waste problems by re-using spent chemicals for some down-graded application in the process. The petroleum industry, as an example, uses and re-uses caustic soda for several different purposes before it is discarded. I cannot think of any good opportunities for this practice in the plating industry, but I hope further study will be given to it. Perhaps some of the stronger spent acids such as pickles and bright dips can be used for weak acid dips after caustic cleaning; although contamination by unwanted metal ions is a dangerous possibility. At the least, waste acids and alkalies can be employed to neutralize each other before discharge.

Water, of course, can be re-used several times in the plating shop, even without intermediate purification. Used cooling water, for example, has no contamination except an increase in heat content, and the higher temperature may be an advantage if the water is used for rinsing. Countercurrent flow of rinse water through a series of tanks has obvious advantages, and has been mentioned previously.

Good Housekeeping

My last topic, good housekeeping, has less romantic appeal -- less glamor -- than methods for waste reduction already discussed: engineering design, process alterations, and the recovery of materials and by-products. To the uninitiated, good housekeeping may even sound somewhat sissified. To the experienced industrial man, this is not so; since he recognizes the complexities as well as the simple factors of good housekeeping, and the very tangible benefits realized from its practice. The food and drug manufacturers maintain and boast of their housekeeping activities for sanitary objectives; platers and other industries have not this same incentive, but should take pride in a neat and clean plant as a part of their good-neighbor policy in the community.

Good housekeeping in any company involves all of the company's employees. There are problems in plant operation, in engineering, and in administration. Without group effort, the goal is unattainable.

Typical of poor housekeeping in the plating-room is the spilling of process solutions, so they enter the waste stream. The old-time plater considered spills an inevitable part of plating work; modern industry will not tolerate them. I do not mean to say that spills no longer occur -- we have not reached that Utopia -- but spills are regarded as mistakes; mistakes, if foreseeable, can be prevented; and if a mistake or a spill does occur, because no one could or did foresee it, there is certainly no excuse for a second error. One helpful practice, long used in the petroleum and chemical industries and now becoming common in plating, is the construction of curbs or dikes around possible spill areas to prevent the escape of process liquids.

Common causes of spills in the plating room include tipping of small tanks, breakage of bottles and other fragile containers, slopping of liquids during transport, and overflowing of process vessels. All of these, and of other un-named causes, are avoidable. The process and design engineers have a part of the responsibility: they can plan tanks that will not tip, choose container materials that resist breakage, plan piping and pumping systems to get rid of manual transportation of chemicals, and install float valves or alarm systems to prevent overflows. The operator has his part, much of which is obvious. No engineer can design a safety system which will resist forever the persistent attack of fools and ingenious operators. Plating-room foremen and others of the administrative staff have their task in everlastingly keeping themselves and everyone else on their toes to prevent spills and other accidents. This is largely a job of persuasion, as the modern plant operator, with his independent attitude, does not take kindly to orders unless he understands the reasons behind them.

Another example of poor housekeeping is persistent dripping and leaking. Drips and leaks are bound to occur, but they should be corrected promptly, and in as permanent a manner as possible. It is the maintenance department's job to make the repairs, but it is the duty of the machine operator and of all other people to report the faults as soon as they are observed. Routine inspection and maintenance of known trouble-spots is a good idea, especially because it may correct trouble before it actually occurs; but this does not eliminate the responsibility of all to keep a constant lookout for leaks.

Dripping from work in process, as it passes between tanks, can usually be overcome by drip pans spanning the region between tanks and pitched to return collected liquid to the tank from which it came. Dripping may also occur from tank ventilation systems, particularly from gassy plating process that cause a heavy mist of droplets to form over the solution. It is easy to say that proper design of the ventilating system and air ducts will prevent such drips; it is better to be prepared for small inadequacies in the design and to collect or correct the dripping if and when it occurs.

Leaks can occur at many points -- all bad. Packing glands of pump and agitator shafts are bound to leak at times, and can be cared for by a regular routine of preventive maintenance. Corrosion, erosion, temperature changes, and other effects can cause leaks at many points in the process liquid system. These cannot always be anticipated, and only constant surveillance will keep them to a minimum.

I have spoken of the desirability of maintaining a clean plant; this implies the necessity for occasional clean-up operations. The cleaning process may itself be a major source of industrial waste and a cause of stream pollution unless it is properly planned and controlled. Floor washing, and cleaning of the outsides of tanks can be done frequently enough and at such staggered intervals that pollution from these sources is usually minor. If a waste treatment plant, even an equalizing basin, is available, these wash waters should of course pass through it. A greater problem arises from periodic -- perhaps semi-annual -- cleaning of the insides of plating and process tanks, including the removal of dirt, sludges, scale, corrosion products, and plated parts that have fallen into the tanks.

A recommended technique for cleaning plating tanks involves pumping the complete contents, including movable sludge and such wash water as is necessary, to a temporary holding tank of adequate capacity. This liquid is allowed to settle while the plating tank receives a thorough cleaning, including scraping, removal of heavy sludge, and any other operations that are needed. The settled liquid is then pumped back to the plating tank, usually through a filter to remove solids that escaped settling. Addition of a small amount of plating chemicals may be required, to make up for dilution caused by the wash water. Sludge and liquid remaining in the holding tank can be processed more leisurely, by one or another recovery technique or, if necessary, by treatment to destroy it as waste.

Treatment and Disposal

I promised earlier that I would devote most of my talk to the in-plant and in-process reduction of plating-room wastes, and I have done so. To some degree, this is the viewpoint of the chemical engineer, in contrast to that of the sanitary engineer, who is primarily concerned with discharge of the wastes and their effect on streams and on other wastes. I do not wish to belabor this distinction, however, since it is largely artificial. But let me, before I close, spend a few minutes on the treatment and disposal of plating wastes.

Knowledge regarding the treatment or destruction of electroplating wastes continues to advance steadily each year. There have been no spectacular changes in commercial practice in recent years; present techniques perform an adequate duty, although at some expense. Chlorination remains the most common process for destroying cyanides; it is best conducted in the absence of unnecessary metals, especially nickel. This can be done only by segregating cyanide wastes within the manufacturing plant — a desirable practice for other reasons as well. Research studies on cyanide oxidation by means of ozone or by biological treatment have shown promise, but widespread adoption of these methods on a commercial scale is for the future. Metal salts that cannot be salvaged economically are commonly removed from the waste stream by precipitation with alkali; this procedure has been used for years. Chromate wastes from chromium plating and anodizing, if not recoverable, can be chemically reduced and precipitated.

Municipal sewer authorities show greater willingness to tolerate plating-room waste in sewage than they did a few years ago. This may be in part a growing acceptance of industry as a partner in the community, and recognition of inudstry's tax payments as a major factor in municipal economics.

Metal-finishing wastes intended for disposal to city sewers must continue to be regarded with respect and perhaps suspicion. Their toxicity may affect the secondary treatment of sewage, the digestion of sewage sludge, or the receiving stream at the sewage plant outfall. Adequate dilution at all points in highly important; this is most readily accomplished if waste reduction is practiced in the manufacturing process, and if pretreatment by equalization and neutralization is provided before discharge into the sewers.

Disposal of plating wastes directly to natural waterways is even more critical than when dilution by sewage is possible. Toxicity is again the important criterion, and adequate dilution must be provided under rigorously controlled conditions. Rural plants, which have no choice except discharge to a water-course, must generally employ extreme measures for in-plant elimination, and must then follow up with a treatment plant to destroy those wastes that cannot be prevented.

Conclusion

Treatment operations and final disposal of metal-finishing wastes both emphasize the importance of eliminating or at least reducing the wastes at their points of origin. In-plant waste abatement aids both the economics and the efficiency of treatment and disposal steps. It is also an aid to overall plant economy, since reduction in waste means reduction in operating costs. My intended emphasis that industry as a whole is giving to pollution abatement, are both on waste reduction by means of proper engineering design and water usage, process changes if these are possible, salvage and recovery of useful constituents in waste streams, good plant housekeeping, and all other possible improvements in the manufacturing plant.

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TASTE PRODUCING SUBSTANCES IN WATER

- by -

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Estimates based on "population equivalents" (1) rate industrial wastes as responsible for more than twice as much stream pollution in the U.S. as municipal sewage discharges. It has been further estimated that between 1950 and 1975 population will increase by about one third and industrial production will double. Estimates by chemical industry (2) of future expansion make these statements on industrial growth seem highly conservative. Production increase will obviously be accompanied by increasing use of water.

The future growth of water use is likely to occur in a framework of shrinking availability of surface water. Supplementary irrigation in areas which formerly depended solely on rainfall is increasing rapidly. This consumption of water occurs during dry summer periods, when most streams have their lowest flow of the year, and it has been estimated (3) that it can use the entire flow of many streams, even if only a small fraction of 1% of the land in a watershed is irrigated.

Municipal use of water is increasing faster than population. Thus, the average urban dweller now uses 150 gallons of water daily, whereas 30 years ago he used only 20 gallons (4). Recreational use of water is harder to assess, but both increased leisure time and increased income are causing the public to demand more water resources for recreation.

Requirements for discharge of wastes to surface waters will, of necessity, become increasingly critical, and one of the most critical items is likely to be the taste and odor imparted to water by organic materials in wastes. In 1948 there were 422 water plants in the U.S. serving communities having populations in excess of 25,000; 133 of these communities with a population of about 14,000,000 included some provision for taste and odor control in their water plants (5). In 1954, there were 570 water plants serving communities having populations in excess of 25,000; 201 of these plants serving about 34,000,000 people included facilities for taste and odor control (6). This well defined trend in water plant facilities and practise clearly indicated the rapidly increasing pressures and costs borne by water plants because of impairment of raw water quality by odorous material.

The total taste and odor problem has many facets. A severe and sustained drought forced Dallas, Texas to supplement a normally adequate municipal water source with unsuitably salty water. The same drought caused Chanute, Kansas to fall back on treated sewage effluents as a raw water supply in order to keep water in its faucets. The tainting of fish flesh by chemicals in surface waters is another type of taste and odor problem. In streams and lakes the biological synthesis of chemicals causing taste and odor is becoming more important because of man-caused increases in stream fertility. These are all matters for serious concern. This discussion will, however, limit itself largely to consideration of chemical impairment of water quality for municipal or industrial use.

Sources of Tastes and Odors

Odors may be attributed to chemical materials produced by biological growths and to the presence of organic pollutants or other objectionable matter naturally present in the water. The distinction is not clear-cut as the introduction of a polutant may greatly stimulate the growth of objectionable organisms. Chemical oxidation of carbonaceous material increases the supply of carbon dioxide, which stimulates organic growth. Nitrogen and phosphorus from sewage also stimulate the growth of photosynthetic organisms.

Incredibly small amounts of many odorous materials can cause sensory stimulation. Experiments in the SEC laboratories have frequently yielded a detectable odor from recovered materials in concentrations of 2 parts per billion and less. Sometimes materials have been isolated (but unfortunately not identified) which could be detected by odor in concentrations as low as 10 parts per trillion. Very substantial odors, therefore, can be caused by extremely minute amounts of such material. In terms of quantities that are easier to visualize, a single teaspoonful of pollutant can impart odor to 1 million gals. of water.

Utilizing adsorption and extraction techniques for concentrating the odorous organic pollutants of drinking-water supplies, it has been found that neutral compounds are usually the most abundant odorous organic pollutants. These neutral organic materials usually have intense tastes and odors. The second most abundant group of odorous materials is usually the organic acids, which also have intense odors and tastes. Small quantities of other materials have been recovered, including organic bases (which may have a tobacco-like odor), water-soluble compounds (which frequently have caramel-like odors), and a group usually referred to as the "weak acids", which include phenolic compounds, if they are present in the water.

Phenolic compounds are present infrequently and have probably been over-emphasized because they are one of the few materials detectable by analytical techniques generally available in water plant laboratories. Before chlorination, commonly occurring phenolic materials have but little taste or odor. Ordinary chorination of these materials greatly increases the taste and odor; free residual chlorination destroys the odor.

Characteristics of Tastes and Odors

Odors are subject to seasonal cycles. Industrial pollutants show reasonably well-defined patterns of behavior and may be divided into two general categories, depending upon whether they are susceptible or resistant to biological destruction during transportation in surface waters.

1. With pollutants subject to biological destruction, odor intensity is likely to reach a peak during the winter months. Unless the water plant is immediately adjacent to the source of pollution, the peak winter odor intensity is likely to occur when the river undergoes a moderate rise, especially after a period of low water. This is caused by a combination of scouring of bottom deposits and more efficient transportation of dissolved materials. Although the rise in the river increases the amount of dilution water, the reduction in the time of travel between the source of pollution and the point of water consumption is likely to result in an over-all increase in the amount of odor-producing material reaching the water plant inlet. Where a river freezes over solidly and perhaps becomes anaerobic in certain area, maximum odor loads may occur during low-flow periods in the winter.

2. Some pollutants are resistant to destruction during transportation in surface waters. (Fortunately, few odorous materials of industrial origin are in this group.) When a water source is polluted by such materials, maximum odor difficulty or other disturbance may accompany any low-flow period.

Algal blooms or spurts of microbiological growth frequently have a definite seasonal incidence and can be expected at reasonably well-defined periods at each locality. Local and regional experience is the best guide available and should be fully explored

Sometimes algal growth and industrial pollution may take turns as the dominant nuisance in a particular situation. In one water plant studied, phenol from a nearby refinery is present throughout the year, and there is usually a very definite chlorophenolic taste in the water. At certain times of the year, however, algal blooms cause tastes and odors of such intensity that the phenol odors are not noticed.

The river flush-out is sometimes the cause of acute taste and odor problems as well as other stream disorders. For example, it was recently observed (7) that organic wastes from a refinery were not transported by the receiving stream and apparently were subject to bottom storage with very imcomplete self-purification. Periodic river rises flushed out the bottom deposits. In our experience some of the most severe water quality problems have been frequently associated with the first river rise after a long, dry spell with the accompanying flush-out of pollutional material retained in bottom deposits. It is believed that such incidents are sometimes wrongly attributed to industrial spillage or dumping.

The taste and odor of a raw water presents a problem at the water plant which must be faced on several fronts. These include the following considerations:

1) The water must be made palatable and acceptable to almost the entire using population.

2) Surface supplies must be disinfected to give water of satisfactory bacteriological quality.

3) The cost of high quality water must be compatible with the ability of the community and its industrial comsumers of "city" water to pay for the water.

The control of water quality by water treatment has been discussed recently by Ettinger and Middleton (8) and presentation of this material is beyond the scope of the present discussion. It is appropriate, however, to discuss simple approaches to the evaluation of the odor-producing potential of organic wastes. To do this intelligently it is necessary to take at least nominal cognizance of the nature of water treatment procedures currently in use.

Water supplies taken from surface sources subject to pollution almost invariably are chlorinated and the taste and odor of the water after chlorination become important factors. Chlorine frequently reacts with organic material to develop or decrease odor. When this occurs the odor intensity will vary with the amount of chlorine added. Schematic presentation of this pattern of behavior is shown in Figure 1. The reactions occurring between chlorine and waste components are sometimes influenced by dilution. Since water treatment plants cannot handle extremely polluted water such as an industrial waste stream, the organic waste under consideration should be suitably diluted to concentration levels approximating those handled by a severely loaded water plant. Chlorine reactions produce acid, making it desirable to buffer the solution being chlorinated with sodium bicarbonate, thus simulating the bicarbonates which buffer natural waters. In large water distribution systems, a long period elapses between the time water leaves the treatment plant and the time it reaches the most distant consumer. Odors which develop in a water distribution system as the result of slow reactions between residual chlorine and organic contaminants must be given due consideration.

Odor is necessarily a subjective quantity, amenable to measurement and interpretation only in terms of people. This requires that odor test procedures and their interpretation be bases on the characteristics of the reactions of people to odors Figure 2 shows a log-probability chart of the variation in the amount of a specific chemical, n-butyl alcohol, required to give a detectable odor in a series of 785 tests made by 33 water-plant operators over a five-month period. This chart leads rather simply to certain interpretations. In reaction to the n-butyl alcohol, the most sensitive five per cent of the population is at least seventeen times as sensitive as the least sensitive five per cent. The "fifty-per cent" man, or median observer, has less than one-quarter the sensitivity of the most sensitive five per cent, and is more than four times as sensitive as the least sensitive five per cent of the population.

Obviously, any attempt at quantitative appraisal of odor requires a large random group of observers, or a panel of several people selected because they show at least reasonably good capacity for odor detection in general. The most meaningful value with a small panel is the panel median T.O. Use of the "median" prevents one unusually dull or unusually sensitive observer from throwing the panel results too far one way or another. If a mean is used it should be the geometric mean.

There is no real advantage in attempts to characterize odor-strength too precisely. In the laboratories of the Sanitary Engineering Center we do not attempt to differentiate between odor intensities of solutions that differ by a concentration factor of less than two.

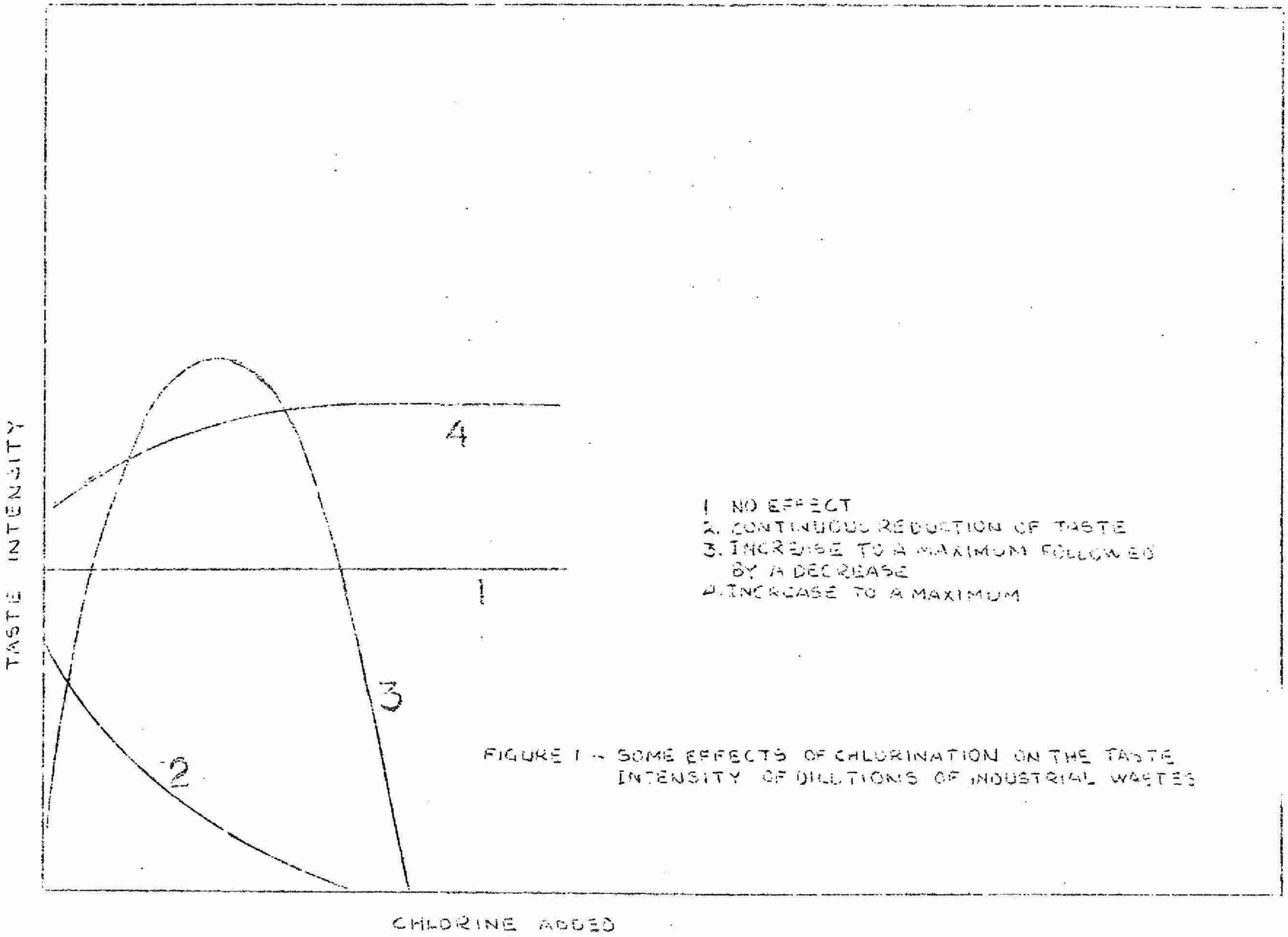

FIGURE 1 - SOME EFFECTS OF CHLORINATION ON THE TASTE INTENSITY OF DILUTIONS OF INDUSTRIAL WASTES

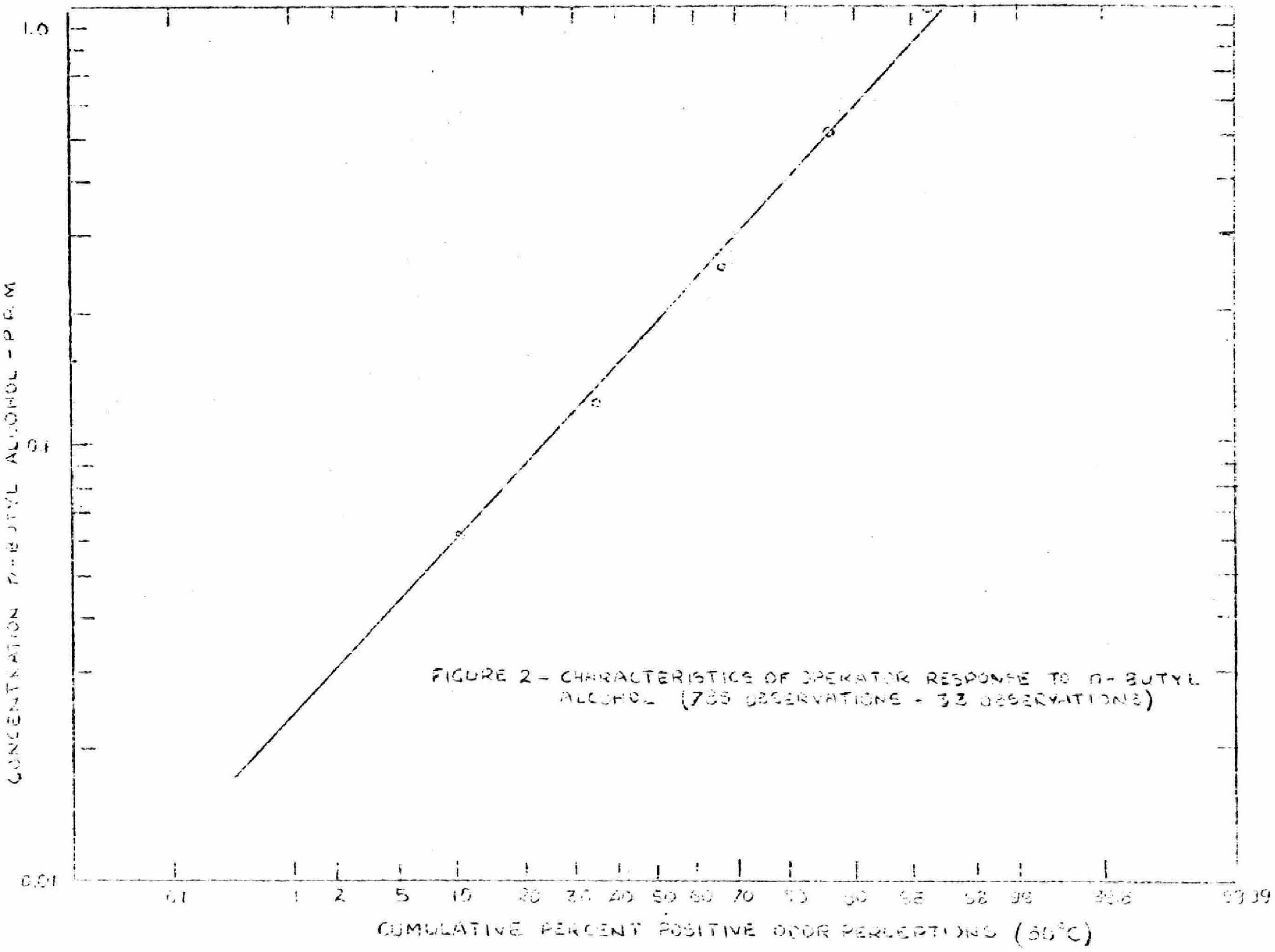

FIGURE 2 - CHARACTERISTICS OF OPERATOR RESPONSE TO n-BUTYL ALCOHOL (785 OBSERVATIONS - 33 OBSERVATIONS)

Observers have further characteristics which require consideration in a prescribed test procedure. They tend to lose sensitivity when asked to detect a trace of a material after exposure to a gross quantity of the same material. Because observers are suggestible, it is difficult to secure an impartial judgment without asking the observer to discriminate between unknowns and a blank. Fatigue and boredom combine to make observers less sensitive and more erratic during prolonged odor observations. Further details of our ideas on odor and taste-testing protocol have been described elsewhere (9) and need not be repeated here.

Another facet of the problem of assaying the odor-producing potential of wastes lies in the question of whether or not odors are additive. To over-simplify, assume (1) a chemical plant has only two odorous plant waste streams, one of which contains only an organic alcohol, and a second which contains only a pyridine base; (2) that the total plant stream enters a body of water in which neither compound will be sufficiently concentrated to give a detectable concentration on the basis of concentration in the waste stream.

Questions to be answered are:

a) Are the waste streams unimportant in terms of stream odors since they will be present below threshold concentration?

b) Can both waste streams together give the stream an odor increase if neither one can do it alone?

Assuming that chemical reactions are not involved, the answer to the questions above lie in the determination of whether odors stimuli by unrelated individual materials are additive and/or synergistic or whether they are non-additive and/or antagonistic.

If it be assumed that the threshold concentration of material A is "a" and the threshold concentration of material B is "b" the question posed by the statement:

$$\frac{a}{2} + \frac{b}{2} \gtreqless \mathrm{TOC}$$

where TOC is the threshold odor concentration.

Investigation of this question is just getting well under way in the SEC laboratories. So far we have measured human response to odor stimuli by combinations of two and three specific chemicals at a time, but only a limited number of chemicals have been investigated. To date our findings give the answer:

$$\frac{a}{2} + \frac{b}{2} \geqq \mathrm{TOC}$$

We have little reason to believe that this finding will not hold up in most circumstances and it represents the best basis presently available for considering the questions involved. In words, the mathematical notations say that human sensory response to individual odorous chemicals in a mixture is at least additive and that it may be greater than an additive response.

Accepting this premise, the questions listed previously can now be answered.

a) The hypothetical waste streams suggested previously are important to stream odor quality because they join with other materials to increase the total odor load even though the waste streams individually will not add a threshold concentration of the chemicals they contain.

b) Even though waste streams are unlike in odor or chemical structure and do not react, the two streams can jointly impart detectable odor to the receiving stream even though neither one can do it alone.

The additive or even synergistic character of odor stimuli is important in approaching such complicated situations as those presented by the boundary waters. Few plants can be charged with contributing enough organic material to give detectable taste and odor to 175,000 sec.ft. of water. Each waste source must, however, be regarded as a definite contributor to total impairment of odor quality.

CONCLUSIONS

The evident trend in the taste and odor quality of raw water is downward. Estimates of stream pollution in terms of population equivalents show an ever-upward trend. Taste and odor loads may be expected to increase more rapidly than loads in terms of "population equivalents" because of many factors, some of which have already been discussed.

Subject to relief by self-purification in streams, organic pollutants of surface waters present an additive assault on water quality, and each tangible organic source is a factor in determining the odor of the resulting water.

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PROGRESS REPORT ON THE BIO OXIDATION OF PHENOLIC AND 2,4-D WASTE WATERS

- by -

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The economic and satisfactory disposal of our phenolic and 2,4-D waste waters is one of the major problems in waste disposal facing our Company today. As high as 99.9% of the phenolic bodies in these wastes must be destroyed before it can be discharged to the receiving stream.

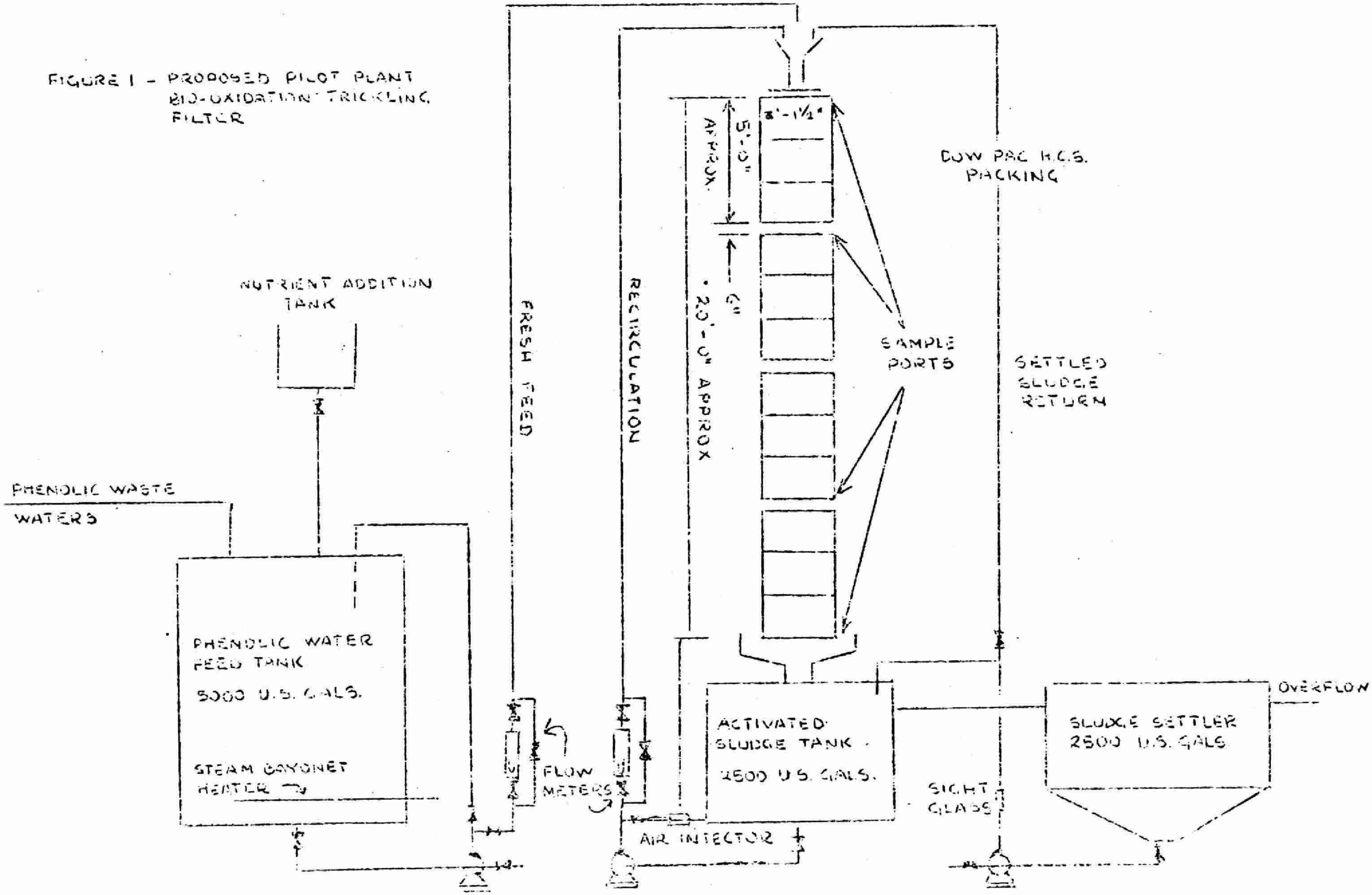
In a paper presented at this conference last year (1) our past and present methods of treating our phenolic and 2,4-D waste waters were discussed. Since it is our intention to reduce the high cost of treating these wastes and to do away with the present practice of discharging the treated waste to closed pits the biological oxidation process has been chosen for study as a future method of treatment. Preliminary laboratory work had indicated that our plant phenolic and 2,4-D waste waters could be treated in this manner. This data, along with the flow diagram of the proposed pilot plant trickling filter, Figure 1, were also given in last year's paper.

The plant phenolic waste water consists of a liquid waste containing phenol (carbolic acid) from several plant processes. The 2,4-D waste water is from the 2,4-dichlorophenoxyacetic (2,4-D) acid process and has a composition as shown on Table I. This waste contains primarily dichlorophenol. The information recorded in this report discusses the difference in these two "phenolic" compounds with regard to their oxidation on biological slimes.

This work has been carried on in collaboration with the Dow Chemical Company. Their Dowpac HCS has been used as the packing media for the tower of the pilot plant trickling filter. The packing in this experimental unit is interrupted for sampling purposes at three intermediate positions. The bulk properties of the packing media (2) and tower size are as follows:

DIMENSION	DOWPAC HCS
Tower area, ft.^{2}	9.5
Tower Height, ft.	20
Packing surface area, ft.^{2}	5100
Void Space, %	94
Unit Dimensions, in.	37½" x 37½" x 21"
Units	12
Surface area, ft.^{2}/ft.^{3}	25
Unit Weight, lb./ft.^{3}	3.8

FIGURE I - PROPOSED PILOT PLANT BIO-OXIDATION TRICKLING FILTER



PILOT PLANT OPERATION - PHENOLIC WASTE

The installation of the pilot plant trickling filter was completed by Sept./56. The filter was seeded with activated sludge from the Spring Valley Sewage plant at Kitchener, Ontario. The plant phenolic waste water was applied to the filter but it did not respond and "take off" as it should have done. The actual cause was not discovered until nearly the end of December when it was learned that the air injector was not functioning as it should, due to its location relative to the activated sludge tank. The controls, including the air injector had been installed inside the building to which the filter was attached to provide convenience of operations. As a result of this, there was little or no agitation within the activated sludge tank with the result that the sludge settled to the bottom of the tank and became septic. For this reason the data obtained during the first four months operation was not reliable.

During this initial period of operation, however, several modifications were made in the flow diagram in Figure 1 to improve the operation of the filter.

The tower of the trickling filter was initially covered with styron 475 plastic sheeting. Three sides of the tower were later covered with 1/4" plywood to withstand the occasional high winds. The side facing the bldg. was not covered. To further prevent heat loss within the filter the sampling ports and most of the bottom of the tower were closed in as well.

During the installation of the trickling filter there were no steam coils installed in the activated sludge tank. It was originally thought that hot coils in this tank would inactivate the sludge. Steam tracing and insulation were put around the outside of the activated sludge tank and the cone part of the sludge settler.

The steam tracing, however, proved to be inadequate. The only means of controlling the temperature was by heating the phenolic feed water. An attempt was made to manually control the temperature of the filter at about 80°f. by controlling the temperature of the incoming feed water. Depending on the atmospheric temperature, the feed water temperature varied from 100 to 160°F. By this procedure the operating temperature of the filter was maintained between 70 and 90°F. During this peri of time the main recirculation pump had occasionally failed for undetermined reason. This failure left only the hot strong phenolic feed water being applied to the packing. To avoid this unfavorable condition, a pressure operated alarm system was installed on the pump to indicate the moment of pump failure. This corrected the difficulty since there was always an operator within hearing distance who could quickly reset the pump switch. To overcome these problems and to provide better temperature control a steam bayonet heater and temperature controller were installed in the activated sludge tank. This installation provided adequate temperature control and did not appear to have a noticeable affect on the sludge in this tank. In addition, this installation permitted the feed water to be applied to the top of the tower at a much lower temperature. At the same time all steam return lines were diverted to the waste water neutralization tank to prevent freezing in this tank during the winter.

During the installation of the bayonet heater in the activated sludge tank it became apparent that there was a large volume of settled sludge in the tank as a result of insufficient agitation as has already been mentioned. This difficulty was immediately overcome by placing a 1/2" air line across the bottom of the tank. The air line provided much more agitation and aeration than was required and it was thought that over aeration might occur bringing about the oxidation of the sludge in this tank. For this reason the air line was later replaced by the air injector which provided a rolling action to the contents of the activated sludge tank. With the installation of the air injector it was found that lime and sludge began to build up on the bayonet heater, thus, reducing the heat transfer and it was found necessary to institute a program of daily bayonet scraping.

