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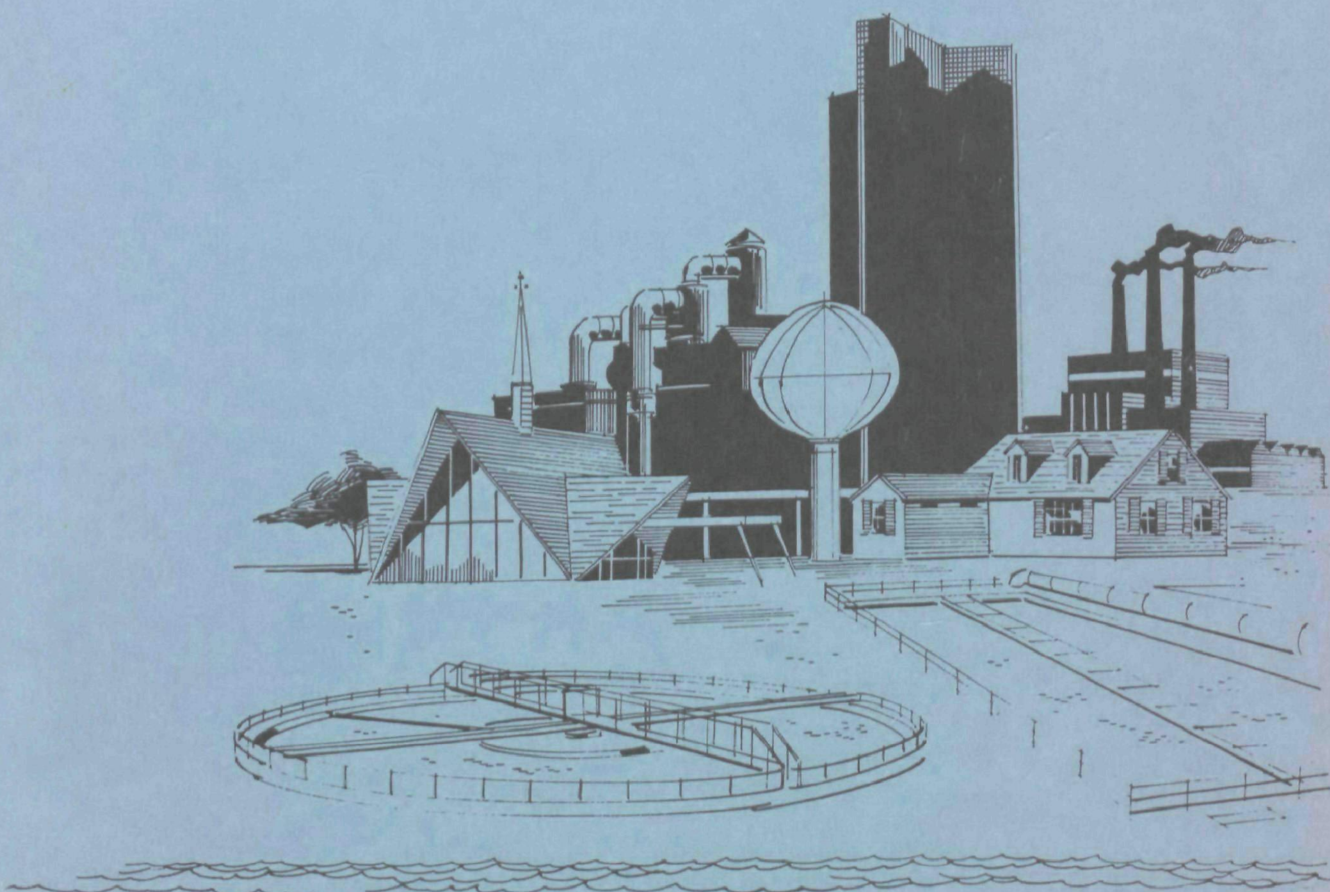
Joint Municipal and Semichemical Pulping Waste Treatment



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ORD-1

JOINT MUNICIPAL AND SEMICHEMICAL PULPING WASTE TREATMENT

A PILOT PLANT STUDY EVALUATING COMBINED TREATMENT OF DOMESTIC SEWAGE AND WEAK SEMICHEMICAL PULPING AND PAPERMAKING WASTES

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DEPARTMENT OF THE INTERIOR

By

THE CITY OF ERIE, PENNSYLVANIA
AND
HAMMERMILL PAPER COMPANY

PROGRAM NO. 11060 EOC
GRANT NO. WPRD-223-01-68

JULY, 1969

FWPCA Review Notice

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration.

ABSTRACT

The City of Erie, Pennsylvania and Hammermill Paper Company made a study of the joint treatment of domestic sewage and pulp and papermaking wastes. A pilot plant was constructed and operated in a series of controlled experiments. Supplemental studies were conducted in the Hammermill laboratories including the operation of a bench-scale activated sludge plant.

It was demonstrated that a joint treatment plant could effectively treat a mixture of domestic sewage and pulp and paper mill wastes from Hammermill's Erie Division. A full-scale joint treatment plant should obtain a BOD removal of approximately 90% in summer months and 80%-85% in winter months. Primary treatment should achieve a 25% reduction in BOD and a 60% reduction in suspended solids. Treatment of mixed wastes by the activated sludge process will require a long solids aeration period and a relatively low BOD to volatile solids loading to avoid high sludge volume indicies. The activated sludge process does not reduce the color of the mixed wastes and the final effluent will have about 40 mg/l of suspended solids. The chlorine demand of the final effluent averaged over 60 mg/l. A NH_3-Cl_2 mixture added at a level of 2.61 ppm NH_3 and 15-17 ppm Cl_2 showed promise as a disinfectant with coliform counts generally below 1,000/100 ml.

This report was submitted in fulfillment of Research and Development Grant Number WPRD-223-01-68 between the Federal Water Pollution Control Administration and the City of Erie, Pennsylvania.

Key Words:

Pilot Plants - Pulp Wastes - Municipal Wastes - Sewage Treatment - Activated Sludge - Sludge Disposal - Oxygenation - Disinfection - Annual Costs.

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I

CONCLUSIONS & RECOMMENDATIONS

The operation of the pilot plant, the Hammermill bench plant and the associated studies demonstrated that a joint treatment plant could effectively treat a mixture of domestic sewage from the City of Erie and pulp and paper mill wastes from Hammermill's Erie division. A BOD removal of approximately 90% during summer months when mixed liquor temperatures are 70° F. or higher and 80% to 85% reduction in winter months when mixed liquor temperatures are around 50° F. should be attained by a plant treating mixed wastes.

Combined neutralized Hammermill waste mixed with sewage in 1 to 1 proportions is effectively treated by primary sedimentation. Treatment of Hammermill waste by itself was less effective. Pilot plant primary treatment removed 76% of the suspended solids in mixed wastes and reduced BOD and COD by 25%-30%. The high concentration of soluble COD and BOD kept the percentage reduction low. The pilot plant was operated at a constant flow. Flow fluctuations in a joint treatment plant would make primary treatment less effective but reductions of at least 25% of the BOD and 60% of suspended solids should be obtained. Sludge from the primary treatment plant contained 1.5% solids, substantially less than expected in normal primary municipal solids. The pilot plant primary sludge averaged 80% volatile, while municipal primary sludge is normally less than 70% volatile. The suggested primary tank design is 1,000-1,150 gal./sq. ft./day.

No trouble was encountered in treating the mixed wastes by the activated sludge process. The addition of supplemental nitrogen or phosphorus was not required to obtain good BOD reductions. Nitrogen content of the wastes ranged between 3%-5% of its 5-day BOD and phosphorus ranged from 2%-4%. High sludge volume indices were encountered and microscopic examination showed the presence of heavy filamentous growths. Methods to control these growths other than increasing aeration time were not investigated. A joint treatment plant should be designed for a sludge volume index of at least 200. To avoid even higher indices the volatile content of the activated sludge must be prevented from exceeding 80% by the use of long solids aeration periods and relatively low BOD to volatile suspended solids loadings. A ratio integrating these factors was established and used in the preliminary design calculations.

$$\frac{\text{BOD Loading/Day (lbs)} \times 100}{\text{Total VSS (lbs)} \times \text{Aeration Period (hrs)}} \leq 6$$

Additional verification of the ≤ 6 figure used as a limiting factor in the preliminary design calculations might show that a higher figure could be used. Additional studies of methods for controlling the volatile content of the suspended solids and the sludge volume index are also advisable.

Pilot plant operations demonstrated that a 10^{o} C. change in mixed liquor temperature effected a fourfold change in reaction rates when treating a 50-50 mixture of Hammermill waste and municipal sewage. Experience indicates that the reaction rate change is two or threefold per 10^{o} C. for municipal sewage.(1)In treating mixed wastes a high oxygen requirement and low floc build-up will be encountered at high temperatures, the reverse will be true at low temperatures. Conventional activated sludge operation without use of sludge reaeration is indicated for low temperature operation of a joint treatment plant. Sludge reaeration is indicated during warm weather operation.

Conventional spiral flow aeration tanks such as those now in use at the City of Erie experience serious short-circuiting. Aeration periods in a joint plant should be increased by about 25% over those established by pilot plant studies where completely mixed aeration tanks were used. Use of turbine type dispersers and single pass tanks is recommended to reduce short-circuiting. Preliminary design calculations indicated that the total aeration tank volume should be equal to approximately one third the average daily flow with return sludge rates of 75%-100% in the summer. Twenty to thirty per cent of the total aeration tank volume would be used for sludge reaeration in warm weather. In cold weather sludge reaeration would be discontinued and all tanks would be used for mixed liquor aeration. About one third of the tanks should be constructed so they can be used for either mixed liquor aeration or sludge reaeration.

The processing of the low phosphate pulping and papermaking wastes with domestic sewage in a joint treatment plant reduced the incoming phosphates by 30%-43% but left 3 to 7 mg/l in the final discharge. Some type of supplemental treatment would be required to obtain higher phosphate removal. The nitrate content of the effluent seldom exceeded 1 mg/l.

The overall removal of suspended solids by the pilot plant activated sludge process was in the 70% to 80% range. A full-scale plant treating mixed wastes could produce lower suspended solids than the pilot plant but the final effluent would probably contain 40 mg/l of suspended solids.

The activated sludge process does not reduce the color of the mixed wastes. The extensive investigation conducted by Hammermill did not turn up a method which was economically feasible. Additional investigative work may be in order on other techniques.

Tests of gravity thickening and air flotation indicated that either process could produce a sludge containing 3% solids when handling excess activated sludge, or a mixture of primary and excess activated sludge. Thickening by air flotation released less phosphate. Gravity thickening of primary sludge and air flotation thickening of waste activated sludge may be desirable.

The final effluent had a high chlorine demand averaging over 60 mg/l. The high cost of such a chlorine usage dictated a search for a less expensive method of disinfection. The investigation showed that a premixed NH_3-Cl_2 solution applied at the rate of 2.61 mg NH_3 and 15-17 mg Cl_2 per liter resulted in coliform counts generally below 1,000/100 ml in the final waste effluent. The use of the premixed NH_3-Cl_2 solution was found to work equally well on City of Erie effluent. The cost of the NH_3-Cl_2 treatment for the mixed waste effluent was 75% less than the use of chlorine by itself. Additional investigation work could well be done on the stability of the solution, the ratio of the two chemicals, the amount required for disinfection and on methods of application.

Variations in hourly uptake of oxygen needs further investigation since aeration devices must be designed to meet maximum oxygen needs. Additional corrosion studies and studies of coatings are indicated. Detailed design work may indicate need for supplementary sludge concentrating studies.

Tests conducted in the Hammermill laboratories indicated that a 40-day retention period with a loading not over 0.1 lb. volatile solids per day per cubic foot would be required for effective anaerobic digestion of the mixed sludge. Considerable lime would be required to maintain suitable alkaline conditions. It was concluded that anaerobic digestion would not be practical in a joint treatment plant. Incineration is the preferred ultimate disposal method. Studies of the use of centrifuges and vacuum filters for sludge dewatering prior to incineration indicated that the lower cost and potentially higher per cent solids in the cake obtained by filtration made it the preferred method. No pilot studies of incineration were possible but sufficient information is believed to be available to size the equipment.

The cost of constructing the addition to the present Erie municipal plant to provide additional sewage capacity and for the treatment of Hammermill Paper Company wastes was not estimated in detail. Rough preliminary estimates indicate that Hammermill's share, before any subsidy, of the capital cost for the addition to the plant required to handle the increased waste flow would be approximately $16,000,000. If apportioned in relation to effluent flow, the Hammermill share would be $37,000 per ton of daily pulp production and $4,600 per ton of daily paper production. The operating costs were also roughly estimated and it was indicated that the cost would be $4.00 per ton of pulp produced plus $.45 per ton of paper produced. The treatment costs for the combined wastes, using the disinfection procedures developed in the project, were roughly estimated at $.05 per 1,000 gallons. Phosphate removal would add an estimated $.01-$.015 per 1,000 gallons of mixed wastes.

II

INTRODUCTION

The City of Erie through its Bureau of Sewers and Hammermill Paper Company of Erie, Pennsylvania are studying the feasibility of treating the sanitary waste from the City jointly with the pulp and paper mill effluent from the Erie Division of Hammermill. Both the City and Hammermill are under orders from the Sanitary Board of the Commonwealth of Pennsylvania to provide additional degrees of treatment in order to improve the quality of Lake Erie. A joint treatment venture appears desirable for a variety of reasons, including the economy of scale.

The prime factor in the research program was the construction and operation of a pilot plant to provide joint treatment under a variety of controlled conditions. The general purpose of the pilot plant and the associated laboratory studies was to demonstrate the feasibility of such a venture, to determine optimum parameters for full plant design, and to establish the nutrient removal which could be obtained. The treatment of a relatively high BOD waste from wood pulp bleaching and papermaking operations in conjunction with sanitary sewage has industry-wide application.

The City of Erie made application to the Federal Water Pollution Control Administration for a Research and Development Grant for this work as provided in the "Clean Water Restoration Act of 1966".

The City of Erie on June 20, 1968 accepted an FWPCA Research and Development Grant (WPRD-223-01-68) of $88,230 or 75% of eligible project costs, whichever was less. Eligible costs for the grant were limited to the preliminary studies and reports and postconstruction studies and reports. These costs were 25% of the estimated total cost of the project. This report was prepared to make the findings of the pilot plant study available in a form requested by the Water Pollution Control Administration.

Hammermill constructed the pilot plant immediately adjacent to the municipal plant. The pilot plant started operation in July, 1967, and operated continuously until late in January, 1968. Hammermill wastes were first admitted on August 1 and their proportion gradually increased to the 1 to 1 proportion used throughout the experimental program. Concurrently with the construction and operation of the pilot plant, numerous laboratory and bench scale investigations were conducted in the Hammermill laboratory. These included the construction and operation of the bench scale, continuous flow, activated sludge facility and four bench scale anaerobic digesters. The pilot plant did not contain any facilities for studying anaerobic digestion, but did provide for studies of primary sedimentation, secondary treatment by the activated sludge process with and without separate sludge reaeration, sludge concentration and sludge dewatering.

The bench scale continuous flow activated sludge facility was first placed in operation during April, 1967, and remained in continuous operation throughout the period covered by this report. Bench scale anaerobic digesters were operated by Hammermill during the last half of 1967.

The Chester Engineers of Pittsburgh, Pennsylvania were engaged as consultants and provided technical advice on the conduct of the studies. Professional personnel in Chester Engineers did the majority of the interpretive work on the data obtained in the studies and prepared the design material. They presented a detailed report, the basis for this report, to Hammermill Paper Company on combined treatment of Hammermill and Municipal wastes.

III

BACKGROUND

The pollution problems of Lake Erie have received wide study and documentation. The most comprehensive work is that done by the Federal Water Pollution Control Administration (FWPCA) under the Department of Interior (formerly under the U. S. Public Health Service) and documented in the report on Pollution of Lake Erie and Its Tributaries released in July, 1965. This report formed the basis for the conference on Pollution of Lake Erie and Its Tributaries called by the Department Secretary and resulting in the adoption of a series of recommendations for improving Lake Erie.

The report stated that Pennsylvania's part in the Lake Erie problems stemmed mainly from the Erie municipal treatment plant and from the discharges from Hammermill Paper Company. It was recommended that additional levels of treatment be provided by both of these to accomplish improvement in the Pennsylvania offshore waters of Lake Erie. Special emphasis was placed on reduction of phosphate and nitrate as a means of reducing algae growth.

The Division of Sanitary Engineering of the Pennsylvania Department of Health (Mr. Walter Lyons, Chief) has suggested that the best solution to these two problems might be expansion of the domestic treatment plant to a capacity which would provide both for the needed expansion for the growing domestic population and for the effluent from Hammermill Paper Company. A joint treatment approach appears feasible and has many important advantages such as lower capital cost, reduced operating costs, simplified operation and control, easier regulatory surveillance and qualification for major Federal aid. In addition, phosphate and nitrate discharges should be reduced because of the nutrient requirement of Hammermill's waste which could be satisfied by the excess in the domestic waste.

As a result of this suggestion, a preliminary study was made by the Chester Engineers, Pittsburgh, Pennsylvania, Hammermill's consultants. Their results, which were reviewed and concurred in by Consoer, Townsend & Associates, consulting engineers for the Erie Sewer Authority, indicated that joint treatment might be feasible. However, both engineering firms strongly recommended that prior to design and construction of a major plant, a pilot plant be built and operated. This pilot plant would demonstrate the feasibility of the concept and provide the design information necessary for a successful full-scale plant. The pilot plant was constructed and the appropriate research studies were made.

Present City Plant

The sewage treatment plant serving the Erie community is owned by the Erie Sewer Authority. It is operated by the City of Erie on a lease-back arrangement. This plant provides sewage treatment facilities for a population of approximately 180,000 people and serves the surrounding area including the political subdivisions of the City of Erie, Wesleyville Borough, Lawrence Park Township, Millcreek Township and part of Harborcreek Township.

The sewage from the City flows by gravity to the headworks of the sewage treatment plant. The headworks consist of a coarse bar screen to remove large particles, two aerated-type grit chambers and two barminutors for comminuting the wastes.

The comminuted wastes then flow by aerated channel to the primary settling tanks. There are two sets of primary settling tanks at the plant: the old primary settling tanks, capable of providing primary treatment for a flow of 22.5 mgd; and the four settling tanks placed in operation in 1956, also capable of treating 22.5 mgd. The settling tanks are equipped with sludge collecting mechanisms to remove the settled solids (sludge). The floating scum solids are collected in skimming pipes and removed.

After primary treatment, the settled wastes flow to five aeration tanks. The aeration tanks are of the two-pass type. Air is introduced to the aeration tanks through swinging-type diffusers.

The aerated mixed liquor passes from the aeration tanks to six final settling tanks. The final settling tanks are of octagonal shape and the flow to each settling tank is proportioned by means of a Parshall Flume at the inlet of each tank. In these tanks the majority of the mixed liquor solids are settled and returned by four variable speed return sludge pumps to the influent of the aeration tanks. The clarified liquor is then discharged from the final tanks to the chlorine contact chamber where chlorine is added for disinfection purposes and the 10,500 feet of 72-inch outfall sewer provides the contact time for the chlorination prior to discharging the treated effluent to the lake.

The air necessary to support the activated sludge system is supplied by three positive displacement blowers and the blowers are driven by dual fuel, four cycle, eight cylinder super charged engines.

The mixed liquor solids that are periodically wasted are returned to the primary settling tank. That sludge as well as the sludge settled in the primary settling tanks are pumped to two primary highrate sludge digesters.

The primary digesters are equipped with facilities for gas recirculation for the complete mixing of the sludge. Sludge heaters are also provided to keep the digesters at an optimum operating temperature. The digesters are of the so-called accelerated digestion process. The digested sludge is periodically discharged to the secondary digesters which are conventional digesters used primarily for storage of sludge and supernatant separation. The secondary digesters are not directly heated but remain at a somewhat elevated temperature as a result of the continual addition of heated sludge. Some additional digestion occurs in the secondary system. Gas produced during the digestion process is discharged to a gas storage sphere. The digester gas is used as auxiliary fuel to heat the digester.

The digested sludge solids are conveyed to two elutriation tanks now used as sludge storage tanks. The solids, containing about 95% moisture, are pumped to a tank where a polyelectrolyte compound is added to enhance the filterability of the solids. The treated sludge is then dewatered on two coil vacuum filters. The filtrate is returned to the primary settling tanks and the dewatered solids, containing about 80% moisture, are hauled away to disposal sites.

To serve the growing population of the area and to provide complete treatment rather than a modified degree of treatment, a major expansion is required in the city plant. The expansion will increase the city treatment capacity 20 - 25 million gallons per day.

Complete treatment is defined by the Pennsylvania State Sanitary Water Board as "such treatment that will remove practically all the suspended solids, at least 85% of the organic pollution load as measured by the biochemical oxygen demand (BOD) test, provide satisfactory disposal of sludge and produce a final effluent that is suitable for discharge to the receiving stream."

Hammermill Paper Company

The Erie Division of Hammermill Paper Company operates an integrated pulp and paper mill producing 385 tons per day of Neutracel pulp (a patented neutrasulfite semichemical pulping process) and 360 tons per day of fine printing and writing paper. The Neutracel process is unique in that a fine paper pulp can be produced from typical hardwood trees found in northwestern Pennsylvania. Congruent to the benefits of this process is the absence of any sound technology for reclaiming the pulping chemical and eliminating the pollution load caused by the organic material found in the spent pulping and bleaching liquors.

Hammermill has spent over $4 million in research and installations to find a practical solution to this problem. These efforts have resulted in the installation of two deep disposal wells which are currently disposing of the concentrated spent liquor from the pulping operations. The deep well installations are described in the Journal of Water Pollution Control Federation (2).

Deep well disposal has permitted Hammermill to eliminate 60% of the BOD in the pulping waste. The remaining wastes are very dilute and voluminous and consequently hard to treat. This residual waste consists of the process water from pulp washing and bleaching and amounts to 21 - 25 million gallons per day.

In addition to the dilute wastes from pulping and bleaching, there is also a waste discharge from the paper mill operation which contains the normal materials such as papermaking fiber, starch and paper additives associated with the production of fine writing paper. For many years paper mill wastes have been treated by sedimentation prior to discharge to the lake. The volume and BOD load from papermaking is a small fraction of the total volume but would be included in the total plant effluent. Table I characterizes these wastes.

Activated sludge treatment of pulp and paper mill wastes has been reported in the literature and is in operation. However, there are no known facilities treating wastes with as high a BOD load as is discharged from Hammermill's Erie operation. The treatment of these wastes in combination with domestic sewage is, thus, an unproven concept which requires careful study.

The utilization of the deep wells is essential for an economically successful biological treatment. If the wells were not in operation, the BOD load would exceed the practical level for secondary treatment. Thus, consideration of secondary treatment prior to the deep wells was impossible.

Hammermill is under orders from the Commonwealth of Pennsylvania to effect treatment of its remaining wastes. The City of Erie has submitted to the Commonwealth a schedule for increased treatment of its sanitary wastes up to the point where the decision is made to go or not to go with joint treatment. Beyond this the city's schedule calls for either joint treatment or expansion without Hammermill depending on the outcome of the pilot plant studies and the joint treatment agreement negotiations. The date of compliance is December 31, 1970 in either case. It is seen that the operation of the pilot plant is a necessary and critical part of both the city's and Hammermill's programs.

TABLE I

Characteristics of Hammermill Wastes

	Maximum	Minimum	Average
Present Discharge			
Paper Mill*			
Flow - mgd	3.1	2.2	2.8
BOD_5 - mg/l	280	190	250
COD - mg/l	700	500	570
Suspended Solids - mg/l	360	64	180
pH	7.4	4.4	6.3
Pulping & Bleaching**			
Flow - mgd	25	21	23
BOD_5 - mg/l	700	500	600
COD - mg/l	3,080	2,300	2,680
Suspended Solids - mg/l	292	169	232
pH	3.6	2.8	3.1
Probable Discharge to Joint Plant***			
Flow - mgd	30	25	27.5
BOD_5 - mg/l	650	450	570
COD - mg/l	2,950	2,200	2,550
Suspended Solids - mg/l	335	220	280
pH	7.5	6.5	7.0

* After present primary treatment.

** Excludes spent pulping liquor which is presently disposed in deep wells.

*** Anticipated growth, abandoning paper mill primary treatment and fiber filtering, waste neutralization and continued pulping liquor disposal in deep wells.

IV

DESCRIPTION OF PILOT PLANT

A flow diagram of the pilot plant as constructed and operated is presented on the next page, following pages contain photographs of the plant. As indicated on the flow diagram, Hammermill wastes after pH adjustment with lime are delivered by tank truck to the pilot plant where they are stored in a wooden tank equipped with agitator. They are then pumped to the pilot plant treatment system. Municipal sewage, after grit removal and comminution, is pumped to the pilot plant.