Following the installation of the bayonet heater, the settled sludge was flushed from the system and a program of study of the bio-oxidation of 2,4-D waste water decided upon.

PILOT PLANT OPERATION - 2,4-D WASTE

Treatment of Diluted 2,4-D Waste Water

The first 4 months operation on plant phenolic waste water had been without success mainly due to insufficient agitation in the activated sludge tank. Since the successful treatment of 2,4-D waste water was our main concern it was decided to immediately begin studies on the bio-oxidation of 2,4-D waste water. Therefore, on Jan.3/57, the filter was agin seeded with activated sludge and 2,4-D waste water applied to the top of the tower from the 5000 gal. feed tank in a batch-wise operation. To prepare this feed about 420 U.S. gallons of the 2,4-D waste water were neutralized in the 1000 U.S. gal. neutralization tank with 30% aqua ammonia. Phosphate in the form of di-sodium phosphate was added and the waste water pumped to the feed tank where it was diluted about 10 times with water. The flow rate of the diluted waste water to the top of the tower was set at 4.0 I.G.M. The recirculation flow rate was set at 20 I.G.M. Therefore, the total volumetric flow rate to the top of the tower was 24 I.G.M. or 159 M.G.A.D. higher flow rates tended to wash the slime from the packing. For this reason the hydraulic loading remained at the 24 I.G.M. rate throughout the entire study. Since the biological process is dependent on the intimate contact of the applied waste with the biological slimes on the packing media and on the transfer of organic material contained in the applied waste to these slimes the level of hydraulic loading is an important consideration in this work. It is generally recognized that filter efficiency varies directly with filter depth and inversely with hydraulic loading (3). Since this was a batch operation the flow rate tended to drop as the level in the 5000 gal. tank decreased. For this reason the flow rate was adjusted every hour although the actual daily flow amounted to only 3.0 - 3.5 I.G.M. instead of 4.0 I.G.M. When the waste water in the feed tank decreased to a predetermined level the flow to the top of the tower was shut off and another batch of waste water prepared on the heel of the previous batch remaining in the tank.

After one week of operation on this feed it was apparent that a rapid sludge build-up on the packing was not taking place. Since it had been calculated, from work done by the Dow Chemical Co. (2) that the biological slime on the surface area of this volume of packing was capable of oxidizing 25 lbs. of phenol per day it was decided to apply a synthetic phenol waste water to the filter for a short period of time to check its operation and to obtain, if possible, a rapid build-up on the packing. Accordingly, a synthetic phenol waste water containing nitrogen and phosphorous was applied to the top of the tower at the same hydraulic loading as before. A rapid build-up of slime on the packing was obtained and the suspended solids in the activated sludge tank increased to about 1000 ppm. The maximum level of solids in this tank was not obtained until the sludge return line was diverted from the top of the tower to the activated sludge tank and the settled sludge returned continuously. It was noted that once the suspended solids reached a concentration of 1000 ppm there was no further increase. It has been reported (4) that the sludge concentration will cease to increase after five or six days. This equilibrium in sludge concentration results because the sludge undergoes oxidation, being converted to its fundamental component compounds. The efficiency of the unit was excellent and it is thought that 30 lbs. per day of phenol could be consistently oxidized in this filter at a removal of 99% or better. A summary of the data obtained is shown on Table II. It is believed that the average percent removal would have been higher had operating difficulties not been experienced at the time maximum phenol loading was being approached.

Tower sampling indicates that about 80% of the phenol was removed on the packing and the remaining 20% in the activated sludge tank. This established that the filter was now operating as intended.

On Feb.10/57, the feed water was changed from the synthetic phenol feed to the diluted 2,4-D waste water as before. It was soon noted that the suspended solids in the activated sludge tank were falling off and the level decreased to about 50 ppm in a period of a few days. A summary of the data obtained for an eleven-day period of operation is shown on Table III. An average of 4.6 lbs. of dichlorophenol were removed with an average per cent removal of 83.6%. Sampling over the tower indicated that practically all of the removal of dichlorophenol took place on the packing with no further removal taking place in the activated sludge tank.

On or about Feb.25/57, the filter received a shock as a result of a sudden change in the composition of the 2,4-D waste water due to process difficulties. Some difficulty was experienced in reseeding and acclimatizing a fresh lot of activated sludge. The first lot of new sludge was transferred from drums to the activated sludge tank. The level of water in this tank was lowered just enough to hold the sludge. The acclimatization was carried out by keeping the filter on recirculation only and adding small amounts of liquid phenol plus nitrogen and phosphorous to this tank. The phenol additions never raised the phenol concentration on the filter by more than 50 ppm and the total concentration never exceeded 100 ppm during the acclimatization period. These increments were added only as fast as the bacteria oxidized the phenol from the previous addition.

At first the time interval between phenol additions was quite long but gradually decreased as the bacteria became acclimatized. When the bacteria were judged to be well acclimatized to phenol, the same procedure was carried out with dichlorophenol. The dichlorophenol additions, however, got out of control and the concentration reached 450 ppm before it was detected. This inactivated the bacteria.

The activated sludge tank was again flushed out and a second lot of sludge added. On this occasion the sludge was acclimatized to dichlorophenol without first acclimatizing to phenol. This procedure proved successful and the filter has not been reseeded since.

After a one week acclimatization period in which the sludge was held in the system, a synthetic dichlorophenol waste water was applied to the filter at the same hydraulic loading as before. When the filter was put back on this flow-through basis, the suspended solids in the activated sludge tank again decreased. Although the unit was kept on the synthetic dichlorophenol feed for only 7 days, indications are that only about 10 lbs. of dichlorophenol per day can be continuously oxidized by this trickling filter compared to 30 lbs. of phenol per day. A summary of the data obtained while operating on the synthetic dichlorophenol feed is shown on Table IV.

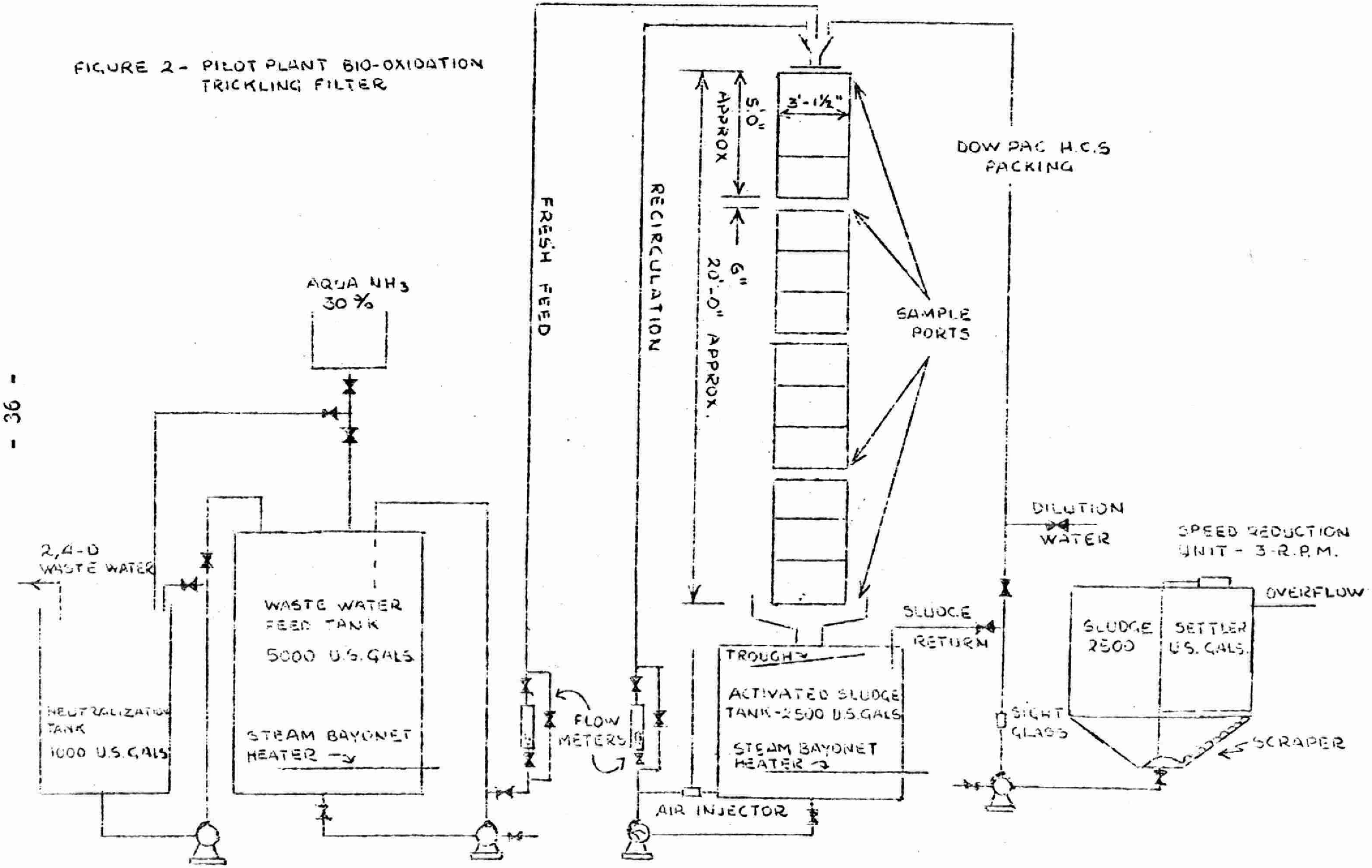
During this acclimatization period, when no water was entering or leaving the system an investigation was made to determine if the sludge was being returned from the sludge settler to the activated sludge tank. It was discovered on draining the sludge settler that a large volume of black septic sludge had built up in this tank. Therefore, it was evident that some means of scraping the sludge down to the outlet was necessary.

A scraper was installed in the settler consisting of a chain suspended at the perimeter of the tank by a horizontal bar. The scraper is shown on Figure 2. An electric motor and speed reduction assembly turned the scraper at the rate of 3 rph.

At the same time a trough was installed directly under the tower to carry the water falling from the tower to the side of the activated sludge tank opposite the outlet. The purpose of this was to increase the retention time within the tank by directing the water down to the bottom of the tank rather than allowing it to fall on the surface in the middle of the tank and be carried away directly to the overflow.

With these changes completed, March 27/57, 2,4-D waste water was again applied to the trickling filter. The diluted waste water was applied to the top of the tower at a total organic loading equivalent to the oxygen demand of 10 lbs. of dichlorophenol per day. To avoid the previous experience of inactivating the filter as the result of a fluctuating waste water the dichlorophenol content of the waste was determined by a bromate bromide titration from a sample taken as it flowed to the neutralization tank. By means of a graph the operator converted the titre of the sample to inches of waste water required in the tank. Thus a greater or lesser volume of waste water was taken so that on dilution in the 6000 gal. feed tank a waste of uniform compo-

FIGURE 2 - PILOT PLANT BIO-OXIDATION TRICKLING FILTER



ition was obtained. This proved to be a very successful method of leveling out variations in this waste. A summary of the data obtained for sixteen days operation is shown on Table V. An average of 8.2 lbs. of dichlorophenol per day were removed with an average removal of 91.1%. It will be noted that almost double the amount of dichlorophenol was removed in this period compared to an average removal of 4.2 lbs. of dichlorophenol as shown on Table III. In addition the efficiency increased from 83.6% to 91.1%. It is felt that the sludge scraper was primarily responsible for this improved efficiency.

An attempt was also made during this period to increase the organic loading to the tower. The efficiency, and quality of the effluent dropped immediately and the flow of feed to the top of the tower had to be cut off completely for a 24 hr. period to allow the system to "catch up" before resuming at the previous feed rate. The data shown on Table V does not include this brief period of increased loading.

A portion of the effluent was taken during normal operation and subjected to the standard bio-assay test for industrial wastes (5). The waste water treated by this process showed no toxicity whatever to the particular species of fish used in the tests. The untreated waste water, whether neutralized with aqua ammonia or caustic soda proved to be extremely toxic to the test animals. Both tests were carried out at the same dilution.

Treatment of Undiluted 2,4-D Waste Water

The study of the biological treatment of 2,4-D waste water had, to this point, been carried out on a 10:1 dilution of waste. This dilution brought the concentration of the principal components shown on Table I within the recommended range of what was thought to be an ideal waste. There was no proof, however, of the actual necessity of making the dilution as high as this. In addition a dilution of this proportion would greatly complicate the problem of scale-up of the filter.

With only a few days remaining until the end of the 2,4-D production season, 6000 gallons of undiluted waste water were collected, neutralized and nutrients added. This was then applied to the filter at the rate of 0.25 I.G.M. The recirculation flow rate was increased to 24 I.G.M. Therefore, the organic and hydraulic loading to the top of the tower remained essentially the same as with the diluted waste water. Under these conditions, however, the salt concentration in the filter increased gradually due to the high salt concentration of 49,400 ppm of the incoming waste water. A summary of the data obtained is shown on Table VI. The quality of the effluent decreased abruptly beyond a salt concentration of 32,000 ppm in the filter. This data, while it is far from complete, would indicate that a dilution as low as 1:1 might be possible. It is a reasonable assumption that a dilution of 5:1 or less would be adequate. Further work will be done to determine more closely the actual dilution required.

PILOT PLANT OPERATION - PHENOLIC WASTE

Following the study of undiluted 2,4-D waste the filter was left on recirculation with a flow of dilution water introduced to lower the salt concentration over a period of a week. The plant phenolic waste waters which were used in our initial work were again applied to the trickling filter. The slime on the packing built up very quickly on spots where it had sloughed off and the biological slime as a whole increased in thickness and became gelatinous in texture. In addition the suspended solids in the activated sludge tank again built up. An efficiency of 99-100% was obtained.

The methods of analysis used in this work are essentially those described in the 9th and 10th edition of Standard Methods for the Examination of Water Sewage, and Industrial Wastes.

Conclusion:

Pilot plant studies at Naugatuck Chemicals Ltd., Elmira, Ontario indicate that the combined liquid wastes containing phenol can be satisfactorily treated by the trickling filter design descussed in this report.

While results are very encouraging these studies indicate that 2,4-D waste water containing dichlorophenol is considerably more difficult to treat than are the phanolic wastes. Additional investigation into such factors as waste water dilution, optimum organic and hydraulic loading, recirculation ratio, temperature and effective filter depth must be carried out in an attempt to achieve greater efficiency of removal before the effluent can be discharged directly to the receiving stream.

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Table I

Composition

of

Untreated 2,4-D Waste Water

Dichlorophenol, ppm	1000 - 1500
Chemical Oxygen Demand, ppm	3700
Inorganic Salts (Percent)	6-8
Total Solids (Percent)	8-10
Sulfuric Acid (Percent)	0.8-1.4
pH	1.2-1.8
S.G. @ 15°C	1.074

TABLE II

SYNTHETIC PHENOL FEED

PILOT PLANT TRICKLING FILTER

(JAN. 20 - FEB. 7/57)

	INFLUENT			EFFLUENT			AVERAGE PERCENT REMOVAL
	MIN.	MAX.	AVG.	MIN.	MAX.	AVG.	
FLOW, GAL. PER. MIN.	2.6	3.8	3.2	2.6	3.8	3.2	-
FLOW, pH	6.9	8.3	7.5	6.7	8.0	7.4	-
NITROGEN, PPM	30	70	44	1	30	21	-
PHOSPHATE, PPM	26	31	28	12	24	18	-
PHENOL, PPM	260	713	480	0	44	7	-
PHENOL, LB. PER DAY	10.8	31.4	17.8	0	1.4	0.3	98.7

	MIN.	MAX.	AVG.
RECIRCULATION, GAL. PER MIN.	20	20	20
RECIRCULATION RATIO	5.6	7.7	6.5
TEMPERATURE °F	80	83	82

TABLE III

2,4D WASTE WATER (10:1 DILUTION)

PILOT PLANT TRICKLING FILTER

(FEB. 10 - 21 / 57)

	INFLUENT			EFFLUENT			AVERAGE PERCENT REMOVAL
	MIN.	MAX.	AVG.	MIN.	MAX.	AVG.	
FLOW, GAL. PER MIN.	2.5	3.6	3.2	2.5	3.6	3.2	-
FLOW, pH	7.4	7.9	7.6	7.8	8.1	8.0	-
NITROGEN, PPM	270	580	380	330	400	350	-
PHOSPHATE, PPM	15.5	36.8	23.7	15.3	26.6	19.6	-
INORGANIC SALTS, PPM	2800	5300	4200	4000	6000	5300	-
DICHLOROPHENOL, PPM	106	198	138	13	35	23	-
DICHLOROPHENOL, LB. PER DAY	3.2	8.0	5.5	0.5	1.3	0.9	83.6

	MIN.	MAX.	AVG.
RECIRCULATION, GAL. PER MIN	20	20	20
RECIRCULATION RATIO	5.5	8.0	6.3
TEMPERATURE, °F	79	83	81

TABLE IV

SYNTHETIC DICHLOROPHENOL FEED

PILOT PLANT TRICKLING FILTER

(MARCH 20 - 27, 1957)

	INFLUENT			EFFLUENT			AVERAGE PERCENT REMOVAL
	MIN.	MAX.	AVG.	MIN.	MAX.	AVG.	
FLOW, GAL. PER MIN.	2.7	4.1	3.4	2.7	4.1	3.4	-
FLOW, pH	7.3	8.1	7.9	7.4	7.9	7.7	-
NITROGEN, PPM	10	20	13	10	20	10	-
PHOSPHATE, PPM	6.4	7.9	7.4	2.9	6.0	4.1	-
DICHLOROPHENOL, PPM	202	296	262	0	30	11	-
DICHLOROPHENOL, LB. PER DAY	6.2	15.0	11.3	0.0	1.5	0.5	96.3

	MIN.	MAX.	AVG.
RECIRCULATION, GAL. PER MIN.	20	20	20
RECIRCULATION RATIO	5.1	7.4	6.0
TEMPERATURE °F	77	82	79

TABLE V

2,4-D WASTE WATER (10:1 DILUTION)

PILOT PLANT TRICKLING FILTER

(MAR. 27 - APR. 4/57 & APR. 9 - 11/57)

	INFLUENT			EFFLUENT			AVERAGE PERCENT REMOVAL
	MIN.	MAX.	AVG.	MIN.	MAX.	AVG.	
FLOW, GAL. PER MIN.	3.0	3.8	3.4	3.0	3.8	3.4	-
FLOW, pH	7.6	8.3	7.8	7.6	7.9	7.7	-
NITROGEN, PPM *	-	-	-	-	-	-	-
PHOSPHATE, PPM	-	-	20.8	-	-	16.4	-
INORGANIC SALTS, PPM *	-	-	-	-	-	-	-
DICHLOROPHENOL, PPM	170	252	203	7	62	30	-
DICHLOROPHENOL, LB. PER DAY	7.2	12.5	9.1	0.2	2.5	1.3	91.1
CHEMICAL OXYGEN DEMAND, PPM	405	784	585	134	215	170	-
CHEMICAL OXYGEN DEMAND, LB. PER DAY	16.8	38.6	24.0	4.9	9.5	7.3	69.7

	MIN.	MAX.	AVG.
RECIRCULATION, GAL. PER MIN	20	20	20
RECIRCULATION, RATIO	5.3	6.7	5.9
TEMPERATURE °F	75	82	80

* Assumed to be approximately equal to values shown on Table III

TABLE VI

2, 4-D WASTE WATER (UNDILUTED)

PILOT PLANT TRICKLING FILTER

(APR. 12 - 19 / 57)

	MIN	MAX	AVG.	MIN	MAX	AVG.	Average Percent Removal
FLOW, GAL. PER MIN.	0.25	0.25	0.25	0.25	0.25	0.25	-
FLOW, pH	7.2	7.4	7.3	7.7	8.0	7.8	-
NITROGEN, PPM *	-	-	-	-	-	-	-
PHOSPHATE, PPM	-	-	270	-	-	53	-
INORGANIC SALTS, PPM	49,400	49,400	49,400	13,000	32,000	-	-
DICHLOROPHENOL, PPM	1502	1502	1502	12	55	27	-
DICHLOROPHENOL, LB. PER DAY	5.4	5.4	5.4	0.0	0.2	0.1	98.1
CHEMICAL OXYGEN DEMAND, PPM	4346	4346	4346	198	689	430	-
CHEMICAL OXYGEN DEMAND, LB. PER DAY	15.6	15.6	15.6	0.4	2.5	1.5	90.0

	MIN.	MAX.	AVG.
RECIRCULATION, GAL. PER MIN	24	24	24
RECIRCULATION RATIO	96	96	96
TEMPERATURE °F	80	84	83
DISSOLVED OXYGEN	4.1	6.5	4.8

* Waste neutralized with Aqua Ammonia, thus nitrogen assumed to be adequate.

EFFECTS OF SUSPENDED MATTER IN WASTE WATER

- by -

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Water pollution control is a topic replete with firmly held opinions that rest on insecure foundations. This arises from a widespread public and professional concern over the effects of pollution, coupled with a sad dearth of the kind of technical information that is essential to the development of rational measures for pollution control.

The effects of suspended solids discharged to rivers is a subject about which a variety of similar statements have been made. These pronouncements have been uttered so many times that they have become a kind of dogma that no one questions. It is said, for example, that suspended matter diminishes photosynthesis. But what concentration will diminish photosynthesis by what percentage. Some 90 per cent of incident light is absorbed by clear water in a depth of about six feet. How much suspended matter must there be to increase light absorption to 100 per cent in the same or some other depth? How does natural silt affect photosynthesis as compared with suspended material from industries and municipalities?

It is claimed that suspended solids destroy fish spawning grounds. How much of such material will do what damage to what kind of spawning ground? Similarly, suspended matter is said to smother benthic organisms and thus prevent them from playing their role in stream self-purification. What depth of what kind of solids will smother what sort of organism? A monomolecular layer? A millimeter? A quarter inch? A foot?

A consideration of these questions led to an investigation whose object is to provide quantitative data for many of the speculations which have long been accepted as indisputable, if unprovable, fact. A casual observation of rivers shows that suspended matter deposits where proper conditions exist for sedimentation. River bars form and reform with fluctuations of discharge rate. Dredging must be resorted to where stream velocity cannot flush deposited solids away. Where such conditions exist it is clear that streams are overloaded with suspended solids, whether of natural or industrial origin. There are loads less than this, however, where quantitative data on effects are scanty indeed. It is concentrations in this range upon which research is now in progress.

The steel industry recently completed a comprehensive survey of blast furnace flue dust production and recovery in the Ohio Valley. The survey disclosed that an average of 204 pounds of dust is made per ton of iron manufactured but that only 10 pounds per ton is discharged to streams. Recovery of 95 per cent of this material invited speculation about the degree of recovery needed for proper protection of streams, and this led to a shift of emphasi in research on pollution control by the industry. Dr. C.A. Bishop aptly illustrated the shift when he said that increasing attention was being given to the diagnostic, as compared with the prescriptive, approach to the problem. In the past, the industry has concentrated its efforts on improving recovery efficiencies in general without paying serious attention to the ultimate effects on water quality. It has now been recognized, however, that an understanding of the actual effects of constituents of waste water is essential to intelligent recovery practice. This change in research emphasis does not mean that the prescriptive approach has been abondoned; it means only that research is being expanded to include studies of the effects of various materials on the receiving water.

There are several aspects of the problem of suspended solids which require investigation. One of these is the relationship between natural silt and suspended solids flowing from sewers. It should be recognized, of course, that a significant proportion of so-called natural silt results from the activities of mankind: poor agricultural practices, strip mining, road building, and the like. But until satisfactory land management can be co-ordinated with water conservation, there is little that can be done to reduce the wash load carried to streams by rainfall.

Many studies have been made to develop formulas to be used for prediction of silt loads in rivers. All of these formulas have been based on flume studies, yet findings on actual streams often contradict experimental results. It is usual practice to differentiate the bed-material load from the suspended load. Bed-material flows along stream bottoms, but more or less of it can become suspended sediment, depending on channel configuration and water velocity. It is sometimes assumed that suspended solids, whether of natural or industrial origin, will eventually settle in streams. But this cannot really be true; if it were, stream channels would be choked with sediment. Suspended particles do settle in water at rates dependent upon their size and density, and upon the physical condition of the stream. But much of the settled material apparently does not stay where it drops to the stream bed; it flows at a rate governed by the stream itself and eventually reaches the ocean.

A recent statistical study of data on suspended sediment showe a good correlation between loads and discharge rates for a number of rivers in the Middle Atlantic States. There was also a good correlation between mean load and drainage area, even though the physical condition of the drainage basins differed considerably. For example, the mean load at Sewickley, just below Pittsburgh on the Ohio river, was 4339 tons/day and at Mound City, Illinois, 950 miles downstream, the mean load was 128,600 tons/day. The relative proportions of these loads that were natural, industrial and municipal is not known, but the close correlation between loads and discharge rates suggests that most of the sediment had a natural origin.

The same paper reported a study of a flue-dust clarifier made over a four-month period. The average concentration of suspended solids in the clarifier effluent was 99 ppm, but the concentration in the raw water was 47 ppm. Thus the net discharge of the clarifier was roughly half flue dust and half natural silt. A similar but shorter study of a scale-pit effluent indicated that only about 15 per cent of the suspended matter was iron oxide; the bulk of the material was silt in the raw water.

These points have been raised to illustrate the necessity for considering the role of natural silt in evaluating the problem of suspended solids.

Data from flume studies may not provide accurate information about the effects of suspended solids in a natural stream. Nevertheless, a flume should yield useful qualitative data on the behavior of particles suspended in flowing water. A straight rectangular flume 50 ft. long and five inches square was therefore built for preliminary studies. It has rectangular weirs about 18 in. from each end to provide a flow about 47 ft. long and four inches deep.

The original development of a plan of study shows the hazard of the commonsensical approach. It was decided to circulate through the flume a suspension of particles with a maximum diameter of three microns. The suspension was made by mixing a quantity of -325 mesh flue dust with water, allowing it to stand for eight hours, and syphoning off the supernatant. It was assumed, from the manner of making the suspension, that the rate of subsidence in the flume would be very low. It was therefore planned to circulate the suspension through the flume at a given rate, gradually decrease the rate until settling occurred, then raise the rate to determine the velocity at which the settled material would be suspended again. Following this, the plan was to use suspensions of larger and larger particles, and calculate the relationship between particle size, water velocity, and settling tendency.

Unfortunately, this plan could not be used. In the first run, the flume was filled with tap water and the suspension was pumped into the chamber behind the influent weir. The impeller of an electric mixer was placed directly over the opening through which the suspension entered, so that good dispersion would be assured. It soon was obvious that, contrary to sedimentation theory, settling was taking place fairly rapidly. The final result was that very little of the suspended matter ever flowed over the effluent weir. It was evident that settling had been promoted by agglomeration of the fine particles.

A quantity of -140 mesh (maximum particle size, 100 microns) flue dust was suspended in a liter of water and poured into the influent chamber, which was supplied with a steady flow of tap water providing a velocity of 2 ft/min. in the flume. According to theory, if there were no agglomeration, the 100-micron particles should have settled about a foot from the inlet weir, the smaller particles should have settled at distances depending on their size and density, and the 6-micron and finer particles should have passed over the effluent weir. Instead of this, roughly a third of the material settled in the influent chamber, in spite of thorough agitation, and practically all of the remainder settled within ten feet of the influent weir.

A series of runs was made with -325 mesh (theoretical maximum particle size, 44 microns) flue dust suspended in tap water. Concentrations of influent and effluent solids were measured after equilibrium conditions seemed to have been attained, and particle-size determinations were made on the solids that settled and those that passed over the effluent weir. The Lamar photometric method was used for particle-size measurements. A portion of the data is summarized in Table I; complete data are available from the author.

Table I. Data on Flume Studies

Run No.	1	2	3	4*	5	6
Water velocity, ft./min.	3.07	2.03	1.02	4.22	4.22	4.22
Reynolds Number	2620	1746	873	3632	3632	3632
Influent, ppm	67	57	61	79	69	73
Effluent, ppm	19	12	10	22	16	10
Amount discharged, %	28.4	21.1	16.4	27.9	23.2	13.7
Particles discharged**	16-20	80-100	80-100	8-16	60-80	40-60

* A layer of pebbles, 1/8-1", on flume bottom to simulate roughness.
**Size range of largest particles discharged.

Run No. 1. Of the particles that settled five feet from the influent weir, 76 weight per cent were in the range 8-40 microns, and 5 weight per cent were in the 80-100 range. At ten feet these percentages were 57 and 12, respectively.

Run No. 2. Of the particles that settled 15 ft. from the influent weir, 75 weight per cent were in the range 8-40 microns, and 6 weight per cent were in the 80-100 range. At 30 ft. these percentages were 41 and 15, respectively. Of the particles passing over the effluent weir 19 weight per cent were in the 80-100 range.

Run No. 3. Of the particles that settled 15 ft. from the influent weir 65 weight per cent were in the range 8-40 microns, and 24 weight per cent were in the 80-100 range. At 30 ft. these percentages were 48 and 12, respectively. Of the particles passing over the effluent weir 38 weight per cent were in the 80-100 range.

Run No. 4. This run was made with a layer of pebbles in the flume to simulate a rough bottom. The weight percentages of the solids in the range 8-40 microns that settled at 2.5, 5, and 10 ft. were 34, 81 and 72, respectively. The corresponding percentages of particles in the 80-100 range were 0, 2.5, and 7.

Run No. 5. A duplicate of No. 4 without pebbles. The weight percentages of the solids in the range 8-40 microns that settled at 2.5, 5, and 10 ft. were 65, 69 and 90, respectively. The corresponding percentages of particles in the 80-100 range were 8, 4 and 0. Although 80 per cent of the particles leaving the flume were 16 microns or finer, 20 per cent were in the 60-80 range.

Run No. 6. A duplicate of No. 4 without pebbles. The weight percentages of the solids in the range 8-40 microns that settled at 5, 15, 26.5, and 38 ft. were 87, 83, 71, and 64, respectively. No particles were present beyond the range 40-60 microns. In this run the solids that settled were syphoned from one-foot sections of the flume bottom at the midpoints of above sampling points. The solids were filtered, dried, and weighed. The weights were taken to represent the average amounts settled in the four flume sections. In the order given above, the percentages of the total were 49,31,12, and 8.

These preliminary results seemingly contradict some firmly held beliefs. According to theory, particles settle most rapidly where water is quiescent, and sedimentation basins are designed to avoid disturbance of the fluid medium. Yet data from the flume studies indicate that the amount of settling with laminar flow is less than it is where the flow is turbulent. Since agglomeration of particles occurred, and since this can result only from contact between particles, it is probable that turbulence increases the number of contacts, and the tendency of the particles to clump results in an increase in their settling rates. Apparently these agglomerates do not break up readily. Even though the largest particles in a -325 mesh fraction are 44 microns, particles up to 100 microns were found in the size analysis. It had been assumed that any agglomerates in the suspension would be dispersed on passage through a centrifugal pump. If this does occur the particles evidently reform promptly in the flume.

This work has led to a long-range research project for evaluation of a number of variables that affect the behavior of suspended particulate matter. Flue dust contains considerable magnetic iron oxide, and it may be that this material is a factor in agglomeration. This aspect will be studied by using suspensions of completely inert material such as ignited alumina or silicon carbide.

It is known that dissolved salts affect the tendency of particles to agglomerate, but there is little information about concentrations and species of salts and the effects they have on various sorts of suspended particles.

The density of agglomerates should be determined, as well as the factors which control the final sizes of the clumps.

These aspects of the problem will be studied initially under controlled conditions in the laboratory. The flume will then be moved to a field station where actual waste water can be used at various dilutions with raw river water. The field work will also provide an opportunity for study of light penetration and its effects on photosynthesis, composition and distribution of settled solids, and other factors which may arise.

This paper is a progress report which has described preliminary flume studies, and which outlines the problems for which solutions are being sought. It will be followed by other papers as experimental data are accumulated.

Acknowledgment

This paper is a contribution from the Multiple Fellowship which the American Iron and Steel Institute has sustained at Mellon Institute since 1938.

THE COLLECTION, PRETREATMENT AND BIO-OXIDATION OF CRESOL BEARING WASTE WATERS FROM A CATALYTIC CRACKING UNIT

- by -

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INTRODUCTION

Shortly after our refinery at Sarnia went on stream in the summer of 1952, it became evident that considerable amounts of phenolic compounds were finding their way into the refinery effluent waters. Immediate action was necessary to reduce drastically the output of these compounds. Examination of the various waste water streams showed that virtually all the phenolic compounds originate at the Catalytic Cracking Unit. The principal sources are spent caustic from treating, and condensate and water wash streams which have come into contact with cat cracked gasoline. These two sources present rather different problems since the spent caustic is small in volume but may entertain 20% or more of cresols and other phenolic compounds, while the water streams comprise large volumes with phenolic contents below 1000 p.p.m. This paper deals only with the water streams and is intended to outline the means which we have used to combat the problem and our experience to date, with particular reference to our present system of collection, pre-treatment and bio-oxidation.

Historical Summary

Since the fall of 1953 various combinations of four different methods have been used for the disposal of phenolic water as follows:

1) Injection as spray water in the Catalytic Cracking Unit Regenerator.

2) Evaporation in the Catalytic Cracking Unit flue gas stack.

3) Injection as desalting water into the crude oil desalting system.

4) Stripping with steam and flue gas followed by biological oxidation.

The principal features of each of these are discussed below:

1) Injection as Spray Water in the Catalytic Cracking Unit Regenerator

Our Catalytic Cracking Unit is of the fluid type in which coke is continuously burned off the finely divided catalyst by a stream of air which also serves to maintain a fluid condition in the lower portion of the regenerating vessel. The space above the fluidized catalyst bed is cooled by injection of an appropriate quantity of water. Originally condensate was used for this purpose, since the fall of 1953 phenolic water has been employed. No corrosion problems have arisen and we have no reason to believe that the catalyst is adversely affected. The normal operating temperature of the Regenerator is about 1120°F. Analyses of the effluent gases indicate that over 90% of the phenols are destroyed. More recently a CO boiler has been installed in which the effluent gases undergo further combustion and this appears to effect virtually complete oxidation of the phenolic compounds. This means of disposal is still in operation and normally handles about 30 i.g.p.m. of phenolic water.