Separate V-notch weir boxes with adjustable heads are provided to measure the volume of both sewage and Hammermill wastes delivered to the pilot plant. After mixing, the two wastes enter a flash mixer having an effective volume of approximately 420 gallons from which the mixed wastes enter a rectangular clarifier 2-1/2 feet wide by 10 feet long and approximately 7 feet deep, which has an effective volume of 1,340 gallons. Incoming wastes enter the tank at one end, after passing under an inlet baffle, flow longitudinally across the tank and out over a single effluent weir 2-1/2 feet long at the opposite end of the tank. Solids settling to the bottom of the tank are drawn to the hopper bottom sludge outlet by means of a screw conveyor.

After primary treatment the mixed wastes discharge over adjustable weirs to either or both of two circular wood stave aeration tanks equipped with sparger rings and turbine-type gas diffusers. Each of these tanks has an effective volume of 6,600 gallons when operated singly. When operated in series, i.e. for sludge reaeration ahead of mixed liquor aeration, the first or sludge reaeration tank, has an effective volume of 6,960 gallons while the volume of the second or mixed liquor tank remains 6,600 gallons.

Two tanks originally intended for aeration were used for the storage and thickening of both primary and excess activated sludge resulting from pilot plant operations.

After aeration, mixed liquor flows to a single, hopper bottom, final clarifier having a 7 ft. diameter and 7-1/2 ft. side water depth. Thus, its effective volume is approximately 2,180 gallons. The conical bottom is an additional 7 ft. in depth; therefore, the total volume of the tank is approximately 2,800 gallons. The tank is arranged for peripheral feed and center overflow, i.e. it utilizes the "rim flow" design promoted by Chain Belt Company.

Two calibrated, positive displacement, Moyno Pumps are provided, one for withdrawing sludge from the primary clarifier, and one for withdrawing sludge from the final clarifier. Final clarifier sludge is pumped to a headbox from which it is discharged over adjustable weirs to either

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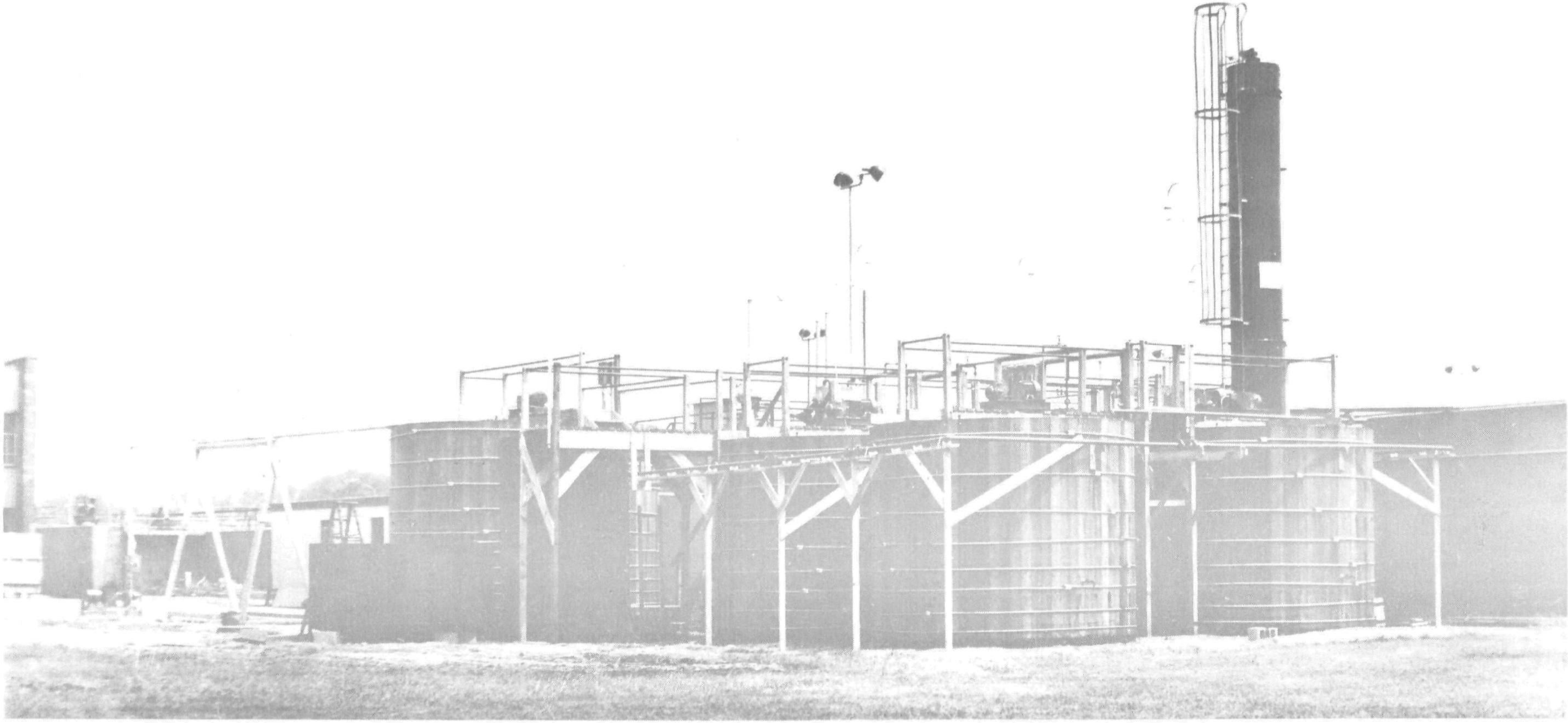


EXHIBIT II - Pilot Plant - Aeration tanks in center, Surfpac Tower at right, Hammermill effluent unloading and storage at left.

EXHIBIT III - Pilot Plant Operating Level - Primary sedimentation in center foreground, Surfpac Tower at left, Erie Sewage Plant Flume in background.

waste or process return. Both waste activated sludge and primary sludge are discharged to one or both of the two wood stave sludge storage tanks.

A "Surfpac" pilot trickling filter, rented from Dow Chemical Company, was installed and piping was arranged so that it could be operated as a roughing filter between the primary clarifier and the activated sludge process.

As indicated on the flow diagram, two chemical feeders were provided, one arranged so that nutrients, either diammonium phosphate or ammonium hydroxide, might be fed to the Hammermill wastes and mixed with them in the Hammermill waste storage tank prior to pumping those wastes through the pilot plant. The other feeder was provided to permit pH adjustment of the mixed waste in the flash mixer immediately ahead of the primary clarifier. Although the pH of the Hammermill wastes was adjusted at the paper mill prior to trucking them to the pilot plant, it was feared that further pH adjustment might be required at the pilot plant. This fear was not realized and there was no need for additional pH adjustment. The pH of the wastes ranged from 6.5 to 7.5, but was generally about 6.8.

In October, the pilot plant facilities were expanded to permit the installation of rented sludge flotation, vacuum filter and centrifuge units so better studies on the dewatering characteristics of the resulting sludges could be conducted than were found possible with conventional laboratory equipment.

Normally the plant was manned two shifts per day, seven days a week. The shifts were 7 a.m. to 3 p.m. and 7 p.m. to 3 a.m. each day. Thus, there were two 4-hour periods during which no one was in attendance.

Tests were run on 24-hour composite samples. Those samples were measured into a refrigerated jar at 2-hour intervals, missing two a day (5 p.m. and 5 a.m.). The composites taken were:

1. Influent
2. Primary effluent
3. Final effluent
4. Mixed liquor (last tank in series if applicable)
5. Return sludge
6. Reaerated sludge or other special samples as required.

The pilot plant operators took DO's and settleabilities on the mixed liquor (and reaerated sludge when applicable) every four hours. The pH of the neutralized Hammermill waste was checked twice a shift, as it had a tendency to drop gradually. Other duties included pumping out primary sludge periodically, skimming off floating surfaced solids, and a number of mechanical tasks necessary for the maintenance and operation of the plant.

The operators kept a daily log of pilot plant operations. Operating data sheets were completed daily and then compiled for each month's operation.

During the construction phases of the pilot plant, a batch aeration system and a bench-scale activated sludge plant were operated to show the general treatability of a mixture of Hammermill and City wastes. Each of these systems is briefly described below:

Batch System: Activated sludge from the City of Erie treatment plant was gradually acclimated to a 50-50 mixture of Hammermill and City wastes in a series of three-gallon aerated pails. These were maintained by settling, drawing off the supernatant and adding fresh waste once each day. This system showed that the 50-50 mixture could be treated to 90% BOD removal levels. The BOD removal curve with time showed no evidence of any toxicity.

Bench Plant: An activated sludge system has been in operation in Hammermill's laboratory since April, 1967. It is designed to handle a mixed liquor flow of 1.5 gallons per hour. This flow can be proportioned between influent and sludge return at the discretion of the operator. Influent for the system is subjected to a screening operation designed to simulate primary treatment. Hammermill waste is neutralized with lime in the laboratory before use.

The plant used City waste with sufficient glucose added to bring the BOD level to 300 mg/l. This was treated successfully without supplemental nutrient addition, showing the feasibility of handling a BOD load equal to that of the 50-50 mixture of Hammermill and City wastes. Subsequently, the glucose was gradually replaced with Hammermill waste, making a smooth transition to joint treatment of a 50-50 mixture of Hammermill and City waste. The system was run at three different loadings using the 50-50 mixture to show the effect of loading on BOD and COD removal.

V

OBJECTIVES

The general objective of this project was to build and operate a pilot plant to demonstrate the feasibility of joint treatment and to obtain certain design parameters. The plant was designed to provide answers to the following immediate objectives:

1. To demonstrate the success of activated sludge treatment of domestic sewage from the City of Erie and industrial pulp and paper mill wastes from Hammermill's Erie Division in a joint treatment facility.

2. To determine the reduction in phosphate and nitrate discharged to the lake in the treated combined effluent through the utilization of the nutrients by biological treatment of industrial waste.

3. To determine the proper design criteria and consequently the cost of a joint treatment facility.

4. To determine the parameters necessary to estimate the costs of facilities to treat Hammermill's waste alone and of facilities to take care of the City's needed expansion so that these costs may be compared to those of joint treatment.

5. To estimate the operating costs.

6. To determine the characteristics of the treated wastes to assure they meet regulatory requirements.

It is anticipated that any joint treatment facility would be capable of treating almost all of the pollution load attributable to domestic sewage and industrial waste which is discharged to Lake Erie from almost all of the Lake Erie drainage basin in Pennsylvania.

Hammermill retained the Chester Engineers to determine the feasibility of joint treatment. Their preliminary study indicated that such a plant was feasible from a process standpoint. They recommended that prior to the design and construction of a joint plant, a pilot plant be built and operated. This pilot plant was to demonstrate process feasibility and provide the design information necessary for a successful full-scale plant. The Chester Engineers prepared a detailed report on the operation of the pilot plant and supporting studies, and this report is largely drawn from it.

To expedite the accomplishment of the objectives, Hammermill built and operated a batch aeration and a bench-scale activated sludge plant. The bench plant continued in operation during the operation of the pilot plant to complement the pilot plant program and to determine the feasibility of treating 100% Hammermill waste by the activated sludge process.

In addition, Hammermill conducted laboratory studies on analytical methods, sludge digestion, primary settling, neutralization, disinfection, corrosion, tertiary treatment, phosphate removal, foaming and color.

VI

PRIMARY TREATMENT

Pilot Plant Operation

The primary clarifier of the pilot plant was in continuous operation from July 18, 1967 to January 21, 1968 to provide primary treatment ahead of the activated sludge process.

Initially, the clarifier inflow consisted of 20 gpm of municipal sewage. Hammermill wastes were first admitted to the clarifier late on July 31, at a rate of 1 gpm, together with 19 gpm of City sewage. The proportion of Hammermill waste was gradually increased, while that of sewage was correspondingly reduced. With only a few exceptions, the influent to the clarifier has generally consisted of a 50-50 mixture of sewage and Hammermill waste from August 6 to the end of the run. The principal exception was the holiday season from December 22 to January 2, when the inflow consisted of only 9 gpm of City sewage. Composites of hourly samples of both influent and effluent were collected and analyzed almost daily throughout the run. The results of those analyses are summarized in Table II.

The table also summarizes rates of inflow to the clarifier during the periods when samples were collected. The rates varied from 15 to 24 gpm at various times. However, the inflow was always uniform throughout a single day. At an inflow of 20 gpm, the theoretical detention period in the flash mixer was 21 minutes and that in the primary clarifier was 1.1 hours. The surface settling rate in the clarifier was 1,150 gallons per square foot per day and the weir overflow rate was 11,500 gallons per foot per day.

To study the various factors bearing on the performance of the clarifier, the data upon which Table II is based have been subdivided into 14 chronological periods. The duration of the various periods ranged from as little as four days to as much as 28 days; their length was dependent upon the particular factors being considered.

Period 1 covers the last 11 days of July during which the pilot plant was in full operation on municipal sewage, but had not received any Hammermill waste. During that period the inflow to the clarifier averaged 138 mg/l of total suspended solids (TSS) and 107 mg/l of 5-day biochemical oxygen demand (BOD). The annual report of the Bureau of Sewers of the Erie Department of Public Works for 1965-66 indicates that for the year 1966, the sewage influent averaged 136 mg/l of TSS and 105 mg/l of BOD. Therefore, it is apparent that the inflow to the clarifier during Period 1 may be considered typical of present sewage composition.

TABLE II

Primary Treatment

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14
From	7-20	8-5	8-9	9-1	9-12	9-16	9-26	10-1	10-6	10-12	10-29	11-27	12-1	1-4
To	7-31	8-8	8-31	9-8	9-15	9-25	9-29	10-4	10-11	10-24	11-25	11-30	12-21	1-21
Flow, gpm														
Sewage	20	12.5	10	10	7.5	10	10	8.4	10	7.5	9	12	9	9
Hammermill	0	11.5	10	10	7.5	10	10	8.4	10	7.5	9	12	9	9
Total	20	24	20	20	15	20	20	16.8	20	15.0	18	24	18	18
Total Susp. Solids														
Influent, mg/l	138	353	290	295	404	467	429	710	268	350	264	201	278	223
Effluent, mg/l	30	100	73	82	70	65	62	73	99	62	68	59	57	60
Percent Removed	78	72	75	72	83	86	86	89	63	82	74	71	80	73
Vol. Susp. Solids														
Influent, mg/l	96	278	208	218	-	296	-	-	-	-	225	-	221	172
Effluent, mg/l	26	75	58	63	-	65	-	-	-	-	42	-	42	49
Percent Removed	71	73	72	71	-	78	-	-	-	-	81	-	81	72
5-Day BOD														
Influent, mg/l	107	314	327	301	328	452	453	410	316	370	330	370	305	274
Effluent, mg/l	56	262	216	239	213	340	313	233	237	280	241	295	218	213
Percent Removed	48	17	34	21	35	25	31	42	25	24	27	20	29	22
COD														
Influent, mg/l	273	1336	1199	1129	1167	1709	1715	1391	1223	1573	1245	1333	1316	966
Effluent, mg/l	145	1036	830	923	858	1091	1215	995	997	1244	947	1125	899	847
Percent Removed	47	22	31	18	26	36	29	29	19	21	24	16	25	12
Phosphates as PO_4														
Influent, mg/l	19	13	10	10	10	12	11	-	-	7	5	6	6	6
Effluent, mg/l	17	9	9	10	9	10	9	-	-	6	5	5	5	5
Percent Removed	10	31	10	0	10	17	8	-	-	14	0	17	17	17
Organic & Ammonia Nitrogen														
Influent, mg/l	23	10	10	5	6	13	11	-	-	-	10	11	11	12
Effluent, mg/l	20	9	7	5	6	8	8	-	-	-	9	9	10	11
Percent Removed	13	10	30	0	0	38	27	-	-	-	10	18	9	9

The weighted average of the various analyses of the inflow to the clarifier for Periods 2 to 14 inclusive, indicates that it had the following average composition:

TSS	312 mg/l
BOD	337 mg/l
Chemical Oxygen Demand (COD)	1,285 mg/l

As this inflow consisted of a 50-50 mixture of Hammermill waste and sewage and based upon the assumption that the sewage handled during Period 1 was typical of the City sewage, it may be calculated that during the entire period that Hammermill wastes were handled in the clarifier, they had the following average composition:

TSS	486 mg/l
BOD	567 mg/l
COD	2,297 mg/l

Table I indicates that the probable future average discharge of Hammermill wastes will contain 280 mg/l of TSS, 570 mg/l of BOD, and 2,550 mg/l of COD. From a comparison of the two analyses it is apparent that the actual inflow of Hammermill waste during the period of pilot plant operation was quite similar to the expected composition of those wastes insofar as BOD or COD is concerned, but contained far more suspended solids. This difference is attributed to the fact that it was impossible to prevent a certain amount of sedimentation and concentration of suspended matter in the sampling and storage facilities provided at the Hammermill plant and, therefore, the wastes tank-trucked to the pilot plant were abnormally high in suspended solids. However, it is apparent that the solids which become insoluble were of an inert nature and so did not affect either the BOD or the COD of the wastes delivered to the pilot plant.

It is believed that the removals of BOD and COD, as shown in Table II, are typical of what can be expected. However, we were concerned that the removal of total suspended solids may be somewhat high because of the abnormally high concentration of suspended solids in those wastes.

Studies were made on the settling characteristics of Hammermill and City wastes in the Hammermill laboratory concurrently with the operation of the pilot plant. Those studies indicated that when considered separately, the sewage settled better than did either the pulp mill or the paper mill wastes, but that when the three wastes were combined in the proportions of 40% pulp mill, 10% paper mill and 50% sewage and neutralized to a pH of 7, a 60-minute settling of the mixed waste generally effected substantially the same percentage removal of suspended solids as did a 60-minute sedimentation of sewage alone.

Laboratory testing of four different samples of mixed wastes containing initial suspended solids concentrations of 196, 228, 276 and 536 mg/l respectively, produced effluents after 60 minutes sedimentation containing 96, 96, 74 and 134 mg/l respectively, thus indicating corresponding percentage reductions in suspended solids of 51, 58, 73 and 75 per cent. These data seem to indicate that the abnormal concentration of solids in the influent to the primary clarifier may have had far less effect upon its performance than one would initially anticipate.

Pilot Plant Performance

The following tabulation summarizes the effect of variations in flow of mixed waste on the performance of the clarifier.

Rate of inflow of mixed wastes, gpm	24	20	18	16.8	15
Number of days in operation	8	51	67	4	17
Average reduction in TSS, %	71	76	76	89	82
Average reduction in BOD, %	19	29	26	42	27
Average reduction in COD, %	19	28	21	29	22

It is probable that the four days of operation at 16.8 gpm was too short a period to be of much significance, and might well have been omitted from the above tabulation. The data give an indication that the primary clarifier could effectively handle flows up to 20 gpm without sacrificing treatment efficiencies, but that at flows in excess of that, efficiencies dropped off, particularly BOD and COD removals.

Nothing in Table II indicates that changes in temperature materially influence the effectiveness of primary sedimentation. Percentage reductions obtained during December (Period 13) were comparable with those obtained during August and September. The removals of BOD and COD obtained during January (Period 14) were somewhat lower than had been obtained during previous periods, but both the BOD and COD of the incoming waste were also lower during Period 14.

Insofar as percentage removals of total and volatile suspended solids are concerned, it seems apparent from Table II that the mixed waste is as amenable to primary treatment as is the municipal sewage alone, and this fact was substantiated by work in the Hammermill laboratory. However, primary treatment cannot effect as great a reduction in BOD and COD of the mixed waste as it does in the municipal sewage. This result was to be expected since the pulp mill wastes are far higher in soluble BOD and COD than municipal sewage.

On or about September 16, a malfunction of the deep well disposal system caused a considerable increase in the BOD and COD of the industrial waste delivered to the pilot plant. Although that discharge was corrected within a day or two, considerable time elapsed before the strong wastes stored in the neutralization and pilot plant storage tanks was worked off. As a result, the BOD of the influent to the pilot plant was abnormally high during Periods 6, 7 and 8. Apparently this discharge had no deleterious effect insofar as percentage reductions in either solids, BOD or COD by primary treatment are concerned. In fact, the percentage reductions in suspended solids were higher during those periods than during the periods preceding or following them.

During the initial period of pilot plant operation, the City was feeding a polyelectrolyte to the sewage ahead of the pilot plant. Such polyelectrolytes might affect the performance of the pilot plant primary unit. On September 9, the City temporarily discontinued the use of polymers. From a comparison of runs of Periods 6 and 7, during which no polymer was used with Runs 3 and 4 during which the polymers were used, it does not appear that the polymer had any appreciable effect on the performance of the pilot plant primary clarifier.

The pH of the primary effluent was quite uniform throughout the period covered by Table II. Normally it ranged from 6.8 to 7.2.

Primary treatment did not reduce the color and generally yielded only very insignificant reductions in nitrogen or phosphate. (During Periods 8 and 9 di-ammonium phosphate was being added to the Hammermill waste and ammonium hydroxide was added during Period 10. Therefore, some of the data on nutrient removal by primary treatment during those periods has been omitted from Table II.)

Normally, good primary treatment of municipal sewage can be expected to effect a 60 to 70 per cent reduction in suspended solids, and at least a 35 per cent reduction in BOD. However, as indicated by the result of Period 1 in Table II, primary treatment of municipal sewage alone in the pilot plant yielded considerably higher reductions.

In contrast, the annual report of the Bureau of Sewers of the Erie Department of Public Works for 1965-66 indicates the following for the year 1966:

	Raw Sewage	Primary Effluent
TSS, lb/day	36,992	29,858
BOD, lb/day	28,468	18,692

Based on these data alone, it would appear that the primary clarifiers at the Erie Municipal Plant were effecting reductions of only 20% of the suspended solids, but 34% of the BOD.

Those reductions are misleading however, for the Erie clarifiers received not only raw sewage, but also waste activated sludge, digester supernatant and filtrate from the sludge filters. The volume of these three in-plant wastes is quite small, in fact, their combined volume represents less than 1% of the average sewage flow. However, all three wastes are extremely high in suspended solids and the supernatant and filtrate are also high in BOD. Although the aforementioned annual report contains no data on the BOD of these in-plant wastes, it does contain some information from which their solids content may be estimated. Calculations showed that the average annual removal of suspended solids through the Erie clarifiers during 1966 was approximately 56% instead of 20%.

VII

ACTIVATED SLUDGE TREATMENT

Pilot Plant Operation

The number of microorganisms present and their health and activity influence the results obtained by the activated sludge process. Figure 4 is a plot of the weights of BOD removed per 100 pounds of total suspended solids under aeration against the weights of BOD applied to those solids for each day the necessary tests were run at the pilot plant during the period of August 8 to October 27, inclusive. Figure 5 is similar to Figure 4, except that the BOD loadings and removals are calculated on the basis of volatile suspended solids, instead of total suspended solids, under aeration. Note that in either chart the points tend to fall along a straight line. The deviation from that tendency is slight when consideration is given to all the possible errors that might occur in a single day's sampling and analysis.

Both charts indicate that the mixture of Hammermill waste with Erie sewage may be more difficult to treat by the activated sludge process than is municipal sewage alone, i.e. the treatment of the mixed waste yields a BOD reduction of nearer 84% than the 90% reduction that could be obtained by the treatment of municipal sewage. Figure 5 indicates that an 84% BOD reduction might be expected at BOD loadings as high as 55 pounds per day per 100 pounds of volatile suspended solids under aeration (MLVSS). At higher loadings the reduction drops off gradually.

The start-up of the pilot plant activated sludge process covered the period from July 18th through 30th. Initially the two aeration tanks and the final clarifier were filled with mixed liquor drawn from the aeration tank of the municipal plant. City sewage alone was then fed to the pilot plant at a rate of 20 gpm. The activated sludge process followed the conventional flow diagram, i.e. the two aeration tanks were operated in series for mixed liquor aeration. Sludge was withdrawn from the final clarifier and returned to the aeration tanks at a rate of 8 gpm. Dissolved oxygen levels in the aeration tank were maintained between 3 and 5 mg/l. The incoming sewage was relatively weak and primary treatment was quite efficient, (see Period 1 of Table II) and the BOD to solids loading was low. The average for the entire period was only 8.2 pounds per 100 pounds of MLVSS. Although no activated sludge was wasted, the concentration of mixed liquor solids decreased throughout the period, indicating that "autodigestion" was taking place. On July 30 there were only 77 pounds of suspended solids under aeration and the volatile content of those solids was only 42%.