2) Evaporation in the Catalytic Cracking Unit flue gas stack

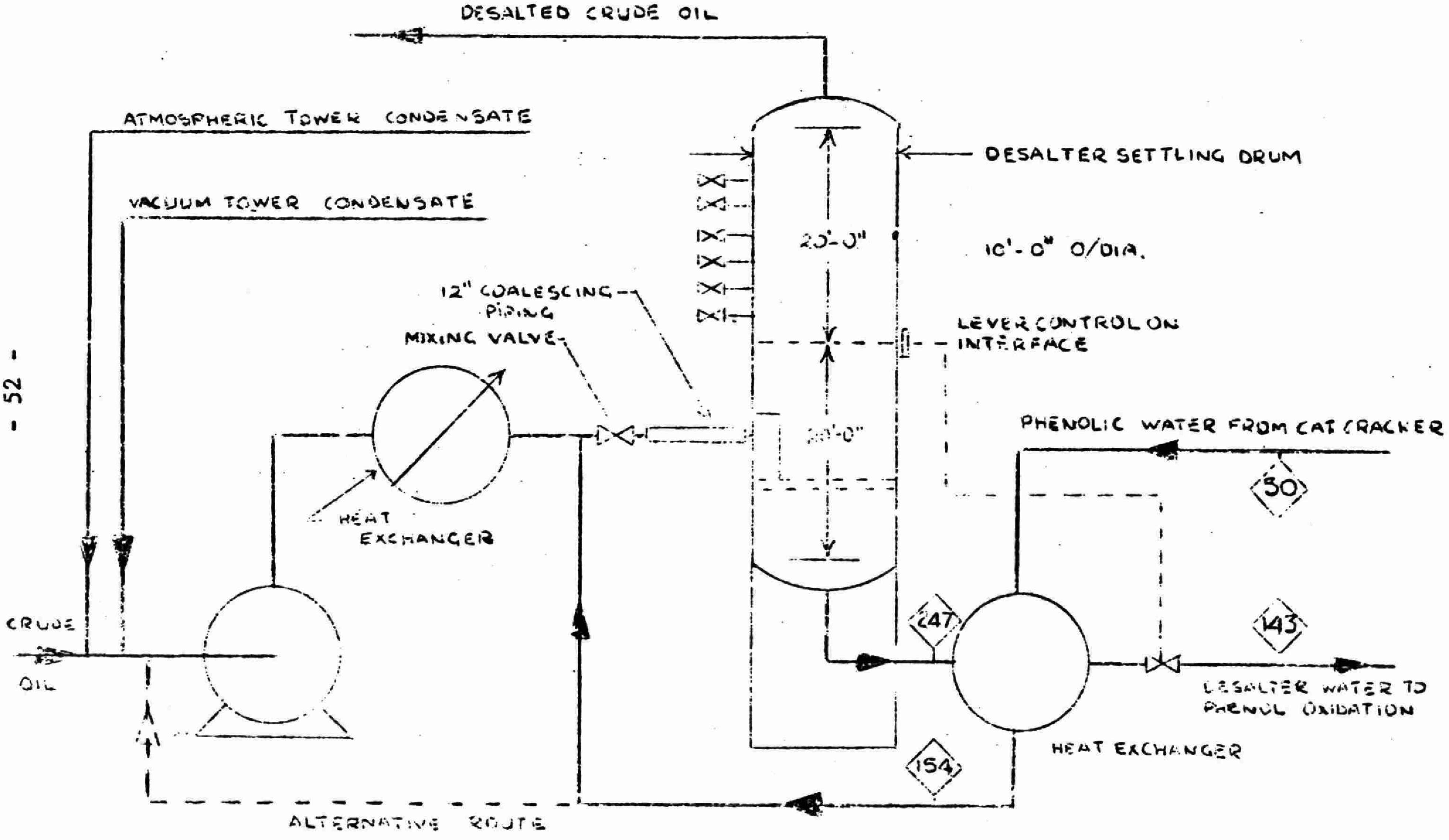
In January 1954, the excess phenolic water over that required by the Regenerator sprays was injected into the flue gas stack of the Cat. Cracker. The stack was 62 feet high, lined with refractory in the lower portion and insulation in the upper part, and contained a number of horizontal orifice plates. Injection of the phenolic water took place through 2 nozzles at a point about 29 feet from the top, 4 feet above the top orifice plate. About 33 i.g.p.m. were successfully evaporated in this manner. There did not appear to be any special corrosion problems associated with this operation. In November 1955 the installation of a CO boiler precluded further use of this means of disposal. It should be pointed out that this procedure evaporated phenolic compounds to the atmosphere rather than destroying them.

3) Injection as desalting water into the Crude Oil Desalting System

In our Crude Unit about 7% wash water is used for salt removal. The crude oil and water are mixed and after heating to about 250°F are separated with the aid of a demulsifying chemical. Laboratory examination showed that if phenolic water from the Cat. Cracker were used for this purpose about 90% of the phenolic compounds present would be transferred to the crude oil. In September 1954, phenolic water which had previously been going to the Cat. Cracker Regenerator stack was diverted for use as crude desalting water. The system is shown diagramatically in figure 1. As anticipated the effluent desalter water contained only some 10% of the phenolic compounds originally present. It was found that a major proportion of the phenols passed into the feed to the Catalytic Reforming Unit where it is believed they were reduced to the corresponding hydrocarbons. However, some appeared in the crude atmospheric tower aqueous

FIGURE 1 - CRUDE DESALTING WITH PHENOLIC WATER

FLOW PLAN



condensate which was returned as desalting water and some in the caustic washes on light gasoline and stove oil products.

Considerable trouble was experienced with fouling of the exchanger train by calcium carbonate scale which appeared to result from the presence of calcium in the crude and carbon dioxide in the the desalting water. This was overcome by injecting the atmospheric and vacuum condensate streams ahead of the exchanger train and the phenolic water after it. Calcium carbonate fouling was then experienced in the mixing valve which is placed immediately downstream from the point where the phenolic water was introduced into the crude oil and in the desalter water exchanger. Although some success in alleviating this was achieved by the addition of various anti-fouling agents, frequent cleaning of the valve and exchanger was necessary. During the period that phenolic water was injected into the crude there was a considerable increase in corrosion in the flash and atmospheric tower furnace tubes. While a simultaneous increase in crude oil through-put prevented a definite diagnosis of the the cause, the use of the phenolic water is believed to have been the major contributor.

4) Stripping followed by biological oxidation

After some deliberation it was decided that the best method available for further reduction of the cresol content of our waste water was to instal a hydrogen sulphide stripper and a biological oxidation unit. The intention was to collect the desalting water and other phenolic streams at the Crude Unit and to treat them in the new installation, and the design was carried out on this basis. However, considerable trouble was experienced with fouling of the stripper with calcium carbonate scale and satisfactory operation for more than about a week was never achieved.

As a result of this, in October 1956 the excess phenolic water was temporarily taken out of the Crude Unit and an attempt made to process it directly. This scheme was so successful that it has been in operation ever since. The stripper and bio-oxidation units are considered in more detail later in the paper.

DESCRIPTION OF PRESENT SYSTEM

General

The flow plan of our present Phenolic Disposal System is shown in figure 2. The phenol bearing water streams from the Cat. Cracker are collected in the phenolic water drum. This serves as surge capacity and separates any entrained oil from the water. From it water is supplied to the Regenerator sprays as well as to the stripper. The means for disposal to the Crude Desalting system has been retained for use in an emergency. The hydrogen sulphide free effluent from the stripper, after cooling, flows directly to the Aero-Accelator where biological oxidation of the phenolic compounds takes place.

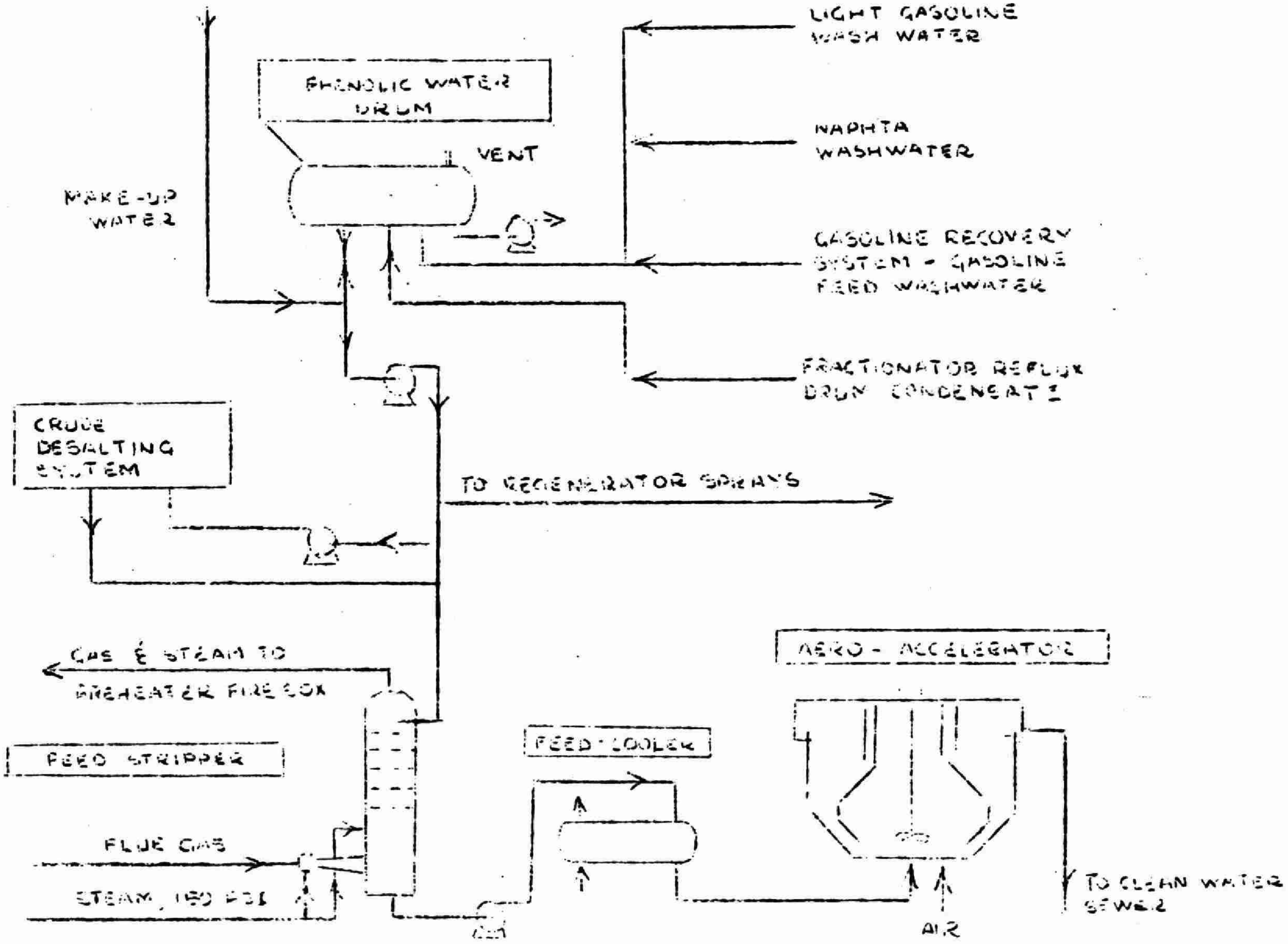


FIGURE 2 - PHENOLIC WATER FLOW PLAN

Collection System

Figure 3 shows the collection system in more detail. It will be seen that the collection drum is divided into two sections. The effluent water streams flow into the bottom of the main section. An oil level is maintained in this section by means of an interfacial level controller. The excess oil overflows into the smaller section of the drum and is pumped away periodically. The effluent water from the drum is divided into three streams each at constant flow, to the Regenerator sprays, to the stripper and to the Crude Desalting system respectively. To permit this a small continuous make-up of cooling water is maintained by means of the interfacial level controller.

Typical analyses of the original phenolic water streams are shown below:

Table I

Typical Analyses of Phenolic Water Streams from Catalytic Cracking Unit

	Approx. Flow I.g.p.m.	Phenols ppm	Phenols lbs/day	H_2S ppm	pH
Fractionator Condensate	25	760-900	274-324	2500 -4000	7.5-8.5
Wash Waters:					
Gas Rec. System Gasoline Feed	11	480-680	76-108	4000 -5000	7.5-7.9
Light Gasoline	20	200-260	58-75	nil	7.5-8.8
Naphtha	4	120-195	7-11	nil	7.5-9.2

The main source of phenolic compounds is the aqueous condensate from the main fractionator. This stream carries about 300 lbs. of phenol equivalents per day (as determined by the Gibb's method). Second in respect to the amount of phenol is the wash water which has been used for treating the light gasoline stream from the main fractionator. These two streams also contain high concentrations of hydrogen sulphide. The last two water streams shown in table 1 are from water washes following after a caustic wash. They are therefore normally free of hydrogen sulphide and appreciably lower in phenol content.

Phenolic Water Stripper

Figure 4 shows a diagramatic representation of the stripper. The feed passes through a spray nozzle at the top of the tower and flows down through five grid trays against an upcoming stream of steam and flue gas. The treated water is pumped from the bottom of the stripper through a level control valve to a cooler and thence to the Aero-Accelator.

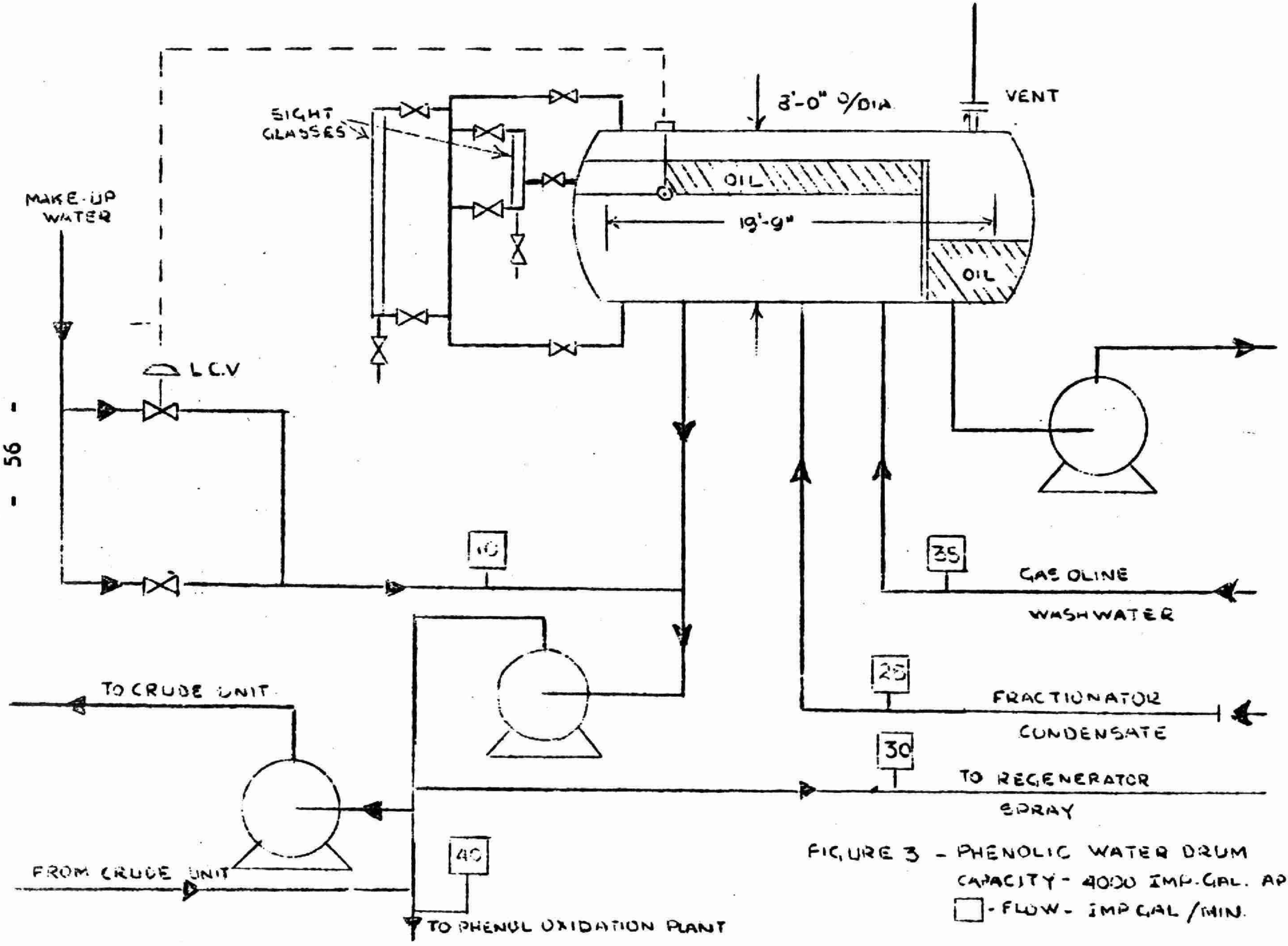


FIGURE 3 - PHENOLIC WATER DRUM
CAPACITY - 4000 IMP. GAL. APPR.
☐ - FLOW - IMP GAL/MIN.

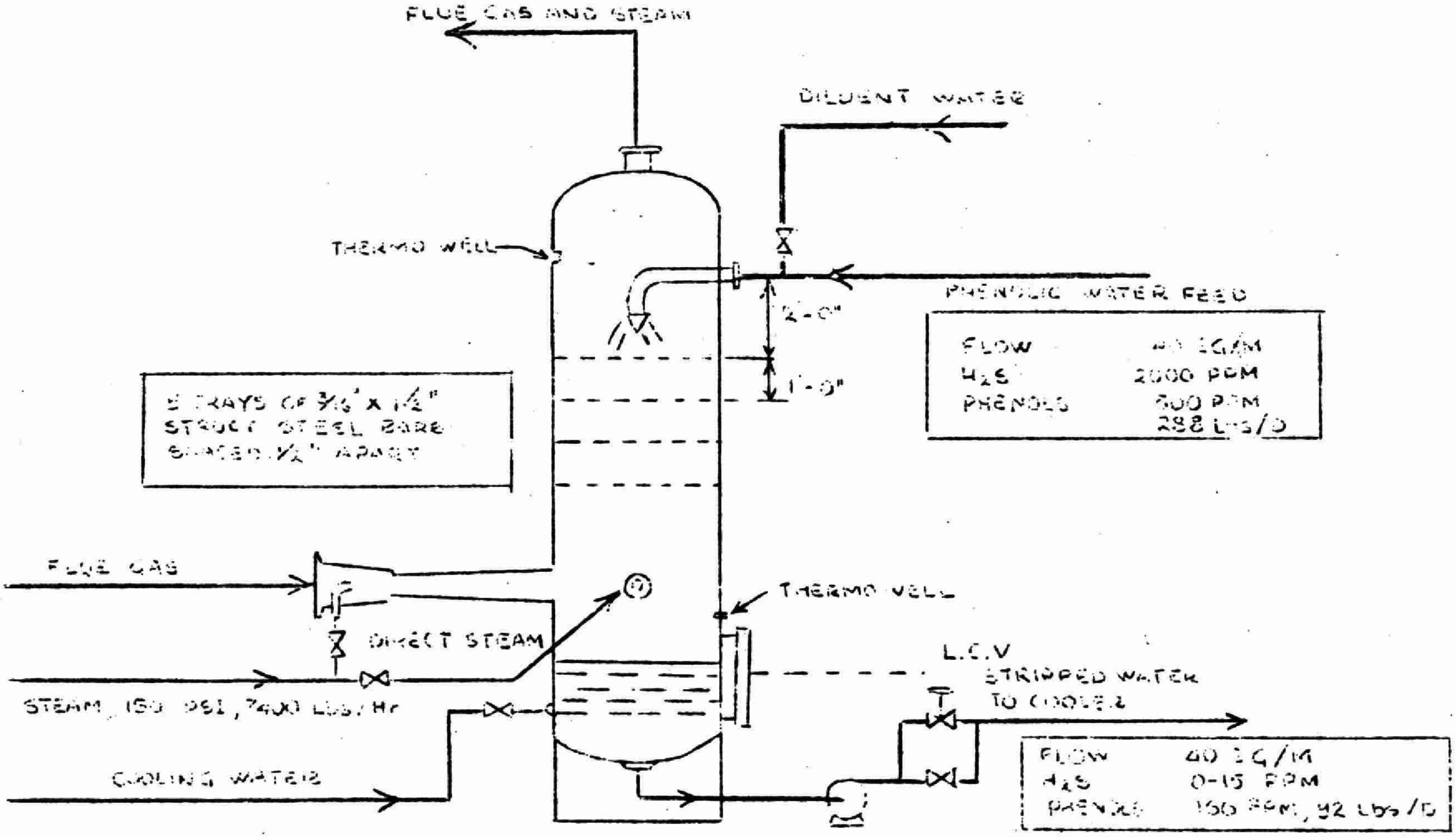


FIGURE 4 - PHENOLIC WATER STRIPPER
TOTAL HEIGHT — 15'-5"
INSIDE DIAMETER - 4'-0"

The flue gas is supplied from the Cat. Cracker at a pressure only slightly above atmospheric and about 1600 s.c.f.m. are drawn in by means of a thermocompressor using 150 lb. steam. Additional steam is also injected directly. Steam and flue gas leaving the top of the stripper pass into the fire box of a heater.

The stripper removes all or practically all the hydrogen sulphide from the feed at a pH of about 8.0 to 9.0, with a bottom temperature of 190 - 200°F. At the same time the phenol concentration is lowered to about one third of its original value.

The stripper is checked four times per shift for approximate pH and H_2S content. The phenol contents of the feed and effluent are determined three times a week.

The tower is of unlined carbon steel and some corrosion has taken place. This is especially the case in the lower part of the tower where the steam and flue gas inlets are placed. Opposite the flue gas inlet the corrosion over a period of a year was about 1/10th of an inch. However during the early part of the period considered flue gas from a heater stack was used. This had an SO_2 content of about 2.5 wgt.% and it is believed that this may have been responsible for most of the corrosion. Use of this flue gas for stripping was discontinued mainly because of the difficulty of obtaining satisfactory H_2S removal without introducing an excessive sulphite concentration. In the top of the tower the corrosion rate appears to have been negligible.

Aero-Accelator

Figure 5 shows a cross section of the Aero-Accelator, a biological oxidation unit of the activated sludge type designed by Infilco Corporation, Tucson, Arizona. Our installation was designed to process a flow of 75 i.g.p.m. of waste water with a phenol loading of 150 lbs/day. The installation consists of a tank 16 feet high and 27½ ft. in diameter divided by baffles into an aeration zone which is equipped with a vortimixer, and a settling zone. Air is fed in through a distributor directly below the vortimixer blades by three Roots Connersville centrifugal compressors of 150 c.f.m. capacity each. The feed enters the tank at the bottom in the centre and leaves by overflowing a weir along the outside edge of the settling zone. The settled sludge and a considerable internal recycle are recirculated to the aeration zone by the action of the vortimixer.

Start-up is achieved by seeding with a truckload of sludge from an activated sludge sewage disposal plant at London, Ontario. As soon as the dissolved oxygen has been brought up to a concentration of 2 p.p.m. the full flow of phenolic water feed can be rapidly assimilated.

Approximately 24 hours is required from seeding to full operation.

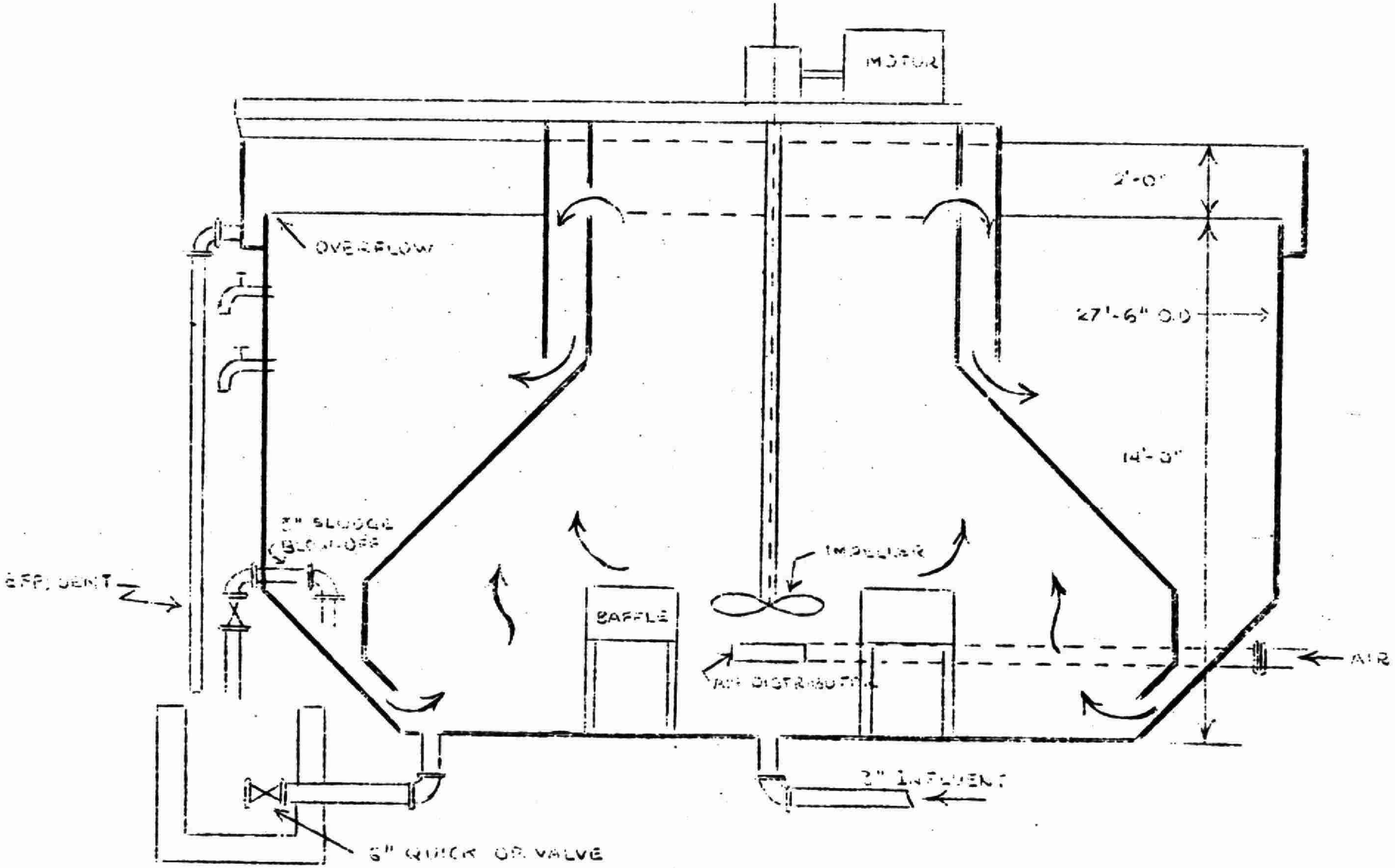


FIGURE 5 - INFILCO AERO-ACCELERATOR
TOTAL VOLUME 52,000 U.S. GALS.

Once the plant is operating little attention is necessary so long as proper stripper operation is maintained. Initially some trouble was experienced from lack of ammonia and phosphate which is now added by hand once per shift in the form of ammonium phosphate at the rate of 30 lbs/day. Typical operating conditions are shown in table 2.

Table 2

Typical Operating Conditions for Aero-Accelator

Feed Rate i.g.p.m.	40
Temperature °F	95
Air added, cu.ft./min.	150
Blow-off, % of time	3-7
Ammonium Phosphate added lbs/day	30

Analytical Data:

% Slurry settled in 30 min.	15 - 35
% Slurry by centrifuging	2.1 - 4.0
Dissolved Oxygen p.p.m.	3

The oxygen content of the effluent from the aeration zone of the Aero-Accelator is determined and the volume and quality of the sludge floc checked twice per shift. The phenol content of the Accelator effluent is checked three times a week.

The overall operation of the stripper and Aero-Accelator is summarized in the analyses shown in table 3 below:

Table 3

Typical Analyses of Phenolic Water before and after Stripper and of Accelator Effluent

	Phenols		H_2S	
	ppm	lbs/day	ppm	pH
Phenolic Water before Stripper	500	288	2000	8.5
Phenolic Water after Stripper	160	92	< 10	8.7
Accelator Effluent	0.02	0.01	0	7.5

Phenolic contents of the stripper feed have varied between 250 and 670 ppm and of the accelator feed between 45 and 220 ppm. The phenol content of the accelator effluent has remained close to 20 p.p.b. regardless of feed concentration.

No attempt has been made to assess accurately the operating costs of the unit. However the principal contribution would appear to derive from steam consumed by the stripper.

CONCLUSIONS

1) Cresol bearing waters from a Catalytic Cracking Unit can be virtually completely destroyed.

a) by injection as spray water to the Regenerator bed of the Cat. Cracker to the extent that such cooling effect is necessary.

b) by stripping with steam and flue gas followed by biological oxidation.

2) Within the limits of phenol concentrations experienced and so long as proper stripper operation is maintained, large scale storage is not essential to proper operation of an Aero-Accelator on a continuous basis.

3) Injection of phenolic water into the crude stream as desalting water offers a practicable means of emergency disposal.

BIOLOGICAL OXIDATION OF OIL REFINERY WASTES IN COOLING TOWER SYSTEMS

- by -

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Biological oxidation of effluent waters has become an established process in oil refinery practice in recent years. Several commercial-scale activated sludge and trickling filter units have been installed for organic waste reduction by various refiners since 1953. This equipment has operated successfully, proving the applicability of bacterial oxidation to refinery effluents containing phenols and other oxygen-consuming contaminants.

Coincident with the need for improved quality of refinery effluent waters to prevent pollution of reciving streams has been the growing requirement for new water supplies to satisfy the increased demands of industrial expansion. The shortage of existing water supply facilities has led refiners to develop new sources and in some cases to treat waste waters for re-use within the refinery to reduce requirements from external sources. Until recently the need for costly intermediate treatment procedures has been a deterrent to the application of additional re-use procedures.

A new method of utilizing waste waters has been developed that does not require extensive pretreatment and achieves pollution reduction of the over-all effluent. This dual benefit is accomplished by selective segregation of waste waters at their source, simple gravity separation of oil and settleable solids in conventional API separators, four to five days retention in an impounding basin for equalizing the flow, and then biological oxidation in refinery cooling towers. The use of cooling tower systems for bacterial oxidation represents a departure from the conventionallly usedtrickling filter or activated sludge equipment.

Waste Disposal and Re-Use System

Biological oxidation of waste waters in cooling tower systems has been employed in the Toledo, Ohio, refinery of the Sun Oil Company. Following a 5-year period of design and construction a new process revision to the refinery's water supply and waste disposal system has been completed. The new facility embodies comprehensive pollution control of all refinery waste waters, extensive re-use of waters within the refinery with minimum pretreatment and a virtually unlimited water supply for emergency fire protection

The need for installing new water supply lines and treatment facilities or purchasing increased quantities of municipal water has been eliminated.

Cooling towers were selected as the equipment to utilize the "re-use" waters primarily because of their high volume demand and their potential ability to serve as treatment units for biological oxidation of pollutants in the waste waters. Effective oxidation of phenolic compounds and reduction of chemical oxygen demand in conventional cooling towers would obviate the need for extensive waste treatment equipment for improvement of the final effluent. Cooling towers also have the advantage of requiring a relatively low quality make-up water, compared with other process equipment, thereby eliminating costly pretreatment of the water re-used. Furthermore, the towers would reduce by evaporation during recirculation the over-all quantity of waste discharge.

Installing the Re-Use System

Figure 1 is a flow diagram showing the segregation of the various classes of waste waters, the collection, storage, and re-use of the effluent and the quantities involved. The indicated flow rates represent the calculated theoretical water balance for the refinery when the entire system is placed in operation.

The first step in the program was the installation of a flue gas stripping tower to remove sulfides and mercaptans in the process waste waters. These sulfur compounds would be undesirable contaminants in the re-use supply since they could reduce the efficiency of biological oxidation and could be corrosive to tubular equipment used in the cooling system. Approximately 200 g.p.m. of process waters containing sulfides and mercaptans are fed to a 5-ft. diameter by 31 ft. vertical stripping tower packed with Raschig rings. A flow of 120,000 cu. ft. per hour of 950°F. flue gas from a catalytic cracking regenerator is passed through the stripper for sulfide removal. Temperature in the tower is maintained at approximately 190°F. Recently, sulfuric acid has been used for pH adjustment and better stripping. This unit has performed efficiently and maintained a satisfactory quality in the subsequent re-use system.

The second phase of the project consisted of completely segragating refinery waste waters according to chemical characteristics. Low alkalinity process waste waters from such operations as steam stripping, once through cooling of pump bearings, and miscellaneous wash waters together with contaminated storm water from ground run-off, flow through the existing refinery drainage system to the API separator for primary removal of oil and settleable solids.

An impounding basin, 1,200 ft. long by 200 ft. wide and 10 ft. deep, with a maximum liquid capacity of 8,000,000 gal., was constructed at the outlet end of the API separator to provide four to five days storage, flow equalization, removal of residual free oil and settleable solids, and preliminary reduction of chemical and biochemical oxygen demand. A minimum of 1,500,000 gal. of waste water is reserved in the impounding basin to provide an emergency fire water supply for not less than 10 hr.

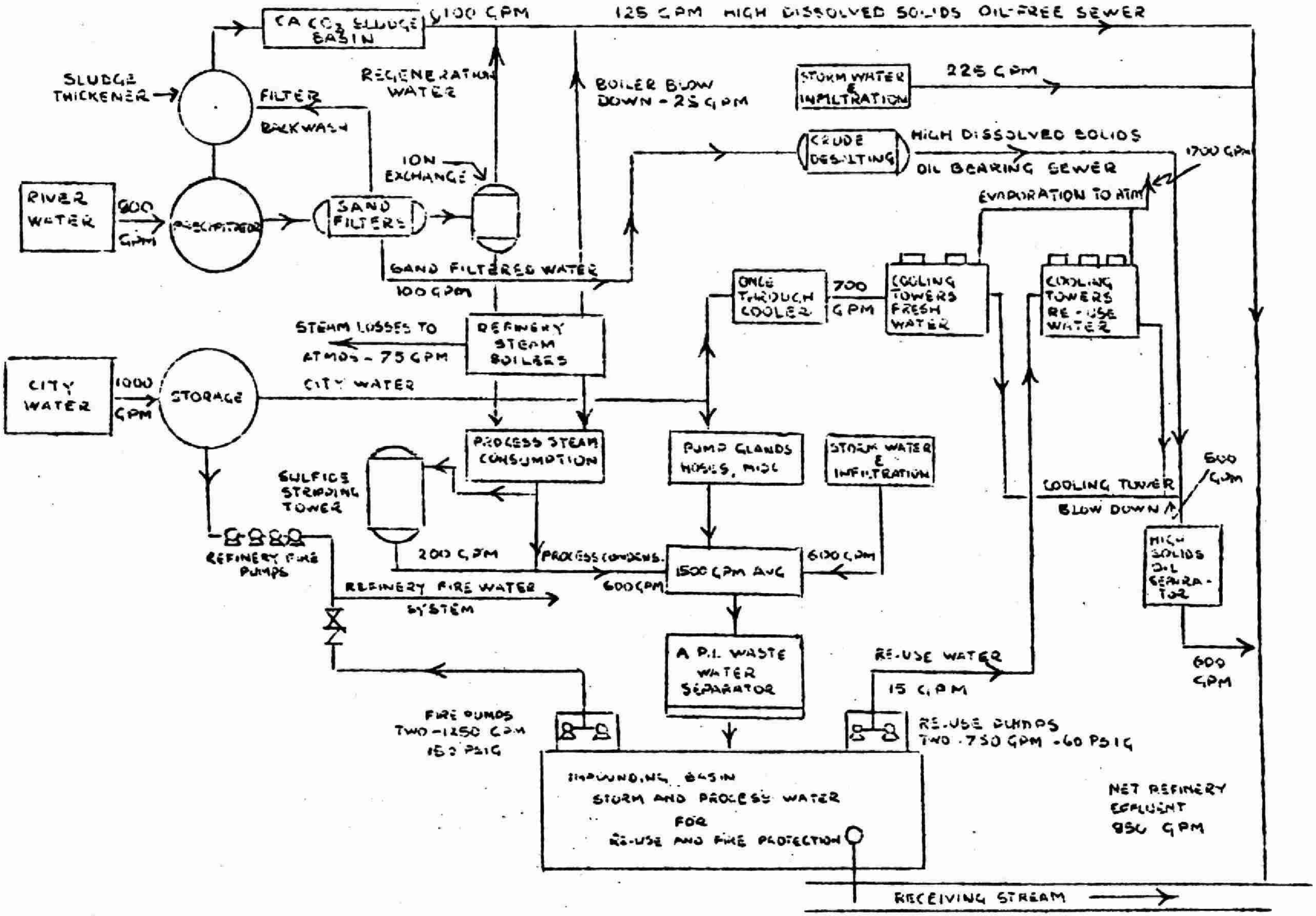

FIGURE 1 - FLOW DIAGRAM OF "RE-USE" WATER SYSTEM
SUN OIL COMPANY - TOLEDO, OHIO

Oil-free waste waters, high in alkalinity and not suitable for re-use, including ion exchange regeneration water from the water plant and blow down from steam boilers, are collected and sewered directly to the receiving stream. Oil-bearing, high alkalinity waste waters, including cooling tower blowdown and crude desalting wash water, are segregated in a new sewer system and delivered to an auxiliary API high-solids separator for oil removal before discharge. The main quantity of refinery waste waters is collected in the low alkalinity re-use sewer and impounding basin system. Two 750-g.p.m. pumps were installed at the impounding basin to return process and storm water to the existing refinery cooling towers for make-up water. No treatment except gravity separation and impounding has been required prior to re-use of this water. Additional details of the over-all installation were presented in another paper (1).

Re-Use Operation

In November 1954, the first re-use of waste water was started at the Toledo Refinery. One pump was operated to return 600 g.p.m. of waste water to the main return line of a large forced draft cooling tower. This tower cools circulating water for conventional condensers and coolers in a catalytic cracking plant.

Within a few hours after the start-up of re-use operation, there was evidence of a good bacterial floc in the system. Bacterial seed was not necessary to initiate the growth of an active colony of bacteria. The phenol content of the blowdown water from this system was reduced more than 99 per cent. From the initial data, it has been proven that the active bacterial sludge contained phenol-oxidizing microorganisms. These bacteria are apparently both water and air-borne.

Examination of the bacterial sludge by means of the optical and electron microscopes has shown the presence of rod-shaped bacilli and circular cocci, and bacterial indentification studies are now in progress. Previous investigators (2) have indicated that such genera as Achromobacter and Micrococcus are effective phenol oxidizers.

In this type of biological oxidation, the microoroganisms present are heterotrophic bacteria which depend on organic compounds as a source of energy. These bacteria are classified as mesophilic since their optimum activity is in a temperature range of 60° to 100°F.

According to Rudolfs (3) the destruction of aromatic compounds by biological oxidation is initiated by oxidation of the side chain and this is followed by the splitting of the nuclear ring and subsequent oxidation. The end products of the reaction are carbon dioxide and water.

The rate of destruction of phenolic-type compounds is dependent upon several variables including the types of compounds, the concentration of the compounds, the temperature of the water, the availability of auxiliary nutrients such as nitrogen and phosphorus compounds, and the presence in the system of microfauna and microflora.

TABLE I

COOLING TOWER OPERATING DATA

ITEM	DETAIL
TYPE	FORCED DRAFT
NUMBER OF CELLS	15
CELL DIMENSIONS (FT):	
WIDTH	30
LENGTH	16
HEIGHT	24
FANS	12-FT., 4-BLADE PLASTIC, ONE PER CELL
WATER RATES (G.P.M.):	
CIRCULATING	17,500
MAKE-UP	600-1,000
BLOWDOWN	100-500
AIR RATE (C.F.M.)	3,000,000
AIR-WATER RATIO	1.58
TEMPERATURES (°F)	
WATER INLET	83 TO 98
WATER OUTLET	64 TO 80

The data presented in Table I shows that the forced draft cooling tower offers exceptionally good physical conditons for biological oxidation by providing extensive internal contact surfaces. The dilution factor ranges from 17 to 29, and this prevents any shock to the established biological equilibrium when large variations are encountered in the phenol load of the make-up water. An ample supply of available oxygen is insured by the air to water weight ration of 1.58. A temperature range of 64° to 98° F. is conducive to a high rate of bacterial growth.

Ammonium compounds are present in the phenolic make-up water and serve as nutrients for the growth of the bacteria. Phosphates are added to the circulating cooling water to improve the food balance and establish a high degree of bacterial activity. This biological oxidation process functions with a light bacterial floc circulating from the cooling tower through all of the plant cooling equipment before returning to the tower. This system combines the high-rate trickling filter and and recirculating sludge processes into one highly effective waste treatment installation.

Comprehensive data on the phenol removal efficiency of the re-use water operation are listed in Table II. The average reduction exceeded 99 per cent under widely variable concentrations of phenol and fluctuating refinery operating conditions.

When the success of the first phase of operation was, the second re-use pump was placed in service to determine the performance of the biological oxidation under approximately double the initial load. No Perceptible loss in efficiency was noted even after process waters from two Houdriflow catalytic cracking plants were included in the make-up water.

A peak phenol loading occurred on February 7, 1956. At this time, 840 lb. per day of phenolic compounds were fed to the cooling tower. Only 2.5 lb. per day of phenols were discharged in the oxidized blowdown water. The per cent of removal was 99.7 under these conditions.

Chemical oxygen demand efficiency data are summarized in Table 111. The first section of the table includes results obtained during periods when the cooling tower was receiving a make-up water supply of 600 g. p. m. The daily quantities of C. O. D. present in the make-up water varied between 1,435 and 3,860 lb., with an average reduction of 89 per cent.

The second set of data in Table 111 illustrates the C. O. D. reduction attained when both re-use water pumps were operated. In considering the results, it appears that a loss in efficiency is encountered when the blowdown rate is increased. The average C. O. D. removal was 68 per cent under these conditions. Present operation is based on a minimum blowdown rate so that the optimum oxygen demand is satisfied.

A complete program for evaluating this system included frequent chemical control tests for all significant components in the make-up and circulating water.

From the standpoint of quality, the high alkalinity of the make-up water is undesirable. Concentrated sulfuric acid is added to the circulating cooling water to depress the alkalinity to approximately 100 p. p. m. as calcium carbonate. Because the bacteria produce carbon dioxide as an end product in the destruction of organic compounds, appreciable acidity is contributed; therefore sulfuric acid consumption is correspondingly decreased below the stoichiometric demand.

Sodium polyphosphate is fed into the cooling water three times each day. This surface-active agent is considered beneficial in controlling corrosion and scale deposition in the refinery boilers. As previously mentioned, phosphates also are very essential nutrients in the biological oxidation process.

The bacterial floc accounts for almost all of the suspended solids in the circulating water. Although most of the operation was carried out with 2.1 cycles of concentration based on chloride content of the make-up and circulating water, the average dissolved solids content shows only a slight increase in the recirculating cooling water system. This trend is a result of biological oxidation and the volatilization of certain compounds from the cooling tower. Since a problem of excessive concentration is avoided, the tower requires only a small blowdown rate.

At times, appreciable concentrations of copper are noted in the circulating water. No decrease in the activity of the bacteria has been detected in spite of these surges of copper. A recent publication (4) stated that phenol-consuming bacteria can tolerate up to 100 p. p. m. of copper.

Approximately 50 per cent of the ammonia is consumed in the biological oxidation system. It is believed that the ammonia content is quite important in the preservation of a good level of metabolic activity. Other pertinent chemical data are included in Table IV.

Operating Effects

Sludge and Algae

The possible detrimental effect of the bacterial sludge on heat transfer in the refinery cooling equipment was a subject of some concern. A program of backwashing all condensers and coolers once each shift was inaugurated at the time water re-use was started. The fluid characteristics of the bacterial sludge gave a reasonable assurance that backwashing could prevent fouling of the boiler tubes.

During the first few weeks of water re-use operation, a weekly shock treatment of chlorine was used as added insurance against a reduction in heat transfer efficiency. This treatment was discontinued after six weeks and no build-up of bacterial growths has been encountered.

Periodic surveys before and after initiating the re-use system show a consistent heat treatment coefficient of 50 Btu. per square foot per hour per degree Fahrenheit. It is planned to continue this program of checking plant units on a routine basis.

No objectionable algae or slime growths have been detected in this cooling water system since the start of biological oxidation. The phenol-destroying bacteria are believed to consume algae and thus exert a strong controlling influence in curbing such conditions.

Corrosion

The last major investigation was concerned with the study of corrosion rates in the re-use water system. Miniature heat exchangers were installed so that frequent observations could be made to determine the condition of the brass and steel tubes. In addition, two new flanged elbows were placed in service so that line thickness measurements and inspection data could be secured during scheduled shutdowns.

Thus far no tuberculation or pitting of steel has been evident. The dissolved organic wastes in the re-use water exert a high oxygen demand in the water pumped from the cooling tower to the plant tubular equipment and probably serve to control some of the corrosive tendencies usually exhibited by oxygen-saturated cooling water.

Table V includes corrosion rate data for steel and brass tubes. The average rate for steel was 0.005 in. per year, whereas that for brass was 0.0035 in. per year. These measured corrosion rates are at essentially the same low levels as previously observed when fresh water make-up was used.

Examination of wood specimens obtained from the 18-year old cooling tower, after four months of water re-use operation, disclosed no evidence of biological deterioration. Additional periodic inspections are planned, including checks on fresh-wood specimens.

Conclusions

Biological oxidation of refinery waste waters in cooling tower equipment represents a highly efficient and economical treatment process. This practical method for pollution reduction offers an attractive alternative to conventional trickling filter or activated sludge methods. Selective segregation of process wastes at their sources and elimination of undesirable constituents such as oil, sulfur compounds, alkalinity and settleable solids must be accomplished before re-use streams are fed to cooling towers in order to maintain satisfactory quality of the circulating water.

Extending waste segregation, storage, and water re-use to the entire refinery provides an integrated system for pollution control, water conservation, and emergency fire protection.

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Table II

Phenol Removal Efficiency in a Forced Draft Cooling Tower

Date	Sample Location	Flow		Phenols					
		G.P.M.	M.G.D.	Million Lb/Day	P.P.M.	Lb/Day	Removal Lb/Day	Removal %	Oper-ation
1954									
Dec. 16	Make-up	600	0.865	7.210	18.4	133	--	--	
	Blowdown	100	0.144	1.198	0.194	0.23	132.8	99.8	*
Dec. 29	Make-up	565	0.815	6.790	15.7	107	--	--	
	Blowdown	100	0.144	1.198	0.211	0.25	106.8	99.8	*
1955									
Feb. 23	Make-up	1,100	1.590	13.250	8.6	114	--	--	
	Blowdown	600	0.875	7.280	0.167	1.2	112.8	98.9	+
Mar. 22	Make-up	1,100	1.590	13.250	12.7	169	--	--	
	Blowdown	600	0.875	7.280	0.208	1.5	167.5	99.2	=
Mar. 24	Make-up	1,185	1.706	14.220	12.7	181	--	--	
	Blowdown	600	0.875	7.290	0.324	2.4	178.6	98.7	=
Nov. 7	Make-up	600	0.865	7.210	19.6	141	--	--	
	Blowdown	100	0.144	1.198	0.800	0.96	140	99.4	#
Nov. 11	Make-up	600	0.865	7.210	48.0	346	--	--	
	Blowdown	100	0.144	1.198	0.082	0.099	345.9	99.9	#
Dec. 8	Make-up	600	0.865	7.210	43	310	--	--	
	Blowdown	100	0.144	1.198	0.055	0.066	309.9	99.9	#
Dec. 29	Make-up	600	0.865	7.210	53.5	386	--	--	
	Blowdown	100	0.144	1.198	0.016	0.019	385.9	99.9	#
1956									
Feb. 7	Make-up	1,000	1.440	12.000	70.0	840	--	--	
	Blowdown	500	0.720	6.000	0.41	2.46	337.5	99.7	x
Feb 16	Make-up	1,000	1.440	12.000	25.6	307	--	--	
	Blowdown	500	0.720	6.000	0.052	0.31	306.7	99.9	x

*2.1 cycles of concentration. Phenolic water from Houdry fixed-bed unit.

+1.2 cycles of concentration. Phenolic water from Houdry fixed-bed unit.

=1.2 cycles of concentration. Phenolic waters from Houdry fixed-bed and Houdriflow units.

#2.1 cycles of concentration. Phenolic waters from two Houdriflow units.

x1.2 cycles of concentration. Phenolic waters from two Houdriflow units.

Table III

Chemical Oxygen Demand Removal Efficiency in a Forced Draft Cooling Tower

Date	Sample Location	Chemical Oxygen Demand (p.p.m.)	(lb/day)	Removal lb/day	Removal (%)	Operation
1955						
Nov. 3	Make-up	280	2,020	---	---	
	Blowdown	188	225	1,795	88.9	
11	Make-up	463	3,340	---	---	
	Blowdown	285	341	2,999	89.8	
22	Make-up	331	2.390	---	---	
	Blowdown	141	169	2,221	93.1	
Dec. 6	Make-up	541	3,905	---	---	2.1 cycles of concentration. Phenolic waters from two Houdriflow units 600 g.p.m. make-up water, and 100 g.p.m. blowdown waste
	Blowdown	369	442	3,463	88.8	
13	Make-up	339	2,802	---	---	
	Blowdown	194	232	2,570	91.8	
21	Make-up	536	3,860	---	---	
	Blowdown	344	412	3,448	89.4	
29	Make-up	441	3,178	---	---	
	Blowdown	369	442	2,736	86.1	
1956						
Jan. 4	Make-up	304	2,190	---	---	
	Blowdown	196	235	1,955	89.4	
11	Make-up	199	1,435	---	---	
	Blowdown	168	201	1,234	86.1	
Feb. 1	Make-up	227	2,725	---	---	
	Blowdown	152	912	1,813	66.5	
7	Make-up	303	3,630	---	---	
	Blowdown	237	1,420	2,210	60.8	1.2 cycles of concentration. Phenolic waters from two Houdriflow units 1,000 g.p.m. make-up water, and 500 g.p.m. blowdown waste.
17	Make-up	233	2,790	---	---	
	Blowdown	133	798	1,992	71.4	
23	Make-up	301	3,610	---	---	
	Blowdown	142	850	2,760	76.3	
28	Make-up	266	3,190	---	---	
	Blowdown	165	990	2,200	69.0	
Apr. 4	Make-up	368	4,420	---	---	
	Blowdown	263	1,580	2,840	64.3	

Table IV

Chemical Quality of Cooling Tower Re-use Water

	Cooling Tower Make-up			Coolingtower Blowdown		
	Max.	Min.	Avg.	Max.	Min.	Avg.
pH	9.15	6.75	8.20	7.85	6.50	7.25
Alkalinity, as CaCO3 (p.p.m.)	284	68	163	160	52	93
Sulfates, as CaSO4(p.p.m	431	193	286	645	212	436
Iron(total), as Fe(p.p.m	3.36	0.57	1.19	3.84	0.63	1.68
Copper (total), as Cu (p.p.m.)	4.90	0.18	0.75	5.76	0.28	1.31
Suspended Solids(p.p.m.)	57	10	28	164	24	72
Dissolved Solids(p.p.m.)	678	336	501	1,000	397	684
Nitrogen (basic), as NH_3 (p.p.m.)	124	53	80	132	39	81
Phenolic compounds, as phenol (p.p.m.) *	74.0	8.4	25.9	1.20	0.004	0.092
C.O.D. (p.p.m.)	541	172	327	436	141	231
B.O.D. (p.p.m.)	259	82	158	208	67	111

* Phenolic compounds determined by the 4-aminoantipyrine method

Table V

Corrosion Rate Data--Re-Use Cooling Water System

Metal	Date	Water Temp. (^{0}F.)	Corrosion Rate	
			Inches Year	Milli grams Sq. Decimeter Day
Steel	1955			
	Jan. 13-Feb.11	90	0.005	27
	Jan. 13-Feb.11	130	0.005	27
	Feb. 23-Mar.17	90	0.003	16
	Feb. 23-Mar.17	130	0.005	27
	1956			
	Jan. 6-Apr.23	90	0.007	45
	Jan. 6-Apr.23	130	0.004	25
Brass	1954			
	Nov. 26-Dec. 9	90	0.004	25
	Dec. 10,'54-Feb. 11,'55	90	0.002	14
	1955			
	Jan.13-Feb.11	90	0.006	30
	Feb.16-Mar.17	90	0.006	30
	Feb.23-Mar.23	90	0.003	19
	Nov.1,'55-Apr.23 '56	90	0.001	8

SOME EFFECTS OF POTASSIUM CYANIDE ON SPECKLED TROUT (SALVELINUS FONTINALIS)

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INTRODUCTION

Several excellent studies have been made on the lethal effects of cyanide (Herbert and Merkens 1952), and on the changes in toxicity brought about by various environmental factors, such as oxygen concentration and temperature (Southgate et al 1933) (Wuhrmann 1953), and the influences of pH (Doudoroff 1956). A number of other publications are available, but unfortunately little information is given on the environmental conditions under which the experiments were carried out, so that much of the value of this information is lost.

In the experiments described in this paper, two general aspects of the effects of cyanide were investigated, firstly, a comparison of survival at lethal concentration between fish acclimated to cyanide and those having no previous contact, and secondly, the effect of exposure to sublethal quantities of cyanide on the ability to perform work. This information was derived from the following four individual studies:

(a) The relation between concentration of cyanide and the time-to-permanent-turnover.

(b) The effect of prior exposure to sublethal cyanide concentrations on the time-to-death at lethal concentrations.

(c) The effect of prior exposure to sublethal cyanide concentrations on the ability of the fish to perform work.

(d) Influence of the duration of exposure on the effect of those sublethal concentrations of cyanide and the rate of recovery from them.

These experiments were carried out with speckled trout Salvelinus fontinalis (Mitchill) of one size and at one temperature.

The results of the lethal experiments have provided some additional information on the direct toxicity of cyanide to speckled trout. The investigation into the effects of sublethal cyanide concentrations has provided information on deleterious effects below the lethal level, and has described a new method by which future studies of sublethal quantities of toxic substances may be made.

While a variety of factors influencing toxicity have been investigated, little or no information is available as to the effect of sublethal amounts of toxic substances on the ability of fish to carry out the normal requirements of life. Fry and Hart (1948), Graham (1949), Job (1955) and Basu (ms. 1957) have presented information on the relationship between activity of fish and temperature and concentrations of the respiratory gases, but little else has been contributed.

If unfavourable conditions interfere with the ability of the fish to perform work, then feeding and growth are reduced, and with the lowering of the general health, disease and predation may assume unnatural proportions. Interference may also take place in the movement of fish to breeding areas, new feeding grounds, or movement to escape an unfavourable environment. Disability at any of these stages can lead to the elimination of a population.

MATERIALS AND METHODS

The speckled trout used for the cyanide experiments were all one year old and were supplied by the Ontario Department of Lands and Forests from the Chatsworth hatchery in January of the years 1956 and 1957. Fish of approximately the same size were selected, ranging from 10 to 13 cm. in length and 10 to 22 gm. in weight.

The trout were held during periods of acclimation and exposure to the sublethal cyanides in metal tanks which were carefully painted with a plastic-type paint, so that at no time was any metal surface exposed in tanks or apparatus where contact with cyanide solution was possible.

Experimental Conditions

The source water for the Laboratory maintains a very constant temperature. As this was satisfactory for the purposes of these experiments, no supplementary control was used. In parts (b), (c) and (d), the controls and fish exposed to the sublethal cyanide concentrations, as well as the solutions used in the various apparatus, were held at a temperature of 8.8 ± 0.2° C. In part (a), the experiments were carried out at 9.5 ± 0.3° C., the somewhat higher temperature resulting from the lower flows and longer transmission lines.

All fish were maintained under these conditions for a period of fifteen days or more before the experiments began.

Care was taken to ensure that the dissolved oxygen content of the water remained sufficiently high to obviate any error which might be introduced from this source. In each group of experiments, dissolved oxygen determinations were made, either on each individual test or each group of tests, and periodic checks of the holding tanks ensured that no oxygen deficiencies occurred there. At no time did the dissolved oxygen drop below 9 ppm (80% saturation), and it generally remained closer to the saturation level, i.e. (11.5 ppm). The dissolved oxygen content was maintained by the inflow of fresh water, so that no supplementary aeration was necessary.

Fish used in all experiments were not fed for a period of forty-eight hours before use.

The Laboratory is supplied with water from deep wells which is rather hard and high in mineral content. Treatment consists of aeration and filtration for iron removal. There is no chlorination of the supply. An analysis of this water supplied by the Laboratory of the Sanitary Engineering Division of the Ontario Department of Health provided the following results:

Hardness as $CaCO_3$	269.0 ppm	Nitrite	0.0 ppm
Alkalinity " "	216.0 "	Ammonia	0.0 "
Iron as Fe	0.02 "	Silica	21.0 "
Chloride as Cl	2.7 "	Aluminum	0.0 "
Nitrate	0.0 "	Copper	0.0 "
		pH	8.2 "

Cyanide Solutions

Potassium cyanide was used in all the experiments performed in this study. Concentrated stock solutions were made up in the Laboratory and the concentrations determined by chemical analysis. The pH was adjusted to above nine to maintain the strength of solution, and no concentrated stock solution was used for more than two weeks. For these solutions and for all cyanide determinations, the author is indebted to staff members of the Sanitary Engineering Division of the Ontario Department of Health.

As a check on the concentrations reached at the point of final dilution, analyses were performed (Standard Methods 1955) and a good correlation was found between the estimated and the analytical concentrations. When analyses were attempted on the lower concentrations used in the experiments, considerable difficulty was found in obtaining accurate results. No good analytical procedure is available at these levels, and although care was used, the results were not sufficiently reproduceable to be of use in estimating the final concentrations. In some of the experiments repeated as a check, the fish apparently gave a more accurate estimation of cyanide than did the chemical analysis. This problem has been encountered by other investigators working with cyanide. For this reason, all concentrations quoted are those estimated from the degree of dilution of the stock solution.

Before and after each experiment, flows were measured. In the longer runs, a number of checks were made and little difficulty was encountered in maintaining the required flows.

Herbert and Merkens (1952) performed careful analyses on the cyanide content of the water in which their time-to-permanent-turnover experiments were conducted, and found that in all cases some loss in cyanide occurred. This was described as the "cyanide demand" of the water. At the higher concentrations used in the tests to estimate turnover time and time-to-death, such a loss is not likely to have had a significant effect on the results. If, however, a similar reduction occurred in the low levels to which the fish were acclimated for the measurement of resistance and activity, the "cyanide demand" could have materially lowered the final concentrations.

The relationship between cyanide concentration and time-to-permanent-turnover (part a) was investigated by maintaining fish in a continuously-flowing cyanide solution of calculated strength. The cyanide concentrate was made up daily from a stock solution of cyanide diluted with distilled water in a five-gallon glass carboy. The pH of this solution was adjusted to nine. This concentrate was siphoned to a float chamber which provided a constant head and thence through a stopcock adjusted to a flow of 15 ml. per minute. A flowmeter was set in the system as a check on the rate of flow. Dilution water was passed through an overflow bottle and run to a stopcock adjusted to a rate of 1.5 litres per minute. The two streams were then combined and passed through two mixing bottlesto ensure thorough mixing before entering the chamber containing the fish. A cylindrical jar with a volume of 18 litres was used to hold the fish during the experiments.

The procedure followed in each experiment was to drain the system completely, then allow it to fill with solution of the required concentration. Ten fish from the holding tanks were quickly placed in the chamber and the time recorded.

The end point was considered as the time when each fish turned over on its side and became helpless. This was tested by tapping the fish with a glass rod and if no response occurred, the fish was removed and the time noted. Each fish was measured (fork length) and weighed at the time of removal, marked by fin clipping, then placed in fresh water to revive. In most cases, the fish would remain quietly on the bottom for a period of ten or fifteen minutes before turning upright and beginning to swim.

The experiments were under constant surveillance excepting those lasting the longest times, and in these cases, they were not left unwatched for periods longer than four hours.

Fish used in experiments where a period of prior exposure was necessary (parts b, c and d) were all allowed a period of acclimation of at least fifteen days before use. Three tanks containing the trout were maintained at cyanide concentrations of 0.05, 0.03 and 0.01 ppm, as well as a fourth receiving no poison for the control fish.

The cyanide was fed through a multiple pump built for this purpose which was capable of feeding a number of solutions simultaneously. Concentrations of the required strength were made up in carboys using tap water and fed to a mixing funnel at the rate of 15 ml. per minute. This concentrate was diluted with a flow of 4 litres per minute of water giving the required strength of solution.

The effect of exposure to sublethal concentrations of cyanide (part b) was investigated for fish having varying histories of cyanide exposure, to determine whether the prior exposure would alter their sensitivity to cyanide. For this purpose, two polyethylene wash basins were used as test chambers and a flow of 1.5 litres per minute of dilution water was run to each basin. The dilution water was mixed with a cyanide solution of the required strength, pumped from a reservoir at 15 ml. per minute. The cyanide solutions were made up in distilled water with the pH adjusted to nine.

Time-to-death was determined for fish at three lethal levels of cyanide, 0.5, 0.4 and 0.3 ppm, using fish previously exposed to the cyanide levels of 0.05, 0.03, and 0.01 ppm, as well as a control group (part b). Each experiment was run with a group of five fish, and two experiments were performed for each lethal cyanide level. When each experiment involving previously-exposed fish was made, two control fish were marked by removing the adipose fin, and these were placed in the test chamber as a further control.

For purposes of these experiments, death of fish, as indicated by lack of opercular movement for a period of thirty seconds, was used as an end point. Fish were periodically returned to clean water and none revived. The fish in these experiments were continually watched and removed for weighing and measuring as they died.

The effect of exposure to sublethal cyanide concentrations on the ability of fish to perform work (part c) was investigated by requiring fish to swim in a rotating chamber until they are unable to maintain the required speed. Ten fish from the control group and ten from each of the exposure concentrations were used. The order of testing these forty fish was determined from a table of random numbers.

The apparatus used consisted of a circular glass chamber 12½ inches in diameter, with a second smaller cylinder 6 inches in diameter forming an inner core (Fry 1948). The circumference of a point midway in the swimming chamber was 2.5 feet, and this was considered as the distance a fish swam in one revolution.

The chamber was turned by an electric motor connected to a variable speed gear which adjusted the rate of revolution.

The procedure used in evaluating the ability of the fish to perform work was determined in the following manner. The chamber was filled with six litres of water or cyanide solution from the influent mix to the tank in which the fish had been held. One fish was quickly transferred from the appropriate tank and placed in the chamber where a short interval was allowed for the fish to become accustomed to the new surroundings. The chamber was then set in motion and the fish was required to swim steadily for consecutive four-minute intervals at speeds of 20, 28 and 36 rpm. The speed was then increased to 45 rpm and kept there for as long as the fish was able to maintain its position. If the fish dropped back, it was tapped on the tail with a stirring rod to keep it from moving around with the chamber. In this way it was encouraged to swim until unable to maintain its position and consistently dropped back (four revolutions) despite the stimulus of the stirring rod.

For the purposes of this experiment, the ability of the fish to do work was considered to be the length of time it swam at 45 rpm. For those unable to attain the speed of 45 rpm, a minus quantity was assigned, depending on the time the fish swam at 36 rpm. Thus, if a fish swam only three and one-half minutes at 36 rpm, a value of -0.5 minutes was recorded, while 2.5 minutes was recorded for a fish swimming two and one-half minutes at 45 rpm.

No supplementary aeration of the water was used as the oxygen level did not enter the range where the ability to swim would be affected (Graham 1949). A maximum drop of 1.2 ppm from near saturation was noted in the chamber for the fish swimming the longest time. A stream of refrigerated water was passed over the outside of the glass to maintain a temperature of 8.8 ± .2° C. in the chamber during the period of the experiment. Fish used in these experiments had a mean length of 12.0 cm. and a mean weight of 17.9 gm.

The rate of effect on activity from exposure to sublethal cyanide concentrations (part d) was investigated by placing five fish that had had no previous contact with cyanide in concentrations of 0.05 ppm and determining the effect on immediate contact and after exposure for one day, four days and twenty-nine days. In a similar fashion, the activity of fish that had been exposed to 0.05 ppm cyanide for forty days was measured upon immediate return to fresh water and after one day, four days and twenty-four days. Fish used in these experiments had a mean length of 12.5 cm. and a mean weight of 19.9 gm.

OBSERVATIONS

Survival Experiments

Figure I is a plot on a logarithmic scale of the relationship found between cyanide concentration and time-to-permanent-turnover for fish unacclimated to cyanide. Each point represents the arithmetic mean of observations on ten fish.

The line expressing the relationship between time and concentration appears to have two slopes. Between 0.40 ppm and 0.10 ppm, the log time and log concentration are linearly related. At concentrations of more than 0.40 ppm, the fish lived a longer time than would be expected from examination of the line for lesser concentrations. This curve shown at the higher levels of cyanide appeared to become asymptotic and represents some minimum time required for a fish to die that becomes independent of the cyanide concentration.

The dependent phase of the curve (0.10 to 0.40 ppm) may be described by the equation used by Herbert and Merkens (1952):

$$n \log C + \log T = \log k,$$

where C is concentration in parts per million, T is survival time in minutes and n and k are constants. The constants of the best fitting straight line are $n = 3.48$ and $\log k = -0.26$.

For purposes of calculation, the experiment at 0.08 ppm cyanide was not included as the point at 5220 minutes is the time of permanent turnover of the fifth fish and not the mean, because mechanical failure terminated the experiment before complete mortality occurred.

The minimum lethal concentration of cyanide occurs between 0.08 ppm and 0.05 ppm, the former being demonstrated as lethal and the latter as not lethal in at least forty days. As the expected turnover time from the equation described for fish in 0.05 ppm cyanide is approximately thirteen days, the linear relationship cannot reach this concentration under the experimental conditions of this study. It is apparent that the

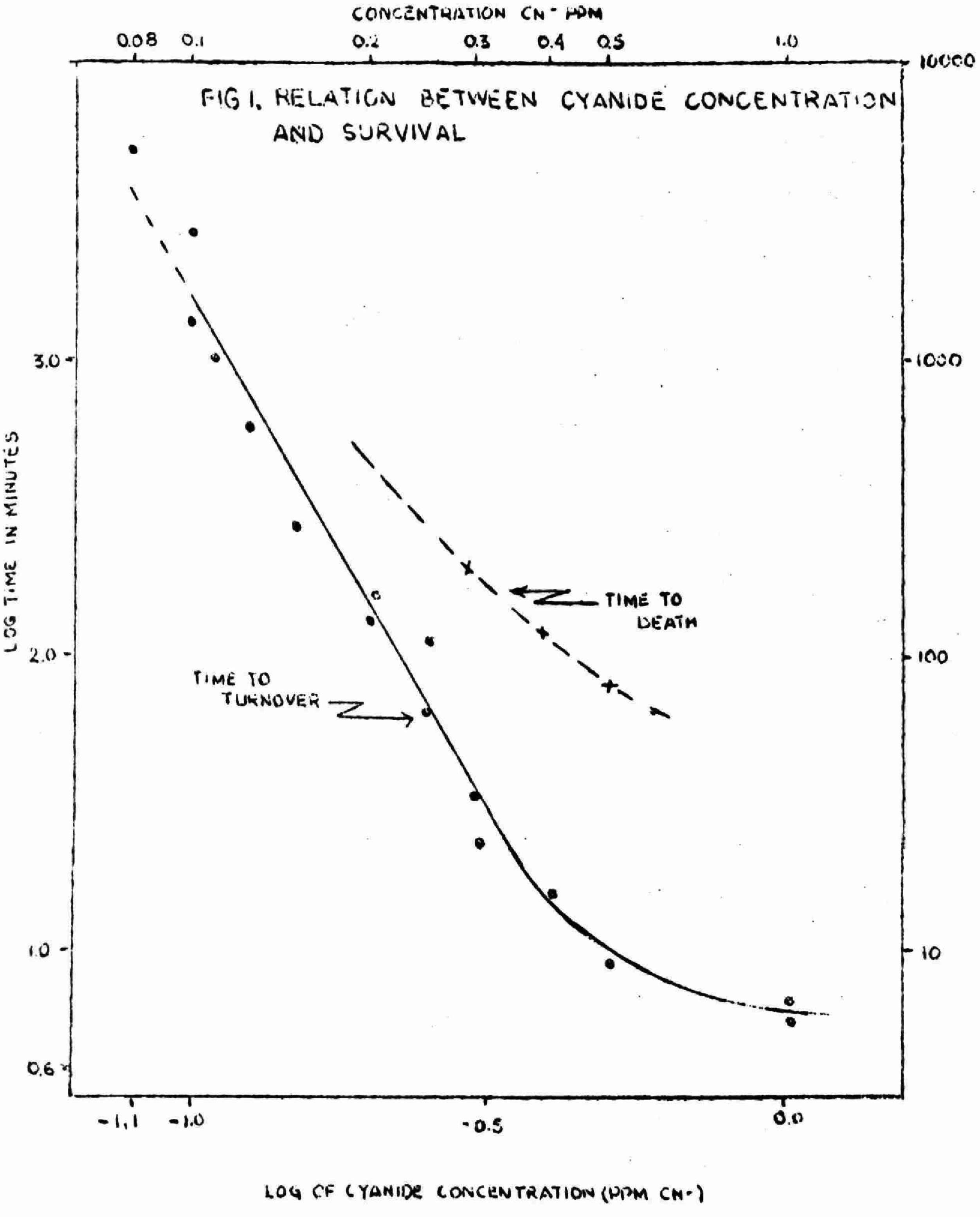

FIG I. RELATION BETWEEN CYANIDE CONCENTRATION AND SURVIVAL straight-line relationship continues only to some point between these two values where a break occurs and the fish are no longer completely incapacitated by the cyanide.

Fish subjected to the various cyanide concentrations used in these experiments showed typical reactions within various ranges of cyanide levels. At concentrations of 0.50 ppm or more, the fish turned on their sides in a few minutes and remained on the bottom of the chamber. When stimulus was applied, erratic swimming would occur, but they would shortly settle to the bottom. At the times indicated in Figure I a stimulus would fail to excite the fish and the end point of the experiment was reached. At concentrations between 0.50 and 0.25 ppm, the fish dropped to the bottom on their sides within a few minutes, but after a period of repose, all the fish would regain their equilibrium and remain in an upright position until they turned over for a second time. When this occurred, the fish soon lost their response to stimulus and were removed from the chamber. In those experiments conducted at concentrations below 0.25 ppm, there was no loss of equilibrium for a protracted period of time. When it did occur, any recovery was of short duration and was soon followed by permanent turnover.

At concentrations of 0.50 ppm and greater, the time-to-permanent turnover has been described as approaching a constant which is presumably the minimum time that is necessary for fish to reach the end point regardless of further increases in the cyanide concentration. This minimum time is approximately five minutes. A similar observation was made by Shepard (1955) for trout exposed to lethal concentrations of oxygen where a minimum time-to-death was observed to be fifteen minutes. In describing his data, a linear relationship was shown at all concentrations when the minimum time-to-death was subtracted from the total time observed. When the same procedure is followed for the cyanide data (Figure II) using five minutes as the minimum time-to-permanent-turnover, the relationship approaches linearity for all concentrations. The points for the highest concentration are still somewhat off the line, but these observations may be slightly in error because of difficulties in interpreting the end point where turnover occurs so rapidly.

Subsequent to the investigation of the relationship of reaction time to cyanide concentration for fish unacclimated to cyanide, a study of the effect of prior exposure to sublethal cyanide concentrations on survival was undertaken.

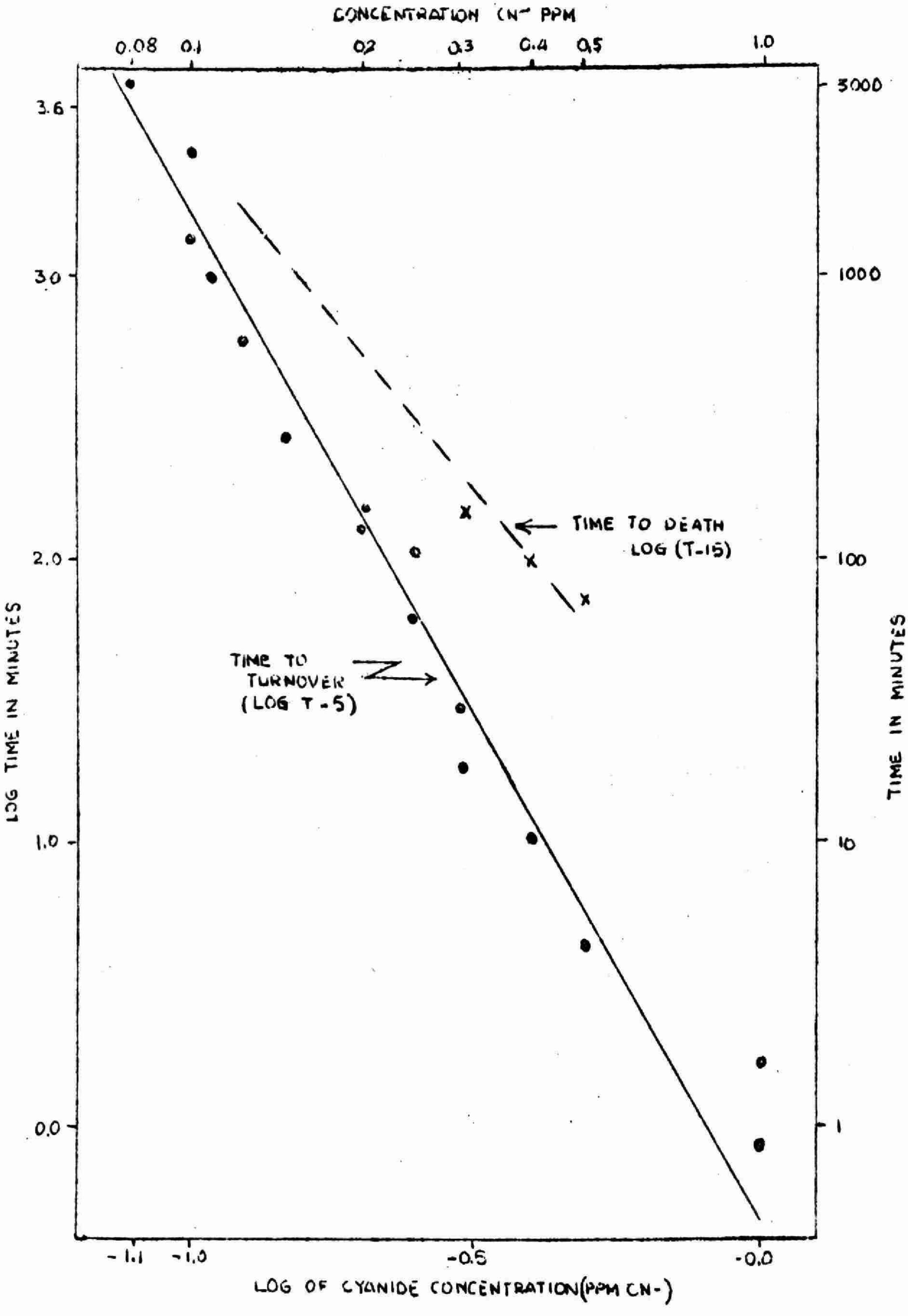

FIG. 2 RELATION BETWEEN CYANIDE CONCENTRATION AND SURVIVAL

(PLOTTED AS T-5 AND T-15)

From the results illustrated in Figure III and IV, it was noted that a change in resistance was developed by fish exposed to the three cyanide levels to which they were acclimated. When the four groups were subjected to 0.50 ppm, the controls lived the shortest time, while the time-to-death of the groups previously exposed to cyanide varied inversely with the concentration of their acclimation.