Hammermill wastes were first admitted to the pilot plant on July 31, and at the same time the pattern of flow was changed to sludge

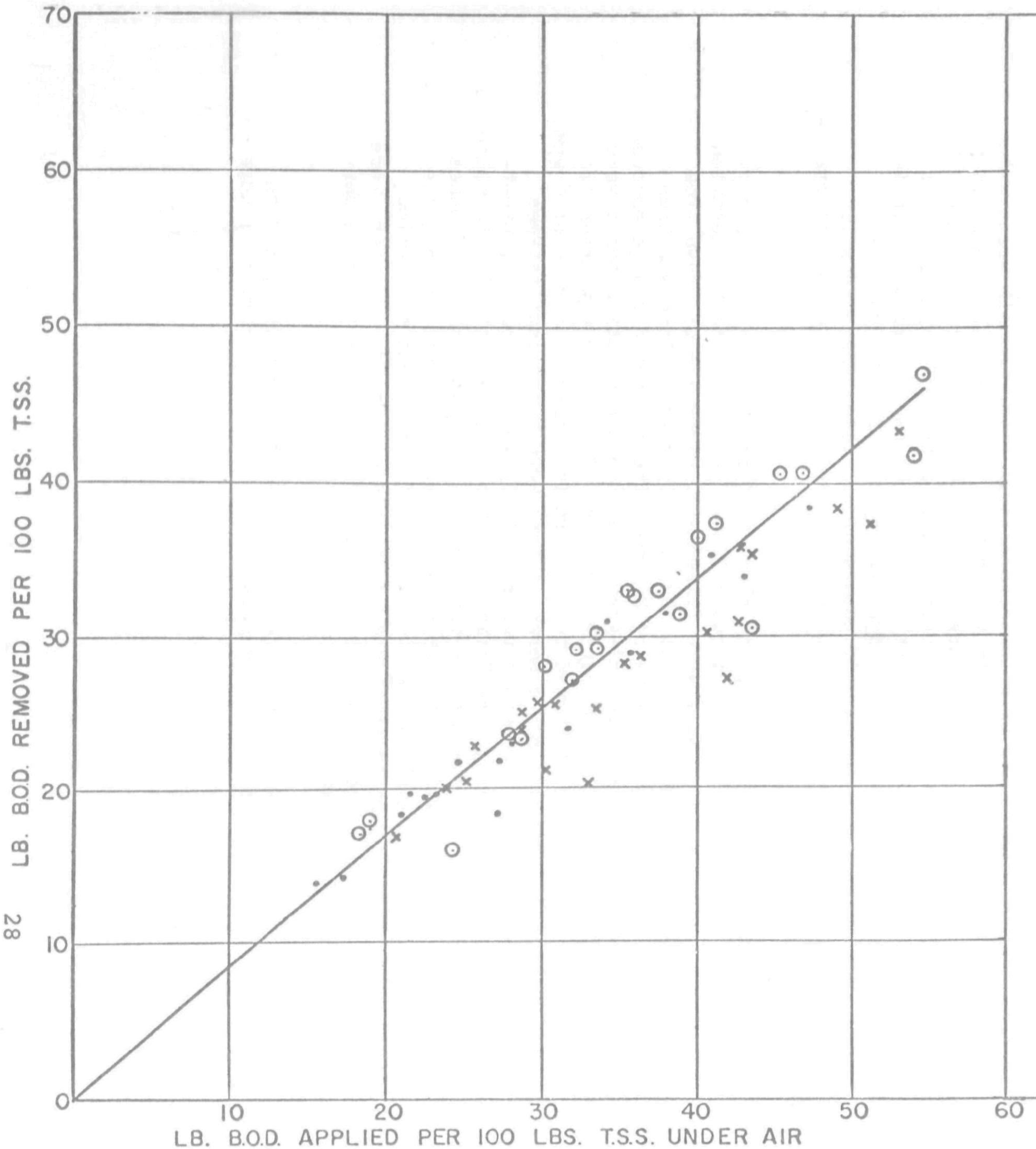


FIGURE 4 - PLOT OF BOD REMOVED vs BOD LOADING PER 100 LB TSS.

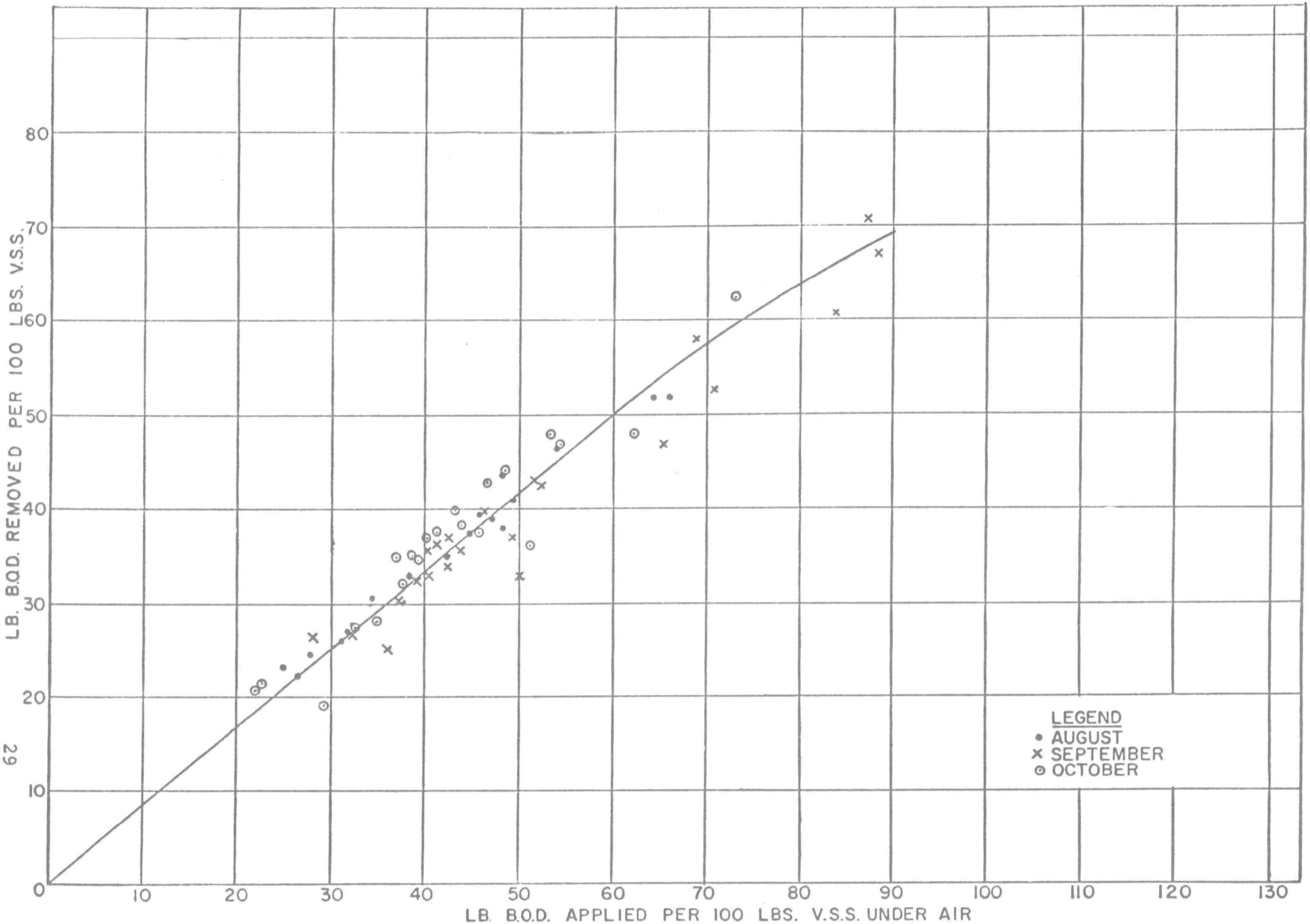


FIGURE 5 - PLOT OF BOD REMOVED vs BOD LOADING PER 100 LB VSS

reaeration. During the next seven days the proportion of Hammermill wastes was gradually increased. Starting August 8 the inflow to the plant consisted of equal volumes of sewage and paper mill waste. The admission of Hammermill waste increased the BOD or food supply and hence the number of microorganisms and the amount of sludge under aeration increased. On August 7, the plant had 315 pounds of suspended solids under aeration, about 60% of which were volatile.

From August 9 to September 5, the plant operated at a constant flow of 20 gpm and the sludge return rate was also 20 gpm. Appendix II summarizes the performance of the activated sludge process during this period. As indicated therein, BOD reductions by the activated sludge process alone ranged from 79 to 89 percent and averaged 83%. However, the reductions in phosphates and suspended solids were considerably lower and varied from day to day over wide limits.

Total BOD input to the plant remained in the range of 45 to 55 pounds per day most of the time, see Figure 6. Some activated sludge was wasted daily and the rate of wasting was purposely varied to study a number of loading variations. The rate of wasting exceeded the rate of buildup for on September 5, the plant contained only 117 pounds of suspended solids under aeration, 77% of which were volatile, i.e. the inventory of volatile suspended solids on September 5 was only half of what it had been on August 7. Because of this change in sludge inventory, there was a wider fluctuation in the BOD loading per 100 lb. MLVSS than there was in the total BOD input. It ranged from 27 to 64 pounds and averaged 43.

From September 6 through the 20th, the plant continued to operate on a 20 gpm inflow of a 50-50 mixture of sewage and Hammermill wastes with a sludge return rate of 20 gpm. No excess sludge was wasted during this 15-day period and as a result, the sludge inventory gradually increased, reaching 280 pounds of total suspended solids, 76% of which were volatile on September 20. Appendix III summarizes the performance of the plant during this period. BOD loadings per 100 lb. MLVSS were highest at the start of this period. They exceeded 80 pounds per day on September 6th, 7th and 8th. As the inventory of solids under aeration increased, the loading per 100 pounds of those solids gradually diminished through September 15, (total BOD entering plant was normal) and then jumped up again because of the accidental pulp liquor discharge and sharply increased total BOD load. For the entire 15-day period the BOD loading averaged 56 pounds per 100 lb. MLVSS, as compared with only 43 pounds per 100 lb. MLVSS during the first period. The sludge volume index remained relatively low and, was slightly less during this second period than it was during the first period. BOD reductions were essentially the same during the two periods. The removal of suspended solids was particularly poor during the latter period. Phosphate removal was considerably better during the second period than the first, but still averaged only 39%.

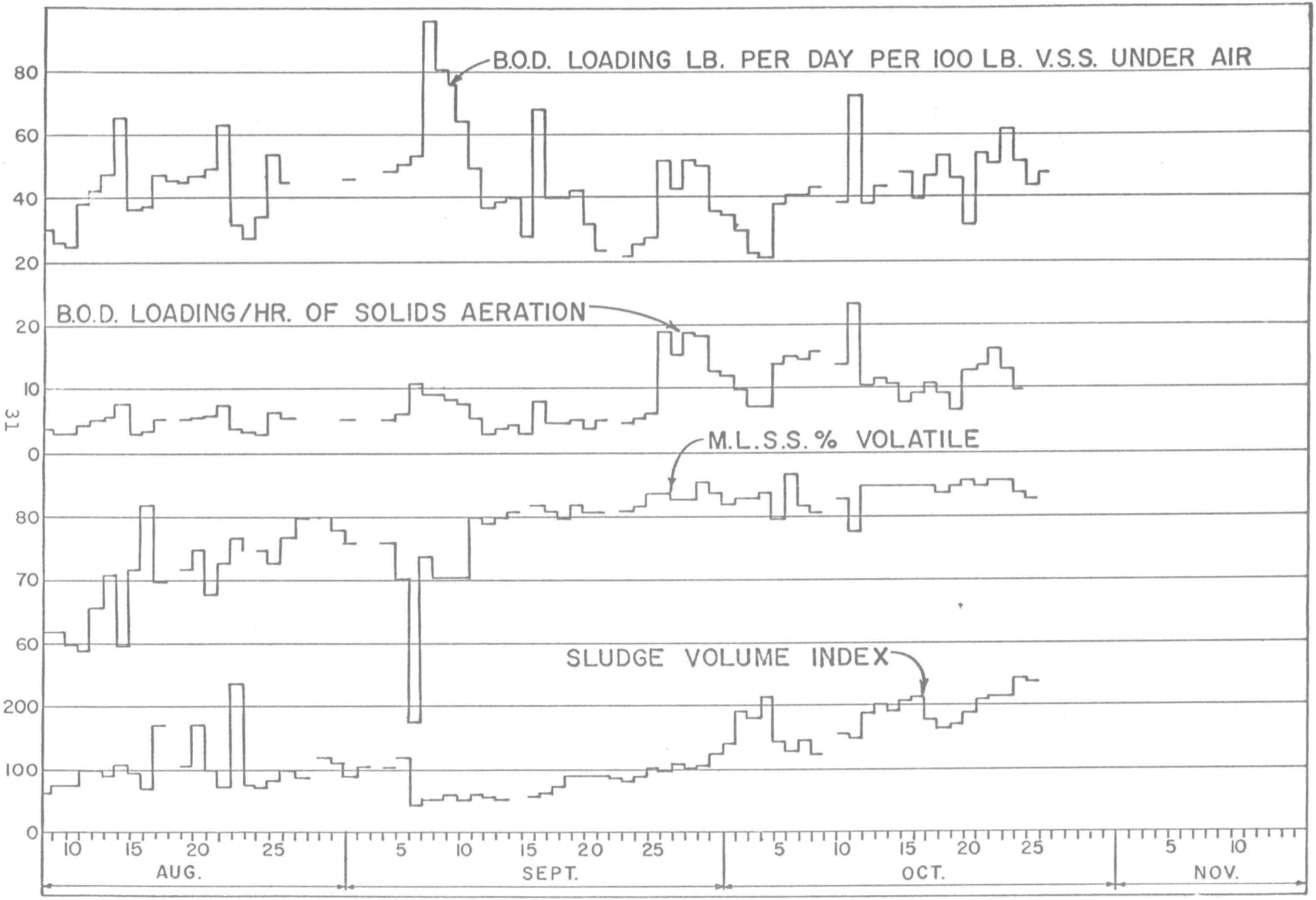


FIGURE 6 - PLOT OF VARIOUS LOADING PARAMETERS FOR ACTIVATED SLUDGE PROCESS

During both periods the rate of returning sludge was approximately 100% of the rate of waste inflow and as a result the return sludge was quite dilute. Generally, it contained less than 0.2% suspended solids. This high rate of return had been used in the hope that it would improve the removal of phosphates and suspended solids by the activated sludge process. It resulted in a much shorter sludge reaeration period than would have obtained had a more concentrated sludge been returned at a lower rate.

The periods of both mixed liquor and sludge reaeration were cut in half on September 21 by the use of "float" pumps, which were so operated as to reduce the depth in both the aeration tanks to about 60% of what it had been previously. Obviously this not only shortened the aeration periods, but also practically doubled the BOD loading per 100 lb. MLVSS. The microscopic life in the sludge deteriorated sharply after the charge was made. Due in part to these changes, and in part to the physical effect of pumping the mixed liquor to the final clarifier, the performance of that clarifier was extremely poor during the period September 21st to 25th.

On September 26, the pumping was discontinued as was the practice of sludge reaeration. From September 26 to October 27, the conventional flow diagram was followed with all primary effluent and return sludge delivered directly to a single mixed liquor aeration tank.

Normally it is assumed that for good operation, the amount of ammonia plus organic nitrogen entering the plant should be not less than 5% of the BOD entering the plant. However, as indicated by Appendix II and III, it had been almost constantly less than that amount. From August 8 to September 5, it averaged only 3.3% of the applied BOD, and from September 6th to 20th, it averaged only 2.8%. It was decided to investigate the effect of nutrient addition. From October 1 to the 5th inclusive, diammonium phosphate was added to the paper mill waste before it entered the primary settling tank, but this increased the phosphate feed and masked the effect of the activated sludge process on phosphate reduction. Therefore, from October 6 to November 2, ammonium hydroxide was substituted for the ammonium phosphate.

Appendix IV covers the performance of the plant from October 1 to 27 inclusive, except that the data on phosphates for the first six days of the period are omitted from the table. Throughout this entire period the nitrogen content of the primary effluent remained very close to 5% of its BOD. The BOD loading per 100 lb. MLVSS during this period ranged from 26 to 60 pounds, and averaged 42 pounds, i.e. about the same as it had been during the period from August 8 to September 5. However, without sludge reaeration, the solids aeration period was drastically reduced, i.e. it ranged from 2.75 to 4.9 hours and averaged only 3.3 hours, whereas during the previous two periods, it had averaged close to 8.6 hours. With this shorter aeration period the volatile content of the solids under aeration increased as did their sludge volume index. In fact, the sludge was in a semi-bulked condition throughout most of the period. It was during this period that the presence of microscopic filamentous organisms were first observed in the sludge and it is quite possible that the development of these filamentous growths contributed to the sludge bulking.

Despite the bulking, BOD reductions were about as good during this period as they had been during either of the previous periods. The removal of suspended solids was intermediate between that prevailing during the periods covered by Appendix II and III. Phosphate removals ranged over wide limits, from 0 to 75 percent, but averaged only 40%, i.e. about the same as had been obtained during the September 6th to 20th period.

During October the bottom half of one tank was filled in and the turbine aerator modified so as to effect a 50% reduction in the effective volume of that tank. The two tanks were then operated in series, with conventional flow from October 28 to November 10, and the results obtained are summarized in Appendix V. As indicated therein, the rate of waste feed to the aeration tank was maintained at 18 gpm and the rate of sludge return was 67%, i.e. 12 gpm. Thus, the mixed liquor aeration period was slightly more than 5.5 hours.

Despite the fact that the BOD loading per 100 lb. MLVSS averaged 50 pounds per day as compared with only 42 pounds per day during the previous period, both the volatile content of the sludge and its sludge volume index decreased as a result of the longer aeration period. However, there was a sharp decrease in the reduction of both BOD and suspended solids. In fact, the final effluent contained more suspended solids than did the primary effluent throughout much of the time. It is possible that temperature had much to do with the deteriorations of the purification processes for, during this period, mixed liquor temperatures ranged from 54 to 65^{o} F., whereas during the previous period, i.e. the period covered by Appendix IV, they had ranged from 61 to 71^{o} F.

On November 11, conventional operation was discontinued and the use of sludge reaeration restored with the smaller half tank being used for sludge reaeration and the full size tank being used for mixed liquor aeration. This mode of operation was continued throughout the remainder of November and the results obtained are summarized in Appendix VI. Again the final effluent contained more suspended solids than did the primary effluent and BOD reduction by the activated sludge process was extremely poor, i.e. only 56% as compared with 74% during the previous period and 81 to 84 percent during the periods covered by Appendix II to IV inclusive. The BOD loading was just slightly less than during the previous period and the solids aeration period, of course, was much longer. However, there was little or no change in the average volatile content of the sludge or its SVI.

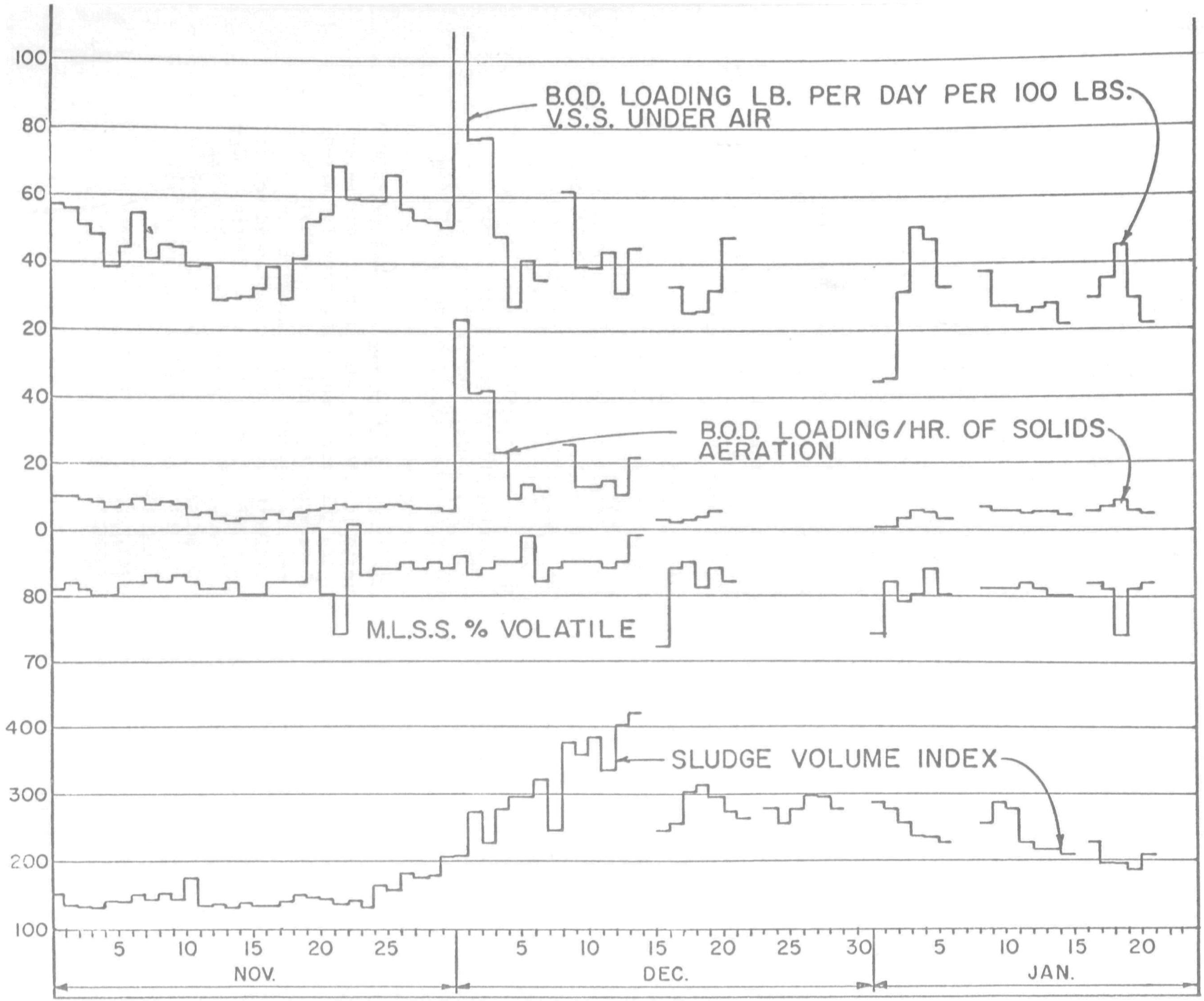


FIGURE 6A - PLOT OF VARIOUS LOADING PARAMETERS FOR ACTIVATED SLUDGE PROCESS

Inspection of Figure 6-A shows that during the early part of the period, i.e. November 11th to 16th, there was a slight decrease in the volatile content of the sludge solids and also in the SVI, but that from about November 22 to the end of the period, both parameters increased markedly. BOD loadings per 100 lb. MLVSS were lower and temperatures were higher during the first few days of this period than they were toward its end. The average mixed liquor temperature for the entire period was 11.7° C.

Until this time the "Surfpac" trickling filter unit had not been in operation. However, during the last four days of November, the filter was acclimated with a 6 gpm side stream of primary effluent. Then from December 1st to the 14th, it was used as a roughing filter, without recirculation, between the primary sedimentation basin and the activated sludge process. Appendix IX summarizes its performance. Effluent from the filter was treated by the conventional activated sludge process, but only the small or half tank was used for mixed liquor aeration. Appendix VII summarizes the performance of the activated sludge process during this period.

On the whole, the performance of the "Surfpac" unit was disappointing. It effected only an average of 22% reduction in BOD, a 9% reduction in COD and its effluent contained more suspended solids than did its influent. No doubt the low temperatures prevailing during the period of its operation contributed to the poor performance. It is also quite possible that the acclimation of only five days was too short to properly condition the filter. At any event, it is obvious that the filter was totally incapable of effectively treating a flow of 18 gpm which was applied to it during the first few days of December.

The flow to the filter, and hence to the activated sludge process, was reduced on December 4, and thereafter was generally about 9 gpm. At this reduced flow, BOD loadings per 100 lb. MLVSS ranged from 30 to 50 pounds per day (see Figure 3-A) and after only one day of operation at this reduced flow, there was a remarkable recovery in the microscopic activity of the sludge which had been very low during the high flow. However, its volatile content remained high and its SVI increased steadily, being in excess of 400 on the last day of the period. The mixed liquor temperature during this period averaged only 10.2° C., but despite this fact, BOD reduction was slightly better, i.e. an average of 60%, than the average of 56% that had been obtained during the period covered by Appendix VI, and furthermore, the activated sludge process did effect a 33% reduction in suspended solids. In fact, the suspended solids of the effluent averaged 47 mg/l during this period, which is less than the average obtained during any of the periods covered by Appendix II to VI inclusive.

It is possible that the improved removal of suspended solids by the activated sludge process during this period can be attributed to the pretreatment effected by the roughing filter. However, far more data would be required to positively confirm the correctness of such a presumption.

On December 15, the operation of the "Surfpac" unit was discontinued and the mode of operation of the activated sludge process was changed back to sludge reaeration, using the shallow half tank for sludge reaeration and the full tank for mixed liquor aeration. From December 15th to the 21st, the flow through the pilot plant ranged from 10 to 18 gpm and consisted of 50% City sewage and 50% Hammermill wastes. Because of the brevity of this period, the results obtained have not been tabulated or presented herein. However, in general, the performance as regards both BOD and suspended solids were quite comparable to previous data.

From December 22 to January 3 inclusive, the pilot plant received no Hammermill waste whatsoever and the flow of sewage through it remained constant at only 9 gpm. The sludge return rate was 7.5 gpm, or about 83% of the sewage inflow. Analytical work in the laboratory was curtailed and therefore samples of influent and effluent were not collected or analyzed. However, it is obvious that BOD loadings per 100 lb. MLVSS must have been very low throughout the period, while both solids and mixed liquor aeration periods were considerably longer than prevailed at any time since August 8. Nevertheless, there was very little change in sludge inventory.

On December 21 the plant contained 144 lbs. of total suspended solids under aeration, while on January 3 it contained 148 lbs. The corresponding inventories of volatile suspended solids under aeration were 118 and 117, respectively. Thus, it is apparent that "endogenous respiration" was progressing at a very slow rate and hence there was no "autodigestion". This is in sharp contrast with the high rate of autodigestion that was encountered late in July, the only other period in which the pilot plant was operated on City sewage alone. It clearly demonstrates the marked effect of temperature upon the rate of endogenous respiration. During the July period the mixed liquor temperature was approximately 23° C, while during the December period it was only 6° C.

The SVI also remained high and practically constant throughout the period of low loading and long aeration, being 272 on December 21, and 257 on January 3. However, the number of filamentous organisms diminished greatly during this period.

Hammermill wastes were readmitted to the plant on January 3 and thereafter, until the plant was shut down on January 22; the flow to the plant consisted of a 50-50 mixture of Hammermill wastes and municipal sewage. From January 3 to January 7 inclusive, sludge reaeration was practiced. However, this period was so short that a tabulation of the results obtained during it does not appear to be warranted.

From January 8th to the 21st, conventional operation was followed using both aeration tanks in series, i.e. primary effluent and return sludge first entered the small aeration tank with the mixed liquor overflow from that tank receiving further aeration in the large tank. The results obtained during this period are summarized in Appendix VIII.

Although mixed liquor temperatures remained extremely low and averaged only 6.3° C, performance was relatively good. The average BOD reduction was 72% and the suspended solids in the final effluent were practically the same as those in the primary effluent. As indicated by Figure 6-A, the BOD loading per 100 lb. MLVSS was relatively low and very uniform throughout the period, as was also the volatile content of the mixed liquor solids. The SVI decreased gradually throughout the period.

Bench Scale Activated Sludge Plant

In addition to the afore-described pilot plant operations, Hammermill constructed a small bench scale continuous flow activated sludge system which was in continuous operation from April 1967. It was designed to handle a mixed liquor flow of 1.5 gal per hr. Said flow could be proportioned between influent and sludge return at the discretion of the operator.

The plant consists of a 55-gal plastic storage drum, from which the flow is pumped to a single plastic aeration tank. Flow is then transferred by gravity to the settling tank, also plastic, from which sludge is continuously returned to the aeration tank, or wasted. Free flow plastic tees were used as aeration spargers. All pumps, stirrers, and other equipment used is plastic, rubber, stainless steel, or glass, thus avoiding color change or contamination. Combined return and primary flow was 1-1/2 gph.

All pulp mill waste used was first passed through a 200 mesh screen to remove approximately 50% of suspended solids, similar to that achieved in many municipal primary tanks. All City sewage used was primary effluent. Prior to screening the pulp mill waste (about pH 3), lime was added to bring it to a pH between 8.0 and 8.5. This allowed for its characteristically rather rapid decrease in pH and worked well in actual practice.

City samples were grab samples taken between 10:00 and 11:00 each morning, midway between minimum and peak flow. Suspended solids, BOD, and phosphates are also known to be near the average daily values at this time. Pulp mill samples were 24-hour composites. No nitrogen or phosphorus was added.

Initially the plant was operated on settled sewage alone or settled sewage to which glucose had been added in order to increase the BOD loading. After a good biologic sludge was accumulated, Hammermill wastes were combined with City sewage in the influent to the plant and the proportion of Hammermill waste to City sewage was gradually increased until June 6, at which time the influent to the plant consisted of a 50-50 mixture of Hammermill waste with City sewage. Operation on this mixture continued until August 9, at which time the operator began phasing out the City sewage for a gradual changeover to 100% Hammermill waste. From August 17 to December 20, the plant operated on 100% Hammermill waste. No nutrients were used throughout the period between June 6 and August 9, i.e. the period during which the plant was handling a 50-50 mixture of City sewage and Hammermill waste, and at no time was there any indication that nutrients were required.

The following tabulation will serve to summarize performance of the plant when operating on a 50-50 mixture of the two wastes. It covers the period July 17 to August 8 inclusive, and indicates that bench scale performance was quite comparable to pilot plant performance under conventional operation and similar temperature conditions.

	Median	Maximum	Minimum
Waste influent TSS (mg/l)	132	232	77
Final effluent TSS (mg/l)	50	70	8
TSS removed, %	65	94	43
Waste influent BOD (mg/l)	252	356	126
Final effluent BOD (mg/l)	38	77	11
BOD removed, %	84	95	70
Waste influent COD (mg/l)	1,215	1,347	991
Final effluent COD (mg/l)	755	868	651
COD removed, %	36	48	22
MLSS (mg/l)	3,986	4,372	3,348
MLSS, % volatile	82	83	81
Mixed liquor sludge volume index	108	218	82
Return sludge, % of waste inflow	38	52	31

The changeover from a 50-50 mixture of sewage and Hammermill wastes to 100% Hammermill waste was accomplished over an 8-day period. Nutrients were added during and after the changeover period. Appendix X summarizes the performance of the plant on 100% Hammermill wastes for the period September 21 to December 20, inclusive. From August 9 through November 8, the nutrient addition consisted of varying amounts of a solution of diammonium phosphate. The amount of this solution used was varied from time to time as indicated in Appendix X in order to study various nitrogen levels.

It is significant to note that the use of diammonium phosphate resulted in the feeding of an over-abundance of phosphate.

Starting on November 9, the use of diammonium phosphate was discontinued. From then until December 20, nitrogen was supplied by feeding ammonia, while phosphorus was supplied by feeding a solution of sodium phosphate. The data presented in Appendix X and the effect of these various changes in nutrient feed is discussed under the heading "Nutrient Requirements".

In addition to facilitating a study of nutrient requirements and demonstrating the feasibility of treating 100% Hammermill waste, the bench scale plant complemented the operation of the pilot plant.

Sludge Bulking and Sludge Microscopy

Throughout this report wherever mention is made of a "bulked" or "semi-bulked" activated sludge, it refers to a sludge having a high SVI regardless of whether the final effluent is low or high in suspended solids. Generally, a SVI of about 100 is considered ideal and a bulked sludge might be considered as one having an SVI of 200 or higher.

Generally, the sedimentation and compaction of sludge are impaired by high BOD loadings and short aeration periods, whereas an underloaded, over-aerated sludge, i.e. one undergoing autodigestion, will be less flocculant and more granular than a normal sludge and settle quite rapidly to a low SVI. However, because of its granular character, such an over-aerated sludge might not have as good a clarifying capacity as a normal or semi-bulked sludge.

However, other factors, in addition to BOD loading and aeration, influence the SVI. One of these factors is the concentration of sludge floc itself. A mixed liquor of low suspended solids concentration will have a lower SVI than will a liquor of high solids concentration, even though the microscopic character and specific oxygen uptake rates of the two sludges are identical.

Another factor greatly influencing the SVI is the presence or absence of filamentous organisms in the sludge. A prolific filamentous growth can produce a structurally bulked sludge even though the BOD loading and the aeration period of such sludge are well within acceptable limits. Periodic microscopic examinations of the sludge are of value in determining the presence or absence of filamentous organisms and they also reveal the presence or absence of protozoa or higher organisms, some of which appear to be good parameters of the oxidation adsorption balance of the sludge, i.e. its reactivity.

Throughout the pilot plant operation microscopic examination of mixed liquor, reaerated sludge and return sludge was made at frequent intervals.

In the activated sludge process life forms may consist of bacteria, flagellates, free-swimming ciliates, stalked ciliates and rotifers. All have been seen in the pilot plant and it is interesting to note that in the early stages of the test program, while using two full aeration tanks and with temperatures between 70 and 80 degrees Fahrenheit, life forms much larger than that of the rotifers were seen. These forms included brightly orange-spotted worms which were 20 times the size of the rotifer. There were also microbes approximately one fourth larger than the rotifers which appeared to be crustaceans. Their bodies were fixed or rigid as opposed to the "soft" body of the rotifer and stalked ciliates. This appeared to be a life form considerably higher than the rotifer. Over-all activity at this time by all microorganisms was tremendously great with free-swimming and stalked ciliates predominating in relative numbers present.

Generally, as the BOD loading decreased, the stalked ciliates predominated over the generally more active free-swimming ciliates. This may be due to bacteria population shifts which they probably feed on. The stalked ciliates served as the best indicators of stress to the system--other than whole population shifts--simply because they were present throughout the entire program almost without exception.

The changes made on September 22nd and 26th reduced the effective volume by 50%. This proved to be a shock to the system and on September 27 there were none of the higher forms of life--no worms, no rotifers, very few stalked ciliates. Free-swimming ciliates predominated but were not in a healthy state. During the next two weeks a recovery gradually took place and rotifers returned, though few in number and slow in activity. During this time there became evident a previously unseen animal which remained throughout the month of October--it predominated most of the time. Its size was slightly greater than that of the common free-swimming ciliate; its body appeared firm with rather long legs on the underneath side. (They did not at all appear to be cilia). Movement was always quick, climbing over and around the biological floc. It had the ability to stop and change directions rapidly.

On October 28 the use of 1-1/2 tanks of conventional sludge was begun and a few days later the animal just described was gone. Stalked ciliates grew fat and round and during the next week returned to their normal shape. They remained large, however, with large vacuoles. Rotifers did not increase in activity and remained very few in number. Process temperatures were now approximately 55° F. and this may well have been the reason rotifers remained generally inactive and few in number. There were very few free-swimming ciliates.

Sludge reaeration using 1-1/2 tanks was begun on November 11 and continued for three weeks. There was no apparent change in the biological world other than slightly less over-all activity. It is interesting to note that the relative microorganism populations did not change even though the suspended solid's aeration was increased from 5.6 hours in the conventional method to 8.5 hours in sludge reaeration.

After the introduction of the Dow Surfac at flows of 18 gpm rotifers were no longer seen and nearly all stalked ciliates were lifeless. For all practical purposes there was no visible life at 100x or 450x. Nearly half of all stalked ciliates were in an extremely parched state. The bubble which appeared at the mouth was often as large as the microbe itself and appeared to be protoplasm. It was very clear and contained no vacuoles. Unparched ciliates also had very small or no vacuoles at all.

After only one day of 9 gpm flow and a raw flow detention of 6.3 hours, the stalked ciliates had made a terrific recovery. Those which were parched were nearly gone and those which were not parched but totally inactive now showed at least some activity. At this time some mastigophora were seen, probably introduced by the Surfpac. They later increased in numbers and their activity was great. By December 10 the free-swimming ciliates also increased in activity but remained generally inactive. There were no rotifers and no free-swimming ciliates during Surfpac use. Temperatures were approximately 50° F.

Samples of Surfpac effluent were centrifuged and examined along with Surfpac influent (primary effluent). The influent revealed no activity; the effluent was alive with very active mastigophora and other life. The various microorganisms viewed had large vacuoles. At a magnification of 1000x much small life was seen, this small life did not appear in the activated sludge. Only the mastigophora were seen in the activated sludge and were less active, but considerably larger than in the Surfpac effluent.

On December 15 sludge reaeration was again begun using 1-1/2 tanks. Activity remained as it was under Surfpac use, but with decreasing numbers of mastigophora.

A 13-day run on City sewage only was begun December 22 by abruptly stopping all Hammermill flow and continuing use of 1-1/2 tanks, detention times increased from 9.4 hours to 18.8 hours. The third day of this run revealed reasonably active stalked ciliates as the only group of protozoa. No higher life forms were seen. Examination of the City plant biological floc on this same day revealed identical activity and there were no other life forms seen. By the end of the City sewage run there were nearly no stalked ciliates and the bacteria were no longer seen. (No change took place in City plant.) The biological floc now appeared very lifeless but BOD removals remained good. The work was obviously being done by bacteria not seen at 450x.

Full flow Hammermill waste was returned on January 3 using contact-stabilization as the mode of aeration. Small animal activity returned and as this activity became increasingly greater a number of stalked ciliates appeared.

Plant operation was terminated on January 21. During this last run no evident biological harm was done by abruptly introducing Hammermill effluent. Temperatures were now approaching 40° F. and were sometimes lower. Stalked ciliates for all practical purposes remained, as in previous weeks, the sole protozoa and source of observable activity.

Filamentous fungi, usually identified with poor settling were not specifically looked for prior to October when the SVI's were very low, and it is not known if their numbers were less. The observations since October revealed such a terrific network of these growths that it was very difficult to see any difference between a SVI of 150 and 250. There did appear to be some decrease at the lower SVI's. The biological floc could be very clearly seen clinging to these long growths. Their diameter is such that it is very difficult to see the inner structure. Though this fungus was very difficult to see, it did not appear to be branched.

In December when the plant was run on City sewage in the absence of Hammermill effluent, these filamentous growths diminished greatly. The fact that some did remain as long as 12 days later, however, indicates that over-aeration and high return rates may be a cause. As usual, City plant activated sludge revealed none at this time. Their aeration times, return rates, and DO's were greatly less than the pilot plant. These growths were also seen in the Surfpac effluent but in vastly reduced numbers. None were present in the influent (Primary effluent).

The last month of pilot plant operations (Jan. '68) revealed microscopic bubbles which were best seen at 100x. These bubbles were seen in both aeration tanks and in the return sludge and are believed to be entrapped air or oxygen. Because they were so numerous and large, it was initially thought that these bubbles were the sole cause of floating sludge. But it was later found that these bubbles grew to full size within the 2 or 3 minutes it takes to prepare a slide. Examination outdoors, where the air temperature was nearly as cold as the water (40° F.), revealed few such bubbles and of such size they were barely visible at 100x. They did, however, obviously contribute to the generally poor settling at this time. City plant activated sludge revealed some, but far fewer bubbles--temperatures were close to 55° F. It was interesting to note that each bubble had one, and only one, particle of floc attached to its surface.

Another interesting observation was that of life--believed to be bacteria--within the Hammermill fibers. Very few of these fibers exist in the activated sludge, but those viewed at 1000x were "alive". It was at first thought that bacteria from the sludge entered these cells. But further examination revealed that this action was present in the Hammermill storage tank. Movement was vibratory in nature and always within the cell. No bacteria were observed outside these cells. It appears that the cell wall serves as a protective envelope. It is not known if this activity exists in the pulp mill or paper effluent, or both. That this activity was found helps explain the gradual decrease in BOD's with time.

The presence of prolific growths of microscopic filamentous organisms greatly impairs the sedimentation and compaction of the sludge floc. This seems to be a purely physical phenomena and may be true for any type of filamentous growth.

The filamentous growths observed in great numbers during October were probably a species of sphaerotilus and such growths probably remained predominant throughout November and early December. However, it is doubtful that they could survive the 13 days of prolonged aeration at low BOD input that prevailed over the latter part of December. The condition prevailing at that time would be more suitable for the development of a growth of leptothrix and the fact that the SVI decreased instead of increased when the load on the plant was again increased during January, might further indicate that the filaments observed during January were leptothrix instead of spaerotilus.

The joint treatment of Hammermill wastes with municipal sewage will produce conditions favorable to the development of spaerotilus growths and therefore, sludge volume indices of 200, or even slightly higher, may be frequently encountered in any activated sludge plant designed to treat such a mixture of waste.

Temperature Effects

Before oxygen can be utilized by the activated sludge process it must be in solution. Both the rate of solution and the rate of utilization are greatly influenced by the temperature of the liquor in the aeration tanks. The rate at which oxygen may be put in solution in raw or partially treated sewage or industrial waste steady state aeration is given by the formula:

$$\alpha K_{1a} = \frac{r}{\beta C_s - C} = \frac{SaR\ X10^{-3}}{\beta C_s - C} \qquad (1)$$

α = relative oxygen transfer coefficient - dimensionless
K_{1a} = overall oxygen transfer coefficient for clean water - units per hour
r = oxygen uptake rate - mg/l/hr
β = relative oxygen saturation coefficient - dimensionless
C_s = concentration of oxygen in clean water at saturation - mg/l

C = concentration of liquor under test - mg/l

Sa = average volatile suspended solids in liquor under aeration - mg/l

R = Specific oxygen uptake rate - mg per gram of volatile suspended solids per hour

Variations in temperature do not materially change the value of either α or β, but exert a tremendous influence on biological activity and hence upon oxygen uptake rates. In most activated sludge plants the influence of temperature on biological activity far exceeds its effect on oxygen solubility. Where the supply of food is high (concentration of BOD) the following formula approximates.

$$K_1 = \frac{b\ Lr}{Sa\ K} \qquad (2)$$

Where the rate of biological growth is restricted by a limited food supply the following formula approximates.

$$\frac{L - Lr}{L} = K_2\ Sat \qquad (3)$$

These roughly correspond to the inlet and outlet of long spiral flow tanks such as those used at Erie. In a completely mixed liquor aeration tank such as that used in the pilot plant.

$$\frac{Lr}{L} = \frac{K_2\ Sat}{1 + (K_2\ Sat)} \qquad (4)$$

K_1 = logarithmic growth rate of organisms during the log growth phase (natural logarithms)

K_2 = logarithmic growth rate of organisms when growth rate becomes BOD concentration dependent (natural logarithms)

b = fraction of Lr which is synthesized to sludge over any time period

L = total amount of ultimate oxygen demand or BOD - mg/l

Lr = ultimate BOD removal - mg/l

Sa = average volatile suspended solids in liquor under aeration - mg/l

t = time - hours

The rate of oxygen utilization will be uniform throughout a completely mixed aeration tank. However, the total amount of oxygen utilized in such a tank will still be the summation of that required effect "L_r" and that needed for ultimate BOD removal and for endogenous respiration.

Formulas (2), (3) and (4) all involve a sludge growth or reaction rate "K". This rate is highly dependent upon temperature. Using formula (4) K_2 values were calculated for a number of different periods. It was assumed that $\frac{Lr}{L}$ was equal to the 5-day BOD. Table III summarizes the results of the calculations.

TABLE III

Calculation of K_2 Values

Appendix Numbers	IV	V	VII*	VIII	II	III	VI
Period Considered							
From	10-1	10-28	12-1	1-8	8-8	9-6	11-11
To	10-27	11-10	12-14	1-21	9-5	9-20	11-30
Mode of Operation	CONVENTIONAL				SLUDGE REAERATION		
Sludge Return, % of Waste Flow	89	67	75	87	100	105	67.5
5 Day BOD, mg/l							
*Primary or "Surfpac" Effluent	266	248	180	201	220	273	241
Final Effluent	43	65	72	57	38	51	105
Aeration Tank Influent	161	175	134	134	129	158	186
Removed	118	110	62	77	91	107	81
L_r/L	0.732	0.629	0.463	0.574	0.706	0.677	0.435
Sa = MLVSS, mg/l	2209	1239	1958	1770	707	743	935
t = Mixed liquor aeration, hr	3.3	5.61	2.50	5.0	2.75	2.90	3.70
Sat x 10^{-3}	7.29	6.95	4.90	8.85	1.94	2.15	3.46
K_2 x 10^{-3} at average mixed liquor temperature	0.374	0.244	0.099	0.152	1.215	0.973	0.223
Average mixed liquor temp. °C	18.8	15.2	10.2	6.3	23.5	22.7	11.7
K_2 x 10^{-3} at 20°C	0.442	0.476	0.390	1.035	0.745	0.732	0.711

*Waste feed was "Surfpac" effluent during period covered by Appendix VII, and primary effluent the remainder of the time.

The general formula expressing the influence of temperature on biological oxidations is

$$\frac{K@T_1}{K@T_2} = \theta^{(T_1 - T_2)} \qquad (5)$$

Trial calculations indicated that θ is probably about 1.15 for the pilot plant. Conversion of K_2 values to 20° C is shown in the bottom line of Table III.

From an inspection of the 20° C "K_2" values shown in Table III for the periods covered by Appendices II to VI inclusive, it appears that for the particular plant and waste mixture under consideration, the value of "K_2" at 20° C is about 0.46×10^{-3} when sludge reaeration is not practiced, and 0.73×10^{-3} when sludge reaeration is being used.

Table III indicates a "K_2" value at 20° C of only 0.39×10^{-3} for the period covered by Appendix VII, which is the period the "Surfpac" filter was in operation ahead of the activated sludge process. This is also the period during which the highest BOD loading per 100 lb. MLVSS, the highest volatile contents, and the highest sludge volume indices were experienced. It may be that the "Surfpac" unit was removing the material most easily oxidized or synthesized by the sludge organisms and hence their rate of attack on the remaining material was slower than if the filter had not been in service.

The question of just what the true "K_2" value for conventional operation at 20° C became even more confusing after the results of the January operation became available, for as indicated in Table III, the 20° C "K_2" value of 1.035 for the period January 8th to 21st was much higher than any other period of operation, be it conventional or sludge reaeration. A heavier organic load just prior to this period may have created peak activity during this period. It is felt that the high figure should be disregarded.

Therefore, it was assumed that the value of "K_2" at 20° C would be 0.46×10^{-3} for conventional operation, and 0.73×10^{-3} for sludge reaeration in any plant design calculations.

It is of interest to see how much the individual daily results depart from those values. Figure 7 covers the period from August 8 to October 27, i.e. the data summarized in Appendices II, III and IV. Sludge reaeration was practiced from August 8 to September 20, inclusive (Appendices II and III). During that period mixed liquor temperatures ranged from 21 to 26° C and averaged about 23° C. A curve has been plotted by use of formula (3) and a "K" of 1.11×10^{-3} which is believed to represent the performance to be expected from that mode of operation at 23° C. Of the 38 daily points, 7 are on or very close to the curve, 14 are below it, and 13 are above it.

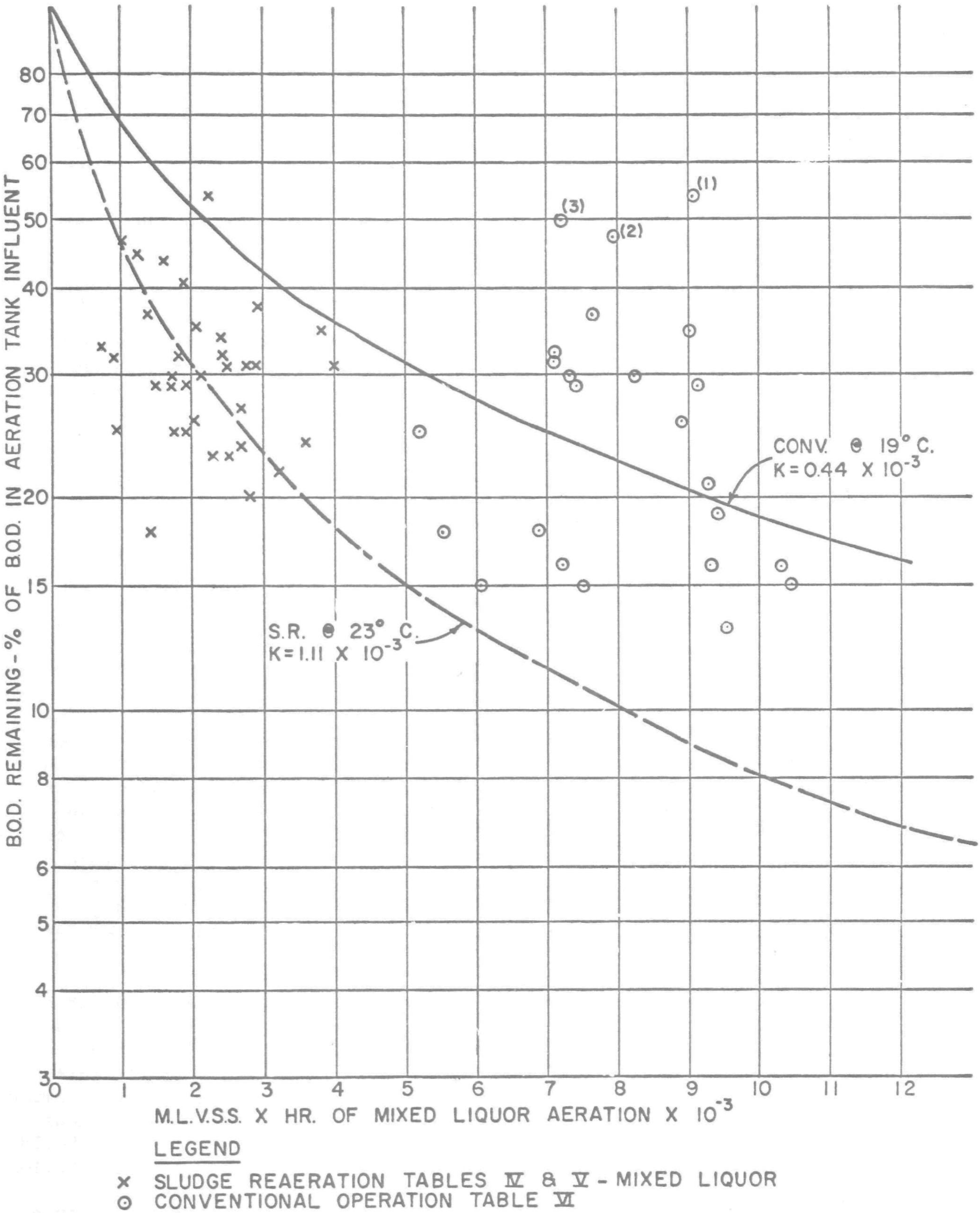


FIGURE 7 - PLOT OF BOD REMAINING vs MLVSS and TIME IN AERATION TANKS FOR CONVENTIONAL and SLUDGE REAERATION

Appendix IV covers conventional operation during the period October 1st to 27th inclusive, when mixed liquor temperatures ranged from 15 to 21.7° C and averaged 18.8° C. The upper curve on Figure 7 was plotted by the use of formula (12) and a "K" of 0.44×10^{-3}. It is believed to represent the performance expected from conventional operation at 19° C. Of the 26 daily points, 4 were near or on the curve, 10 were below, and 12 above the curve. Points 1, 2 and 3 represent results when the mixed liquor volatiles were very high and the return sludge was heavily loaded with adsorbed organic matter.