The same order was observed for the fish killed at 0.40 ppm. The order changed, however, when the fish were killed at 0.30 ppm, as those having an acclimation history of 0.05 and 0.03 ppm became less resistant than the controls while the 0.01 acclimated fish remained more resistant. Thus, while fish show a resistance to cyanide, at higher concentrations this advantage is lost at the lesser concentrations where the time-to-death is longer.

Activity Experiments

The ability to do work of fish acclimated to small amounts of cyanide was observed to be notably reduced (Figure V). The mean swimming time for control fish was 25.5 minutes at 45 rpm, while fish subjected to 0.05, 0.03 and 0.01 ppm swam only 0.4, 2.5 and 6.1 minutes, respectively. Thus, if the swimming time at 45 rpm (112 fpm) is used as a basis of comparison of ability to perform sustained labour, a reduction is noted of approximately 98%, 90% and 75%, respectively, of that of the controls.

When fish that had had no contact with cyanide (controls) were placed in the activity apparatus and required to perform work under the standard conditions previously outlined, little or no hesitation was shown or accessory stimulation required at any of the swimming rates. They took up a position in the chamber and swam steadily until the point of exhaustion was reached. Fish which had been exposed to the highest (0.05 ppm) cyanide concentration differed markedly in their behavior in the activity apparatus. Most of the fish appeared reluctant to swim, and even at the slower speeds stimulation was required to prevent them from rotating with the chamber. Of the ten fish tested, five were unable to complete the time required at the third speed. Fish at intermediate concentrations (0.03 and 0.01 ppm) were physically somewhat better able to perform work, although the same recalcitrance in putting forth the required effort was evident.

Because of the serious effect noted on the

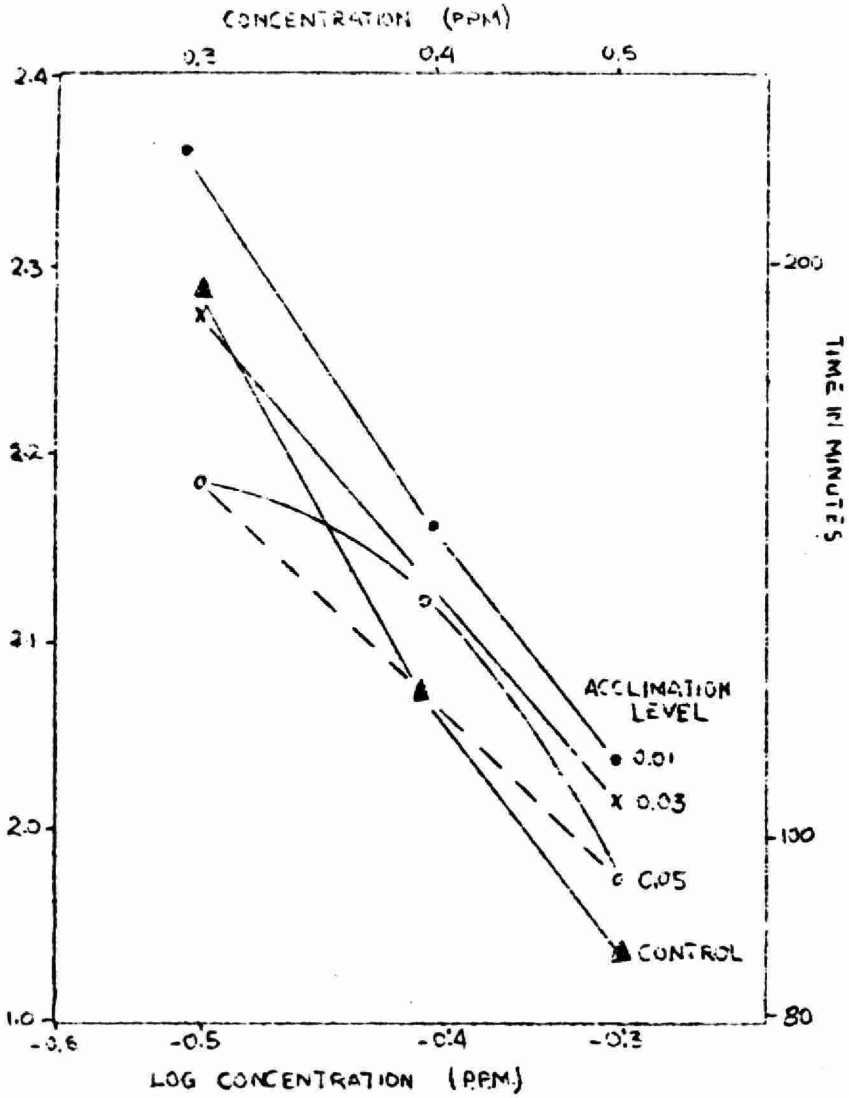

FIG. 3

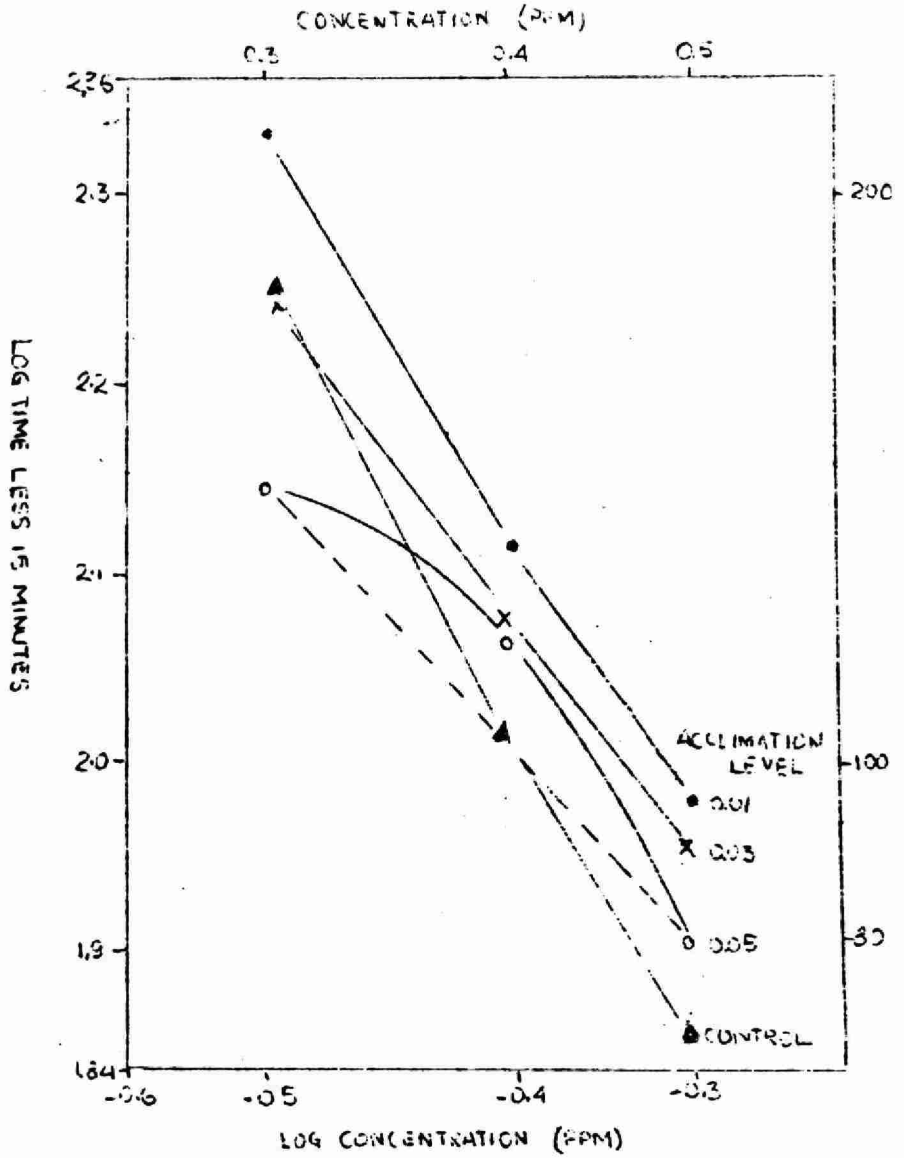

FIG. 4

EFFECT OF ACCLIMATION ON SURVIVAL

MEAN RESISTANCE TIMES FOR FISH ACCLIMATED TO SUBLETHAL CYANIDE LEVELS THE KILLED AT THREE LETHAL LEVELS

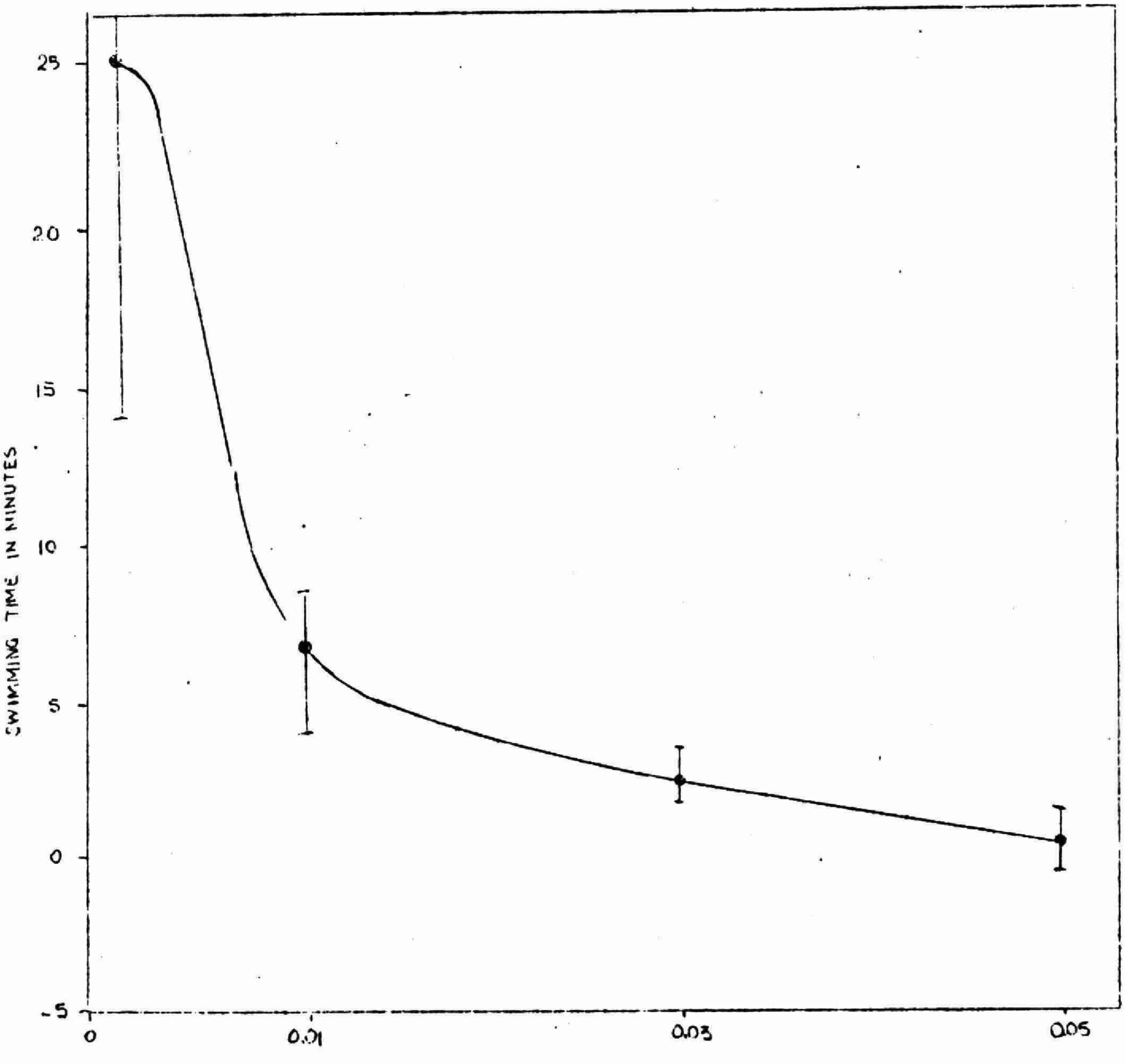

FIG. 5

EFFECT OF CYANIDE ACCLIMATION ON ENDURANCE

MEAN SWIMMING TIME AT 45 RPM (112 F.T/MIN) FOR FISH ACCLIMATED TO CYANIDE AND SWIMMING IN CONCENTRATION OF ACCLIMATION ability to work of fish that had been exposed to the sublethal cyanide concentrations for a relatively long time (twenty-nine days or more), information on the rate at which fish were affected and the rate at which they returned to normal was desirable. Figure VI illustrates the findings of experiments used to derive this information. It was found that the fish from clean water were rapidly affected by exposure to 0.05 ppm cyanide, for after only twenty-one minutes contact (i.e. twelve minutes preliminary swimming plus nine minutes at 45 rpm), they were only able to perform about one-third of the work of the controls. After one day in the exposure tank, the ability to work had been reduced by 95%. Only a slight further reduction was noted for fish that had been exposed for twenty-nine days.

The rate of recovery for fish placed in clean water after a prolonged exposure to 0.05 ppm cyanide was slow. Some immediate improvement was noted (from 0.3 to 3.3 minutes) when the fish swam in clean water, but no further recovery occurred after one day. After four days, the fish were able to swim 7.7 minutes (30% of the controls), and after twenty-four days, 20.0 minutes (80% of controls).

It was of interest to note that two of the five fish that had been in the clean water for twenty-four days still swam only a relatively short period of time, i.e. 6.4 and 9.2 minutes. These fish had retained the dark colour typical of fish exposed to cyanides over a period of time, while the remaining three had returned to their natural colour and swam twenty-two or more minutes.

DISCUSSION

Cyanide enters the blood stream of fish through the gill. Respiration in the cell is inhibited by the cyanide and death occurs when the first essential function breaks down. This is generally considered to take place in the nervous system.

The effect of cyanide in inhibiting respiration within the cell would suggest that the behaviour of fish dying from the effects of cyanide would be similar to fish suffering from hypoxia. The behaviour of speckled trout subjected to various lethal oxygen concentrations (Shepard 1955) is almost identical to the behaviour of trout dying from lethal amounts of cyanide. In both cases where the most unfavourable conditions are encountered, the fish react by violent activity before dropping to the bottom where death shortly ensues. In a middle range of lethal concentrations (i.e. for cyanide 0.40 to 0.25 ppm), in both cases the fish also drop to the bottom and lose

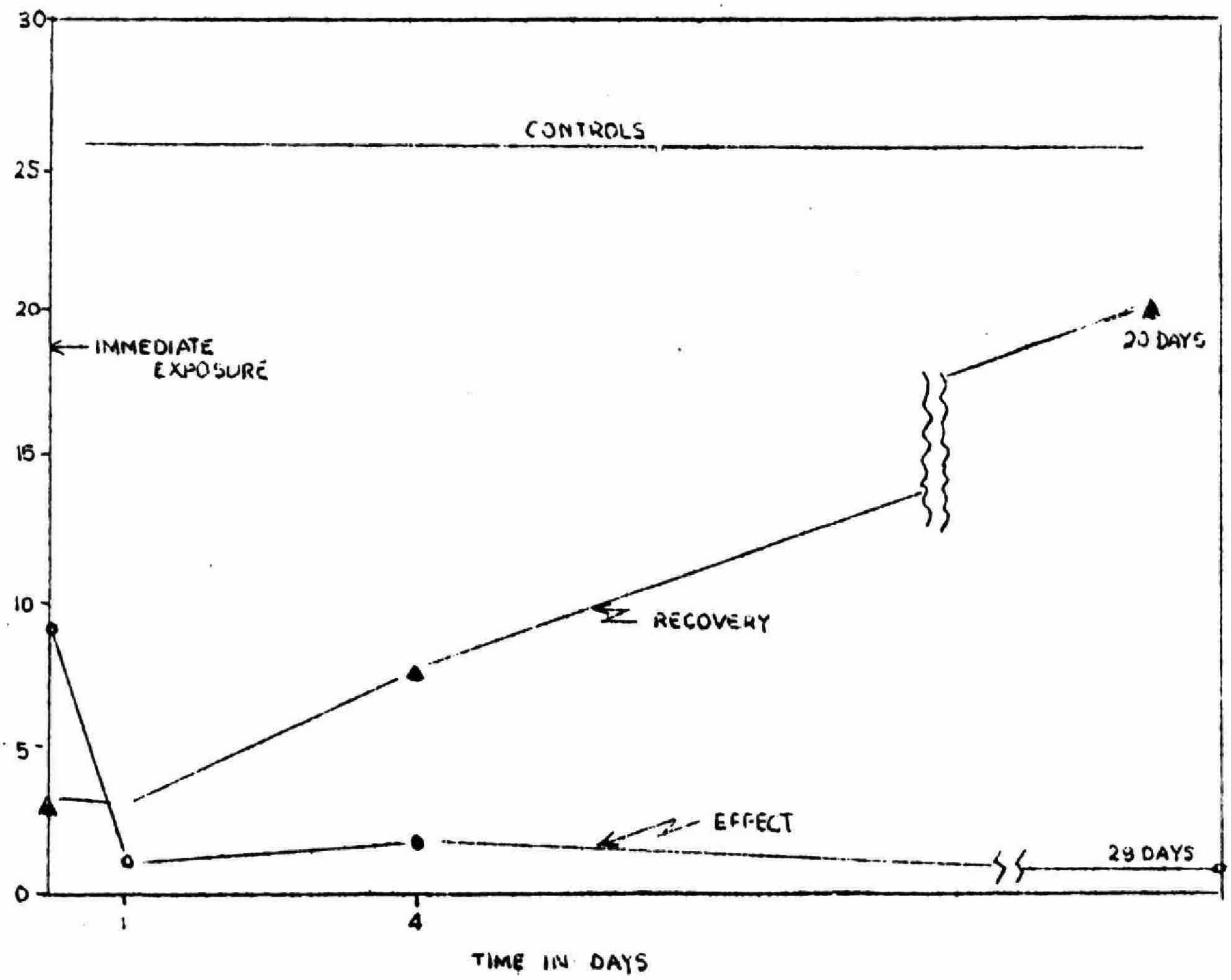

FIG. 6 RATE OF EFFECT AND RATE OF RECOVERY

EFFECT - INDICATES SWIMMING TIME OF FISH EXPOSED TO 0.05 PPM CN- FOR INDICATED PERIOD

RECOVERY - INDICATES SWIMMING TIME OF FISH EXPOSED TO 0.05 PPM CN- FOR 38 DAYS THEN TESTED IN CLEAN WATER their equilibrium, but recover. Later there is a second loss of equilibrium and death occurs. Where death does not take place for a protracted period of time, this first loss of equilibrium does not occur and when the fish finally overturn, death follows soon after. These observations suggest that cyanide and oxygen deficiency cause death by inhibition of the same body function.

A number of references are available in the literature on the toxicity of cyanides where experiments were carried out in standing water under a variety of environmental conditions using various species of fish. Because of a loss of cyanide from the standing water and absorption by the fish, the results of these experiments are not comparable to those carried out under constant flow conditions.

There are, however, two published papers by different authors that somewhat parallel the information presented on the relationship between time and concentration. Karsten (1934) used a continuous flow apparatus to determine the time-to-death of speckled trout at various cyanide concentrations. A lower lethal limit of 0.05 ppm was found where all of the eight, 6-inch speckled trout died after an exposure of 8000 minutes. Unfortunately, no information on the temperature or chemical composition of the water was published. While this lower lethal limit is somewhat below that found by Herbert and Merkens or by the author, the use of larger fish under less favourable environmental conditions might well reduce the lethal limit to concentrations of this order.

Herbert and Merkens (1952) describe the results of a series of experiments using the rainbow trout (Salmo gairdnerii) in a continuous flow system where the time-to-permanent-turnover was determined in various concentrations of potassium cyanide. Between the concentrations of 0.25 ppm and 0.07 ppm, a linear relationship between log time and log concentration was found. At concentrations of more than 0.30 ppm, the time-to-permanent-turnover did not conform to their equation, and became independent of the concentration. While the species and size of fish and the temperature differed from the experiment herein described, the nature of the curve is much the same. The somewhat different slope found by these authors is probably a reflection of the higher water temperature (Wuhrmann 1953) maintained in their experiments ($17.5 \pm 0.5^{\circ}$ C.). A lower lethal limit of 0.07 ppm cyanide was found to occur at approximately 4500 minutes. A further study of the independent phase of the curve by Herbert and Downing (1955) suggests that:

"a biological difference exists between the two regions into which we have divided the concentration-survival-time relation". Their data demonstrate that a correlation exists between factors causing turnover at the lesser concentrations (dependent phase), but that there is no correlation between factors causing turnover in the two sections of the curve.

While no specific investigation was made into the relationship between time-to-death and time-to-permanent-turnover, three points were determined for time-to-death from experiments performed in estimating the effect of prior exposure on survival. As would be expected, a considerable time difference was noted between these two criteria for the highest concentrations and proportionally smaller differences were noted at lesser concentrations (Figure I). The time-to-death points appear to have fallen in the curvilinear range of cyanide concentrations. These may be straightened by following Shepard's (1955) procedure, where the information is plotted as time-to-death less fifteen minutes (Figure II), the fifteen minutes being the minimum in which speckled trout will die at lethal oxygen concentrations. If these curves for time-to-death and time-to-permanent-turnover are extrapolated, the slopes should be such that they would intersect at a point representing the minimum lethal concentration. The slope of the line found experimentally on the basis of three points is somewhat in error, although the expected result is indicated.

The time-to-death relationships between the fish acclimated to the various concentrations of cyanide and their controls all appear to be curvilinear in nature (Figure III). For this reason, the results are plotted as T -15 to straighten the curves and render the interpretation of the data less difficult. With allowances made for some apparent experimental errors, straight lines of varying slopes appear to be developed. It is evident that some resistance in accordance with the level of acclimation is developed where the time-to-death is short. As time increases, however, it appears that the advantage of developed resistance is either lost or reduced. Where fish were killed at 0.3 ppm, those acclimated to the two higher concentrations were already more susceptible than the controls. The slope of the line for fish that had been exposed to 0.01 ppm would indicate that they too would have become less resistant than the controls had the time-to-death been extended.

The discussion thus far has concerned the lethal effects of cyanide by direct toxic action. If, however, fish die not by a direct toxicity but as a result of starvation, predation or other environmental factors because sublethal concentrations reduced the ability to perform necessary work, then this becomes the limiting factor in the success of a fish population. Such a condition may occur far below any demonstrable lethal effect and will probably worsen with factors that increase toxicity.

In this paper, the adverse effects of very small quantities of cyanide have been demonstrated on the ability of speckled trout to perform sustained labour. The restrictions are imposed almost immediately and rapidly become worse, while fish that have been exposed for a period of time recover only slowly over a number of days. The criteria used to evaluate the effect on ability toperform sustained labour (swimming time at 45 rpm) was not a maximum speed which the fish could attain, but corresponded to the cruising speed established by McCauley (ms. 1956). While the percentage loss in ability might not have been marked if a less demanding criteria had been used, it does indicate that where a considerable output of energy is required, fish which have been in contact with as little as ten parts per billion cyanide are seriously affected.

While proof has not been provided that such reductions in ability will necessarily eliminate a fish population, it may be assumed that any interference with activity will be deleterious.

In addition to the demonstrated lack of ability, all the fish that had been acclimated to cyanide did not respond well to the stimulus of the turning chamber and failed to settle down to swim effectively as did the controls. This was observed to occur before the fish were physically incapable of performing the task. The failure to swim under the strong stimulus that was provided might well indicate an effect which under natural conditions would be more serious than physical inability.

A relationship appears to occur between the effects of acclimation on survival and the effects of acclimation on the ability to perform work. An apparent loss of a portion of the oxidative processes makes the animal less resistant to lethal cyanide concentrations and incapable of performing sustained labour. The deficit incurred is proportional to the concentration of acclimation.

The bio-assay technique for determining safe levels of discharge of toxic industrial effluents has recently come into general use. (Hart et al 1945), (Doudoroff et al 1951), (Henderson and Tarzwell 1957) established a standard procedure which suggests one-tenth of the forty-eight-hour median tolerance limit as a concentration safe for discharge. This figure was suggested with the assumption that a margin of safety would be provided, although little information was available on the effects of toxic substances below the levels known to kill fish.

From the data presented on time-to-permanent-turnover and cyanide concentration, the forty-eight-hour median tolerance limit would be approximately 0.09 ppm. If one-tenth of this concentration is applied to Figure III illustrating the effect of cyanides on activity, it will be noted that this amount of cyanide will reduce the ability of trout to swim by about fifty percent. It is, therefore, apparent that the suggested safe level of discharge of toxic substances may not be sufficiently low for cyanides.

These experiments have included information for only one toxic substance and for one species of fish at one temperature. The environmental conditions under which the work was done were purposely made as favourable as possible, so that other adverse conditions would not interfere with the information obtained. Under natural conditions, such a favourable environment may not occur. For this reason, estimations of safe concentrations of toxic substances must be made on the basis of the most unfavourable conditions likely to occur.

Other fish and other toxic substances may or may not indicate similar effects, but their investigation by methods outlined in this paper seems necessary to determine whether the observations made in these experiments are valid for other toxic substances. If they are, and the restrictions on activity noted in these studies may be considered sufficiently deleterious to a fish population to warrant the establishment of minimum concentrations on this basis, then a convenient method of determining this information has been established.

SUMMARY

1. Experiments were performed to investigate the effects of potassium cyanide on speckled trout Salvelinus fontinalis at both lethal and non-lethal concentrations, using fish 9.5 to 13.0 cm. in length, temperatures of 8 to 10° C. and oxygen concentrations of greater than 80% saturation.

2. A linear relationship was found between log of time-to-permanent-turnover and log of cyanide concentration between 0.10 and 0.40 ppm. This relationship may be expressed by the equation:

   $$n \log C + \log T = \log k,$$

   where C and T are concentration and time and the constants $n = 3.48$ and $k = -0.26$. At concentrations greater than 0.40, the time-to-turnover is independent of the cyanide concentration. The minimum time in which permanent turnover occurred was found to be approximately five minutes regardless of the cyanide concentration.

3. Speckled trout acclimated to sublethal cyanide concentrations and killed at lethal concentrations were found to be more resistant than the controls when the time-to-death was short. When death did not occur as rapidly, the fish became more sensitive than the controls, the extent of sensitivity depending on the acclimation level.

4. Fish acclimated to sublethal cyanide concentrations were tested for their ability to perform the labour of sustained swimming. At all concentrations tested, a reduction in ability and efficiency was noted.

5. The rate of effect on ability to swim was determined by requiring fish that had not previously contacted cyanide to swim in 0.05 ppm. A notable immediate reduction in ability was observed and further reductions were found upon testing on subsequent days. Fish acclimated to this concentration were found to recover gradually within a period of twenty days.

6. Increased sensitivity and reduced ability to perform work both suggest a reduction in the capacity of the oxidative processes which is proportional to the concentration of acclimation.

7. From the results of the activity experiments, it appears that the proposed safe concentrations of toxic substances as determined by standard bio-assay procedure may still exert a deleterious effect on fish populations and should be revised for cyanide. Further study is necessary to determine whether these observations are also valid for other toxic substances.

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BIOLOGICAL SURVEYS AS A TOOL IN INDUSTRIAL WASTE DISPOSAL STUDIES

- By -

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Industrial wastes are very varied in their composition, their origin and the types and magnitude of the problems they pose, but they have one common factor in that they nearly always find their way eventually to some body of natural water. It is usually at this stage that they make themselves felt as a problem and it is very often because in some way or another they are affecting the plants or animals that normally live in that body of water. This is the reason why biological surveys are a valuable tool in the study of Industrial Waste Disposal problems.

I intend to illustrate the use of Biological Surveys in Waste Disposal Studies by reference to three different types of surveys I have carried out in the past eighteen months for Canadian Industrial Organizations. I am indebted to those organizations for permission to make use of the material collected in these surveys in the preparation of this paper and I shall acknowledge each individually in its appropriate place.. Before I start on this, however, I want to refer very briefly to one or two basic biological principles which will be helpful in understanding the theoretical background to this work.

Figure 1 illustrates a very basic biological principle which applies widely in natural communities of animals and plants whether they be on land or in water. In this present case we are concerned only with the communities in fresh water.

The medium in which the plants and animals are living in this case is the water together with the chemical substances dissolved and suspended in it and the substratum, which may be rock, stones, silt, mud or perhaps some other material. The basic component in the biological cycle is always the plant forms, for these contain chlorophyll which alone has the property of bringing about the synthesis of carbohydrates from carbon dioxide and water in the presence of light. On this synthesis the whole of the food supply of both the animal and plant kingdom is based. The plants may vary from minute unicellular plants so small that the highest power of the microscope is required to see them, to very large plants, but they all have this ability to synthesise carbohydrates.

BIOLOGICAL CYCLE

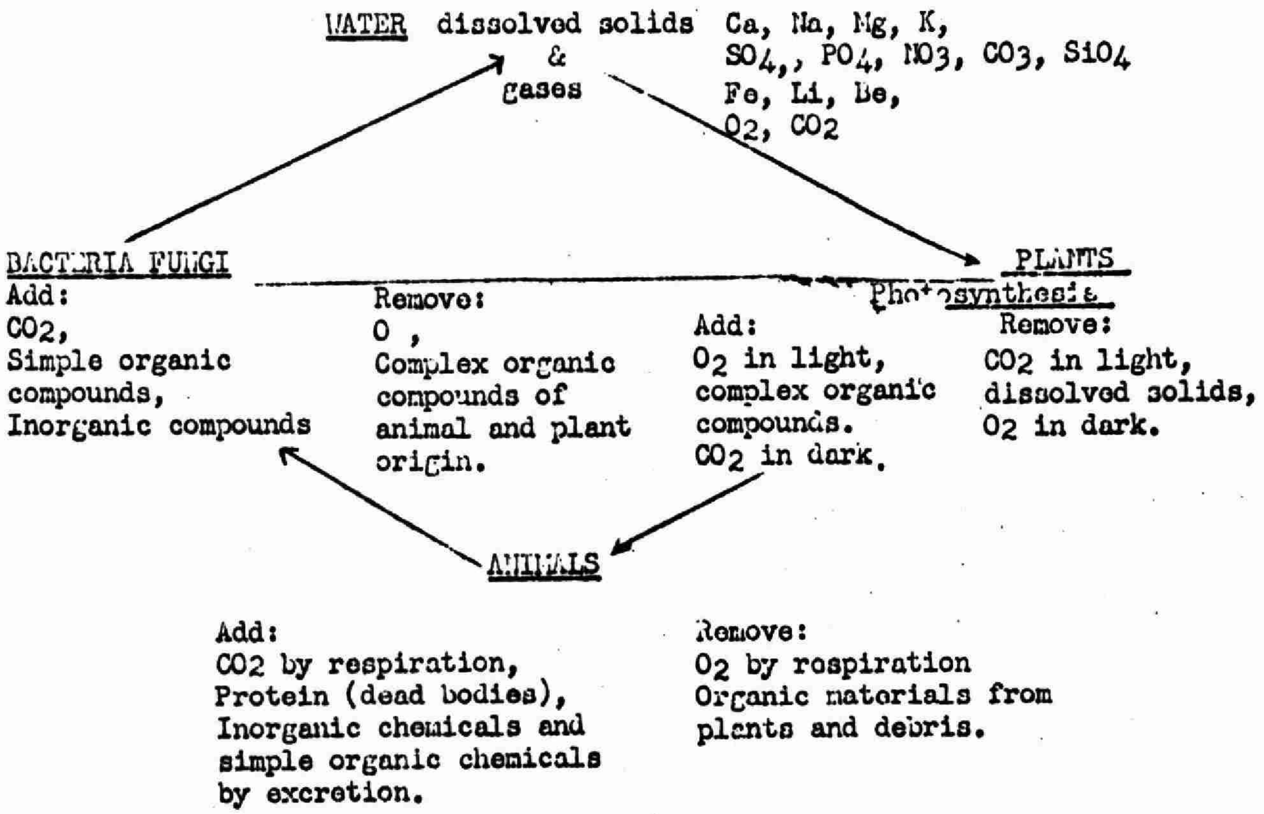

FIGURE 1

The next component is the animal community, in which again the individuals may vary in form and size over an enormous range, but all depend ultimately on the food synthesised by plants for their sustenance. In some cases the dependence is direct, as in the herbivorous animals, or secondary or tertiary as in the animals that eat other animals which in turn eat plants. In the case of others, such as the scavengers, it is even more indirect, but the connection back to plants can always be worked out. Within the animal community many complicated dependencies exist in the form of food chains, but we need not bother ourselves with these at present.

So far we have been considering only the synthesis side of the biological cycle, but if this were all there was to it, long before now all the available non-living material in the world would have been locked up in non-available living material. Another group, consisting principally of the bacteria and fungi complete the cycle, for these forms are concerned chiefly with the break down of complex chemical substances of organic origin to simpler, inorganic forms. In this way the materials absorbed through the plants and animals into living tissue are returned to the medium as chemicals available for re-use.

Under natural conditions this cycle of activities is always striving towards a state of mobile equilibrium in which material is being used and returned to the medium so as to maintain a rough state of balance. If however, something should occur outside the cycle to alter the balance, it is a fundamental natural law that the cycle of actions will change in such a way as to try to restore the state of equilibrium. If, to take a concrete example, some pollutive substance enters a natural water, it may adversely affect some of the plants and animals in the community and the immediate effect will be to throw the biological cycle out of balance. However, another set of changes will take place, for example, an increase of numbers of more tolerant species, to compensate for this and restore a balance. It is because biological communities behave in this orderly, although often complicated manner, that biological surveys can be a useful tool in studying the effects of industrial and other wastes.

In making use of Biological Surveys in waste disposal studies we depend on the fact that in any body of natural water that is not polluted, a certain type of animal and plant community will develop, the qualitative and quantitative composition of which will depend on many factors including the type of bottom, the chemical and physical properties of the water, the altitude and general geographical location and many others. Unfortunately our knowledge of these communities is not so detailed that we can foretell the details of the communities even if we know all about the environment. Fortunately it is not necessary to know the details of the composition of communities for every type of environment before practical use can be made of the surveys, because in most cases we are dealing with comparisons of samples taken above and below a source of contamination. It is necessary to know, however, if any changes we observe are likely to be due to the contamination, or to some quite unconnected circumstance.