Figure 8 covers the period October 28 to November 30 inclusive, i.e. that covered by Appendices V and VI. During the first period, when conventional operation was being followed, temperatures averaged about 15° C. During the second period, when sludge reaeration was used, temperatures of the mixed liquor were lower and averaged about 12° C.

It may be calculated that the value of "K_2" would be 0.229×10^{-3} for conventional operation at 15° C and 0.238×10^{-3} for sludge reaeration at 12° C. These two values are so nearly the same that a single curve could be plotted on Figure 8 to represent the expected performance of both modes of operation during the respective periods covered by Appendices V and VI. Note that most of the points representing daily results with sludge reaeration fell very close to the curve. The points representing daily results with conventional operation are more widely scattered. The mixed liquor temperature for each of those days is shown on the plot. The variation in daily temperatures may account for most of the scattering.

From formula (5) it may be computed that at 10° C the values of "K_2" will be only 0.248 as great as they are at 20° C. At 30° C the corresponding factor would be 4.04. The reaction velocity changes fourfold for each 10° C change in temperature. This is a greater change than is frequently experienced. The literature (1) indicates that for municipal sewage, a two to threefold change per 10° C of temperature change is more normal. However, the literature also indicates that wastes high in soluble BOD are more sensitive to temperature change than is sewage or wastes high in colloidal BOD. Hammermill wastes are high in soluble BOD.

Inspection of formula (4) shows that both the mixed liquor aeration period and the concentration of volatile suspended solids in that liquor also influence the reduction in BOD. Figure 9 has been prepared to illustrate that influence. The curves shown thereon were plotted by the use of formula (4) and the indicated values of "K". Among other things, Figure 9 indicates that if mixed liquor aeration periods and volatile solids concentrations are increased sufficiently, it should be theoretically possible to reduce the BOD of the inflow to the aeration tank at least 75% even at mixed liquor temperatures as low as 10° C. (With a sludge return of 100% of the waste flow, such a reduction would increase to about 86% of the BOD of the waste inflow. If the rate of sludge return was only 50%, the corresponding figure would be about 82%.)

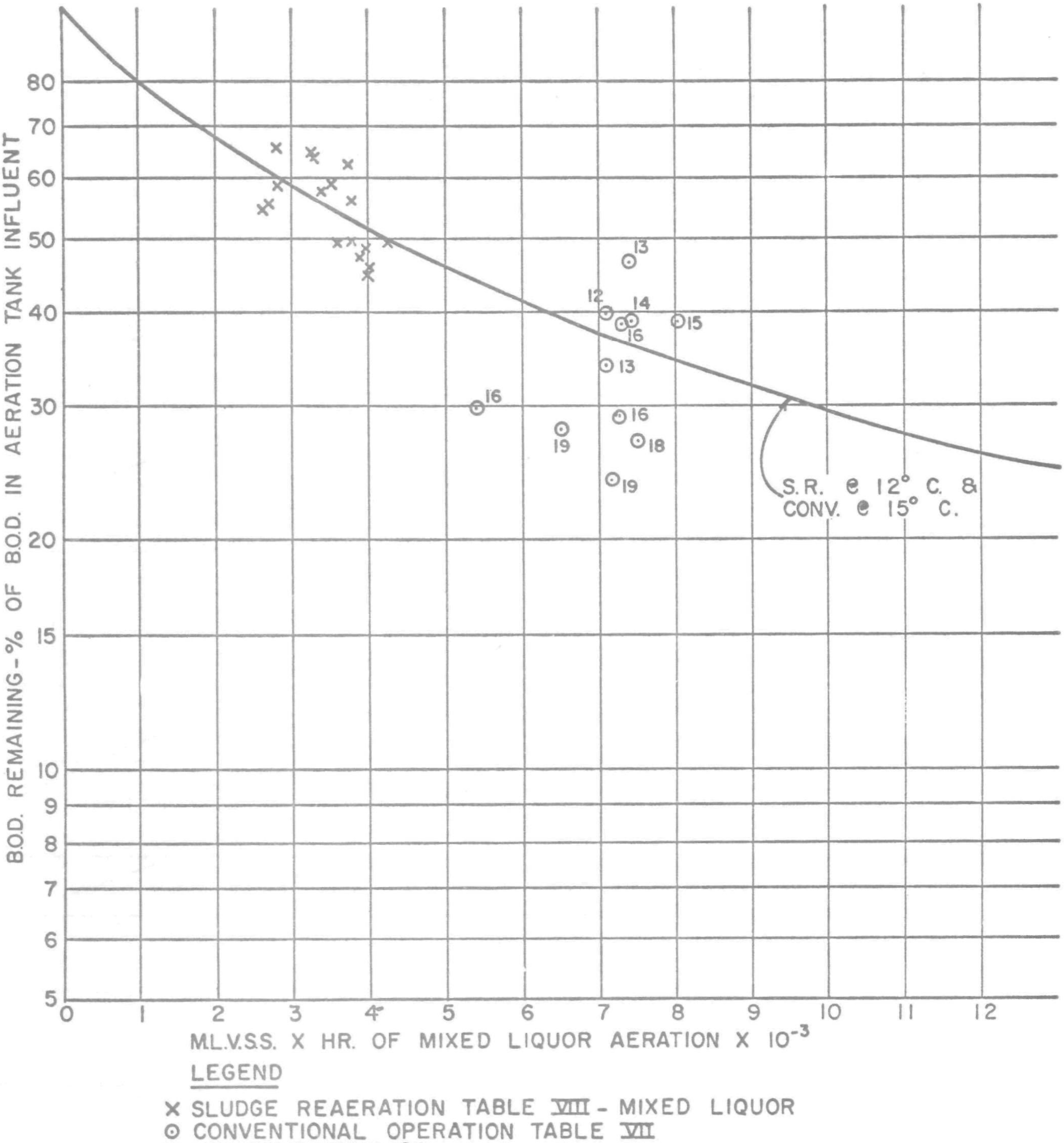


FIGURE 8 - PLOT OF BOD REMAINING vs MLVSS and TIME IN AERATION TANKS

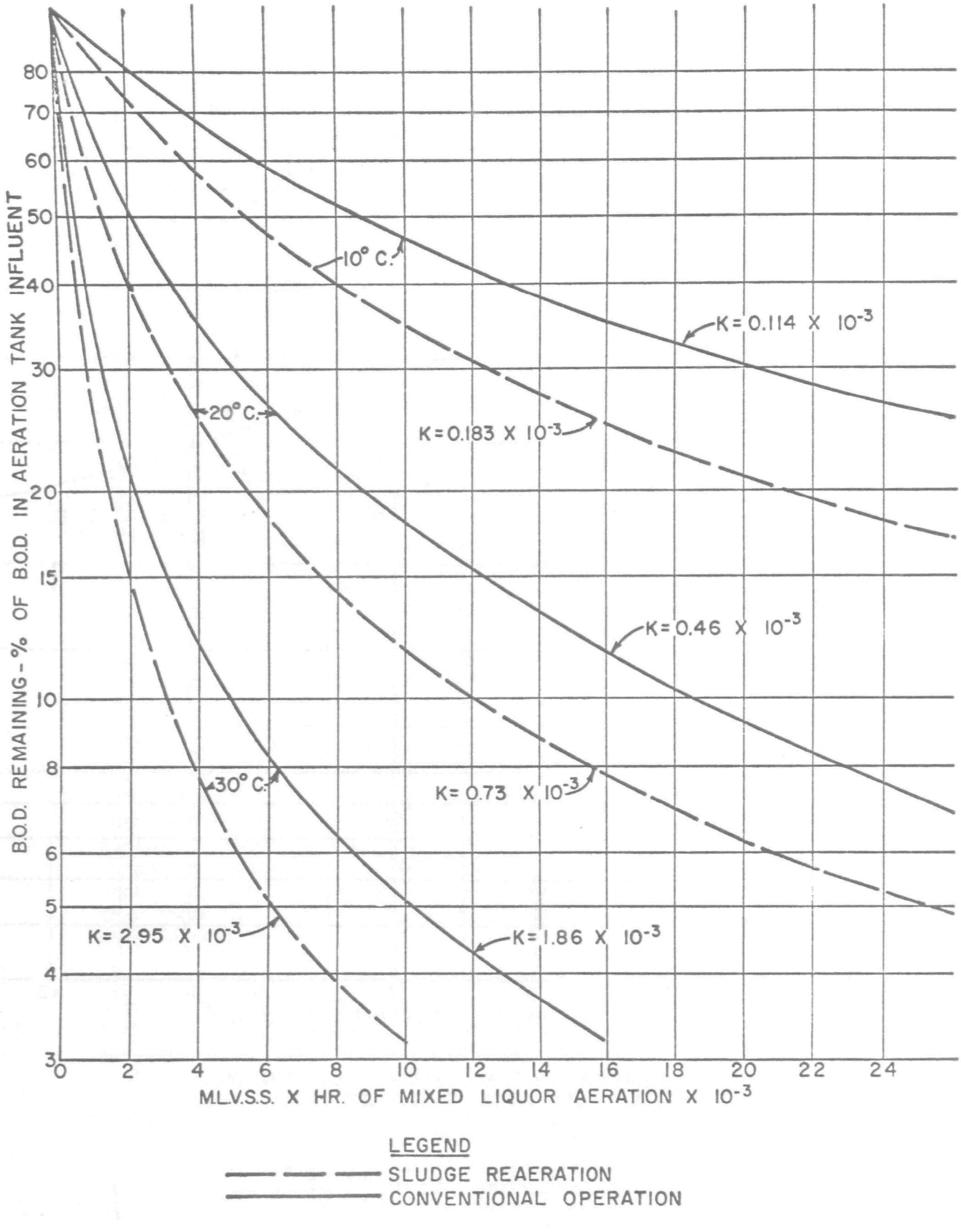


FIGURE 9 - PLOT OF BOD REMAINING vs MLVSS and TIME IN AERATION TANKS FOR VARIOUS OPERATING TEMPERATURES

Oxygen Uptake

Appendices II through VII indicate that average air usage in the pilot plant ranged from 63 to 208 cubic feet per pound of applied BOD. The low air requirements of the pilot plant indicate that the turbine-type gas dispersers used in the pilot plant have a higher oxygenation efficiency than the devices used in many plants.

On October 5, one of the aeration tanks was scrubbed and then filled with clean water. The water was deoxygenated and the reoxygenation capacity of the turbine was measured by the unsteady state aeration procedure, as fully described in (3). Air was supplied at the rate of 9.5 cfm. The effect of sparger submergence was ignored. A test at 62° F. gave a K_{1a} value of 5.67 and a test of 64° F. a value of 7.04. Adjusting to 20° C and averaging gave a "K_{1a}" of 6.72. By using that value of "K_{1a}" in the standard formula (lbs/hr oxygen into solution = K_{1a} (C_s-C) 8.34 Vol. of liquor) it may be computed that at 20° C and 0.0 mg/l of dissolved oxygen the turbine would put 3.31 lb. of oxygen into solution per hour. Air temperature at the blower intake was 70° F so, assuming a barometric pressure of 760 mm, each cubic foot of air contained about 0.0174 lb. of oxygen. On this basis, the oxygenation absorption efficiency of the turbine was $\frac{3.31 \times 100}{60 \times 9.5 \times 0.0174}$ or 33.3%.

This turbine efficiency is higher than normally encountered in the waste treatment field. The high efficiency is primarily a result of a high mixer horsepower in relation to gas (blower) horsepower. As no other tests were run with clean water, there are no means of estimating the numerical effect of variations in rate of air supply on oxygenation efficiencies.

Late in October the depth of one of the aeration tanks was halved. This materially reduced the submergence of the sparger ring. Certainly such a change should decrease both the "K_{1a}" value and the oxygenation efficiency of the turbine, but it was not possible to numerically evaluate that effect.

Note that the calculated oxygen absorbed rate in lb. of oxygen per turbine horsepower per hour for the pilot plant is extremely low due to the abnormally high ratio of mixed horsepower to blower horsepower (15:1).

The rate of oxygen utilization is frequently reported in milligrams per liter per hour and termed the "oxygen uptake rate" - "r". As indicated in Table IV, this rate was measured on several different occasions. The August 15 run was performed by turning off the air supply and turbine to the aeration tanks and measuring the rate of depletion of oxygen by means of a galvanic cell oxygen probe submerged in the tanks. Problems with the submerged probe dictated a new procedure for the remaining tests. In the balance of the tests the procedure was to place a magnetic stirrer in a BOD bottle and then fill it with activated sludge, a galvanic cell oxygen probe was inserted and the dissolved oxygen concentration was read and recorded at 5 to 30 second intervals while the content of the bottle was continually stirred. Ideally the plot of oxygen concentrations against time should be linear from the initial high concentration down to some low residual of 0.5 mg/l or less. The oxygen uptake, expressed in mg/l per hour, is determined by the slope of the plot. This ideal situation only prevailed in the case of the three measurements made on August 15.

In three tests the oxygen decline from the initial high value was uniform for a period of several minutes and then practically ceased despite the fact that the residual DO was still relatively high. In these cases only the first portion of the plot was used to compute the uptake rate. In nine cases the indicated oxygen concentrations dropped very rapidly during the first 10 to 90 seconds and then declined at a slower and more uniform rate thereafter. In these cases the initial decline was ignored in computing the oxygen uptake rates.

From line 10 of Table IV it may be noted that oxygen uptake rates varied from 10.5 to 75.0 mg/l per hour. Had the oxygenation capacity of the aeration system been limited, such a wide variation might have been extremely significant. However, such was not the case in the pilot plant.

Line 11 shows the approximate concentration of volatile suspended solids in the various samples. By dividing the values in line 10 by those in line 11 the "specific oxygen uptake rates", "R", expressed in mg. of oxygen per hour per gram of volatile suspended solids were obtained. They are shown in line 12 of Table IV. At least in this particular case, these specific uptake rates are believed to be much more significant than those shown in line 10.

If retention in the final clarifier does not alter the character or activity of the return sludge then, on the average, its specific uptake should be the same as that of the mixed liquor entering the final clarifier. To evaluate this the data in Table IV may be summarized as follows:

	Specific Uptake		Loading	Sludge
	Mixed Liquor	Return Sludge	BOD/100 lb MLVSS	Return %
Aug. 15 (1 sample of each)	39.5	36.5	36.6	100
Oct. 24-25 (3 samples of each)	10.1	14.6	47.8	95
Nov. 29-29 (2 samples of each)	14.5	20.7	60.0	67

TABLE IV

Oxygen Uptake Determinations

1.	Date	8-15	8-15	8-15	10-24	10-24	10-25	10-25	10-25	10-25	11-28	11-28	11-28	11-29	11-29	11-29
2.	Time	?	?	?	6:30 P.M.		11:00 A.M.		6:00 P.M.		3:00 P.M.			9:00 A.M.		
3.	Sample Source	Mixed Liquor	Return Sludge	Sludge Reaeration	Mixed Liquor	Return Sludge	Mixed Liquor	Return Sludge	Mixed Liquor	Return Sludge	Mixed Liquor	Return Sludge	Sludge Reaeration	Mixed Liquor	Return Sludge	Sludge Reaeration
4.	Sample Temp °C	26	26	26	17	17	15	14	15	13	10	10	10	10	10	10
5.	Time required for meter stabilization, seconds	0	0	0	30	15	10	0	0	10	90	30	60	0	30	30
6.	Length of period of uniform D.O. decline min.	3.5	2.0	8.0	4.5	1.75	5.83	2.0	6.0	1.6	5.5	1.5	5.5	4.0	0.5	2.75
Dissolved Oxygen mg/l																
7.	Initial	2.4	2.4	4.1	4.0	4.0	7.0	4.0	6.8	5.3	6.6	3.0	5.4	5.0	6.0	5.2
8.	Start of uniform decline	2.4	2.4	4.1	3.2	2.5	6.0	4.0	6.8	4.2	4.1	0.9	4.0	5.0	2.4	3.7
9.	End of uniform decline	0.4	0.4	0.4	1.5	1.5	4.2	2.0	4.6	2.2	2.3	0.0	2.9	4.3	2.0	2.8
10.	Oxygen uptake, mg/l/hr	34.3	60.0	27.7	22.7	34.3	18.6	60.0	22.0	75.0	19.7	36.0	12.0	10.5	48.0	18.3
11.	VSS, mg/l	867	1646	1290±	1960	3980	1950	3850±	2400	3850±	1060	2460	2080	1010	1780	2110
12.	Specific O_2 Uptake mg/hr/gram solids	39.5	36.5	21.5	11.6	8.6	9.5	15.6	9.2	19.5	18.6	14.6	5.75	10.4	26.9	8.65

These facts indicate that the higher the BOD to solids loading the more important it may be to utilize a high rate of sludge return, particularly if sludge reaeration is not being used. The wide variation in the specific uptake rates shown in Table IV is also significant. Although some of the variation may have been due to temperature differences or experimental errors, it is believed that much of it was due to variation in BOD input. The BOD of municipal sewage varies from hour to hour and, therefore, it is reasonable to expect variations in oxygen uptake rates, even though the rate of sewage inflow remained constant. Table IV is based entirely on the analysis of only 15 grab samples. Hundreds of such analyses would be required to empirically establish dependable data on oxygen requirements. A review of known relationships might offer a better approach to the problem.

The oxygen requirement is that used by the amount of 5-day BOD removed plus the oxidation of volatile suspended solids. For this particular plant the following empirical formula was developed.

$$\text{lb. of } O_2 \text{ required per day} = (0.5 \times \text{lb. of BOD removed per day}) + (0.2 \times \text{lb. of VSS under aeration}) \div 1.15^{(20-T)} \qquad (6)$$

The value 0.5 is taken from the literature and 0.2 determined by trial calculations.

To illustrate the validity of this formula, Table V has been prepared. The data in lines 3, 12 and 14 are taken directly from the averages shown in the tables listed in line 1. The BOD reductions shown in line 4 were computed from the average BOD concentrations of primary and final effluents shown in the same tables and the temperatures shown in line 2 are averages for the periods covered by those tables.

The oxygen requirements shown in line 7 were computed by formula (6) and are the sums of the quantities shown in lines 6 and 5, i.e. the quantities computed by the two parts of that formula.

The requirements shown in line 7 are expressed in pounds per day per 100 lb. MLVSS. By dividing those quantities by 2.4, the oxygen needs are expressed in mg. per hr. per gram of VSS and are shown in line 8. These quantities are compared with the specific oxygen uptakes shown in Table IV by averaging some of the data.

Although the comparisons are far too limited to prove the dependability of formula (6), they certainly indicate the possibility of its validity. As a further check of that formula, an attempt was made to compare the calculated oxygen requirements shown in line 7 of Table V with the actual average air usage shown in line 14. It was assumed that the barometric pressure averaged 14.7 psia through each period and that average atmospheric temperatures were as shown in line 10.

TABLE V

Calculation of Average Oxygen Needs, Etc.

1.	Period Covered by Appendix	II	III	IV	V	VI	VII	VIII
2.	Mixed Liquor Temp. °C	23.5	22.7	18.8	15.2	11.7	10.2	6.3
3.	BOD Loading, lb/100 VSS/day	43	56	42	50	47	52	29
4.	BOD Removed, %	83	81	80	74	56	60	72
5.	Lb O_2/100 lb VSS for endogenous respiration if rate 0.2 lb/lb @ 20°C	32.6	26.6	17.0	10.2	6.2	5.0	3.1
6.	Lb O_2/100 lb VSS for BOD removal @ 0.5 lb/lb BOD @ 20°C	17.9	22.6	17.7	18.5	13.2	15.6	10.4
7.	Total O_2 lb/day/100 lb VSS @ 20°C	50.5	49.2	34.7	28.7	19.4	20.6	18.5
8.	Total O_2 mg/hr/gram VSS @ 20°C	21.0	20.5	14.5	12.0	8.1	8.6	7.7
9.	CFD of 60°F air/lb VSS @ 100% efficiency	28.5	27.8	19.6	16.3	11.0	11.6	10.4
10.	Assumed atmospheric temp. °F	68	66	50	46	40	38	25
11.	CFD atmospheric air/lb VSS @ 100% efficiency	29.0	28.2	19.2	15.9	10.6	11.1	9.7
12.	Activated sludge, % vol.	73	77	84	81	83	85	81
13.	CFD atmospheric air/lb TSS @ 100% efficiency	21.1	21.6	16.1	12.9	8.8	9.4	7.8
14.	Actual CFD of air/lb TSS	57	56	62	63	24	43	21
15.	Indicated Oxygenation Efficiency, %	37	39	26	21	37	22	37
16.	Number of turbines in use	2	2	1	2	2	1	2
17.	Average air flow per turbine, scfm	3.40	4.32	6.15	2.92	1.68	1.80	1.96

The calculated volumes of atmospheric air shown in line 11 were multiplied by the percentages of volatiles in the sludge (line 12) to obtain the cubic feet of atmospheric air that would have been required per pound of TSS under air had the oxygenation efficiency been 100%, see line 13. These quantities were then compared with the actual air usage shown in line 14 to obtain the indicated oxygenation efficiencies shown in line 15.

The indicated efficiencies for the periods covered by Appendices II, III, VI and VIII are substantially higher than those for the other three periods. The differences in oxygenation efficiencies cannot be attributed to the effect of temperature on "C_s" or "K_{la}". It so happens that sludge reaeration was practiced during three of the four periods of high efficiency while conventional operation prevailed throughout the other periods. However, there is no biological based reason why oxygen requirements should be any different for one mode of operation than for the other. Differences in turbine submergence and air flow rates are apparently responsible for the observed efficiency variations.

It is concluded that for the mixture of sewage and Hammermill wastes, formula (6) is completely valid for computing the daily oxygen requirements of an activated sludge plant. If the variation in the rate of BOD removal throughout the day is known, the formula can be easily modified to calculate the oxygen requirements over shorter periods of time. However, it can only give average oxygen needs for the period under consideration. The formula yields no indication of how the uptake rates differ from that average at various locations within the aeration tanks. In completely mixed tanks, such as those used in the pilot plant, the uptake rate, at any given instance, must be the same throughout.

With a high suspended and colloidal BOD in the waste feed a high proportion of total oxygen will be used in the reaeration tank. On August 15 the pilot plant was utilizing half of its then available aeration volume for sludge reaeration, and judging from the oxygen uptake rates shown in line 10 of Table IV, reaeration required some 45% of the total oxygen needs. On November 28-29, only one-third of the tankage was used for reaeration. From line 10 of Table IV, it may be calculated the same average oxygen uptake, namely 15.1 mg/l/hr, prevailed in each tank. Therefore, sludge reaeration required only 33% of the total oxygen needs.

Much of the oxygen needed for sludge reaeration is utilized for endogenous respiration which progresses faster at high temperatures than at low temperatures. It is concluded that if sludge reaeration is to be used in the joint plant, the reaeration tanks, during the summer and early fall, may use as much as 45% to 50% of the total daily oxygen requirements of the plant, as computed by formula (6). However, during the winter and early spring, they may use as little as 30% to 35% of the formula (6) total. Unduly long or short reaeration periods would probably alter those percentages.

Sludge Production

After numerous trial calculations based on general formulas, it was concluded that for the particular mixture of sewage and paper mill waste under consideration, the net build-up of excess biological floc could be computed by the following variation of the standard formula. The value .55 is from the literature and a temperature effect is included in the formula:

$$\text{excess biological floc lb/day} = (0.55 \times \text{lb/day BOD removed}) - \frac{(0.1 \times \text{lb VSS under aeration})}{1.15^{(20-T)}} \qquad (7)$$

During the operation of the pilot plant the BOD input and removal, the inventory of volatile solids under aeration, and the amount of excess sludge wasted, varied over wide limits. Because of these variations it is impossible to make day to day calculations of floc production. However, as indicated by lines 4 to 12 inclusive, of Table VI, overall calculations for the seven periods covered by Appendices II to VIII inclusive have been made. Lines 13 to 19 of the same table show the application of formula (7) to those same periods. The last line, line 20 of the table, indicates the percentage relationship that the weights of cell material calculated by the formula, bear to those indicated from pilot plant data (line 12). Although these percentages varied from a minimum of 75% during the period covered by Appendix II to a maximum of 134% for the period covered by Appendix V, the average percentage for the seven periods was 101%, which demonstrates the validity of the formula. Therefore, formula (7) may be depended upon for estimating the build-up of excess biological floc under widely varying conditions of BOD loading and mode of operation.

The average BOD loadings, solids aeration periods, sludge volume indices and volatile content of the mixed liquor solids during the periods covered by Appendices II to VIII compare as follows:

Appendices Nos.	BOD Loading lb/day/100 lb VSS under Aeration	Solids Aeration Period Hours	MLSS Percent Volatile	Sludge Volume Index
II	42	7.55	72	101
III	56	8.9	76	66
IV	43	3.3	84	191
V	50	5.61	81	151
VI	47	8.8	82	153
VII	52	2.5	85	316
VIII	29	5.0	81	224

TABLE VI

Calculation of Buildup of Excess Biological Cell Material

1.	Period Considered and Appendix No.	II	III	IV	V	VI	VII	VIII
2.	From	8-8	9-6	10-1	10-28	11-11	12-1	1-9
3.	To	9-5	9-20	10-27	11-10	11-30	12-14	1-21
4.	Susp. Solids under aeration at start, lb	315	117	202	132	167	27	173
5.	Susp. Solids under aeration at end, lb	117	280	132	167	123	52	195
6.	Increase in solids inventory, lb	-198	+163	-70	+35	-44	+25	+22
7.	Solids wasted during period, lb	499	0	464	75	244	130	162
8.	Total solids accumulated during period, lb	301	163	394	110	200	155	184
9.	Length of period, days	29	15	27	14	20	14	13
10.	Gross solids buildup, lb/day	10.4	10.9	14.6	7.9	10.0	11.1	14.2
11.	Average difference between susp. solids in primary and final effluents, lb/day	-6.0	+0.2	-1.4	+4.3	+4.2	-3.7	+0.2
12.	Indicated buildup of excess biological cell material, lb/day	4.4	11.1	13.2	12.2	14.2	7.4	14.4
13.	Average 5 day BOD removed, lb/day	43.9	49.0	43.2	39.0	29.0	16.8	30.9
14.	Average weight of VSS under air, lb	128	118	121	102	114	54	167
15.	Average mixed liquor temp. °C	23.5	22.7	18.8	15.2	11.7	10.2	6.3
16.	Value of "b" at above temp. if "b" is 0.1 at 20°C	0.163	0.132	0.085	0.051	0.031	0.025	0.016
17.	Line 13 x 0.55	24.1	27.0	23.8	21.5	16.0	9.2	17.0
18.	Line 14 x Line 16	20.8	15.6	10.3	5.2	3.5	1.4	2.7
19.	Excess biological cell material by Formula (19), i.e. Line 17-Line 18, lb/day	3.3	11.4	13.5	16.3	12.5	7.8	14.3
20.	Line 19 as a percentage of Line 12	75	103	102	134	88	105	99

It will be noted that although the BOD loadings were almost identical during the periods covered by Appendices II and IV, the volatile content of the mixed liquor and its sludge volume index were much higher during the latter period. The solids aeration time during the period covered by Appendix IV was less than half of that prevailing through the first period. As the BOD loads were the same, the volatile activated sludge solids were absorbing the same amount of BOD during the two periods, but during the period covered by Appendix IV, those solids were not aerated long enough to oxidize all of the adsorbed material. Therefore, their volatile content increased as did the sludge volume index.

On Figure 6, there is plotted chronologically the daily variations in BOD loadings, volatile contents of mixed liquor suspended solids, sludge volume indices and the quotient of the BOD loading divided by the hours of solids aeration for the period August 8 to November 10. All four parameters varied considerably from day to day. However, certain trends are apparent. For example, it appears that generally the SVI did not exceed 100 so long as the volatile content of the mixed liquor suspended solids did not exceed 80%, but that once the volatile content of those solids exceeded 80%, the SVI started to rise. The longer the volatile content remained above 80%, the more rapid the rate of increase in the SVI.

The maximum index that can be carried in any activated sludge plant is a function of final clarifier design and the rates of flow of both incoming waste and return sludge. However, invariably there will be some index that cannot be exceeded without the loss of solids in the final effluent. From Figures 6 and 6-A it would appear that with mixed sewage and Hammermill waste, it would be desirable to prevent the volatile content of the mixed liquor solids greatly exceeding 80%.

Figure 6 indicates that there may be one or more days lag between changes in the above-mentioned quotient and the corresponding changes in the volatile content of the mixed liquor. This is to be expected since the entrainment or adsorption of suspended and of colloidal organic material on the surface of the sludge is an extremely rapid process, while biological cleansing of the sludge requires time.

Figures 6 and 6-A both indicate a tendency for the SVI to rise with or soon after an increase in the volatile content of the mixed liquor solids, and to decline following a decline in the volatile content. However, the rate of decline in the index was frequently very slow and gradual. It appears that once the index is high, it tends to remain high for protracted periods of time, despite the decline in the volatile content of the mixed liquor solids. We believe that this tendency can be attributed to the effect of the large number of filamentous organisms known to be present in the sludge throughout October and subsequent months.

Figure 10 is a plot of the volatile content of the mixed liquor solids against the quotient in BOD loading in lb. per day per 100 lb. MLVSS divided by the hours of solids aeration for the period August 8 to November 10, inclusive. (On the five days where there was a sharp drop or jump of one day duration, the average of the volatile percentages for the days immediately before was used.) Although there is some scattering of the points, it does appear that if the volatile content of the mixed liquor solids is not to exceed 80%, then the value of that quotient must be less than 6. This curve is similar to the "Sat-BOD" removal curve. This conclusion is generally applicable so long as the mixed liquor temperature remains above 15 to 18° C. However, the experience gained during late December indicates that when temperatures are as low as 6° C, even extremely prolonged aeration has little effect upon the volatile content of the mixed liquor solids.

Throughout the operation of the pilot plant, high rates of sludge return were used. Rates as high as 175% of the inflow were used on a few occasions and sludge return rates have averaged 100% or more for the periods covered by Appendices II and III. Rates of less than 50% were seldom, if ever, used and the lowest average rate for any of the periods was 67.5% of the inflow.

From a purely theoretical viewpoint the higher the rate of sludge return, the higher will be the BOD reduction. However, the law of diminishing returns applies to this consideration, i.e. each succeeding increase and rate of sludge return yields a smaller theoretical benefit. The higher the rate of sludge return, the larger will be the aeration or sludge reaeration tanks required to provide the necessary detention time. However, high rates of return are an absolute must when high sludge volume indices in the mixed liquor are encountered.

It was previously stated that because of the likelihood of experiencing infestation of filamentous organisms, any plant designed to provide joint treatment for Hammermill wastes with municipal sewage should be capable of operating with a mixed liquor SVI of 200, i.e. a SDI of approximately 0.5. After careful consideration of various factors, it is felt that during the summer months, the concentration of solids in the return sludge should not exceed 80% of that density index, i.e. 4,000 mg/l, but that during winter time, when mixed liquor temperatures are in the order of 10° C, return sludge concentrations of 1.3 times the SDI would not be particularly harmful.

Suspended Solids Removal

As indicated by Appendices II to VIII, suspended solids reductions by the activated sludge process have been generally low and highly variable. In contrast, when treating only municipal sewage, the conventional activated sludge process generally effects about as high reductions in suspended solids as it does in BOD.

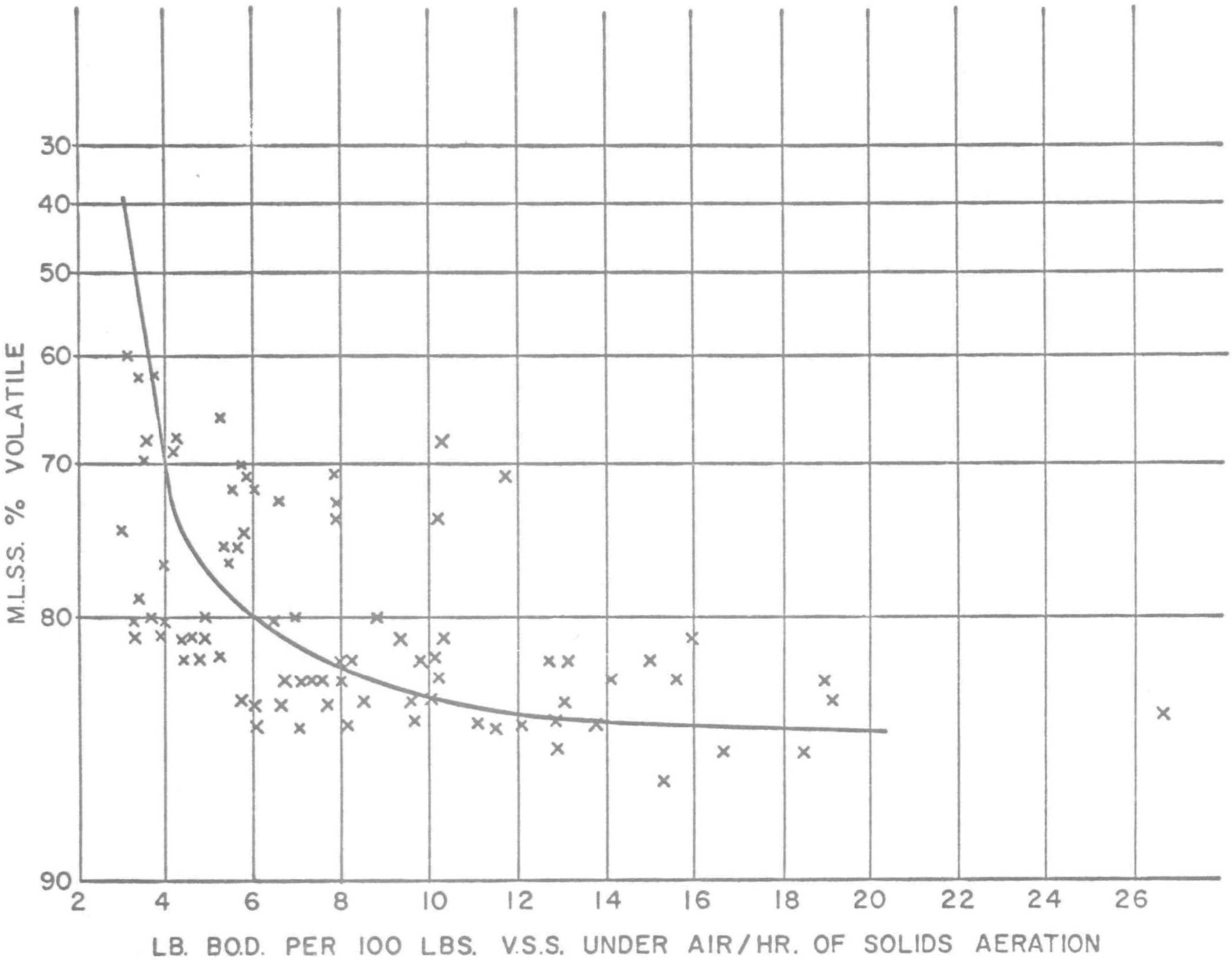


FIGURE 10 - PLOT OF VOLATILE MLSS vs BOD LOADING DIVIDED BY AERATION TIME

Although the loadings on the final clarifier expressed in gallons per square foot per day of waste inflow did not exceed 750 gallons per day, the distance from the inlet to the outlet of the pilot plant clarifier was extremely short when compared with conventional clarifiers used in municipal plants. Therefore, we at first thought it possible that the pilot plant final clarifier was overloaded. To check on this, effluent solids concentrations when treating 20 gpm were compared with those prevailing when treating only 15 gpm. The following tabulation (based on August through October) summarizes that comparison:

Rate of Waste Feed	20 gpm	15 gpm
Number of days included	45	24
Maximum suspended solids in final effluent, mg/l	130	110
High Decil	92	98
High Quatril	60	80
Median	48	57
Low Quatril	32	45
Low Decil	24	28
Minimum	18	20
Average	44	61

Certainly the above tabulation does not indicate that a reduction in inflow to the final clarifier improved its effectiveness. Figure 11 was prepared to see if there was any relationship between the SVI and the suspended solids content of the effluent. It clearly shows that no correlation exists.

During the pilot plant operations the average suspended solids concentration of the final effluent was as follows for the periods covered by Appendices II to VIII inclusive.

Appendix No.	mg/l
II	50
III	64
IV	64
V	91
VI	79
VII	47
VIII	57

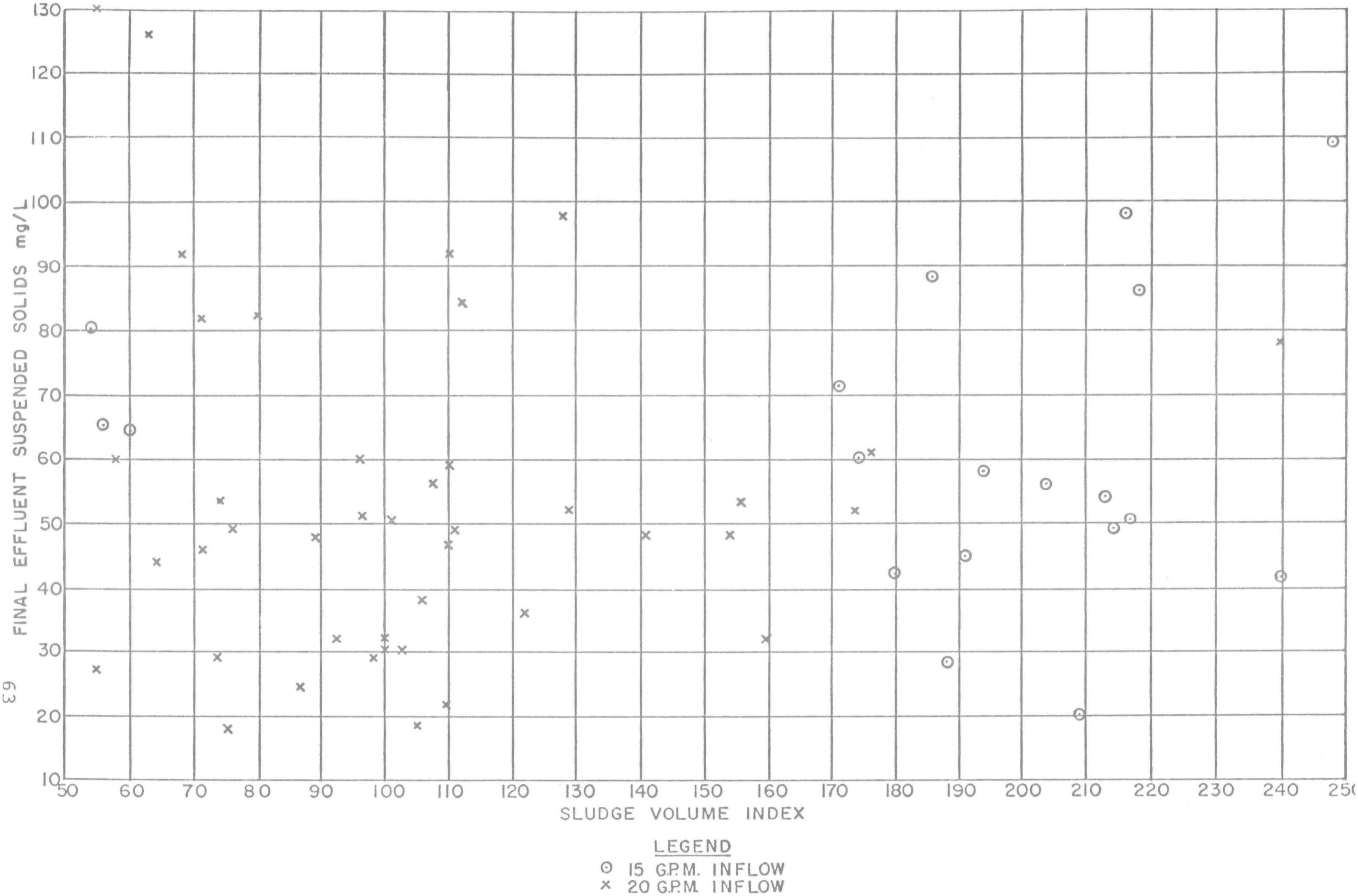


FIGURE 11 - PLOT OF FINAL EFFLUENT SS vs SVI

A full scale clarifier can effect a better removal of solids than did the pilot plant clarifier even though both were operated at the same surface settling rates. However, there is no assurance that the effluent discharged from an activated sludge plant treating the mixed sewage and Hammermill waste will average less than 40 mg/l of suspended solids. Chester Engineers in their work at two paper mills treating wastes by the activated sludge process found that it was difficult to produce a final effluent of low suspended solids concentration. Other paper mills have had difficulty in removing suspended solids by the activated sludge process (4,5) and this may be an indication that similar difficulties are to be expected whenever paper mill wastes are treated by the activated sludge process.

It is possible that the use of polyelectrolytes, flocculation, etc., prior to the final clarifier may improve suspended solids removal if such removal becomes mandatory. Unfortunately, there was no opportunity to fully evaluate the various treatment schemes which can be used to further clarify the effluent.

Effluent Color

Although the activated sludge process is effective in reducing the BOD of the mixed waste, it does not reduce its color. In fact, oxidation seems to intensify the color slightly. This is indicated by the following tabulation:

		Average Color	
Appendix No.	No. of Samples	Primary Effluent	Final Effluent
II	22	1121	1229
III	3	1243	1895
IV	11	1240	1330
V	5	1381	1558
VI	6	1133	1227
VII	4	1041	1165
VIII	0	-	-

Chlorine Demand of Activated Sludge Effluent

Although the activated sludge process generally effected a 30% to 40% reduction in the chemical oxygen demand of the primary effluent, the final effluent from the activated sludge process still had a very substantial chlorine demand. This is indicated by the following tabulation:

Appendix No.	No. of Samples	Average Chlorine Demand, mg/l
II	14	31
III	0	-
IV	6	52
V	3	57
VI	5	66
VII	4	81
VIII	2	38

VIII

SLUDGE DISPOSAL

The primary sludge obtained from the pilot plant had the appearance of municipal sludge, but it contained an average of 1.5% solids, with 80% of the sludge solids being volatile. Although the pilot plant sludge appeared to be of the same consistency and contain as high a concentration of solids as municipal primary sludge, the weight of the solids was surprisingly less. This is attributed to the hydrous condition and properties of the fibrous pulp waste solids. Throughout our pilot plant work, it was noted that the pilot plant primary sludge had the consistency and handleability of municipal sludge containing two or more times the total solids concentration. The excess sludge from the pilot plant was similar to that found in a municipal plant except for the color which was deep (burnt) orange.

Thickening

Sludge thickening was studied in the pilot plant by both settling and flotation. It is practically impossible to simulate a continuous flow gravity thickener in pilot plant operations of the size installed by Hammermill at the Erie Treatment Plant, because of the impossibility of simulating area to depth ratios that prevail in conventional gravity thickeners. Therefore, it was impossible to conduct continuous flow tests of gravity thickening at the pilot plant. Numerous batch settling tests were made and indicated that when the mixed primary and excess activated sludge from the pilot plant was subjected to 2 to 2-1/2 hr. sedimentation periods and solids retention on the order of one day, the resulting sludge contained 2 to 2.5% total solids. By increasing the settling period to 3 hours or more and sludge holding periods to over one day, concentrations in the order of 3% total solids were obtained.

From these rather crude tests, it was concluded that if gravity thickening is to be applied to the mixture of primary and excess sludge resulting from the joint treatment of Erie sewage and Hammermill wastes, such units should be designated for overflow rates of only 600 gallons per sq. ft. per day. Our tests did reveal that retention of the mixed sludge for two to three hours in the batch settling tests resulted in the release of appreciable amounts of phosphates. If sludge were to be retained for a day or more in full-scale gravity thickeners, the effluent from such thickeners might be expected to contain between 100 and 150 mg/l of suspended solids and possibly 30 mg/l of phosphates.

To determine the suitability of flotation thickening of the pilot plant sludge, a 1 sq. ft. pilot flotation unit was obtained from Komline-Sanderson Engineering Corporation. The unit was operated with 65 psi air and internal recycle. The unit's operation was supervised by a representative of the manufacturer, and the results obtained were reviewed and evaluated with Komline-Sanderson engineers.

Waste activated and a combination of waste activated and primary sludges were tested and the results of these tests are set forth on Table VII. The results show that flotation can thicken the waste activated sludge or the combination of waste activated and primary sludges from a joint plant to a concentration of 3% TS. The effluent would contain from 150 to 200 mg-1 of SS and some 12 mg/1 of phosphates. These results are similar to those expected by gravity thickening except that as expected the phosphates did not have as much opportunity to resolubilize as in the gravity thickener because of the prevailing aerobic conditions and were, therefore, significantly lower.

Pilot plant results indicate that a flotation unit can concentrate waste activated sludge to 3% TS if the loading does not exceed 24 lb. solids per sq. ft. per day, and the flow rate 1000 gpd per sq. ft. A combination of primary and waste activated sludge can also be concentrated to 3% TS if the loading does not exceed 48 lbs. solids per sq. ft. per day or 600 gpd per sq. ft.

Polymeric flocculants were used in some of the flotation runs, but they did not materially improve the results. However, it is advisable to incorporate facilities for feeding aids in a plant for we can envision conditions and situations where the flocculants could assist in concentrating the sludge.

The studies indicate that the sludge from a joint plant can be concentrated to 3% TS by using either gravity or flotation thickening on the combined primary and waste activated sludges. There is every reason to believe that a combination of gravity thickening of primary and flotating thickening of waste activated sludge would yield comparable results.

Sludge Dewatering

Vacuum filtration is the most widely accepted means of dewatering sludge in large waste treatment plants. As the name implies, this method consists of placing a filtering medium under vacuum to separate the liquid from the sludge.

The proper pre-conditioning of the sludge is perhaps the most critical and troublesome requirement for good filter performance. The cationic polymers have been used with most success for sludge conditioning. The Erie Plant uses Dow "Purifloc C-31" cationic polymer to condition sludge prior to filtering.

Initial filtration studies were performed with a 0.1 sq. ft. filter leaf test kit. Tests were initially conducted to determine if filtration would work, to establish the proper type and dosage of

TABLE VII

Sludge Concentration with Flotation*

Date	Type Sludge	Feed Rate (gpm)	Feed SS (mg/l)	Float SS (%)	Effluent SS (mg/l)	Aid (C-31) Dosage (%)	Loading lb/hr/sq ft	Loading gpm/sq ft
11/16	WA	1	3,000	2.10	190	0	1.50	1.00
11/16	WA	0.75	3,270	2.76	210	0	1.23	0.75
11/16	WA	0.50	2,370	2.93	188	0	0.60	0.50
11/30	WA	0.95	1,590	1.55	360	3	0.76	0.95
11/30	WA	0.71	1,590	2.46	170	3	0.56	0.71
11/30	WA	0.47	1,620	2.72	160	3	0.38	0.47
11/31	P + WA	0.47	11,860	2.98	1,220	1	2.84	0.47
11/31	P + WA	0.24	10,880	3.12	340	1	1.27	0.24

*Komline-Sanderson Engineering Corporation Model HR/SR-1 used for all runs.