We also make use of the knowledge that when a polluting material is added to a natural water, it will not usually, unless it is very severe, extinguish the entire animal and plant community but will change it either slightly or grossly according to the nature and degree of pollution. Again, we do not know enough in most cases to be able to take one set of samples and from it deduce the exact nature and extent of a pollution, but usually by methods of comparison, we can obtain a great deal of valuable information about it.

Before I go on to describe individual types of surveys I want to refer briefly to one more phenomenon, namely the property of natural self purification that all natural waters possess.

This property of self-purification is connected with the biological cycle I have referred to already. When a polluting material enters a natural water, the biological cycle changes in such a way that there is an increase in the type of organism which is capable of removing the polluting material from the environment by utilising it as a food supply. In this connection, living organisms have a quite amazing capacity for utilising unlikely materials as a food source and thus removing them from a natural environment, one example of which is the property of certain organisms that will develop on biological filters to utilise cyanide and phenols. In the course of this self-purification the water may become grossly polluted, and I am not advocating that this extreme extent of the property of self-purification should be utilised, but I am merely referring to its existance. The property of self-purification can be looked upon as a valuable natural resource, but like all natural resources it will retain its value only so long as it is not misused. Properly used it can be a great benefit to industries with waste disposal problems and therefore to the communities of which they are part. One of the values of biological surveys is to measure this resource and enable it to be used to good effect and to avoid its misuse.

The first Biological Survey to which I shall refer illustrates a situation where there is a long and complicated waste disposal history and the survey was carried out to help in assessing the extent to which a particular plant was contributing to the general load on a river known to have many sources of pollution.

This survey was carried out on the Ottawa river in the vicinity of Hawkesbury at the request of the Canadian International Paper Company, to whom I am indebted for permission to describe the results obtained. The survey was part of a comprehensive investigation which included also the testing in the laboratory of the effects of the effluent from this Company's Hawkesbury Dissolving Pulp Mill on various species of fish, and also an experiment in which fish were retained in cages in various parts of the river to test whether they would live there. Although it is not within the context of this paper to describe these other aspects of the investigation, I will just say that the results confirmed the findings in the survey.

The Biological Survey was carried out during the summer of 1956 and extended from a point about two miles above the plant to a point about six miles downstream of it. The Ottawa river at this point is large, with an average flow in the vicinity of 40,000 cu. ft. sec. A series of rapids starts opposite the plant at Hawkesbury and extends down river for about three miles. Below this the river enters a more placid stretch in which there is a fair depth and considerable variation of current strength. The physical conditions of the river in this lower stretch are comparable with those at the upper stations two miles above the plant.

The effluent from the plant enters the river on the right bank a short distance below the start of the rapids. It does not flow directly into the main river, but into a side channel formed by a group of islands.

The situation is complicated by the fact that the Ottawa river has many sources of pollution from the City of Ottawa downwards, so that by the time it reaches Hawkesbury it is in the recovery stage from these pollutions and also by the fact that the domestic sewage from the town of Hawkesbury enters the river untreated only a few hundred yards downstream from the plant effluent.

The river has no recreational or amenity use for the first three miles below the plant because the extensive rapids make it impossible to negotiate without great risk, and the upstream pollutions make it unsuitable as a source of domestic water without treatment. The most important practical problem was therefore to establish whether, the river, on reaching the more placid section, where it can be used, has recovered at least to the same degree as above the plant.

It was obvious that there was a strip of the river along the right bank immediately below the plant and town sewers which was adversely affected by the effluents from these sewers, and it was also desired to know the extent of this strip.

The biological survey consisted of taking a series of samples of the bottom of the river on two occasions during the summer from a point about two miles above Hawkesbury downstream to Chute-a-Blondeau about six miles below this town. The selection of sampling locations in this case was to some extent dictated by the physical nature of the river. It was quite impossible to sample the rapids, except at one point near an island where limited sampling could be done at some risk. Otherwise it had to be confined to the river above the rapids and below them except for marginal samples that could be taken from the bank.

It would serve little purpose to give the detailed results of these samples, so I will confine myself to describing briefly the overall picture.

The animal community living on the river bottom above Hawkesbury was generally typical of a river well into the recovery stage from a pollution. The principal animals were species of Asellus, Gammarus, Pisidium and Limnodrilus.

The samples immediately below the rapids were very similar generally except that there were more Hyallella than Gammarus and the worms mostly belonged to the family Naididae. Six miles below Hawkesbury at Chute-a-Blondeau the samples were almost identical to those two miles above the plant. The differences between the samples immediately above and below the rapids were small. There was a slight indication of a few more tolerant species below than above -e.g. Hyallella is thought to be more tolerant than Gammarus, but this would indicate only a small degree of difference, and it can generally be deduced that by the time the end of the rapids is reach the river has for all practical purposes recovered to the degree that it had above them.

The sampling also showed that the condition that existed immediately below the outfalls was restricted to a narrow strip along the right bank of the river and was aggravated by the fact that the fast water of the rapids tended to hold this water in against the bank until it reached the deeper water downstream, when eddy action induced mixing..

The second survey to which I want to refer differs from the first in that it concerns a new plant in an area where there is at present no pollution problem and the survey is being carried out to enable a close check to be kept on the situation and so avoid any problem arising. The survey is being carried out at Millhaven on Lake Ontario at the request of Canadian Industries Limited, who have been good enough to give me permission to refer to it, although the survey is not complete.

The plant concerned produces Terylene polyester fibre although additional chemical plants are being developed at the site. A new plant to produce ammonia has been built and will be "on stream" shortly. There is no polluting effluent from the Terylene plant, but as the Lake in this area has a high amenity value, the Company wished to have a thorough Biological Survey carried out, so that should any deterioration take place in the future there could be an early and reliable check on it.

In consultation with the Company's Chemical Engineering staff it was decided to make a thorough bottom sample survey, and to take sufficient samples to obtain results that would have good statistical significance. A programme was worked out which entailed taking six samples at each of eight carefully selected stations every other month for a full year, with single samples at each station on the alternate months. Samples were taken through the ice in winter by cutting holes about three feet square and lowering the sampling devices through them. In consultation with the Company's statistical branch it was decided that six samples gave results that would have good significance.

This survey has been under way for nine months and will continue for a further three. At the end of this time we shall have a very comprehensive picture of the biological conditions from a point in the Lake immediately opposite the plant outwards in all directions for about two miles. We shall know not only the species of animals in the bottom community, but shall have a record of their density and of the manner in which they vary in type and numbers throughout the season.

We shall also know how much variation can be expected due to chance differences in sampling and how much is necessary to indicate a significant change in the community.

It is too early to describe the results of this survey, but already one or two interesting points have come out of it. First we have found that there is a very considerable variation in numbers of animals from sample to sample even when taken at the same time and within a few feet, at the same location, although the bottom is remarkably uniform. This illustrates the importance of taking a sufficiently large number of samples at each point if any significance is to be placed on the numbers of animals present. We have also found that, except at one point where the bottom is different, there is a general similarity in the animal community over the whole area surveyed. This is very useful, because it means that any change in any part of the area could very easily be traced.

I am confident that this survey will produce results that will have great value in the avoidance of pollution problems in the future and which will be very interesting both to chemical engineers and biolgoists who are interested in pollution problems.

The third survey, like the second is at a new plant site where no actual pollution problem at present exists, but there are several differences in the circumstances which necessitated differences in approach. This survey is being carried out in Lake Nipissing and a stream running into it in the vicinity of North Bay. It is being done for Canadian Johns-Manville Limited, who have kindly given me permission to refer to it.

In this case the plant is an Insulating Board Plant using ground wood process. The plant is not situated directly on the Lake, but on a small stream that flows into it. Wash waters are being re-circulated, and an an illustration of the designers' confidence in their anti-pollution measures, the water intake for the plant is downstream of the effluent from it. In spite of this, because of the high amenity value of the lake in the area, and the Company's desire to maintain a very high standard in pollution prevention, it was decided to carry out a survey before plant operation so as to have reliable data against which to check later.

Due to the physical features of the site and the nature of the processes it was decided in this case to carry out a combined chemical and biological survey. Stations were selected in the stream above and below the plant site and in the lake at various distances from the point where the stream enters it. In this way a comprehensive picture is being built up of both the chemical and biological conditions in the vicinity of the plant throughout the area in which there could possibly be any effect from its operations.

This survey has just been completed and it is the Company's intention to continue the surveys after the plant is in operation for a period to make usre that there is no deleterious effect from its operations.

Apart from the major purpose of collecting data on the chemical and biological conditions, one or two interesting points have arisen out of the survey.

The stream is a small one and runs out of some marshy ground over a falls about 100 feet high, down a steep rapid section and opposite the plant becomes a deeper and slower one about one hundred yeards before entering the Lake. The water in the stream is very acid - pH 5 and very deficient in dissolved substances the result is a rather sparse animal population. The pH rises slightly before entering the Lake, which itself varies from neutral to about pH 7.5. Due to the fact that the stream has deposited a thick layer of sand over the lower part of the river and the bottom of the lake in an arc about half a mile radius from the stream mouth, there is very little animal life in all this area, although the Lake itself is a very fertile one, with a flourishing fishery. In order to obtain samples containing a typical number and variety of animals, I had to go more than half a mile from the stream mouth.

This is quite a significant finding, because one might have expected in a Lake with a known high fertility to find a bottom fauna consistent with it much nearer to the stream and had this condition been discovered by sampling only after plant operation there would have been a temptation to blame pollution from the plant for it. In fact it will be interesting to see what effect the plant's operation will have on this area. There will almost certainly be some rise in dissolved solids as a result of losses from the plant's ciculating system and it seems to me that there is just a possiblity that the productivity in that part of the Lake may be raised. This, however, is merely a guess and would need long odds to come off.

I hope that these three examples of the use of biological surveys in waste disposal studies have been sufficient to illustrate that it can be a useful tool. There are of course, other applications of biology to waste disposal, such as toxicity tests, tests of the behaviour of fish and other animals confined in polluted waters, studies of algal blooms, etc. There are also studies in related problems such as stratification in Lake and their effects on waste disposal. These, however, are outside the scope of this paper.

The biological Survey is, of course, but one of the tools available for waste disposal studies. It is a useful tool, but at the risk of over-stretching the metaphor, I should like to make it clear that it is still a "hand tool" that is effective only in the hands of an experienced craftsman; it has not yet reached the stage of becoming a "machine tool" that will give reliable results in an automatic machine. Every survey has something different about it from the one before and if the most is to be made of it, it must be carefully planned to obtain the most useful data with the minimum expenditure of time and effort. In this way biological surveys need not be unduly expensive to carry out, but unless they are carefully planned and carried out they can be wasteful. They are at their best when they are worked out together by the Chemical Engineer who understands his process problems and the Biologist who understands what is likely to be the relationship between these problems and what will happen under various conditions in the natural waters to which any effluents will find their way.

The Pulp and Paper Industry Pollution Abatement Program in the United States

by

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and

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Fourth Industrial Waste Conference, Ontario Water Resources Commission

Introduction

Stream pollution in Canada has not reached the highly developed stage that it has in the States and it appears that it will probably be many years before the problem assumes the proportions it has in the States. The reduced magnitude of the problem is undoubtedly due to (1) the different hydrological and meteorlogical conditions that prevail in the two areas and (2) the less heavily concentrated industrial development and population in Canada as compared to the States. I am not as familiar with physical conditions in Canada as I am with such conditions in the States. It does seem, however, that in view of these conditions and with the more favorable rainfall and stream flow patterns prevailing in Canada, this problem should not be as great as it is in the States.

Let me further develop this point with a few very general statistics from the pulp and paper industry. For instance, more than half the United States' wood pulp production is sulfate pulp and most of this production is concentrated in the deep South. For the past five years or so, many of our southern States have been plagued with abnormally low stream flows and rainfall. In one case the effluent of a large kraft mill is 19 times the volume of the receiving stream. In another case, and this is at one of the largest mills in the south, it has been necessary to reduce the consumption of process water from 15,000 to 9000 gallons per minutes due to sustained drought conditions. Obviously, where such abnormal conditions occur year after year, until the abnormal is looked upon as normal, an aggravated waste disposal problem is created.

For the benefit of those who are not as familiar with our activities I think, it would be in order for me to tell you just what National Council for Stream Improvement is - who supports it - how it operates and what services it renders. Following this, I will report rather briefly on some of the problems involved in our waste treatment activities, how these problems have been handled and finally, what has beeen accomplished in the paper industry in the waste abatement field during the ten years or so that our organization has been functioning.

WHAT THE NATIONAL COUNCIL IS

The National Council for Stream Improvment is a non-profit research and service corporation organized by the pulp, paper and paperboard industry for the purpose of developing solutions to the industry's waste disposal and utilization problems. In addition to our activities in the water pollution field, a study of the pulp and paper industry air pollution problem was initiated last year.

The National Council is supported by pulp, paper and paper board manufacturers in the United States and its operations are financed by dues assessed on a tonnage basis. It operates on a regional committee basis with a paid staff and with management functions centered in a central Operating Committee and a Board of Governors consisting of executives representative of the various broad types of pulp, paper and paperboard manufacture in the United States. It conducts research at regionally located research institutions and disseminates research and other technical information to the industry. It furnishes technical services directly to members on stream improvement problems through the medium of its technical staff and regional resident engineers.

RESEARCH ACTIVITIES

In the early days of our organization the primary accent was on research. This was necessary since at that time, some twelve years ago, there was little organized information on the subject of the treatment of pulp and paper mill wastes and it was necessary to build up a background of fundamental information in this relatively new field.

Accordingly, throughout the years, research projects have been established at a number of the country's outstanding research organizations including the Mellon Institute of Industrial Research, the University of Michigan, Virginia Polytechnic Institute, Rutgers University, Louisiana State University, Purdue University, Oregon State College, the Institute of Paper Chemistry, Kalamazoo College, Bates College, University of Georgia, University of Maine, and Columbia University. Most of these research projects are still being carried on, although some of the institutions mentioned have completed certain phases of their work and new projects have been inaugurated. The projects at these various insitutions deal with waste disposal problems which are of particular interest at the mills in and adjacent to the area in which the research institution is located.

Times does not permit discussing these research projects individually but it would be, I think, of interest to outline the general procedure followed in organizing these projects. The investigation of the prior art and the preparation of a complete bibliography is the first task assigned to the research group. Following this, detailed analyses are made of samples of the waste obtained from adjacent mills to determine its pollutional characteristics. At the same time the Council's technical staff and industry technicians examine the immediate problems at hand. Concurrently, the technical staff recommends certain laboratory investigations based on their knowledge of the waste and their past experience with wastes having somewhat similar characteristics. Any procedures which show promise in the laboratory are explored further in what might be called bench pilot plants and following this, if they still look promising, the procedures are further investigated in larger scale pilot plants, generally at the mill site.

SERVICES TO MEMBERS

Our Board of Governors has long subscribed to the policy that research is merely a means to an end. Expanding this premise, it follows that if the research findings and developments are not applied to actual industry operations, the value of the entire program is nullified, or at best is only of minor and temporary public relations value. In our case, implementing this policy has required that we establish regional engineers in each of the regions of the United States to consult with members and assist them in applying research and pilot plant developments to their actual mill operations. We have six such resident engineers strategically located from New Jersey to Oregon and their services are available to members entirely without charge. They render a variety of services, including mill waste surveys, stream surveys, consultation on local pollution problems and the preparation of preliminary waste treatment plant designs. These engineers each commonly answer as many as one hundred services calls a year and were it not for this service, which due to the cooperative aspects of our program it is possible for us to furnish free to members, expenditures by mills for such services would be many times the actual cost involved to the Council.

I believe it would be of interest to those present to summarize very briefly our procedure in handling individual and local pollution situtations.

HOW LOCAL POLLUTION PROBLEMS ARE HANDLED

An engineer's first visit to a mill which has requested his services is generally of an exploratory nature. In this first call he obtains the details regarding the local problem that is, the nature of the complaint, observes the general situation in the receiving stream and at the same time, investigates the facilities that the mill may have for dealing with the situation. In many cases it is found that no survey of the quantity and characteristics of the mill's waste has been made and, in fact, in some cases provisions for measuring the flow have never been made. Frequently, mill sewers must be re-arranged to permit sampling the waste at various points. Where necessary the engineer provides the mill operators with drawings for the installation of weirs and other devices for measuring and sampling the waste.

Following this, samples of the waste are taken at proper intervals from the various mill sewers and these samples are either analysed on the spot or taken to the laboratory for analysis. Generally the waste is analysed for suspended and settelable solids, BOD, pH, etc. Sometimes it is necessary for a stream survey to be made to arrive at a full understanding of the problem. In this case, the engineer establishes sampling stations along the stream and tries to arrange to sample the stream at average low flow. Such a survey may require several weeks to complete and the data obtained may include time-of-passage studies and the analysis of samples for pH, alkalinity, dissolved oxygen, BOD, color, turbidity, suspended solids and sometimes additional values. All of these activities are carried on in cooperation with the mill technical personnel, the local regulatory agency representative, and consulting engineers who may be engaged in similar activities for the mill management.

With these data in hand the engineer can forecast with considerable accuracy the improvement which can be expected in the stream from any given degree of treatment. Knowing how much money the mill can afford to spend on waste treatment facilities and having these data, then, and then only can a waste treatment plant be designed that can reasonably be expected to meet the requirements of the situation and still fall within the range of economic possibilities.

Much the same procedure is followed in evaluating the new mill sites which, incidentally, is a very important function of our organization, as obviously the logical time to consider pollution problems is before mill construction starts. In new mill site evaluation surveys, a more elaborate streat survey is required as the location of dissolved oxygen sag-points and other critical conditions resulting from existing and further loads must be determined and evaluated in view of existing and future stream usages.

POLLUTION PROBLEMS IN THE PULP AND PAPER INDUSTRY

I stated earlier that I would comment on some of the problems encountered in pulp and paper mill waste treatment. Obviously, this must be done very generally since we have in the United States nearly a thousand pulp and paper mills located in forty different states, with each state having its own individual set of laws or regulations relating to stream pollution control. While it can be said with considerable accuracy that each mill must be considered as an individual case, there are, nevertheless, certain problems which are more or less common to the majority of mills.

The outstanding problems that we have had to deal with fall in several categories. These are:

1. Solids removal.
2. Sludge dewatering and disposal.
3. BOD reduction.
4. Toxicity.
5. Color removal.

Solids Removal

Most stream pollution difficulties resulting from the discharge of paper mill solids are due to the presence of fairly coarse suspended matter, largely fibre and other organic debris. A large portion of this will settle at low stream velocities, causing the usual problems associated with benthal deposits.

On the average, for the paper or board mill without wood pulping operations, the suspended solids average about 100-300 ppm and the BOD about 20-200 ppm. In the pulp mill, suspended solids may vary from 50-150 ppm with BOD's ranging from 200-1000 ppm.

New equipment and processes are constantly being developed and with such equipment and processes, reductions of 70-90% of the suspended matter is possible without the use of coagulants. The use of coagulants will accomplish the settling of virtually all the suspended solids.

The equpment available consists of flotation and clarification devices, sedimentation basins, diatomaceous earth and vacuum filters and other equipment. For certain types of paper mill waste, sedimentation basins offer the most economical solution.

Much has been said regarding the financial attractiveness of recovery of fibre and other materials. However, recovery of fibre beyond a certain point is not profitable, but imposes an actual cost on the manufacturing operations. Also, clarification of some of these wastes imposes a problem since residues are not suitable for re-use and interfere with the manufacturing process or reduce product quality.

Sludge Disposal

Frequently, waste is encountered in certain types of mills which, while presenting no problem of clarification, does present an extremely difficult sludge dewatering and disposal problem. The common method of disposal of these sludges is lagooning in earth embanked lagoons. These are filled with sludge which is allowed to compact, following which supernatant water is syphoned off. The residue is allowed to dry to a point where it can be collected by means of a bulldozer or drag line and hauled to a dumping ground. This represents a considerable difficulty at many mill sites located in highly developed and congested area where no disposal grounds are readily available.

B.O.D. Reduction

Solids removal which is practised quite generally by mills throughout the United States, unfortunately has a minor effect in reducing the B.O.D. of the waste since the B.O.D. is largely encountered in the dissolved solids portion of the waste rather than in the settleable solids portion.

Stream pollution problems resulting from the discharge of wastes high in oxygen demand to receiving streams with insufficient oxygen resources are too well known to require enumeration here. The development of downstream oxygen sag-points which adversely affect aquatic life, recoreational uses and contribute to the development of odour and other nuisances are common under such conditions.

We recognize the importance of this problem but despite the expenditure of hundreds of thousands of dollars on research in the laboratory and on pilot plants, no economically feasible and universally applicable device to effect significant reductions in the B.O.D. of certain pulp mill wastes has as yet been developed.

During the past ten years, The National Council for Stream Improvement has spent over $150,000.00 on research relating to the reduction of the B.O.D. of pulp and paper mill wastes. Some of the treatment processes investigated include trickling filters such as used for treating domestic sewage, anaerobic and aerobic decomposition, heat hydrolysis, methane gas production, fodder yeast production, alcohol production, aeration, the use of oxidation catalysts and employment of waste liquor for soil conditioning and composting. None of this research has as yet resulted in the development of a practical process for treating certain pulping wastes and, in many cases, the processes investigated would require treatment plants equaling the mill in size and rivaling it in cost.

Considerable progress has been made in the sulfite industry in converting to a different cooking bases with some reduction in B.O.D. Here, however, the conversion cost is high and frequently beyond the financial resources of many established sulfite pulp mills. It also should be pointed out that many problems still remain to be solved in such conversions, including evaporator scaling difficulties, corrosion troubles and the possibility that the operation of the process will create an air pollution problem more serious than the original stream pollution problem.

A great deal of progress has been made by the industry in effluent disposal practices to minimize the effect of the oxygen demand of the effluent on the receiving waters. Lagooning of various types of waste is being successfully practised and the use of certain waste liquors for road binding is also successfully employed. In the final analysis, however, the B.O.D. problem is unsolved and this problem is expected to continue to vex the industry for some time to come.

Toxicity

Certain constituents of some pulp mill wastes, when occuring in abnormally high concentrations in the receiving stream, have toxic qualities to fish and other aquatic life and this problem has been intensively investigated.

Fortunately, however, most of the mills who effluents possess this undesirable quality are located on streams where large quantities of water are available for dilution and this prevents the toxic constituents from reaching concentration harmful to the aquatic environment. Research has indicated that in cases where a dilution factor of 20 to 1 is available, the concentration of toxic constituents does not reach harmful levels. In other cases where this fortunate situation regarding stream flow does not exist, efforts have been devoted to devloping automatic methods for detection of critical concentrations and reduction of the concentration of toxic materials by pre-treatment.

Generally speaking, toxicity to aquatic or other life is not now a serious problem to the industry although oxygen depletion to a point where aquatic life is inhibited can be a problem under adverse stream flow conditions.

Color

We do not look on color in waste receiving streams as a pollution problem in the strictest sense of the work. In many streams, particularly those in the south, the water is highly dis-colored due to natural causes, the highly colored appearance being brought about by the presence of decayed vegetation. In such streams the presence of pulp or paper mill wastes may or may not cause additional dis-coloration. In many cases, however, the stream, regardless of whether it receives waste from industry, may be high in dissolved oxygen, have low turbidity and have an abundant aquatic life. The un-informed public may, and in fact does, consider discoloration as evidence of pollution, hence consideration must be given to this problem despite the actual high quality of the water considered purely from a technical viewpoint.

This problem is of most importance to us in the deep south and a considerable portion of our research funds is being devoted to its solution with considerable success having been achieved in developing remedial measures on a laboratory basis.

In general, in the paper industry the construction of waste treatment plants is expensive due to the large volume of waste which must be handled. Some of the larger units in the pulping industry are required to dispose of an effluent the volume of which may amount to as much as 15 to 20 million gallons per day. To treat this waste is must first be held at some point in the system for several hours. This may require providing a tank or basin having a capacity of a million or more gallons. This, together with the necessary piping, valves, pumps, instruments and other accessories, represents a formidable investment in itself and the actual waste treatment mechanism must in addition be provided.

In concluding, I think it proper to make some brief report on the accomplishments of our organization and the industry in pollution abatement.

WHAT HAS BEEN ACCOMPLISHED

Approximately five years ago a National Association of Manufacturers survey of water usage and waste treatment in industry showed that 37% of all paper mills in the United States had waste treatment plants. Since then the construction of waste treatment plants in the pulp and paper industry has proceeded at an accelerated rate. A recent survey of 329 mills by the National Council staff indicated that 180, or 55% of the mills in the survey sample, have constructed waste treatment plants of one type or another. This indicates substantial pollution abatement, particularly when it is considered that many pulp and paper mills are fortunately situated at locations where abundant flows is receiving streams or tidal water discharge make waste treatment plants unnecessary. Based on this recent survey it can be conservatively estimated that the industry has spent in the neighborhood of $75,000,000 for waste treatment plant construction over the past 10 years. While comparable data for other industries are not available it is doubtful if any other industry in the United States has made expenditures of equal magnitude for waste treatment facilities.

It is not my intention to report the progress made on a state by state basis, but a few highlights will indicate the trend. In Pennsylvania, for instance, practically every pulp and paper mill in the state has a waste treatment plant. In Oregon and Washington, where most of the sulfite pulp production of the country is situated, the pulp mills have, by revised effluent disposal practices, reduced the volume and strength of the wastes discharged in critical stream areas by 60%

over the past five years. All of the de-inking mills in Michigan and Massachusetts have installed, waste treatment plants. In the great kraft pulping industry which, incidentally, produces more than 50% of all the wood pulp produced in the United States, the mills over the past ten years, by better recovery methods and other in-mill changes, have reduced the B.O.D. of their wastes on the average from 150 to 30 pounds of B.O.D. per ton of product. In addition , many mills located in critical areas have installed waste treatment lagoons or other treatment devices. These improvements are typical of improvements made in other sections of the country and by other segments of the industry, and are of great significance when the growth record of the pulp and paper industry is considered.

Under the expanding domestic economy of the past ten years, which saw all-time production records established by the pulp andppaper industry during almost each successive year, paper and paperboard production increased by 50%. During this period which, indicentally, coincides with the period that the National Council for Stream Improvement has been in operation, the total pollution load of the industry did not increase, but rather showed a small decrease. This is merely another way of saying that over the last ten years, pulp and paper industry pollution per ton of product has been dedreased by over 50%.

We in our industry feel that this is a decidedly worthwhile accomplishment and I believe that the pulp and paper industry recognizes the contribution our organization has made in accomplishing this desirable result.

Waste Handling Problems Common to the Canadian and U. S. Canning Industries

by

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Introduction and Background

In the course of making a comparison between the waste problems in Ontario and in the States it first becomes evident that there is no wide divergence of products handled in the two countries, therefore the waste characteristics are comparable. Since the majority of the Ontario canning area lies within short distances of the shore lines of Lakes Erie and Ontario, the growing season can be compared with Michigan, Northern Ohio, and Upper New York State.

We then can surmise that there are no major differences in the waste produced in the canning industries of Ontario and the United States. The relatively minor differences would appear to be in the status of legislation and enforcement. Rather than to include a detailed discussion of these differences it will suffice to state that in many areas of the United States legislation and enforcement was initiated many years ago, while in Canada such steps are in somewhat earlier stages.

Some of the background of the experiences encountered in the States may be helpful in this discussion.

Work in the canning waste field in the United States began nearly 30 years ago with the first state-level legislation and enforcement aimed at stream pollution abatement. Since that time there have been steadily expanding activities both by the state agencies to strengthen and enforce the legislation and by industry to meet the treatment demands. Requirements for stream pollution abatement are brought about by public demand which is administered through the various state agencies. The approach of the state agencies to these problems generally has been constructive. The importance of industry to the economy is usually recognized, yet it has become necessary to impose waste treatment requirements. The canning industry has maintained a cooperative relationship with the various state agencies in attempting to supply mutually satisfactory solutions to the problems encountered.

To examine the background of the U.S. Canning Industry let us quote a few over-all statistics. The 1956 pack of canned foods was almost 700 million cases containing more than 21 billion tin and glass containers. The retail value of these products is estimated at over 4 billion dollars. In the canning industry alone production workers receive annual wages amounting to over 350 million dollars. Canners provide employment at peak seasons for about 500,000 persons, and the many related industries - suppliers, distributors, transportation companies, retail establishments - multiply that total many times. Canners annually pay to the agricultural producers of raw products about one billion dollars.

The total National retail expenditures for durable and non-durable goods during 1956 amounted to 167 billion dollars. The 4 billion dollars expended on canned foods represents 2.5 percent of the total, or in other words, 1 dollar in every 40 was spent on canned foods.

To produce 700 million cases of canned food annually the canning industry is estimated to use some 36 billion gallons of water. Although it is true that the water consumed by the canning industry represents only some 0.1 percent of the total industrial water usage the organic content makes the waste equivalent to about 10 times the actual volume.

In terms of the organic load produced in the canning industry's waste the annual biochemical oxygen demand is estimated to be 500 million pounds.

At this point it must be stated in defense of industry that this half billion pounds of B.O.D. represents only the potential organic load to the nation's streams.

In reality only a small portion of the total load ever enters the water courses due to existing treatment practices. Estimates of the ultimate total B.O.D. contributed to the streams are not available. Improvement in the degree of treatment provided by the industry has been steady and is expected in the future to continue in the same direction.

Let us review briefly the sources and character of waste from typical canning operations. Water is used for transporting the raw product and for product transfer within the process, washing at various stages of the operation, make-up of brines, syrups, etc., cooling, and steam production. With the exception of that used for production of steam and the comparatively small amount of water which enters the product, the water used in a canning operation eventually finds its way into a drain as waste. All water leaving the canning plant is contaminated to some degree by organic matter. Spillage of product, brines or syrups; settleable, suspended and dissolved solids contributed from soaking, washing, trimming, grading, or fluming make up the bulk of organic contamination.

Cooling water usually is contaminated with organic matter to such a minor extent that treatment is unnecessary. Thus it is seen that the waste for disposal, with the exception of the brines, syrups, or seasonings, is actually composed of portions of the product carried in a water medium.

Over a period of years there have been interesting trends observed in methods of handling the food products with resulting water consumption variations. Twenty years ago it was commonly considered that to produce the average case of canned product, 25 gallons of water were required. During the intervening years canners have constantly attempted to improve the quality and handling of the product by means that have generally meant the use of more water. Today the average water consumption is nearer to 50 gallons per case.

Now the thinking is beginning to point in another direction. The over-all water needs in the United States and Canada are increasing at a tremendous rate. The enormous industrial potential of Canada will intensify the water supply problem in the future. Even the popular press is now devoting considerable space to the anticipated crisis. The industrial demand by 1975 is expected to be more than double that of today. Domestic demands also increase steadily. It is foreseeable that there may be a serious water supply crisis in the present generation. All industry must realize these prospects and plan accordingly. An example of this is the concentrated effort now being carried on for conversion of sea water to fresh water.

There is reason to believe that the tendency for more efficient use of water with resultant savings will be accentuated in the near future. In the canning industry it means that we must look for a return to 25 gallons of water per case and even less, while still improving the quality of the product.

As might be expected, any decrease in the unit amount of water used intensifies the waste treatment problem. B.O.D. concentrations increase although essentially the same total weight of organic load is present. Where water is not available for dilution, higher B.O.D. concentrations can mean considerably more difficulty in treatment. Therefore flexible planning is necessary to cope with future treatment requirements.

Waste Treatment Costs

As is characteristic of the food industry, much of the canning industry operates on a low profit margin. Therefore waste treatment, which is generally considered as a non-productive expenditure, is viewed with little enthusiasm, especially by those producers who maintain seasonal operations. Frequently those with year-round operations find it easier to justify waste treatment costs since the total gross sale of their production in comparison with seasonal operations may appear considerably different for similar treatment facilities.

Recent estimates show that the total cost of waste treatment in the United States including capital investment and operating charges is in the vicinity of 2/3 cent per case, which represents a total annual outlay of nearly 5 million dollars. However, this figure can be misleading. The reported national average cost of 2/3 cent per case includes the production from many plants at which essentially no waste treatment facilities are provided. If such plants are excluded from the estimates, the average treatment cost is believed to be within the 1 to 2 cents per case range. Ten to fifteen years ago a waste treatment cost of 0.1 cent per case was the estimate. Although production is rising the waste treatment costs are rising at a more rapid rate. The principal reasons are those stemming from the ever-increasing degree of treatment required. Increased labor and material costs have their effect but are secondary to the increased treatment requirements. Due to the changing concepts of necessary treatment facilities the unit cost of waste treatment may be expected to follow the present trend and increase substantially within the next few years.

A striking example of waste treatment cost trends is revealed in the records of one canning firm. During the 14 year period of 1922-35, total capital expenditures for waste treatment amounted to $25,000. This was during the very early stages of waste treatment requirements. During the next 10 years, as enforcement was beginning to be felt, the capital outlay was $100,000. The final 11 years to date show an expenditure of $500,000 for treatment facilities. Obviously the production rate did not follow the increasing spiral of waste treatment costs.

To anticipate future waste treatment requirements, think of a further increase of 600-700 percent to an average cost of 5 to 10 cents per case within the next few years. Add to this the fact that waste treatment, as a non-productive cost, will continue to lower the profit margin and increase the competition for the consumer's dollar. It then becomes increasingly evident that efficiency of operation will play an even more dominate part in canning operations.

Many industries find that recovery of usable or marketable materials is possible to offset at least a portion of the treatment cost. This has not been the case in the canning waste area. There are only a few "successful" recovery operations involving a limited number of products. By "successful" we mean that recovery of some fraction of the total waste is being conducted on a full scale basis with small regard to cost. There is little evidence that a financial profit is possible. The waste recovery field is another that should and must be explored further as treatment requirements increase in intensity.

Peculiarities of Canning Waste

The design of a treatment plant would always be simplified if uniform conditions could be anticipated. This is not encountered in canning waste treatment. The seasonal nature of many operations has already been mentioned, and the disadvantages of designing a biological treatment plant to operate two or three months a year are obvious.

Customarily a plant handles more than one product and at times will pack several simultaneously. Since each waste has characteristics dissimilar to others, the combinations of conditions causing variation can readily be seen. A good example of the difference is seen when the B.O.D.'s of the waste from various products are compared. Asparagus waste B.O.D. may be as low as 16 ppm. while pumpkin and squash waste B.O.D. may be as high as 11,000 ppm.

Other important waste characteristics affecting the design of treatment are variations in solids content, pH, volume, color, temperature, odor, and deleterious mineral content.

Waste Treatment Methods

The following listing includes the general classification of treatment which have been or are being used at the present time:

1. Mechanical
    a) Screening

2. Chemical Treatment
    a) Chemical Precipitation
3. Biological Treatment
    a) Filtration
    b) Aeration
    c) Impounding Lagoons
4. Land Methods of Disposal
    a) Impounding Lagoons
    b) Absorption Beds
    c) Ridge and Furrow Irrigation
    d) Spray Irrigation
5. Discharge to municipal sewer systems.

Screening

Screening is minimal treatment and is nearly universal. At some plants screening is the only treatment used, but in a great many instances screening is a form of pre-treatment. Only the larger floating, settleable or suspended solids are removed, therefore with many products only slight B.O.D. reductions are accomplished. In fact, canning waste analytical data refer to screened samples unless otherwise noted.

Both rotary and vibrating screens are used satisfactorily. Cloth with openings finer than 40 mesh is not commonly used except on some of the circular vibrating units.

Chemical Precipitation

Chemical precipitation following the general principles of water treatment was a logical early step and was well accepted some 15 to 20 years ago. Only suspended solids can be removed, hence the B.O.D. in solution is not affected. As a result maximum B.O.D. reduction limits of 25 percent with fruit waste and 40 to 50 percent with vegetable waste could be expected. In actual practice most reductions fell far below these standards. During this early period such minimum efficiency was satisfactory in many areas, however it soon became evident that primary treatment would not be adequate. As a result chemical precipitation is almost extinct today and can only be recommended at certain plants where a low degree of primary treatment will suffice.