NOTE: WA = Waste Activated. P + WA = Primary + Waste Activated.

flocculant, and the mesh and type of filter medium. Initial tests indicated that undigested combined primary and waste activated sludge produced by the pilot plant and thickened to 2 to 3% TS could be successfully filtered by using 2 to 3% by weight of "C-31" flocculant based on the solids content of the sludge and Eimco Corporation's Filter Medium No. 527-F a 157 x 62 mesh Nylon cloth. Typical filter leaf results were:

Feed TS	"C-31" Dose	Cake TS	Yield
2.2%	3%	18%	3.2 lb/sq ft/hr
2.46%	2%	21%	2.85 lb/sq ft/hr

These results compared favorably with the 1966 vacuum filtration data for the City Plant.

Because of the large quantity of sludge that must be handled at a joint plant and the significant portion of the capital cost that will be reflected in sludge treatment facilities, it was decided to study this method of treatment in more detail and to refine the design parameters.

A 9.5 sq. ft. cloth-belt vacuum filter complete with accessories and a Nylon No. 527 filter medium was obtained from The Eimco Corporation. That pilot unit was operated by Eimco engineers. Chester personnel collected the data and analyzed the results. A series of 16 filter runs were made on four different days. In all cases the combined primary and waste activated sludge produced by the pilot plant and thickened in the fill-and-draw gravity thickener was used as feed to the filter. The results of the runs are presented on Table VIII.

A review of the results will clearly indicate that filter performance is dependent upon the concentration of the solids in the feed and dosage of flocculant aid. With the feed solids constant, yield increases with aid dosage increase and similarly with aid dosage constant the yield increases with increase in solids in the feed, as one normally expects.

With a sludge fed with 3% TS a design filter yield of 3.5 lb/sq ft/hr with 20% TS in the cake and a polymeric flocculant dosage of 1% could be expected. The consistency of the pilot plant filter cake was greater and the filtrate was significantly clearer than that of the municipal plant. The filter cake produced with sludge from the pilot plant came off in sheets. Filter performance and cake quality is likened to the results obtained in the filtration of raw primary sludge, but without any of the associated odors.

The filtrate from all pilot plant runs was of very good quality and was, in fact, without the characteristic rust color. The brief work

TABLE VIII

Vacuum Filtration Studies*

Date	Feed TS (%)	Aid (C-31) Dosage (%)	Filtrate SS (mg/1)	Cake TS (%)	Yield lb/sq ft/hr
10/25	2.5	2.45	35	24	5.70
	2.5	2.45	40	22	5.20
	2.5	2.10	-	20	2.80
	2.5	1.75	50	17	5.00
	2.5	0.56	-	17	1.25
	2.5	1.33	-	18	2.30
10/26	2.2	1.55	36	22	2.55
	2.2	1.90	-	23	3.00
	2.2	1.90	-	23	3.30
11/16	3.0	0.84	-	17	2.65
	3.0	0.85	110	18	3.92
	3.0	0.63	205	17	2.43
	3.0	0.55	-	18	2.05
11/17	2.3	2.10	165	20	3.40
	1.8	1.90	200	18	1.67
	1.8	2.0	-	18	2.86

*Studies conducted with The Eimco Corporation 9.5 sq ft cloth-belt filter.

to determine the cause for the loss of color indicated that the color so prevalent in the waste was apparently adsorbed by the sludge with the long detention time in the thickener. Filtrate suspended solids ranged from 35 to 200 mg/l and contained 22 mg/l of phosphates.

To evaluate filter performance on digested activated sludge, filter leaf tests were made using the standard 0.1 sq. ft. test kit on sludge taken from the four pilot digesters. The filter medium was Nylon No. 527-F and the pickup and drying time as well as the vacuum and the dosage of Dow "C-31" were kept constant in all cases so that the results are comparable. The following tabulation presents the results of these tests as well as the City's average vacuum filtration performance for 1966.

	Feed TS(%)	"C-31" Dose %	Cake TS(%)	Filtrate SS(mg/l)	Yield lb/sq ft/hr
City 1966 Average					
	4.6	1.2	20.4	No data	3.4
Municipal Sludge from Pilot Digesters:					
High Rate I	7.0	1.5	21.6	1080	6.7
High Rate II	4.5	1.5	15.2	1380	3.7
Pilot Plant Sludge from Pilot Digesters:					
High Rate I	2.8	1.5	13.0	440	1.2
High Rate II	2.0	1.5	16.8	870	0.8

The laboratory filtration rate for the municipal sludge from High Rate I pilot digester compares favorably with the actual performance of the City's filtering system. The filtration rates on the pilot plant digested sludges are significantly less than those for the municipal digested sludges. More significant is the fact that the filtration rates for the digested pilot plant sludge are about one-third the rates obtained for the undigested pilot plant sludge. This fact supports the contention that undigested activated sludge can be dewatered more readily and economically than can digested activated sludge.

The possible advantages of centrifugation over filtration and the reasonably good results obtained by dewatering the pilot plant sludge with a clinical centrifuge led to experimentation with a larger machine.

A Model No. P-660 Super-D-Canter was obtained from the Sharples Equipment Division of Pennsalt Chemicals Corporation and operated on three different days on gravity thickened sludge obtained from the pilot plant. Sharples' engineers operated the centrifuge and Chester personnel collected and analyzed the data. The data are presented on Table IX.

The optimum rate for that centrifuge appears to be a 2 gpm feed which contained some 3% TS and a "C-31" dosage of 2% by weight; instead of 1% by weight. This produced a reasonably dry cake with 20% TS and a centrate containing about 1000 mg/l SS, with a solids capture efficiency in the order of 95%.

A joint plant sludge containing 3% TS could be dewatered by centrifuges for about the same capital cost as filters. However, it is believed that the operating costs of the centrifuges would be significantly greater than the vacuum filters and the dewatering results somewhat poorer. Power requirements of centrifuges are three times that of filters and more polymeric flocculants would be required to obtain satisfactory results with the centrifuge. The quality of the centrate would be much poorer than that of the filtrate. Accordingly, it is concluded that vacuum filters would be the most satisfactory and economic means of dewatering the sludge.

Sludge Digestion

Digestion is the most common treatment for readying sludge solids for final disposal. Digestion reduces the quantity of sludge solids, renders them ready for disposal and produces a gaseous end-product which is normally used to sustain the temperatures required for the process and may be used as fuel to drive mechanical equipment or to generate electricity.

Digestion may reduce the quantity of sludge by as much as 50% by the destruction of the volatile solids in the sludge. The reduction of sludge volatile solids is the commonly used gauge of when a sludge is properly digested. The percentage reduction of volatile solids by digestion depends in part on the amount of volatile matter in the raw sludge, see Figure 12B.

If the solids and volatile matter content in the feed are known, the required detention to produce a given reduction in volatile solids can be obtained from graphs, as per Figure 12A.

For a conventional digestion process where the capacity of the digester is dependent upon the detention period, the volume of digester

TABLE IX

Sludge Dewatering Centrifuge Tests

Run No.	Feed Rate (gpm)	Feed Suspended Solids (mg/l)	Feed Volume of Solids (%)	Aids (%)	Centrate Suspended Solids (mg/l)	Centrate Volume of Solids (%)	Cake Total Solids (%)	Capture Efficiency By Volume (%)	Capture Efficiency By Weight (%) (Approx.)
PILOT PLANT SLUDGE									
1	2.0	31,000	-	0	11,400	-	18.0	-	64
2	0.75	31,500	-	0	11,400	-	19.0	-	64
3	1.0	27,200	23.3	1.8	1,040	14	20.0	40	96
4	1.0	27,200	23.3	2.6	940	12	19.5	48	96
5	0.5	27.200	23.3	5.0	560	2	19.5	92	98
6	1.0	27,200	23.3	3.7	530	3.8	20.0	84	98
7	2.0	27,200	23.3	1.9	1,210	13.4	20.0	43	95
8	2.0	34,800	-	0	9,780	-	11.5	-	72
9	3.0	36,000	-	1.0	21,110	-	14.0	-	49

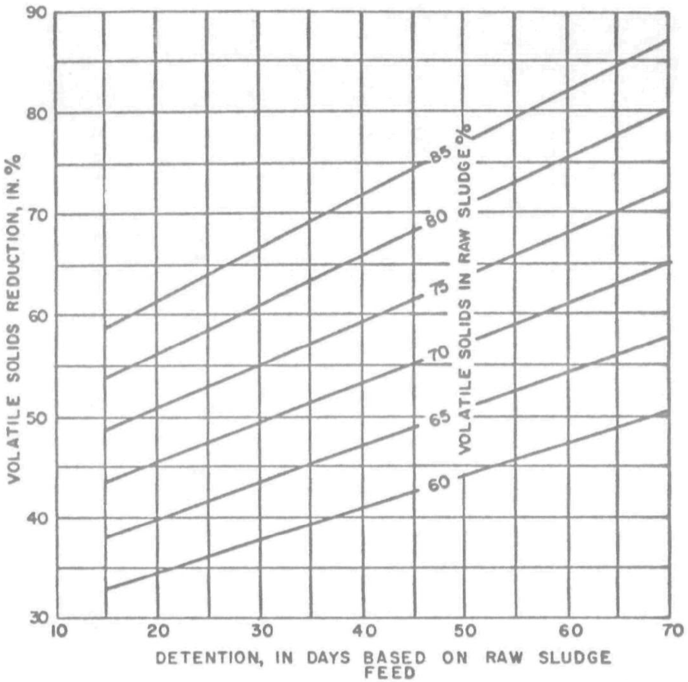


FIG. A - REDUCTION IN VOLATILE SOLIDS IN RAW SLUDGE FOR DETENTIONS FROM 15 TO 70 DAYS T = 85° TO 95°F

Ref. (7)

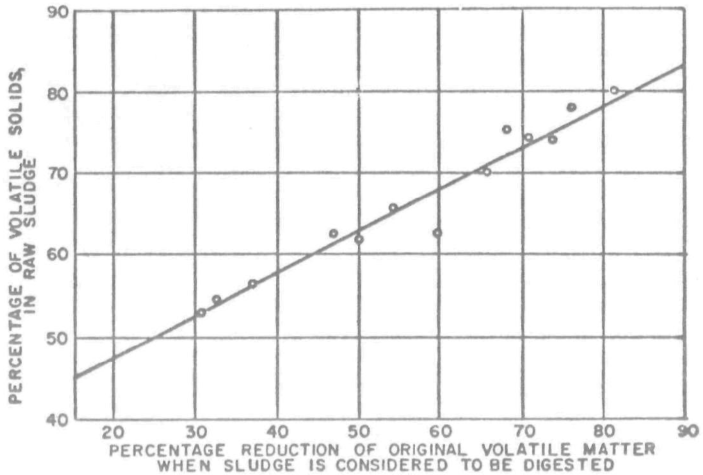


FIG. B - REDUCTION IN VOLATILE MATTER BY DIGESTION

Ref. (6)

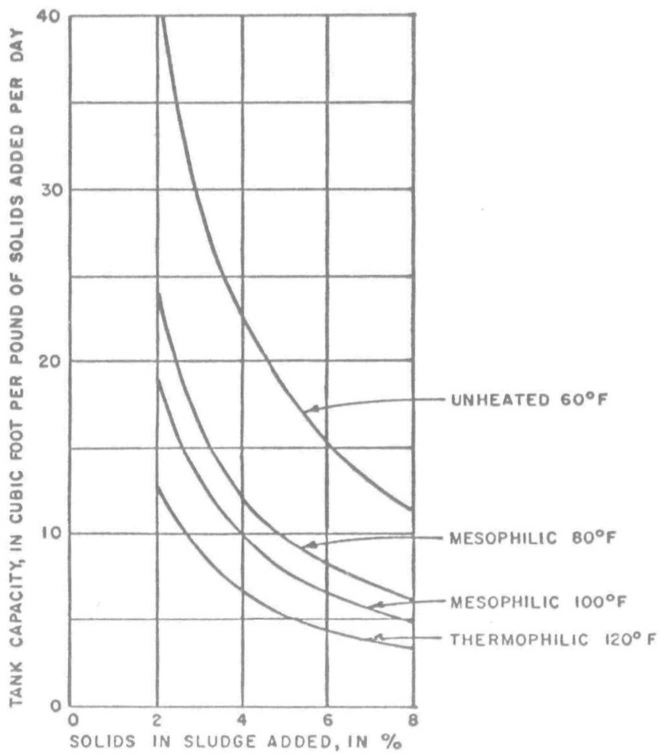


FIG. C - UNIT CAPACITIES OF DIGESTION TANKS (BASED ON LABORATORY BATCH TESTS)

Ref. (8)

FIGURES 12A, B & C - SLUDGE DIGESTION LOADING and REDUCTION CURVES capacity required per pound of total solids added per day would vary with the percentage of dry solids in the feed. This is shown on Figure 12C.

The following factors are measures of the effectiveness of digestion action: gas production (both quantity and quality), solids balance (total and volatile), acidity-alkalinity, pH, volatile acids and sludge characteristics and cation concentration.

In order to determine the design loading and detention time for possible sludge digesters, as well as the suitability of the digestion process for a joint treatment plant, laboratory scale digesters were designed, built and operated by Hammermill.

It was first thought that comparison of sludge from the pilot plant with sludge from the Erie sewage system might be made in simulated High-Rate digesters. On this basis the first digester (Municipal, High-Rate I) was made and filled with municipal sludge about July 12, 1967. By July 28 it was considered to be operational on a daily fill-and-draw schedule to give a 15 to 16 day sludge retention period. After further consideration it was thought advisable to also construct a digester that more closely simulated the present digesters used by the City of Erie, that is, a minimum of 30 days sludge retention. This unit, (Municipal, High-Rate II) was started during the week of August 20, 1967 and was considered operational by September 25, 1967. Meanwhile a similar type digester (Pilot, High-Rate II) was started September 14 on sludge from the pilot plant. Sampling of digested sludge from this digester was started October 6. A fourth digester having 15 to 16 day sludge retention, and treating pilot plant sludge (Pilot, High-Rate I) was started October 12 and was considered operational by October 25. With only a few exceptions, totaling some four days, once digesters were operational, digested sludge was withdrawn and fresh sludge added to each digester every day.

The construction of the digesters is shown in Figure 13. The conventional digesters were inverted 5 gal. bottles filled to the 16 or 17 liter level. Tubular openings near the top of the digester were provided for the withdrawal of supernatant and the addition of fresh sludge. Digested sludge was withdrawn from the bottom of the digester. Through the stopper opening in the top, tubes were installed for the collection of gas and for the recycling of gas to provide agitation for mixing the upper two-thirds of the digester contents when fresh sludge was added. A 1-inch wide by 4 foot long heating tape wrapped around each digester and regulated by a variable voltage controller provided uniform heating for all digesters that seldom varied more than one degree from 32°C.

The operation of the High-Rate II digesters consisted of daily withdrawal of 400 ml of stabilized sludge from the bottom of the digester. Based on a total volume of 16 to 17 liters this provided a calculated retention time of 40 - 42 days for the sludge. At the same

High Rate II High Rate I

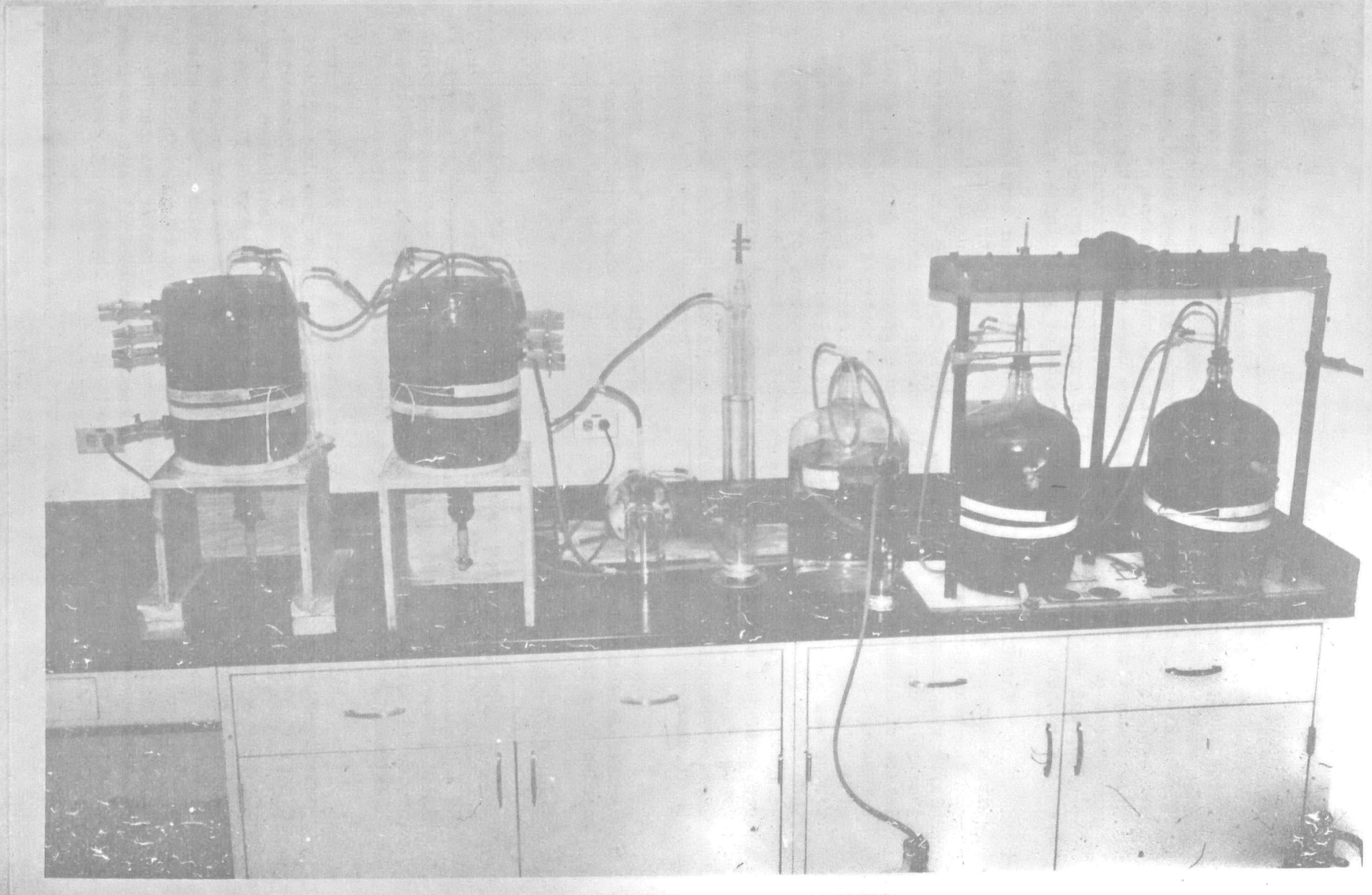


FIGURE 13 - PILOT SLUDGE DIGESTERS

time all the supernatant that was available was withdrawn. The digester was then agitated by recycled digester gas. Following this, fresh sludge equal in volume to the sum of sludge and supernatant withdrawn was added and the upper two-thirds of the digester was thoroughly mixed by recirculated digester gas. Then the digester was not disturbed until the following day when supernatant and sludge were again withdrawn. These digesters were self-regulating in that the amount of supernatant withdrawn controlled the amount of fresh sludge that could be added. This in turn was determined by the total solids content and the liquefaction rate of preceding sludge additions.

The High-Rate I digesters were also 5 gal bottles provided with a tubular opening near the bottom for the withdrawal of sludge and one near the top for the addition of fresh sludge. Mechanical mixing was provided by a stirrer entering from the top of the bottle through a mercury seal. Additional mixing was provided by recirculation of digester gas as in the other digesters. Each day, after a thorough mixing of the entire digester contents by a combination of mechanical stirring and recycling of digester gas, a liter of sludge was withdrawn from the bottom. A liter of fresh sludge was then added through the top tube and the contents of the digesters well mixed. Further mixing was carried out throughout the day except when gas measurements were being made. The volume of the contents of the digester was always maintained at 16 liters. The average retention time of the sludge could then be considered to be 16 days.

The digesters operating on municipal sludge were the control digesters and each digester had a twin operating on the sludge from the pilot plant.

<u>Results:</u>

Daily readings were taken of the TS,VS, of the sludge feed and sludge withdrawn from each of the four digesters as well as the pH and alkalinity of the digesters' contents. The average performance of each of the digesters is presented on Table X and plots of the total solids are shown on Figure 14, volatile solids on Figure 15, alkalinity on Figure 16 and pH on Figure 17.

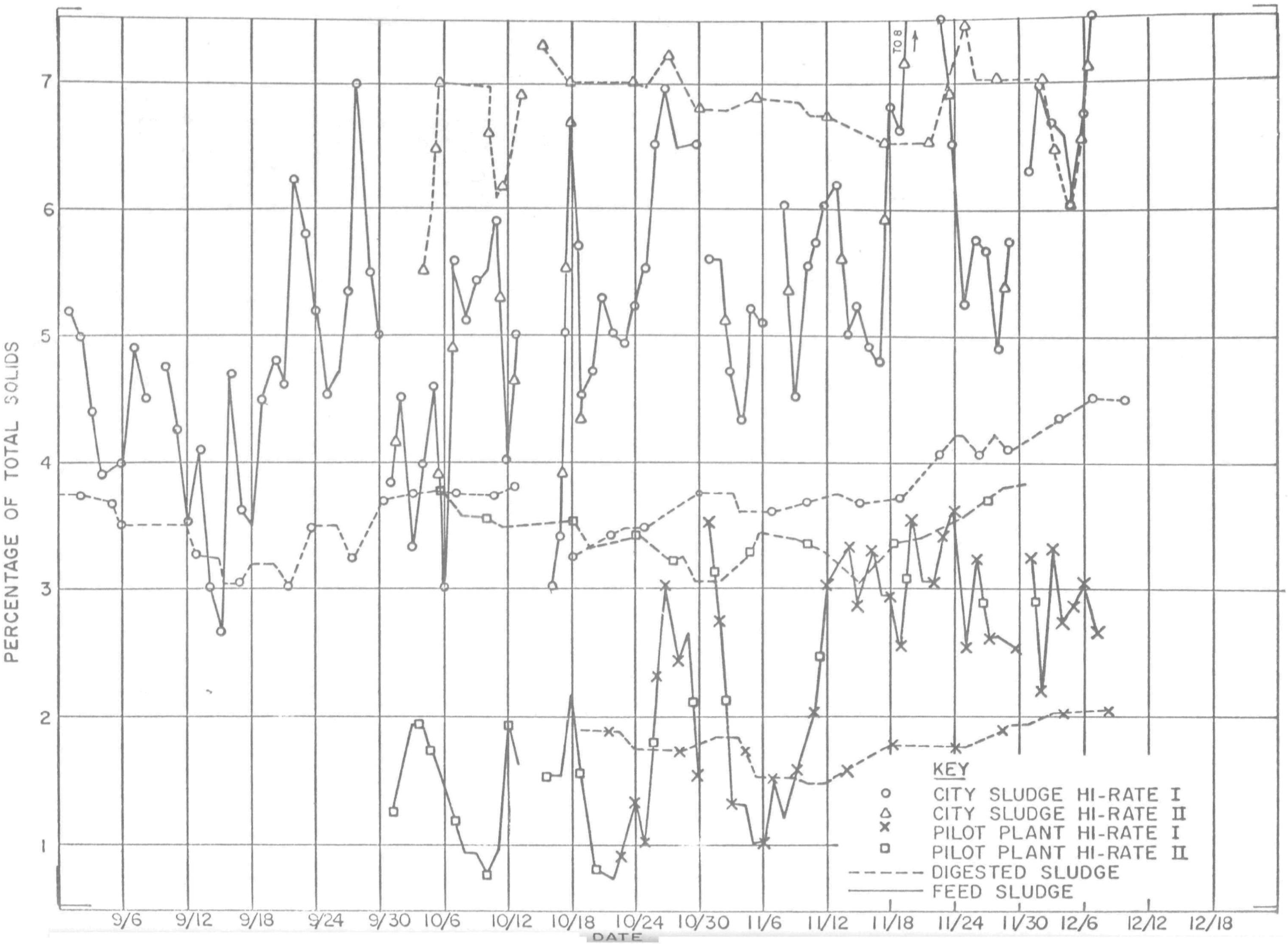
Although one set of digesters had a solids detention time corresponding to conventional digestion, the solids loading of these digesters were in the range normally associated with High-Rate digestion, i.e. greater than 0.07 lb VS/cu ft. We have designated these digesters as Municipal, High-Rate II and Pilot, High-Rate II. The performance of each of these two digesters was quite good and the digestion process progressed to reasonable limits. Some 55% of the volatile solids were destroyed, the concentration of total solids increased after digestion and some 8 cu ft of digester gas per lb VS added was produced in each digester. The municipal unit was loaded at 0.13 lb VS/cu ft and the pilot unit at 0.10 lb VS/cu ft and the