Biological Treatment

Biological forms of treatment were next considered. At this time biological treatment methods were common in the municipal sewage treatment field, and it seemed logical to apply these principles to industrial wastes.

Early attempts at the utilization of standard or high rate trickling filters for industrial wastes met with variable degrees of success. Treatment of combined domestic and industrial wastes is now standard practice where the design loads are not appreciably exceeded. Treatment of canning waste by biological filtration has been done with disappointing results the general rule. Several reasons for these failures are apparent. First, canning waste usually is deficient in mineral nutrients necessary to the functional organisms. Nitrogen accounts for the principal deficiency, although phosphorous, potassium and a number of trace elements are also critical. Correction of these deficiencies must be made by supplements to the waste.

It may also be necessary to make pH adjustments of some wastes in order to maintain the proper environment for the organisms.

The most serious deterrent has been the fact that it is necessary to make a continuous application of waste for a period of several weeks prior to the canning season in order to develop the complex biological growth on the filter medium. Waste must also be applied continuously thereafter. It can be seen that these conditions are not always easy to provide. A year-round packer may find it possible to meet those requirements, but usually a seasonal canner cannot.

Compared with domestic waste treatment, proportionately more filter capacity is necessary for canning waste due to the much higher B.O.D. concentration.

Shock loads of high B.O.D. waste have serious detrimental effects on the valuable bacterial flora inhabiting the filter medium. It has been found that certain groups of bacterial cultures acclimate themselves to limited B.O.D. ranges and when marked deviations in environmental conditions are encountered these organisms are damaged.

Finally the cost is prohibitive for seasonal operations. As a result there are very few such filtration treatment facilities used.

The other biological treatment method of primary importance involves the use of air to supply oxygen to a group of organisms which feed on the organic material in the waste. Various names are applied to this form of treatment such as activated sludge, straight aeration, total oxidation, etc.

Two major factors have been important in the slow acceptance of aeration in the canning industry - the high capital investment required and in many instances the elaborate degree of control necessary to maintain balanced, efficient operations.

Recent experimental work with aeration has indicated that under certain limiting circumstances the method can be applied in a simplified form to obtain a high degree of purification, provided that the cost of treatment can be justified. Aeration appears particularly promising where a canner's waste admittance to a municipal sewer system or water course is dependent on the waste B.O.D. level being within the general range of normal domestic sewage. Under these circumstances the aeration would be a form of pre-treatment.

At the present time the commercial use of aeration is limited to a very few installations. It is predicted that with the increasing requirements for efficiency of treatment, aeration will be utilized further.

Land Methods of Disposal

During the early years it became evident that land forms of disposal were desirable, and as a result several methods of land treatment have been used.

Lagoons first became popular, although today there is less enthusiasm for their use than in earlier years. Lagooning is merely the holding of liquid waste (usually after screening) in a single open pond or reservoir or series of such containers. In reality lagooning combines biological and land methods of treatment. Organisms naturally present in the soil utilize the organic matter in the waste to satisfy their food requirements, thereby providing biological stabilization.

Advantages of lagooning are the relative economy, ease of handling the waste, and under adequate design conditions the elimination of stream pollution.

Disadvantages include the amount of land utilized, possible contamination of ground water supplies, and odor arising from gases produced in the stabilization process. In many instances the odor problem becomes the critical factor. It is then necessary to resort to odor control measures, which vitally affect the economics of treatment.

A number of materials have been used for odor control. Nothing has been found to give complete control, although with proper application some alleviation may be expected. Sodium nitrate in amounts ranging upward from 200 pounds per thousand standard cases has been used extensively. Little success has been experienced with the materials variously described as "enzymes" or "bio-catalysts". Many odor masking agents have been tried. If used in sufficient quantity these materials, containing highly aromatic qualities, actually become the predominate odor. Unqualified endorsement cannot be given to these materials due to mixed reactions of those evaluating the results.

Other land forms of disposal were tried in the lagoon era. These included absorption beds and ridge and furrow irrigation.

Absorption beds had very limited application due to the exacting conditions necessary for success. Wastes are flooded under controlled conditions onto shallow beds or flat land areas and allowed to percolate into the soil. A primary factor for successful odor free operation is the maintenance of rapid percolation. The waste must be free from soil-clogging particles. The ground must be essentially level to obtain even application when flooding. Sufficient area must be available for a system of rotation to allow drying. Ground water contamination is also a factor.

Ridge and furrow irrigation requires conditions similar to absorption beds except that level land is not necessary. The system includes a series of furrows fed by one or more header ditches, all of which follow the existing ground contours for gravity flow. Controlled intermittent waste application is made to the furrows to allow filling and absorption. Advantages and disadvantages are similar to the absorption bed method. There are only a few ridge and furrow irrigation systems in use today for total plant waste, although in recent years extensive use of this method has been made in disposing of pea vine ensilage juice.

About ten years ago the disadvantages of the treatment methods then in use led to the adaptation for waste disposal purposes of the long established overhead sprinkler irrigation as used for agricultural purposes. Since that time the trend has been toward conversion to spray irrigation, until at the present time in some areas more than half the canners use this system.

There are several reasons for these changes. Inadequate degrees of treatment due to increasing requirements, odor problems, the ever-present stream pollution problem, the prospect of large expenditures for questionable biological treatment methods, and the relative simplicity of operation are factors influencing the changing trend.

Spray irrigation if properly designed and operated satisfies the requirements of present-day treatment methods. Complete treatment is provided; odor problems are eliminated or minimized; stream pollution is not present if runoff does not occur; the costs when compared to complete treatment are reasonable; and no highly trained personnel are required to control the operation.

Spray irrigation is nothing more than agricultural overhead irrigation using waste as a water supply with one basic exception in operational practice. This fundamental difference is that in agricultural irrigation a minimum amount of water is spread on a maximum land area while in waste irrigation the reverse is true. The engineering principles of application are the same, however.

There are numerous specific requirements and limitations affecting the operation of a spray irrigation system. It is not adaptable to winter operation in the northern areas. Those who do winter canning usually employ combined lagoon-spray irrigation systems. Winter wastes are stored until weather conditions permit spraying.

Sufficient land area is quite important. With known waste flows and average rainfall records it is possible to conduct a soil survey for basic data to design the necessary area.

A vegetative cover crop is necessary for several important reasons. Without an adequate cover to break the fall the water droplets fracture the bare soil particles to produce fines which effectively seal the surface and encourage erosion. A cover crop supplies countless flexible openings in the soil by the root system. The growing plant with its moisture utilization by the evapo-transpiration phenomenon is responsible for considerable water loss to the atmosphere. A reasonable figure for the amount of water transferred from the soil system during the growing season by evapo-transpiration is 8,000 gallons per acre per day. If a six-day rest period were provided between applications, evapo-transpiration would account for nearly 2 inches of 48,000 gallons of water per acre per day transferred to the atmosphere during one spraying cycle. Bare soil is responsible for only a small fraction of this amount.

Many crops have been used as covers. Some of these include alfalfa, clover, the tall grasses, the low or dense grasses, grain crops, and wooded land. The latter has allowed very high application rates although certain tree species have been susceptible to damage from excessive water and also from bark scoring by the water streams. Of the open land covers the best all purpose crops suitable to the northern United States latitudes have been the low or dense grasses such as the fescues and blue grasses.

In instances where peas, corn, or other canning crops have been tried for cover the tendency has been to overwater and damage the plants. As a result moisture limits should be more carefully controlled with crops of this type.

Canning waste treated by spray irrigation is usually screened to prevent pumping and nozzle clogging problems. The usual rotary or vibrating screen is satisfactory. However there has been some recent work aimed at including all the solid waste with the liquid. To accomplish this it is necessary to comminute the solids and reintroduce them into the liquid waste. The possibility of eliminating the costly solids separation and disposal operations is an incentive as is the added fertilizing potential to the soil. There are at the present time mechanical problems remaining, and further studies are necessary to evaluate the system.

In a spray irrigation system standard pumping facilities are used. These include electric, gasoline, diesel or liquid propane as sources of power. Frequently it is necessary to pump to the spray site with one operation and pump through the irrigation system with another.

Irrigation fields seldom adjoin the plant and many times are more than a mile distant. Common types of pipe are used - uncoated steel, galvanized steel, aluminum, wood, asbestos-cement, concrete, clay, cast iron, or plastic. The economics and waste characteristics govern the selection of the pipe. Usually the laterals which are moved at regular intervals are of a convenient light material such as aluminum.

Where the waste is moved from the plant to a sump in the field, the sump generally is designed to hold only 30 to 45 minutes of plant flow. In this way fresh waste is assured and odor problems are minimized.

Uniform coverage of the spray area is accomplished by designing the area and pipe layout such that each lateral will be moved at frequent intervals to allow a rest period before returning to the original site. Six days is considered to be a reasonable spray interval.

Spray nozzles are self-actuated, revolving sprinklers of various sizes. The very large sprinklers are adaptable to wooded areas while the smaller sizes are best suited to open fields. However nozzle openings less than 1/4 inch are not recommended due to clogging nuisances.

In summation it may also be said that spray irrigation is not without its problems. Ground water contamination is a persistent consideration. Either inadequate area or poor management is often responsible for ponding and run-off. Land costs are frequently unreasonable. Distance to suitable and available sites is often a factor. Recently it has also been noted in a few instances that odor controlling procedures have been necessary due to objections from fresh waste.

Discharge to municipal sewer systems

This brings us to the practice of disposal of canning waste directly to municipal sewage treatment plants. Where possible and permissible this method is by far the most logical and eventually the most economical. Unfortunately the majority of canning plants are located in or near communities which do not have adequate facilities to handle the additional load created by the waste.

In a municipal system there usually is a charge assessed for handling industrial wastes. The present sewer fee trend for industrial waste is on the basis of (1) volume, (2) pounds of B.O.D. in excess of that normal to domestic sewage, and (3) suspended solids in excess of that normal to domestic sewage. Any one or combinations of these factors may be used as the basis for charges.

Future Considerations

We have already observed that the future will see greatly increased requirements for all industrial waste treatment. We have also noted that in the foreseeable future the water supply crisis throughout the two nations will make necessary waste treatment to the potable water level. It is then logical to predict that industry as well as municipalities will be faced with fantastic costs to obtain such treatment degrees. Indeed we can foresee such water shortages and competition for the supply that regulated controls will be necessary.

How can industry meet this challenge? First, there must be concentrated efforts aimed at water economy and increased efficiency of water usage. Work of this nature is presently underway in the Western United States but only on a small scale. A great amount of research is necessary to anticipate and meet the critical problem before it is too late.

Second, there must be widely expanded work to develop new and improve existing waste treatment methods to obtain the efficiencies that eventually will be required. Expanded research activities is the solution to this problem. More investigators must be attracted to the waste treatment field. More funds must be made available for this purpose. More interest must be shown by top management.

Further, the cooperative approach to those problems is necessary. All agencies concerned with the water and waste problem must join in looking for solutions to the problems common to industry and municipalities. Those in the various industries, the research organizations, the conservation groups, the municipal officials, the state regulatory authorities, the Provincial Officials and the Federal and Dominion Governments should develop closer working relationships to get the most good from the available facilities. The benefits from such research studies should be made available to all those interested.

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ECONOMIC ADVANTAGES BY IMPROVED SLUDGE CONDITIONING AND VACUUM FILTRATION

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Introduction

Waste treatment has undergone considerable improvements in technology since the time when treatment practices were thought of solely in terms of burial and stream dilution. Now, when municipalities and industrial firms are planning waste treatment plants, the results of years of research and development on waste treatment are at their command. Data on almost every phase of treatment is becoming more readily accessible in the publishing of more accuarate and complete operational reports by municipal plants as laboratory methods of analysis continue to improve.

In the past few years extensive work has been accomplished on laboratory filtration techniques and analyses, and these methods have been presented to treatment plant technicians and chemists through the literature,(1,2,3,4). Also some information has been published regarding techniques to be used for proper filter operation in the treatment plant (4,5). However, relatively little information is available on correct filter application, and as a consequence, new treatment plants are usually designed to employ equipment which is working satisfactorily in nearby plants, and design rates are calculated by applying a safety factor to the average performance of plants which employ similar equipment (6).

This technique is fundamentally sound and has worked for the majority of plant equipment. However, when filters are designed on this basis there is no assurance that the plant influent contains the same type of solids on which the design calculations were based, and in many cases, sludge characteristics are such that filtration is troublesome at best. This condition has induced some treatment people to believe that filtration is to be avoided as much as possible.

The troublesome conditions that arise which tend to discourage filtration are usually one or more of the following: (1) rapid media blinding, (2) low cake rates, (3) high cake moistures, and (4) high chemical consumption. These conditions are mainly prevalent in activated-digested or digested-elutriated plants where difficult sludges with a low solids content are usually encountered. In most cases, primary sludge filtration is generally considered devoid of the troubles mentioned due to the large particle size of the solids and the usually high solids content of the sludge.

One of the major reasons for much of the four troublesome conditions concerns the effectiveness in the sludge conditioning prior to filtration. Unfortunately, the result of improper flocculation is evidenced not in the conditioning tank but rather in the poor filtration operation, and the filter therefore appears to be performing badly. Thus, in many cases the high costs resulting from media blinding, low rates, high cake moistures, and excessive chemical dosage should be attributed to the conditioning step, rather than the filter. Therefore, an investigation of flocculation techniques was undertaken to determine the proper chemical addition procedure for optimum sludge flocculation.

A secondary, and equally important, cause for the occurrence of filtration difficulties is the poor discharge normally encountered with thin cakes, coupled with the inability to adequately clean the media on cloth-covered drum filters. Incomplete cake discharge on cloth filters results in a gradual build-up or accumulation of solids in the interstices of the media, which effectively blocks liquid flow through the media. This blinding action lowers the productive capacity of the filter in two ways. First, due to a partial blinding of the entire media, the pressure drop across the media itself is increased, and thus the portion of vacuum applied to the actual filtration of sludge is reduced. Consequently, the cake formation rate is lowered and the cake moisture content is increased. Second, due to complete blinding on portions of the media (media blinding generally begins near the caulking strips where the cake is the thinnest and progressively increases in coverage as solids accumulate), the effective filtration area is reduced and the productive capacity is lowered. In order to prevent the gradual blinding of the media, the accumulation of solids in the interstices of the media must be removed or prevented from forming. To do this, a complete discharge must be effected such that there is little chance for solids to adhere o to the media. Also, the filter should be designed in a manner that enables the media to be thoroughly cleaned without interruption of the filtration operation. Thus, by employing a filter which embodies these principles in its design on difficult sludges, sludge filtration should be greatly improved resulting in a more economical operation.

In order that this theory might be tested, filters at several sewage treatment plants which were encountering difficult filtration with their particular sludges were converted to the Rotobelt type filter. This filter incorporates in its design provisions for removal of the filtering medium from the filter drum surface, such that the medium may be passed over a small diameter roller to completely discharge thin cakes to 1/16" while also allowing that the medium may be cleaned at will without interferring with the filtration operation (7). The results of these studies are presented in the "Vacuum Filtration" section.

SLUDGE CONDITIONING

In solving the difficulties surrounding the conditioning step, a complete analysis of the flocculation methods employed in conditioning waste sludge was made. The investigations were carried out both in the the pilot plant and in sewage treatment plants. In the former, the experimental equipment was made sufficiently flexible so that variables associated with agitation and chemical contacting could be studied. In the plant studies, samples of conditioned sludge were obtained at various positions in the feed line to the filter. These samples were then analyzed for filtering characteristics by the leaf test technique (4). It was found that in some cases very poor mixing of chemicals was occurring in the mix tank and either partial flocculation or chemical overdosage was occurring and, consequently, poor filtration was being achieved.

In other cases the sludge was well flocculated on leaving the mix tank, but a gradual reduction in the filtration rate occurred in the passage of the sludge to the filter tank. The reduction in rate was attributed to the large hold-up time in the piping from the mix tank to the filter and the subsequent breakdown of the floccules with time. Thus, it was evident that, shortly after the proper mixing of the chemicals with the sludge, a maximum or peak filtration rate is achieved, after which any increase in retention time is detrimental to filtration. This relationship between peak filtration rate and the time after addition of chemicals has been mentioned previously in the literature (2,4).

The solution of the conditioning problem was determined therefore to be two-fold in nature. The first part lie in designing conditioning equipment to produce sludge flocculation that would exhibit the highest filtration rate at the lowest chemical consumption. The second part lie in the determination of the proper retention time after correct flocculation such that these optimum or peak rates were obtained in the filtration step.

CONDITIONING EQUIPMENT DESIGN

Although there is little information available on the proper design for sludge conditioning equipment, the fundamental requirement is the obtaining of a rapid and intimate interpenetration of the flocculating reagents with the sludge particles in a fluid regime, and therefore design comparisons can be made from mixing equipment operating in other fluid regimes by means of fluid mechanics (8,9). This is possible since the properties, motion and boundary conditions of all fluids can be described in the same dimensional units. By placing these units in dimensionless ratios or groups, correlations have been developed which allow different fluids with different boundary conditions to have the similitude of their motions related to each other (9,10). The dimensionless groups employed in correlating mixing data are (11):

Power Number $N_p = \frac{Pg}{\rho N^3 D^5}$ 1

Reynolds Number $N_{Re} = \frac{D^2 N \rho}{\mu}$ 2

Froude Number $$N_{Fr} = \frac{DN^2}{g} \quad ....3$$

The Power number, N_p, represents the inertia forces in a moving liquid, the Reynolds number, N_{Re}, represents the effect of viscous forces, and the Froude number, N_{Fr}, represents the effect of specific weight and gravity. If the systems under consideration are geometrically similar, it is possible to relate these groups as follows (9).

$$N_p = K (N_{Re})^m \quad (N_{Fr})^n \quad ....4$$

Therefore, in the investigation of the proper flocculation techniques for waste sludges, it was necessary to employ equipment which can be duplicated for full-scale agitation such that geometric similarity will occur and Equation 4 can be used for scale-up. Figure 1 is a sketch of the apparatus used in conducting the flocculation tests. It consists of a cylindrical tank which is divided into three zones by horizontal baffles and in addition vertical baffles to aid in chemical contacting. The design is such that dynamic similarity can be obtained with large scale equipment. The three zones or mixing phases are (1) the initial contacting zone, where the ferric chloride mixing occurs, (2) the secondary contacting zone, where the lime mixing, if any, occurs, and (3) the retention zone, which can be varied by the adjustable overflow arrangement to insure that complete flocculation is obtained before the sludge overflows. It is evident that, if proper mixing is obtained in Zones 1 and 2, complete flocculation will occur soon after the sludge leaves Zone 2, and Zone 3 becomes extremely small.

A mechanical mixer drive fitted with a direct-reading tachometer was mounted above the tank center. Various impellers and baffling arrangements were tested to provide a range in the mixing correlation, so that the most economical operation may be determined, from both a low power requirement and a high filtration rate standpoint. Sludge was fed at constant flow to the bottom of the tank, and filtration rate data were obtained on the flocculated sludge as it overflowed the tank by means of the leaf test technique(4). It was decided to use the leaf test rather than the Buechner funnel test in this instance; for, in the leaf test, the sludge is picked up by the vacuum, and cake thickness, and consequently filtration rate, is a function of the effectiveness of the flocculation. The test leaf was fitted with a Polyethylene cloth with a 1/1 plain weave which has a porosity that permits a high flow while maintaining a good filtrate clarity. The cloth was checked after each run to determine that no blinding had occurred, thus insuring that all test were performed under similar conditions.

PILOT-PLANT MIXING RESULTS

In order to determine the optimum impeller for good sludge floccule formation, the leaf test rate results were correlated with regard to the proper mixing speed. Figure 2 is a plot of Percentage of Maximum Filtration Rate as a function of the mixer speed. The maximum filtration rate, or 100% level, was arbitrarily chosen as the rate produced with a pre-determined minimum chemical dosage by laboratory scale flocculation under ideal conditions. The pilot plant mixing data was then compared with this same rate at the same chemical dosage.

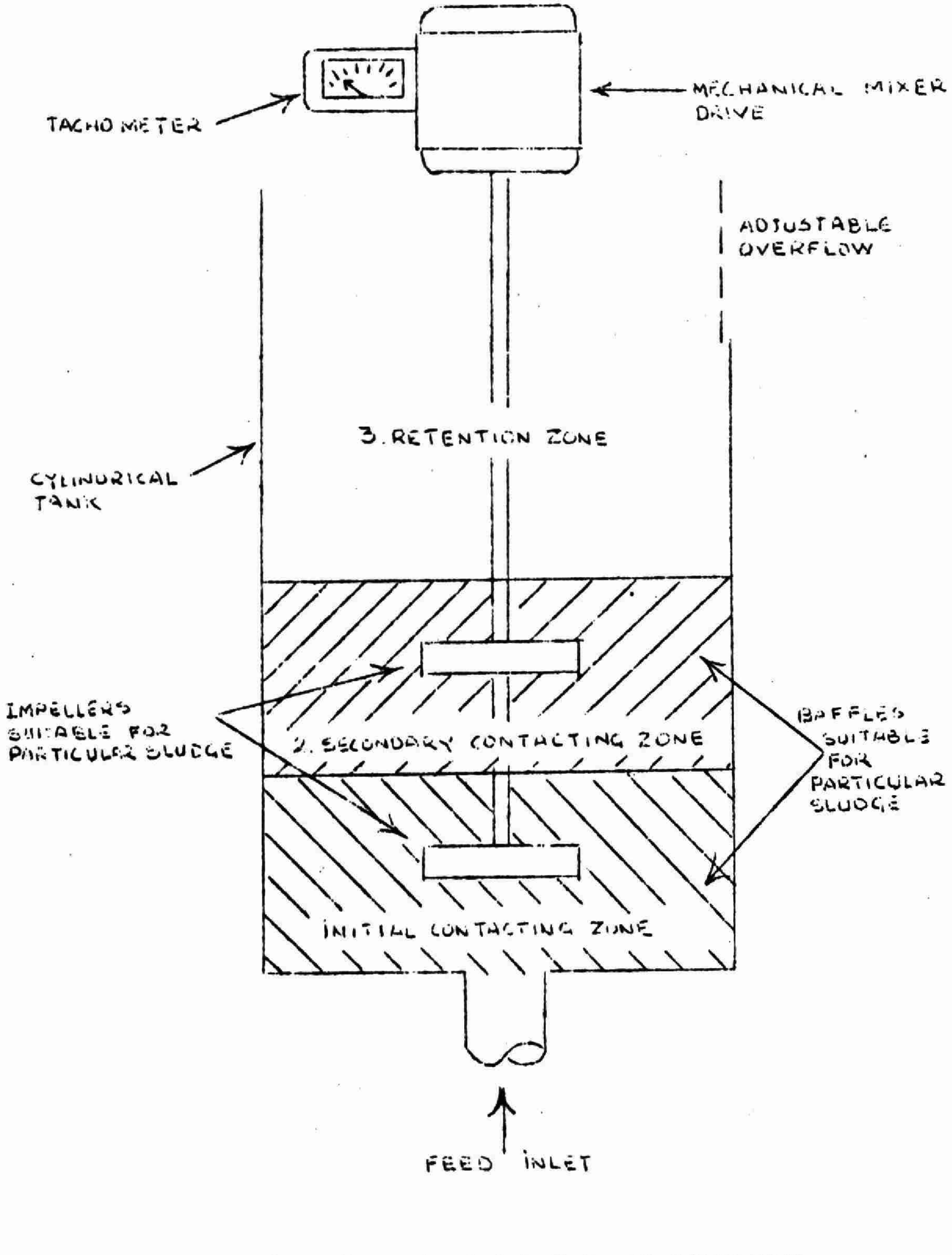
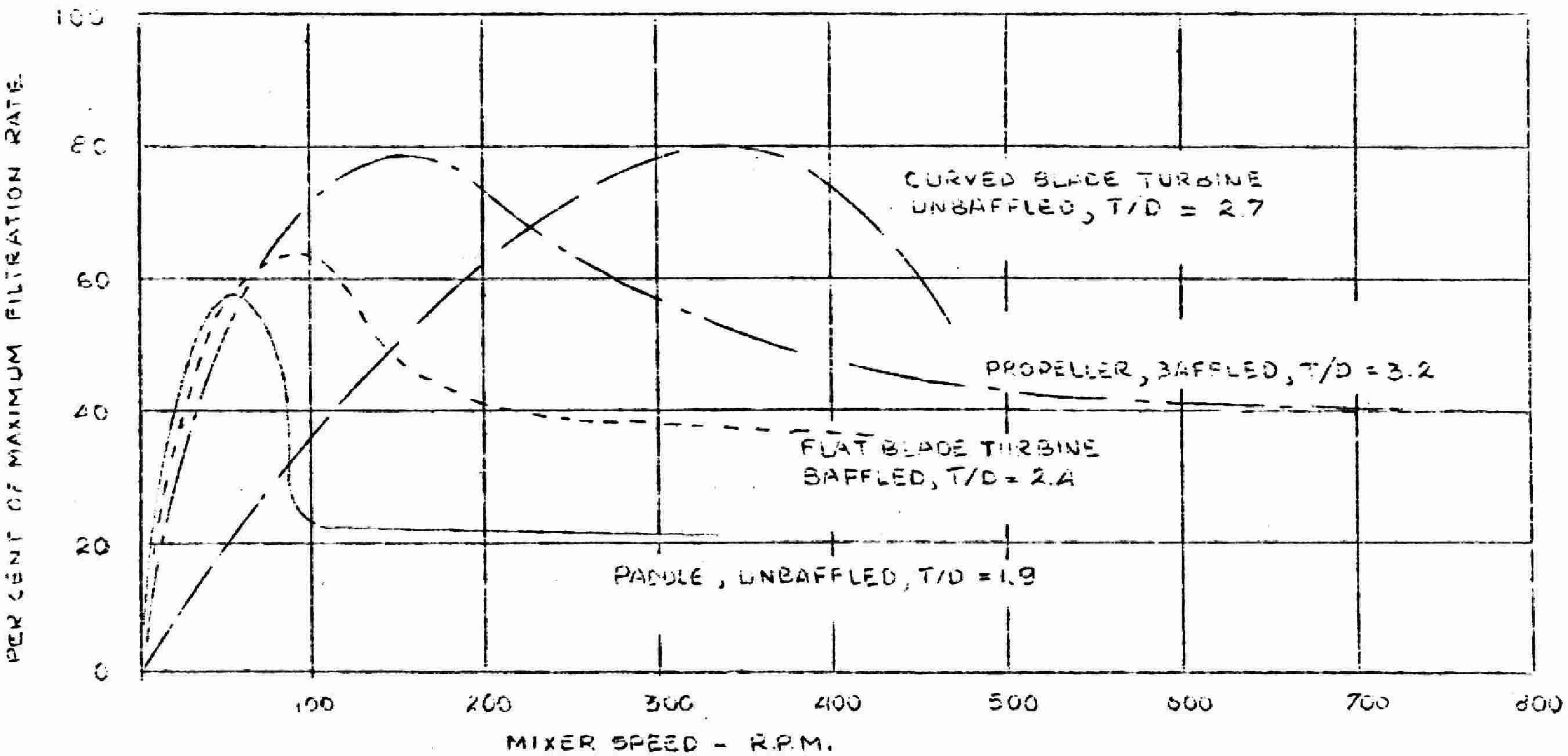


FIGURE 1 - PILOT PLANT MIXING EQUIPMENT

FIGURE 2 - % MAXIMUM FILTRATION RATE AS A FUNCTION OF MIXER SPEED EMPLOYING VARIOUS TYPES OF IMPELLERS

PILOT-PLANT DATA ON FLOCCULATION OF DIGESTED SEWAGE SLUDGE



COMPARATIVE POWER REQUIREMENTS AT MAXIMUM FILTRATION POINTS

C.B.T. - 100%	F.B.T - 40%
PROP - 25%	PADDLE - 20%

All available types of impellers were tested in this investigation, and the curves presented in Figure 2 are typical of some results for various impeller families. Only one ratio of Tank Diameter/Impeller Diameter is shown for each family, and other ratios yield higher or lower filtration rates depending on test conditions.

It is interesting to note that peak filtration rates occur at low rpm values particularly under baffled conditions. Also, it is seen that the peak values extend over a relatively small rpm range. These two conditions point out that mixing speed is extremely critical if intimate contacting and good flocculation are to occur, and speeds less or greater than this critical speed will not produce the most economic sludge conditioning. It should be noted that the critical mixing speed is dependent on the type of sludge treated as well as the particular impeller and baffle arrangement employed.

It was discovered in the investigation of sludge conditioning in various treatment plants, that filtration rate increases were noted occassionally with no change in chemical addition. This change in rate was attributed to fluctuations in sludge quality. However, most sludge conditioning tanks are fitted with variable speed drives and paddle type mixers which are usually set to turn at 15 to 60 rpm. The variable speed drive will fluctuate due to the pulley arrangement, and identical settings will produce slightly different speeds from day to day.

Examining the curve in Figure 2 for the paddle type impeller, it is observed that in the mixer speed range of 0-55 rpm the curve is quite steep, and a change in speed from 7 to 21 rpm will double the filtration rate. Therefore, it can be assumed that the variance in filtration rate noted in sewage treatment plants could be caused in many cases by slight changes in mixing speed from day to day when agitation operation is on the steep portion of the rate-speed curve. This would be particularly true when piping distances from the mix tank to the filter are fairly short, and a variance in mixing effectivenss would be quite noticeable in filtration. Sludge floccules are generally broken down to the same degree in longer piping distances and mixing variances are not as pronounced.

As can be seen from Figure 2, the highest filtration rates were obtained with the curved blade turbine and the propeller, both of which approached 80% of the ideal filtration rate. However, the optimum value for the mixer speed for the propeller was about 150 rpm, whereas the best results for the curved blade turbine were obtained at a mixer speed of about 340 rpm.

As indicated in the Power number expression, power is proportional to the cube of the speed of the mixer. This would mean that, if all other variables were equal, the propeller would draw $\left(\frac{150}{340}\right)^3$ or about 1/8 the power of the curved blade turbine. Therefore, since rate performance appears to be approximately the same for both impellers, indications from the power criteria show the propeller to be the optimum type of impeller to be used for flocculating the particular digested sludge employed in this investigation.

Figure 3 illustrates the typical type of Reynolds number correlation for a mixing impeller (9,11). The exact shape of this plot of $\phi = \frac{N_P}{(N_{Fr})^n}$ as a function of the Reynolds number is not the same for all types of impellers. However this type of plot is helpful in defining mixing intensity, and it is extremely useful for scaling-up to full size mixing installations. For example, a particular scale-up job may require that geometric similarity be maintained, and that comparable results may require a constant Reynolds number. As the tank diameter increases in the large installation, the impeller diameter must increase in proportion to maintain the same D/T ratio. Therefore, as the impeller diameter increases the mixer speed must be reduced considerably to maintain the same Reyholds number. Tests to date indicate that flocculation scale-up will have neither a constant N_{Fr} or a constant N_{Re}, but rather, scale-up will be based on more complex dimensionless groups.

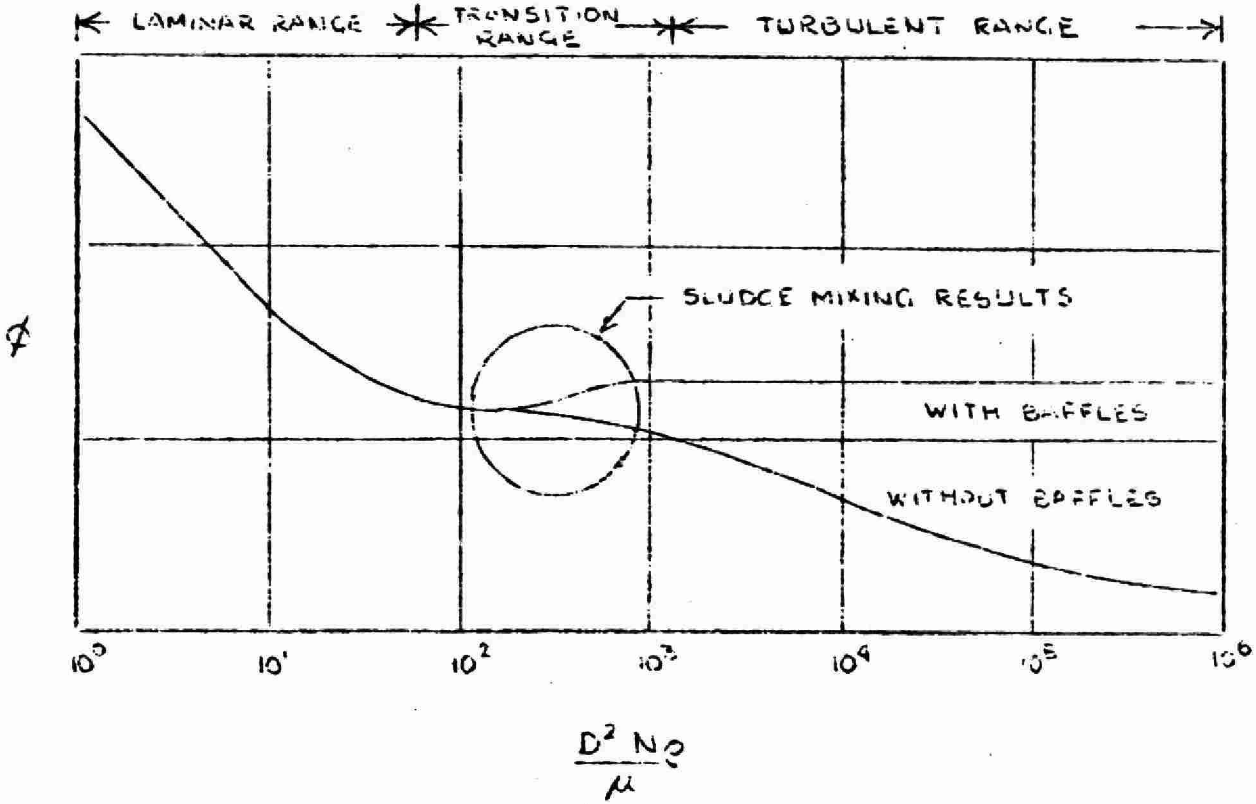
Optimum fluid conditions for successful flocculation depend not only on the impeller speed, impeller diameter, and characteristics of that particular impeller, but also on the properties of the sludge. Figure 3 shows one of the typical charts used for scale-up from pilot plant to full size mixing equipment to produce the desired results. These curves illustrate, among other things, that flocculation of sewage sludge in the tests performed is accomplished in the transition range between laminar and turbulent mixing. In this range, certain factors, which might be neglected in other Reynolds Number ranges, become quite important. For example, the selection of impeller and baffle characteristics in this range becomes quite dependent on the apparent fluid viscosity. Figure 4 illustrates apparent viscosity of one of the typical sludge types studied. All sludges are thixotropic, or false bodied, so it is necessary to correlate apparent viscosity with impeller speeds.

As indicated in Figure 3, the sludge mixing results are shown with respect to the Reynolds number calculated for the system used in the investigation. These results are for a dilute digested sludge of about 2-3% solids obtained at a local, small sewage treatment plant.

An investigation is being continued at the present time to determine the optimum impeller for various types of sludges, including some general types of industrial wastes. However, it is evident from the results on the digested sludge that a proper choice of impeller coupled with the use of a pre-determined critical speed is extremely important if optimum conditioning and the most economical filtration rates are to occur. When new treatment plants are designed and actual sludge to be obtained is unknown or where the characteristics of the sludge are known to vary from day to day, a variable speed drive on the mixer is recommended to achieve peak performance.

It is obvious that these tests would serve no useful value if they could not be scaled up to full scale design data. Thus, every effort was and is being extended to obtain test data in such a manner that established mixing scale-up techniques can be used in the manner previously

FIGURE 3 - GENERAL REYNOLDS NUMBER CORRELATION
FOR A MIXING IMPELLER
LOG-LOG PLOT



$$\phi = \frac{N_P}{(N_{Fr})^n} = K(N_{Re})^m$$

BELOW N_{Re} OF 300, $N_{Fr} \simeq 1$ AND $\phi = N_P$

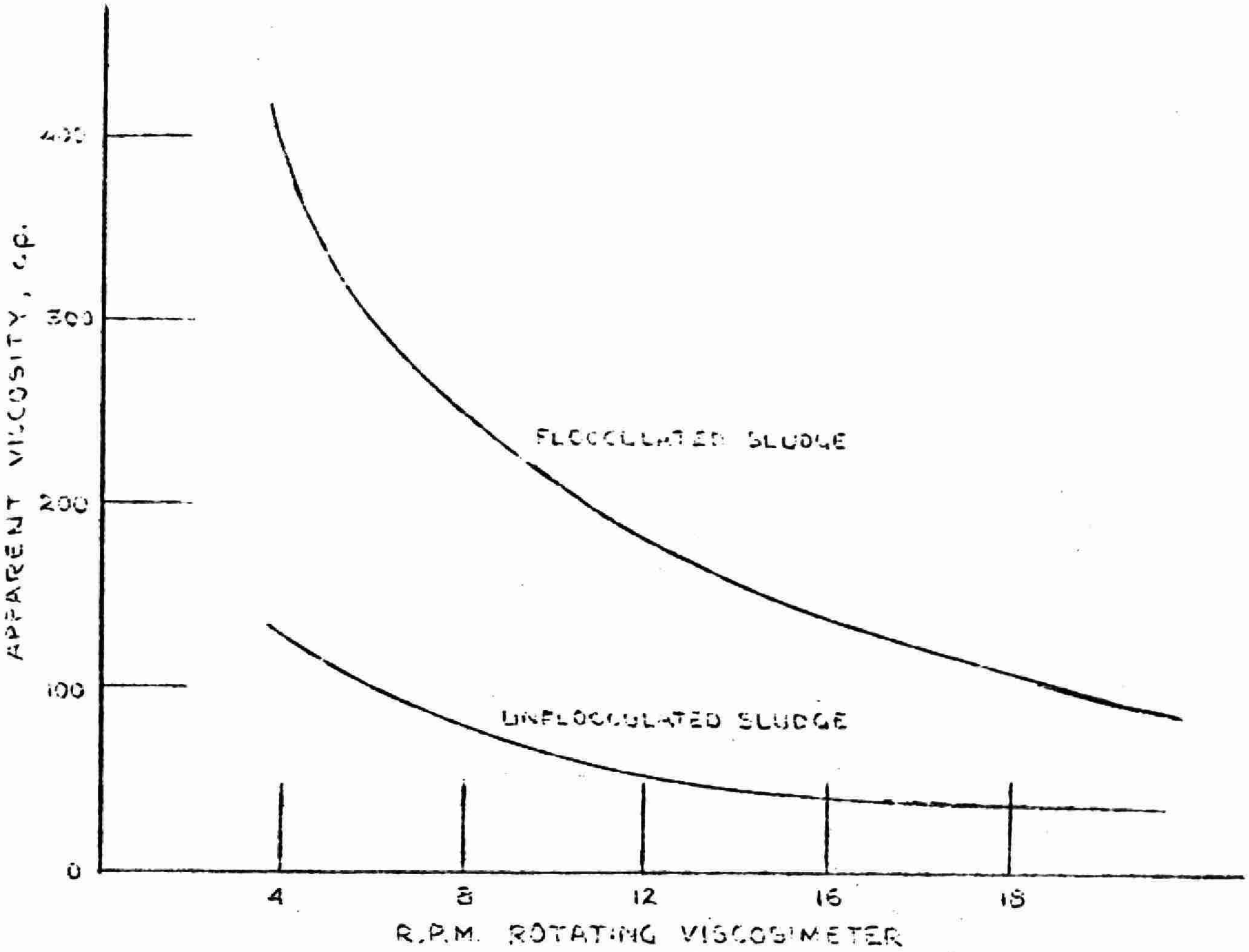


FIGURE 4 APPARENT VISCOSITY AS A FUNCTION OF VISCOSIMETER RPM
DATA OBTAINED ON DIGESTED SEWAGE SLUDGE
SOLIDS CONCENTRATION – 3-4 WT. %
FLOCCULATION DOSAGE: 3% BY WT. $FeCl_3$ 10% BY WT. CAO.

PROPER RETENTION TIME

It was discovered in the sludge mixing investigation that extremely good sludge flocculation would be obtained with the proper selection of impeller and mixer speed. If this selection were made correctly, Zone 3 in Figure 1 became extremely small and retention time was minimized. Thus, it was concluded that the correct retention time with a proper mixer design should range from 2.0-0.25 minutes, dependent on the quality and type of sludge. In order that this can be done, while also minimizing the amount of floccule break-down after flocculation, the chemical mixing equipment should be mounted directly in back of the filtration equipment. In this way, the flocculated sludge will gently overflow the mixing chamber into the filter tank, resulting in no sludge turbulence and a minimum retention time. This type of operation has proved extremely successful in previous installations, notably at the City of Sacreamento, California (5).

Vacuum Filtration

The second phase of the solution to the troubles surrounding the filtration step concerns the design of the filter itself. It has been established from a thorough study and analysis of sludge filtration that the basic criteria for judging filter operation are: (1) the amount of sludge handled per unit area (as measured by dry pounds per hour per square foot), (2) the degree to which the sludge is dewatered (as measured by cake moisture content), (3) the efficiency of the separation of solids from liquid (as measured by the solids content in the filtrate), and (4) the relative cost of the filter operation. The first three criteria have been studied in previous articles (1,2,4,6,7,13, 16), while the fourth will be covered in this paper from actual plant results.

The major factors affecting filtration rate, or the amount of sludge handled per unit area, can be developed from the fundamental Poiseuille Equation for filtration given below (12):

$$\frac{dV}{A\,d\theta} = \frac{\Delta P}{\mu\left(\alpha w \frac{V}{A} + r\right)} \qquad (5)$$

As Equation (5) yields an instantaneous filtration rate while continuous filtration is a cyclic process, the Equation must be integrated to employ it in this application. In order to perform the integration, μ, α, w, r and ΔP would have to be considered constants. For any particular feed sludge, the liquid viscosity μ and solids concentration w (expressed as weight of dry cake solids per unit volume of filtrate) would be constant over a finite period of time. The specific cake resistance α is primarily a function of the nature of the solids, pressure drop across the cake, feed solids concentration and migration of fines within the cake.

Because of the complex theory, it is most convenient to consider feed solids concentration and each individual feed slurry as a parameter. No reliable equation has yet been developed to show the quantitative influence of either of these variables upon filtration rate. Pressure drop across the filter can be considered constant on a continuous filter due to its method of operation. If the fines migrate within the cake, specific cake resistance α will increase. However, in the development to follow, the best method for handling such situations will be shown. If a blinding condition is encountered in a filter application, resistance r will increase over the life of the media or between acid cleanings. The equation may still be integrated assuming r constant as its change in resistance must be slow if the filter application is to be successful.

While μ, α, w, r and ΔP have either been considered constants or have been handled as parameters, it should be stressed that their values may change over finite or long periods of time. However, the final expressions to be developed will still indicate the desirable direction and magnitude of the individual variables in order to maximize filtration rate. The relation between specific cake resistance and pressure drop may be stated as follows:

$$\alpha = \alpha' \Delta P^s \qquad (6)$$

In this expression α' is a constant over a finite period of time while s represents the cake compressibility, which will vary from 0 for incompressible cakes to 1.0 for highly compressible cakes. Substituting for α in Equation (5), the following expression is obtained:

$$\frac{dV}{Ad\theta} = \frac{\Delta P}{\mu\left(\alpha' \Delta P^s \frac{wV}{A} + r\right)} \qquad (7)$$

Cross multiplying Equation (7) and dividing by A, the equation may now be written:

$$\int \left(\mu \alpha' \Delta P^s \frac{wV}{A^2} + \frac{\mu r}{A}\right) dV = \int \Delta P \, d\theta \qquad (8)$$

Integrating between the limits of 0 and V_f and 0 and θ_f where V_f is the volume of filtrate obtained in a cake formation time θ_f,

$$\frac{\mu \alpha' \Delta P^s w V_f^2}{2A^2} + \frac{\mu r V_f}{A} = \Delta P \theta_f \tag{9}$$

Rearranging the above equation to the following:

$$\frac{V_f}{A} = \left[\frac{2\Delta P^{1-s}\theta_f}{\mu \alpha' w} - \frac{2 r V_f}{\alpha' \Delta P^s w A}\right]^{\frac{1}{2}} \tag{10}$$

Equation (10) yields the volume of filtrate obtained per unit area for a cake formation time of θ_f during the filter cycle. However, sewage sludge filtration capacity is usually expressed in terms of pounds of dry solids per hour per foot 2. Thus, the following transformation is employed:

θ_f = (fraction of cycle time for cake formation)(MPR)
= x (MPR)

Therefore, if θ_f and MPR are expressed in minutes, the filtration rate in conventional nomenclature would be:

$$\frac{60 w V_f}{(MPR) A} = Z = \left[\frac{2\Delta P^{1-s} x (MPR)}{\mu \alpha' w} - \frac{2 r V_f}{\alpha' \Delta P^s w A}\right]^{\frac{1}{2}} \frac{60 w}{MPR} \tag{12}$$

where Z = filtration rate expressed as dry lbs. solids/hr./ft.^{2}

Simplifying:

$$Z = \left[\frac{7200 w x \Delta P^{1-s}}{\mu \alpha' (MPR)} - \frac{7200 w r V_f}{\alpha' \Delta P^s (MPR)^2 A}\right]^{\frac{1}{2}} \tag{13}$$

From Equation (13), it is obvious that maximizing pressure drop ΔP

feed solids concentration w, and fraction cake formation time x, and minimizing specific cake resistance α, filter cycle time MPR, and liquid viscosity will increase the solids filtration rate. Pressure drop is maximized by operating at high vacuum levels while feed solids concentration can only be maximized by the method of operating the plant prior to the filter station. In the case of the latter, it is generally always advantageous to operate with filter feeds that are as high in solids as possible and are still in a fluid condition. It is possible to experience too high a feed solids concentration which is characterized by a "sloughing-off" of the cake as it rises out of submergence. Such feeds are usually very difficult to pump and exhibit a very high degree of thixotropy and should be avoided.

The fraction of cake formation time x is usually controlled by the necessary dewatering time in order to obtain a suitably dry cake. As filter cycle time, MPR, is decreased, cake thickness also decreases so that minimum cycle time will be a function of method and completeness of cake discharge. Finally, specific cake resistance, α can only be minimized by employing proper sludge conditioning and handling as discussed earlier.

Filtration rate may also be increased by minimizing or eliminating the resistance r. As this resistance is almost entirely concentrated in the filter media, the selection of the proper one and prevention of media blinding is essential. If this resistance can be made negligible Equation (13) reduced to:

$$[illegible] \left[\frac{[illegible]\; x\, \Delta P}{[illegible]\,(MPR)}\right]^{\frac{1}{2}} \qquad (14)$$

As indicated earlier, if the extreme fines migrate within a cake after deposition, specific resistance α will increase. From experimental work, it has been found that the net effect is to increase the cycle time (MPR) in Equation (14) to a value between 1.0 and 0.5 (4,6). Thus, this would further augment the desirability of operating at minimum filter cycle times in order to maximize filtration rate.

As seen from Equation (14) the relationship between rate and pressure drop can be expressed as follows:

$$Z \; [illegible] \; (\Delta P)^{\frac{1-s}{2}} \qquad (15)$$

Thus, it is seen that a logarithmic plot of rate as a function of pressure drop should produce a straight line (all remaining variables being constant) with a slope ranging from $\frac{1}{2}$ to 0 depending on the value of s. In most of the cases tested to date, the exponent of the pressure drop in Equation (15) has ranged from 0.30 to 0.49, which would mean that the value of the compressibility factor s has ranged from 0.4 to 0.02. These results are summarized in Table 1 (4). Thus, it is quite evident that the highest available pressure drop should be employed to maximize filtration rate, particularly when a low compressibility factor is present.

TABLE I

FILTRATION RATE - PRESSURE DROP RELATIONSHIP

Treatment Plant	Sludge Type	Slope of Log-Log Plot of Rate vs Pressure Drop	Calc. Value of Compressibility Factor$
East Lansing, Michigan	Primary -Activated	0.30	0.40
Dallas, Texas	Primary-Digested	0.31	0.38
Houston, Texas	Activated	0.37	0.26
East Providence, Rhode Island	Primary-Digested-Elutriated	0.49	0.02

To summarize the above discussion, the following general rules apply to maximize dry solids handling rate of a sewage filter:

Maximize-

1. Feed solids concentration as long as the resultant filter cake does not "slough-off" the filter when coming out of submergence.
2. Pressure drop or vacuum level.
3. Fraction of cycle time employed for cake formation. However, this will usually depend on the dewatering rate of the filter cake as will be discussed.

Minimize-

1. Filter cycle time consistent with good cake discharge.
2. Specific cake resistance. This necessitates proper sludge conditioning and handling.
3. Filter media resistance. This is achieved through proper selection and maintenance of a clean media.

Quantitative analyses have been made on all of the above development and substantiated by actual plant performance. The reader is referred to the literature for more detailed discussion(4,5,6,7).

Filter cake moisture content has been investigated in previous studies and found to be a function of the following variables for any particular solids:

1. Cake thickness
2. Dewatering time
3. Pressure drop across the cake
4. Liquid viscosity
5. Air rate through the cake during dewatering
6. Specific cake resistance

Other factors connected with the filter station may also influence moisture content, but the above are by far the most important. Due to their interaction, a multiple correlating factor was employed in the empirical correlation of results for a wide variety of solids.(13,16)

$$\text{Correlating factor} = \left(\frac{CFM}{Ft.^2}\right)\left(\theta_d\right)\left(\frac{\Delta P}{d}\right)\left(\frac{1}{\mu}\right) \qquad (13)$$

Plots of filter cake moisture content for many different solids as a function of the correlating factor yielded a family of curves that asymptotically approached minimum values with increasing correlating factor numbers. As cake permeability decreased, the rate of approach to the minimum value also decreased.

In order to reduce filter cake moisture content by increasing the correlating factor, air rate through the cake $\frac{CFM}{Ft.^2}$, drying time (θ_d) and pressure drop ΔP, should be increased and cake thickness d and liquid viscosity μ decreased. Air rate through the cake is a function of the drying time, vacuum level and cake thickness and is increased as ΔP and θ_d are increased and as d is decreased. However, as sewage filter cakes are generally relatively low in permability, very little air is pulled through the cake. Accordingly, major attention must be concentrated on cake thickness, vacuum level and dewatering time. As the liquid in a sewage sludge is primarily water, viscosity can be decreased by increasing feed temperature. However, it would not be economical to raise the feed temperature for cake moisture content decrease only. It is emphasized though that every effort should be made to minimize unnecessary temperature loss in the treatment plant.

Cake thickness is reduced as cake formation time and thus cycle time is decreased. This is also desirable to increase the productive capacity of the filter. This is similarly true of pressure drop as maximizing vacuum level increases filtration rate and reduces cake moisture content. As cake dewatering time θ_d is increased, the solids handling rate of the filter decreases if the same fraction of cycle time is employed for dewatering due to the necessary increase in cycle time. Thus it will generally be found most economical to reduce cake formation time fraction x by running the filter at a low drum submergence and thereby increase the fraction of cake dewatering time.

It should be stressed that proper sludge conditioning is also essential for minimizing cake moisture content. By this method, cake specific resistance is decreased and dewatering is greatly facilitated.

To summarize, cake moisture content is minimized by:

Maximizing -

1. Vacuum across the cake.
2. Cake dewatering time. As this also affects the productive capacity of the filter, it is usually most economical to run the filter at a low submergence. This will increase the ratio of dewatering time to cake formation time and still employ low filter cycle times for greater solids filtration rates.
3. Maximize filtration temperature. As it is uneconomical to heat the filter feed, this entails maintaining the feed temperature without unnecessary cooling.

Minimize-

1. Cake thickness consistent with good cake discharge. Filtrate clarity is primarily a function of the filter media employed and proper sludge conditioning. It is essential to obtain a sufficiently low solids content in the filtrate to prevent a build-up of a circulating load of solids in the sewage treatment plant. Low solids concentration of 200 p.p.m. or less in the filtrate are possible by correct filter media selection. At the same time, if the sludge is improperly conditioned, unflocculated colloidal slimes will appear in the filtrate in excessive amounts to cause treatment problems in the plant.

In many present-day plants, the filtration of sludge as judged by the four criteria is being accomplished reasonably well. For example the filtration of raw primary sludge in plants such as Saginaw, Michigan is handled quite economically. Rates up to 11 dry lbs. per hour per square foot have been obtained with cake moistures of 50-55% and with a minimum chemical addition of 1.5% Ferric Chloride and 5.0% Lime. In addition, there is no blinding problem in that over 4000 hours are experienced with 1/1 plain weave Polyethylene fabric (some installations report over 12,000 hours operation with other cloth media).

In cases such as this, filter operational economics are almost at an optimum point, and further increases in efficiency could only be accomplished by investigating possible improvements in the sludge conditioning, as covered in the first part of this paper.

However, in a proportionately greater number of plants filtration of sludge is being accomplished quite poorly due to the improper filter design for that particular application. In plants where difficult filtering sludges are encountered, provisions must be made on the filter for coping with thin cake formation, media blinding conditions, and chemical encrustation due to a carbonate build-up.

Figure 5 is a diagram of the basic construction of a filter designed specifically to solve difficult filtering problems, the Rotobelt Filter. The design of this filter consists of a basic drum filter, a woven metallic media, rollers to assist take-off and return of the media, and washing and cleaning facilities.

Unlike conventional drum filters, the media employed on the Rotobelt is not caulked to the filter deck but rather lies on the drum surface until it is transferred to the discharge roller.

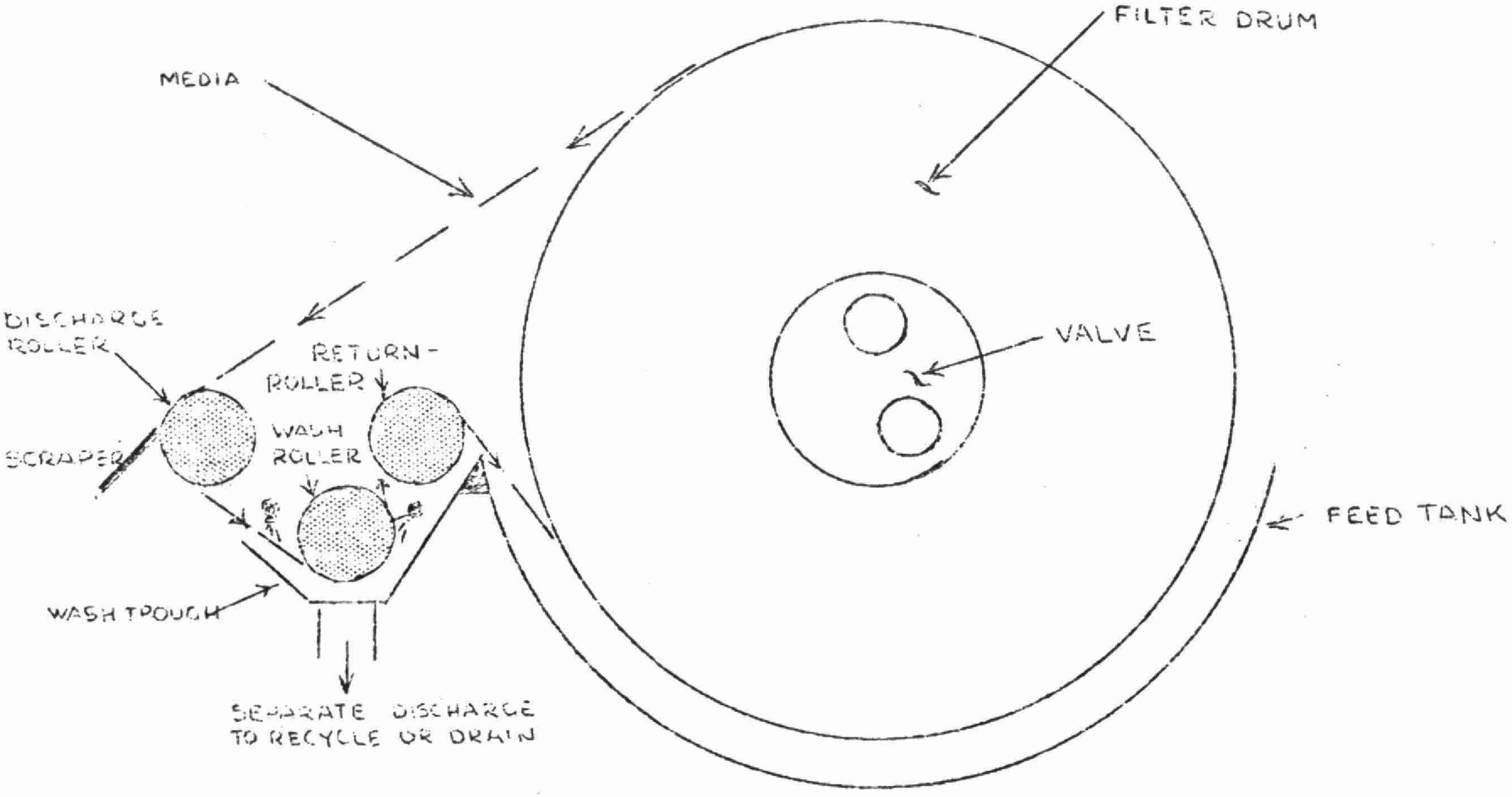


FIGURE 5 = BASIC ROTOBELT MECHANISM

There, the sludge cake is discharged by the combined action of the passage of the media over a small diameter roller and the flexing action of the media itself. This flexing action permits complete discharge of properly dewatered cakes as thin as 1/16-inch while also loosening any solids which tend to become embedded in the media. After discharge, the media travels under a wash roller, where it may be sprayed or passed through a solvent for removal of any possible chemical encrustation.

Also, spray water or solvent is contained in a wash trough which is separate from the filter feed tank, and thus any cleaning operation can be accomplished without interrupting or interferring with the filtration operation. After the possible cleaning operation, the media is returned back to the drum surface (7).

The Rotobelt type filter has been installed in many sludge treatment plants to eliminate difficult filtration problems encountered. The results obtained in three different sewage treatment plants that have installed Rotobelt filters to replace conventional cloth drum filters due to filtration difficulties, are presented on the following pages.
A comparison between the operation obtained on the drum filter and the Rotobelt filter will be given together with the economics of the new operation.

Fond du Lac, Wisconsin

The City of Fond du Lac, Wisconsin Sewage Treatment Plant serves an equivalent population of over 40,000 and treats over four million gallons of sewage per day of which one fourth consists of a tannery waste (14). The plant employs primary settling, bio-filtration of the primary effluent and digestion of the underflows. Since a relatively large portion of the plant influent consistent of the tannery waste, an extremely difficult filtration problem was encountered due to the large amount of hair and grease present which promoted rapid cloth blinding. This blinding problem resulted in a relatively short cloth life, and cloth replacement expense became a major item on the filter budget. Also due to media blinding, the plant filters were forced to use slow cycle speeds of 5.0 minutes or longer to obtain a cake of sufficient thickness to be able to effect cake discharge. With recent population and industrial increases, the plant load became too great for the two 6' by 8' cloth covered drum filters and an additional capacity was urgently needed. This meant that either costly filter plant expansion must be made with increased sludge drying handling facilities or replacement of the present filters with larger-sized filters would soon have to be accomplished.

As either of these methods would mean a large capital expenditure, the plant superintendent decided to convert his cloth-covered drum filters to the Rotobelt type, which offered increased productive capacity while keeping expenses within his budget. Initially, only one of the two 6' x 8' drum filters was converted to a Rotobelt, and thus a good operating comparison was obtained between the Rotobelt and the cloth-covered drum filter on the same feed. Figure 6 is a picture of the initial Fond du Lac Rotobelt in operation. Note the high vacuum of 22-25 Hg resulting from the excellent seal between the media and the drum surface. At the extreme left center of the picture, a view of the clean belt can be seen after discharge, showing the 100% removal of the cake. Figure 7 is a front view of the same filter, again showing the 100% discharge and the excellent seal as indicated by the tightness of the belt against the horizontal division strips.

Table II is a comparison of the operating results from the Rotobelt and the cloth-covered drum filter. As can be seen from this comparison, the Rotobelt rate production is 50% greater than the conventional drum filter. This increase in rate is due to the Rotobelt's ability to completely discharge thin cakes which enables faster cycle speeds to be employed. The most economical filter operation is achieved at the fastest cycle speed which produces an acceptable cake moisture and a dischargeable cake(4). The results tabulated in Table II show that no increase in cake moisture is obtained at the faster cycle speed, and therefore the economic savings produced by the increase in production on the Rotobelt operation is evident.

Several months ago the second cloth-covered drum filter was converted to a Rotobelt. Both Units are now producing more sludge in two shifts than the cloth-covered drum filters were able to produce in the entire day. With this extra productive capacity, the superintendent is planning on reducing operating time with the subsequent saving in labor and power. Thus, by proper filter application in a difficult sludge filtration problem, a costly plant expansion was averted and additional operational cost savings may be realized.

Ann Arbor, Michigan

The City of Ann Arbor, Michigan employs primary settling, activation of the primary effluent, and digestion of the primary and waste-activated sludges. The Ann Arbor plant is also faced with a difficult filtration problem as the plant influent consists almost entirely of domestic sewage coupled with a large amount of fine silt. This combination produced a rapid blinding condition in the fabric employed on the plant drum filters. The superintendent tried virtually all types of fabrics and weaves in an attempt to discover a media which would resist the blinding action of the sludge. However, the best cloth from a standpoint of initial cost and length of service appeared to be the cheapest cotton flannel available, which lasted about 150 hours. Even considering that this media was the best available, this short length of service meant that cloths had to be replaced every week, resulting in down time of the filter plus the labor needed to change the media plus approximately $2000.00 annually in media replacement costs.

In order that this problem might be eliminated, the superintendent decided to convert one of the two 8' x 8' drum filters to a Rotobelt, which would employ a permanent stainless steel media and provide facilities for maintaining a non-blinded media surface. Again, a very good operational comparison between the Rotobelt and the cloth-covered drum filters was obtained, which is presented in Table III. In this case, not only did the Rotobelt show a substantial increase in production, but also a reduction in cake moisture and chemical consumption were realized. The increase in rate and the reduction in cake moisture can be attributed to the use of a non-blinded media which permits a more effective use of the vacuum in cake formation and dewatering.

The savings in chemicals were made possible by operating at the lowest conditioning dosage necessary for proper flocculation. This was not possible with the cloth media as over-dosage was mandatory to maintain proper cake formation on the semi-blinded media with the normal fluctuations encountered in the plant. The reduction in ferric chloride dosage from 10 to 3.5% resulted in a savings of $78.00 per day, and the reduction in lime dosage from 24 to 17% resulted in a savings of $23.52.

The combined savings resulting from the proper filter application in this instance amounted to a $101.52 daily chemical cost reduction, a $2000.00 media replacement cost reduction, and an increased production output of twice the previous rate. Since about 2,400,000 lbs. of solids are handled annually, it will require approximately 100 days of Rotobelt operation to process this sludge whereas previous cloth filter operation required 200+ days. In terms of dollars and cents, this reduction in operating time means that the plant will save about $4,200.00 in labor ($1.75/hr. x 2400 hrs.) and $480.00 in power savings (20 h.p. x 2400 x 1¢) or a total of $4680.00. This savings does not include the labor savings resulting from not operating the incinerator during this period or the savings in down time and labor for elimination of media replacement. Thus, the combined cost reduction totals:

$ 101.52/day x 100 days = $10,152 (chem)
2000.00/yr x 1 year = 2,000 (media)
1.75/hr. x 2400 hrs. saved= 4,200 (labor)
20 h.p. x 2400 hrs. saved x 1¢= 480 (power)

TOTAL $16,832

Again, as proof of the economic reality of the Rotobelt operation on this difficult sludge, the plant has recently converted the remaining cloth filter to a Rotobelt, thus increasing the operational cost savings.

Cranston,Rhode Island

The City of Cranston, Rhode Island Sewage Treatment Plant handles an annual average daily sewage flow of nearly four million gallons from an equivalent population of over 45,000 (15). The plant treatment includes primary settling, activation of the primary effluent, digestion of the primary and waste activated sludges, and elutriation of the digested sludge. The plant also processes a large volume of textile wastes with the normal sewage influent. These wastes produce a difficult filtering material and filtration rates are reduced due to the slow cycle speed required to discharge the thin cake. Cake moistures before handling the textile waste were about 70-75%; however, cake moistures on the sludge including the wastes average 80%.

The two 8' x 8' drum filters employed a napped Dynel cloth and a string discharge to assist the removal of the sticky cake. However, even these measures could not eliminate the media blinding problem resulting from this difficult filtering material. Therefore, to over-come this difficulty, one of the two 8' x 8' units was converted to a Rotobelt filter with a permanent stainless media. The operational results obtained on this conversion unit are summarized in Table IV.

It is interesting to note that again the Rotobelt's ability to completely discharge thin cakes has resulted in a substantial increase in productive capacity as compared to the conventional cloth-covered drum filter. The increased Rotobelt output of 60-80% over the previous production has resulted in a reduction in the necessary operating time. Now, a five day production can be achieved in only four days, resulting in a reduction of 50 operating days per year.

Using the same basis as employed in the Ann Arbor calculations, the savings in labor costs would be $700.00 per year (50 days x 8 hr. day x 1.75 per hour) and the power savings would be about $80.00 per year (20 h.p. x 400 hours x 1¢) or a total of $780.00 per year. This is exclusive of filter media savings and labor costs for replacement of media.

This filter has not been in operation as long as the Fond du Lac and Ann Arbor units, and therefore it is extremely possible that further savings may be realized in chemical dosage reduction. No attempt has been made to reduce the dosage to date, but earlier test work has indicated the possibility that the ferric chloride dosage may be reduced slightly on the Rotobelt without decreasing the cake rate or increasing the cake moisture. However, even if this reduction cannot be satisfactorily accomplished, the excellent operation presently obtained and the savings in operating cost have again illustrated the economics of proper filter application on a difficult sludge.

SUMMARY

The use of vacuum filtration as a means of dewatering waste sludges to a handleable state has developed too rapidly for proper application of the correct equipment design to the particular problem. Due to the employment of one filter design and antiquated flocculation techniques for all types of sludge filtration, troublesome operation is encountered which is characterized by any or all of the following: (1) rapid media blinding, (2) low cake rates, (3) high cakes moistures, and (4) high chemical consumption. To alleviate these conditions, an investigation was undertaken to determine the correct method of conditioning sludge and a survey was made to illustrate the economic advantages of proper filter application.

It was found that to achieve economic mixing of chemicals with the sludge, it is quite important to make the proper selection of the impeller type and the speed of the mixer based on fundamental knowledge of the fluid properties of sludge. By applying the techniques of developing demensionless scale-up constants in geometrically and dynamically similar installations, the correct mixer design will be obtained in the flocculation equipment in treatment plants. Optimum or peak filtration will ensue if this correct design is employed with a minimum retention time of 2.0-0.25 minutes for the flocculated sludge.

The conventional cloth-covered drum filter has been and should be employed where trouble-free operation (good cake rate, low cake moisture, low chemical dosage, long media life) is encountered. When this type of operation cannot be maintained on cloth filters due to difficult filtering sludges, the Rotobelt filter offers a more economical operation due to its design which permits maintenance of a non-blinded media at all times. Operational comparisons between the Rotobelt and cloth-covered drum filters have been made at treatment plants in Fond du Lac, Wisconsin, Ann Arbor, Michigan and Cranston, Rhode Island. In all three cases, difficult filtering sludges must be handled which produce poor operation on cloth-covered drum filters. At Fond du Lac, a costly filter plant expansion due to an increased load was averted by converting to Rotobelt operation, which not only handled the increased load but offered a reduction in operating time due to the increased production.

At Ann Arbor, a total savings of $16,832.00 per year was obtained in the reduction of operating costs by converting to Rotobelt operation. At Cranston, one filter conversion to a Rotobelt saved 50 operating days per year due to the increased production.

Therefore the conclusions reached fromthis investigation are that, if the most economical operation is to be achieved, (1) proper flocculating equipment design should be made using the technique outlined in this paper, and (2) the cloth-covered drum filter may be successfully used on easy filtering sludges such as Raw-Primary, while the Rotobelt type filter should be employed on difficult filtering sludges.

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NOMENCLATURE

Unless otherwise specified, any consistent units may be employed.

Symbol	Definition
A	Area
D	Impeller diameter, feet
d	Cake thickness
g	Gravitational constant, ft./sec.^{2}
K	Proportionality constant
MPR	Filter cycle time, minutes/rev.
m	Exponential function for Reynolds number
n	Exponential function for Froude number
N	Impeller speed, revolutions/sec.
N_{Fr}	Froude Number = DN^2/g
N_p	Power Number = $\frac{P}{\rho N^3 D^5}$
N_{Re}	Reynolds Number = $\frac{D^2 N \rho}{\mu}$
P	Power in ft.-lb./sec.
ΔP	Pressure drop
r	Resistance of filter media and piping
s	Compressibility factor
T	Tank diameter, feet
V	Volume of filtrate
V_f	Volume of filtrate in time θ_f
w	Weight of dry cake solids per unit volume of filtrate
x	Fraction of filter cycle time devoted to cake formation
CFM/Ft.^{2}	Volume of air pulled through the cake per square foot of filter area measured at one atmosphere and 32°F.
α	Specific cake resistance
θ	Time, minutes
θ_d	Cake dewatering time, minutes
θ_f	Cake formation time, minutes
μ	Liquid viscosity, lbs.mass/ft.-sec.
ψ	A function = $\frac{N_p}{(N_{Fr})^n}$
ρ	Density in lbs. mass/ft.^{3}

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Table II

Summary of Operational Results on 6' x 8' Rotobelt
And 6' x 8' Cloth-Covered Drum Filter

Fond Du Lac, Wisconsin

	Conventional Drum	Rotobelt
Cycle Time, MPR	5.0	2.5-3.0
Vacuum, Inches Hg		
Form	23	24-26
Dry	[illegible]	21-22
Filter Medium	Polyethylene	S.S. Woven Wire
Filtration Rate - Lbs. Dry Solids/Hr./Ft.^{2}	3.0	4.5
Cake Moisture Content - Wt. %	69-70	69-70
Chemical Wt. %		
$FeCl_3$	4	4
CaO	16	16
Filtrate Clarity	*	100 ppm or less

* Filtrate clarity depends on condition of fabric used as filtering medium. If fabric is new, clarity is excellent; if fabric is worn, clarity is not too good.

Table III

Summary of Operational Results on 8' x 8' Rotobelt

And 8' x 8' Cloth-Covered Drum Filter

Ann Arbor, Michigan

	Conventional Drum	Rotobelt
Cycle Time, MPR	6.0	2.5
Vacuum, Inches Hg		
Form	25	22
Dry	20-25	20
Filter Medium	Canton Flannel	S.S. Woven Wire
Filtration Rate - Lbs. Dry Solids/Hr. Ft.^{2}	2.5	5.0+
Cake Moisture Content Wt. %	78-80	70-75
Chemical Wt. %		
$FeCl_3$	10	3.5
CaO	24	17
Filtrate Clarity	*	200 ppm or less

* Filtrate clarity depends on condition of fabric used as filtering medium. If fabric is new, clarity is excellent; if fabric is worn, clarity is not too good.

Table IV

Summary of Operational Results on 8' x 8' Rotobelt And 8' x 8' Cloth-Covered Drum Filter

Cranston, Rhode Island

	Conventional Drum	Rotobelt
Vacuum, Inches Hg		
Form	17-20	17-20
Dry	17-20	17-20
Filter Medium	Dacron with Nap String Discharge	S.S. Woven Wire
Filtration Rate - Lbs. Dry Solids/Hr. Ft.^{2}	3.3 (25,000#/7.6 hr.)	5.3-5.9 (40-45,000#/7.6 hr.)
Cake Moisture Content Wt. %	80	80
Chemical Wt. %		
$FeCl_3$	5-6	5-6
CaO	----	---
Filtrate Clarity	*	100-300 ppm

* Filtrate clarity depends on condition of fabric used as filtering medium. If fabric is new, clarity is excellent; if fabric is worn, clarity is not too good.

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