TABLE X

Performance of Pilot Digesters

Digester	Operated (Days)	Detention (Days)	Feed Sludge		Digested Sludge	
			TS (%)	VS (%)	TS (%)	VS (%)
Municipal - High Rate I	128	16	5.17	56.9	3.84	44.5
Pilot Sludge - High Rate I	60	16	2.31	80.1	1.75	59.5
Municipal - High Rate II	76	40	5.65	62.0	6.93	43.0
Pilot Sludge - High Rate II	70	40	2.15	80.1	3.56	62.0

Digester	TVS Destroyed (%)	Loading lb VS/cu ft	Gas Production		Methane Production (%)
			Feed Basis cu ft/lb VS	Destroyed Basis cu ft/lb VS	
Municipal - High Rate I	37.5	0.12	4.1	10.8	59.7
Pilot Sludge - High Rate I	63.5	0.07	6.9	10.8	55.0
Municipal - High Rate II	53.7	0.08	5.7	10.6	60.0
Pilot Sludge - High Rate II	56.5	0.08	6.7	11.8	55.5



PERCENTAGE OF TOTAL SOLIDS
1
2
3
4
5
6
7
TO 8
9/6
9/12
9/18
9/24
9/30
10/6
10/12
10/18
10/24
10/30
11/6
11/12
11/18
11/24
11/30
12/6
12/12
12/18
DATE
KEY
CITY SLUDGE HI-RATE I
CITY SLUDGE HI-RATE II
PILOT PLANT HI-RATE I
PILOT PLANT HI-RATE II
DIGESTED SLUDGE
FEED SLUDGE

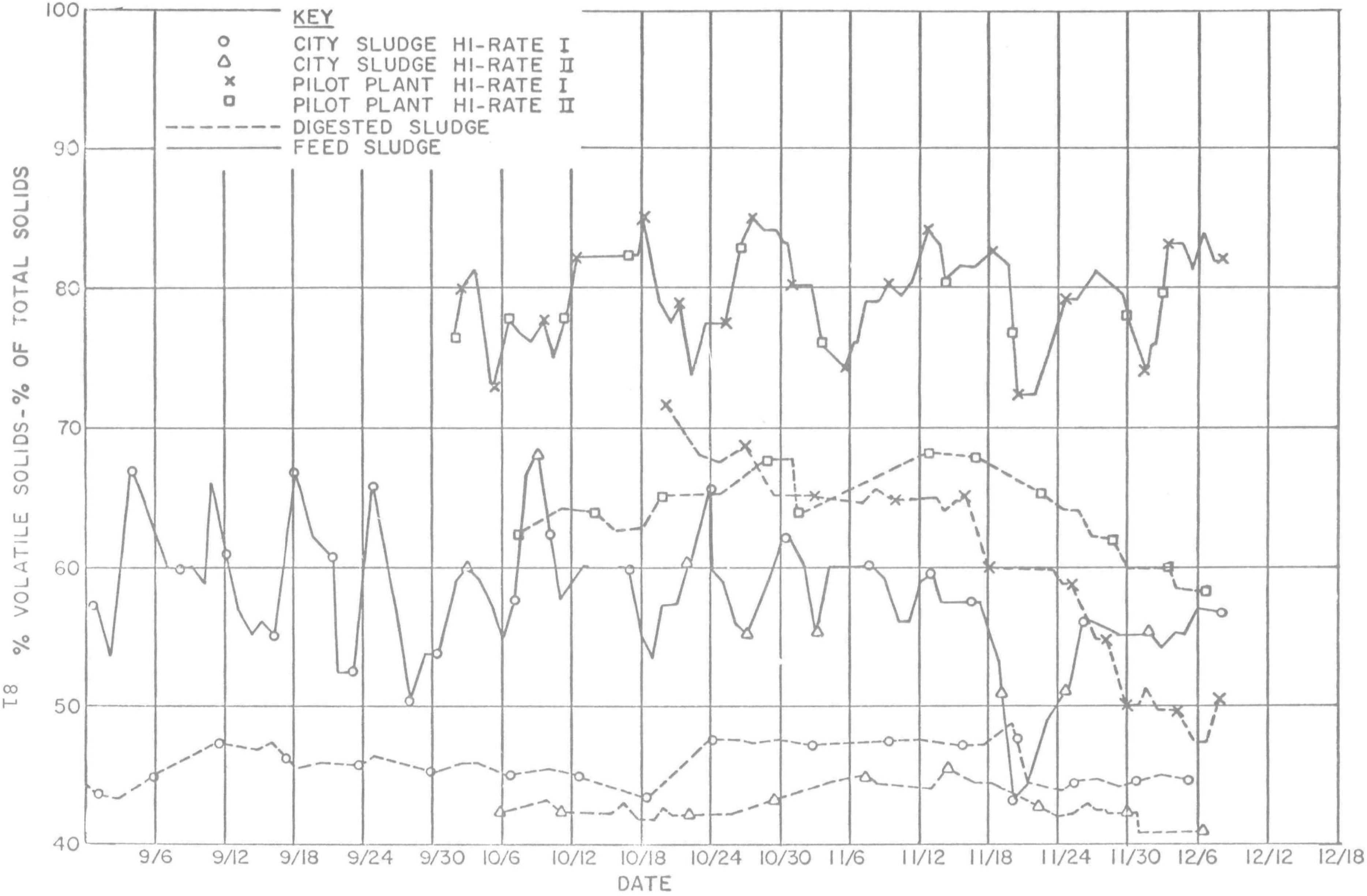
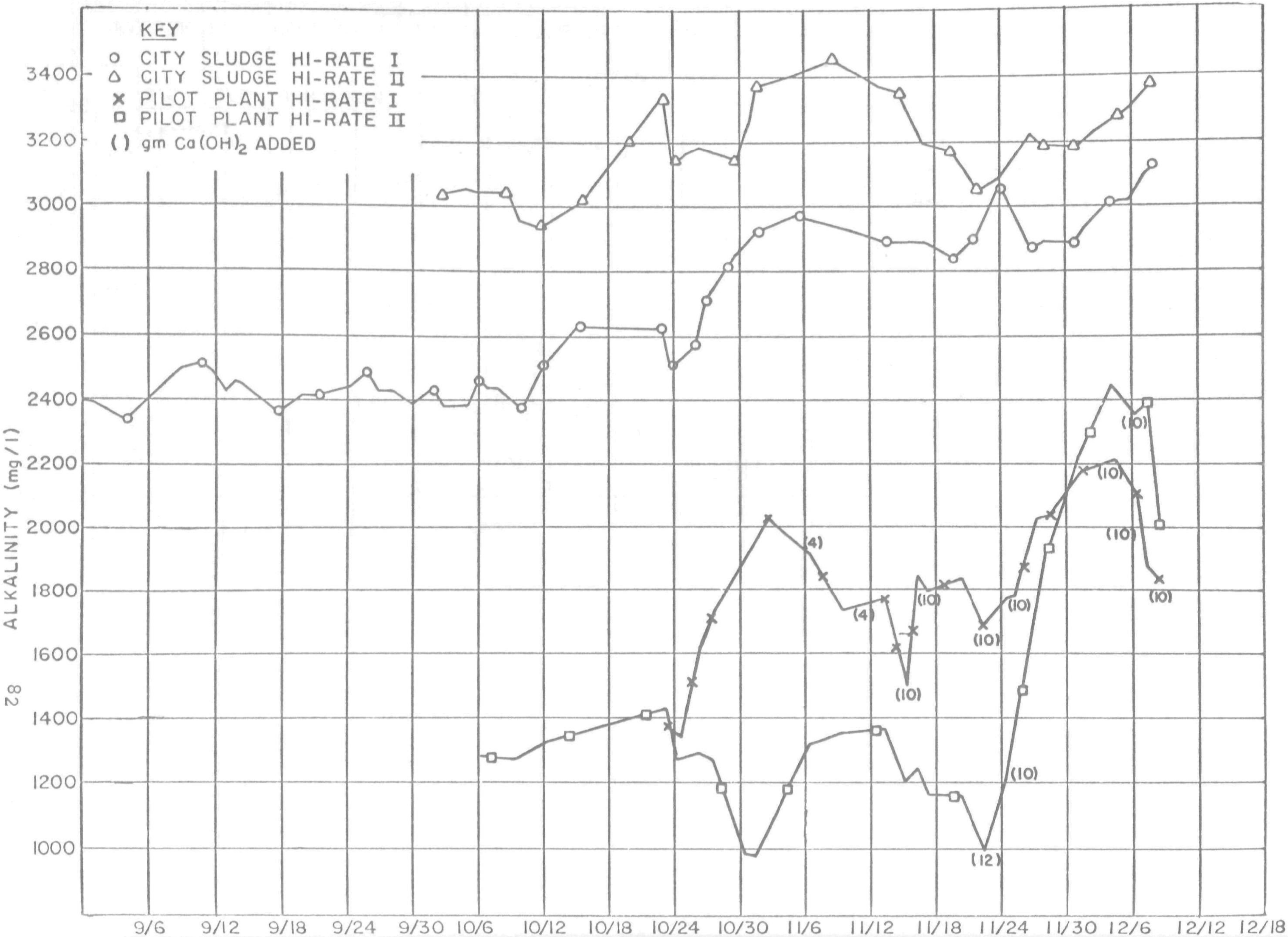


FIGURE 15 - PLOT OF VOLATILE SOLIDS WITH TIME FOR THE PILOT PLANT SLUDGE DIGESTERS


KEY
○ CITY SLUDGE HI-RATE I
△ CITY SLUDGE HI-RATE II
× PILOT PLANT HI-RATE I
□ PILOT PLANT HI-RATE II
( ) gm Ca(OH)2 ADDED
ALKALINITY (mg/l)
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
9/6
9/12
9/18
9/24
9/30
10/6
10/12
10/18
10/24
10/30
11/6
11/12
11/18
11/24
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(10)
(12)

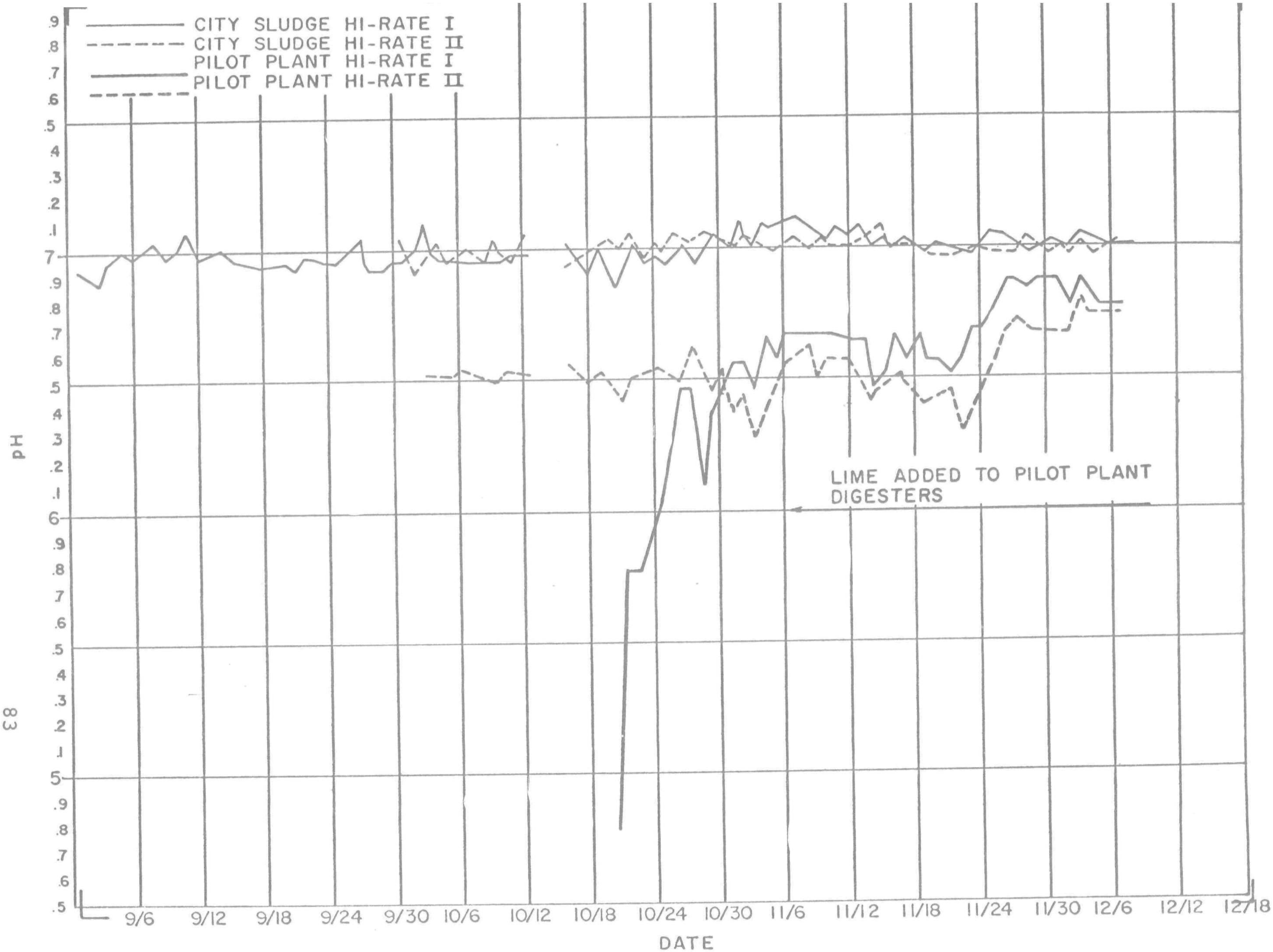

FIGURE 17 - PLOT OF pH WITH TIME FOR PILOT PLANT SLUDGE DIGESTERS

sludge detention period was 40 days in each.

It is interesting to note that although the unit loaded with pilot plant sludge performed nearly as well as the municipal unit, the pilot plant sludge required frequent additions of lime to sustain reasonable pH and alkalinity levels. The volatile acid content of the pilot plant sludge was consistently two times that of the municipal unit. Also of interest is the phosphate content of the supernatant from the pilot sludge digester which averaged 170 mg/l as PO_4.

The two digesters termed Municipal, High-Rate I and Pilot, High-Rate I had a solids detention time of 16 days. The performance of these units was not satisfactory. Although the digester receiving pilot sludge was loaded somewhat lower than High-Rate II (0.07 lb VSS/cu ft), and 64% of the volatile solids were destroyed, large and frequent additions of lime were required to sustain the digestion process. The volatile acid concentration was 1280 mg/l on October 25 and it required daily lime additions for some 10 days to bring that concentration to the 100 mg/l level. Lime dosage averaged 3 mg/l during November.

The performance of the two digesters receiving municipal sludge can reasonably be considered the base line for comparison with the digesters treating pilot plant sludge. Pilot plant sludge requires 70% to 80% destruction (Figure 12B) of volatile matter for reasonably satisfactory digestion.

The results of this pilot study indicate that digesters for a joint treatment plant should provide at least 40 days sludge retention and have a solids loading of no more than 0.10 lb VSS/day/cu ft and have facilities for continual addition of lime in order to have reasonably successful digestion. The digestion volume required for a 40-day loading and a low solids loading indicates that sludge digestion would not be desirable or practical in a joint plant.

Combustion has been considered as the means of ultimate sludge disposal. To evaluate this process, four samples of sludge cake from the pilot vacuum filter were analyzed by "Commercial Testing & Engineering Company" to determine the proximate and ultimate analysis of the filter cake. The analytical results are summarized on Table XI and they indicate that the cake could be readily burned and would be, in fact, auto-combustible with a higher percentage of moisture than municipal sludge.

The proximate and ultimate analysis provide sufficient information for sizing incineration equipment and that information indicates that sludge disposal by this process is most feasible. Multiple-hearth incinerators to properly incinerate the filter cake which may contain 80% moisture are recommended. The filters and

TABLE XI

Analysis of Sludge Cake

Ultimate

Commercial Testing & Engineering Co. Analysis Number	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	Ash	Btu
CL-62026	43.14	5.88	1.96	0.75	34.01	14.26	12,217
CL-62027	42.37	5.93	2.16	0.74	34.76	14.04	12,077
CL-62028	42.34	5.89	2.29	0.78	33.48	15.22	12,218
CL-62029	41.98	5.86	2.26	0.73	35.15	14.02	12,079
Totals	169.83	23.56	8.67	3.00	137.40	57.54	48,581
Average	42.44	5.89	2.17	0.75	34.35	14.36	12,145

Proximate (Dry Basis)

	% Ash	% Volatile	% Fixed Carbon	% Sulfur
CL-62026	14.26	70.78	14.96	0.75
CL-62027	14.04	71.53	14.43	0.75
CL-62028	15.22	70.17	14.61	0.78
CL-62029	14.02	–	–	0.73

incinerator would have to process an estimated 8200 lb/day/million gallon raw waste.

IX

DISINFECTION

The State standards require disinfection to 1,000 coliform per 100 ml, recently revised to 200 fecal coliform per 100 ml. It is generally believed that disinfection to 1,000 coliform of municipal final effluent will meet these new standards and that this will be the case on the 50-50 effluent. Historically the Pennsylvania Department of Health requires that the Erie municipal treatment plant maintain a chlorine residual of 1.5 mg/l after a 15-minute contact period. Preliminary work by Hammermill indicated that to satisfy such a requirement may demand that the effluent from a joint plant be dosed as high as 100 mg/l. Such a requirement gave impetus to the investigation into the actual dosages required to effect a satisfactory kill of microorganisms, as well as possibly substituting other agents to accomplish that kill. There were also some investigations into the possibility of varying the point(s) of application in hope of reducing requirements.

The basic objective was to find an agent which would disinfect without being chemically consumed in the Hammermill-municipal waste solution.

Many systems were given consideration, including gamma radiation, formaldehyde, iodine, colloidal silver, sulfamic acid and bactericides. In addition, the leading manufacturers of bactericides were contacted in hopes of finding a suitable agent. In fact, two companies, namely, Metasol Products, Division of Merck & Company, Inc., and Buckman Laboratories, Inc., conducted extensive investigations into economic means of disinfecting the effluent from the pilot plant.

Bacteriological studies performed by Hammermill and independent laboratories have shown that the chlorine requirements for adequate kill are for all practical purposes equal to those given by the chlorine demand of the effluent. To reach 1.5 mg/l chlorine after 15 minutes requires a 60-100 mg/l dose rate. The information presented in Table XII shows that an average chlorine dosage of at least 60 mg/l would also be required to properly disinfect the joint plant effluent.

The high cost of adequate disinfection by chlorine of the joint plant effluent dictated additional research to find the optimum agent(s) and/or application of such an agent. The final effluent from the bench activated sludge plant was used in the tests made in the research study. As was to be expected, it was found that the chlorine required for disinfection increased with increased COD of the effluent. Stepwise addition of chlorine was tried in an attempt to increase and prolong the chlorine residual. No improvement

TABLE XII

Chlorine Levels Required to Bring Total Coliform Counts to a Level Below 1000 per 100 ml in Final Effluent

Test No.		Chlorine Requirement, mg/l: EMB Agar Plate Method	Chlorine Requirement, mg/l: MPN Method
1			> 50
2			40
3		> 80	
4		< 70	
5		< 50	
6		< 40	
7		< 30	
8		> 50	
9		70	80
10		60	60
11		90	70
12		60	50
	Average	60	52

in the residual or better kill was found. Tests showed no disinfection improvement after one hour even though residuals may be found up to two hours. The addition of chlorine water to the final effluent changes the pH but pH adjustment is unlikely to improve the kill qualities.

Start	Cl_2 Added	Final
7.4	60 ppm	5.8
7.4	90 ppm	5.2

Iodine showed no promise. Sulfamic acid used alone and in combination with chlorine was tried. The kill was very poor with sulfamic acid alone, improved some with the addition of an equal quantity of chlorine and showed further improvement with greater amounts of chlorine. Disinfection with this combination was poor at best. The commercial biocides showed little promise. Colloidal silver gave poor results and had a cost approximately 40 times the cost of chlorine to obtain the same disinfection. After many tests it was concluded that none of these materials were suitable as an economical replacement for chlorine.

Tests on the bench plant mixed effluent for ammonia had shown amounts ranging from 0 to .5 ppm. City final effluent was found to have approximately 8 ppm. It was decided to test to see if the use of ammonia with chlorine would improve the disinfection action. Ammonia at the rate of 2.61 ppm was added to the effluent followed by chlorine. It was found that 30 ppm chlorine was required to obtain disinfection. When the chlorine was premixed with the ammonia it was found that the same disinfection could be obtained with only 15-17 ppm of chlorine. In all the tests the NH_3 solution was prepared by diluting concentrated NH_4OH with distilled water before mixing it with the chlorine solution. The chlorine solution was prepared by diffusing Cl_2 through water until a 5.5 gram per liter concentration was reached.

The timing of the premixing of the ammonium hydroxide and chlorine was found to be critical. Maximum disinfection was obtained when the premixed solution was added to the effluent within sixty seconds of mixing. When the mixture was exposed to the air for even a few minutes the disinfection was poor. It was found that when properly mixed and applied, 2.61 ppm NH_3 premixed with 15-17 ppm Cl_2 resulted in coliform counts generally below 1,000/100 ml. The disinfection action with varying proportions of NH_3 and Cl_2 are shown in Table XIII. The use of the premixed NH_3-Cl_2 solution was found to work equally well on City of Erie effluent at the same dose rates, thus making it too costly for use on effluents with a low chemical chlorine demand.

TABLE XIII

Treatment of Joint Effluent with Premixed NH_3-Cl_2

ppm NH_3	ppm Cl_2	Control Count	1 Hour after Treatment Count
1.31	6.8	710,000	232,000
1.31	8.1	710,000	250,000
1.96	9.9	710,000	18,000
1.96	11.8	710,000	14,000
2.61	13.4	1,100,000	1,000
2.61	13.4	800,000	1,000
2.61	13.4	360,000	0
2.61	13.4	640,000	3,000
2.61	14.3	710,000	3,000
2.61	15.1	3,500,000	300
2.61	15.1	570,000	3,200
2.61	15.3	770,000	2,500
2.61	17.3	3,500,000	1,000
2.61	17.3	570,000	100
2.61	20.2	3,500,000	100
3.26	19.5	3,500,000	0
3.26	20.8	3,500,000	10
3.26	23.1	3,500,000	10

Counts are of the coliform group, tested by the membrane Filter Technique, incubated 18-24 hours at $35^{o} \pm .5^{o}$ C and expressed per 100 ml. Pore size of the membrane was 0.45 micron. 1 ml samples were used except where noted. Controls generally required .01-.001 ml.

Samples were sent to an outside laboratory for testing by the Multiple Tube Fermentation technique as in Standard Methods. Correlation of results was reasonable.

Data accumulated to date indicates that a minimum of 2.61 ppm NH_3 is required to obtain effective disinfection action - there does not appear to be a limiting upper value. At 17 ppm Cl_2 and 2.61 ppm NH_3 the cost is \$.00508 per 1,000 gal effluent (Cl_2 @ \$60/ton, NH_3 @ \$75/ton) nearly 75% lower than the use of chlorine by itself.

A Wallace & Tiernan amperometric titrator revealed a continuous reduction of chlorine residual when the fresh NH_3-Cl_2 mixture was added to the final effluent, or to distilled water. Meter deflection ceased after approximately ten minutes, at which time chlorine residuals are nearly zero. The disinfection tests shown in Table XIV indicate that disinfection is accomplished within the first 15 minutes.

The action of the NH_3-Cl_2 mixture is not completely understood but is by far the most effective and economical. Premixing of the solution and immediate use was found to be critical to the success of the solution. A minimum of 2.61 ppm of NH_3 was found to be necessary in the premixed solution. Cl_2 in the solution at 17 ppm gave good disinfection action, use of more Cl_2 improved the disinfection action but increased the cost. Additional studies of the pH of premixed Cl_2 and NH_3 may indicate a pH where improved kill can be obtained. Additional studies would be required before a disinfection system based on the findings could be installed.

Table XIV

EFFECT OF TIME ON DISINFECTION

ppm Cl_2	Control Count	Count after Treatment 2.61 ppm NH_3 15 min.	30 min.	60 min.
13.2	2,000,000	100	100	300
13.5	1,020,000	200	0	0
15.3	1,020,000	100	100	0
15.5	2,000,000	0	200	100
13.2	--	1,300	--	1,400
13.2 *	--	1,150	--	3,060
15.0	--	0	--	1,800
15.0 *	--	500	--	870
17.0	--	0	--	1,100
17.0 *	--	470	--	810

*10 ml. sample

X

SUPPORTING STUDIES

To complement the pilot plant studies and to provide a complete characterization of the possible process requirements and considerations for the successful treatment of the combined wastes, a number of related studies were performed, as described below.

Analytical Methods

Because of the unusual nature of the Hammermill waste, many standard test methods were found unsatisfactory and required modification. Unless noted otherwise, standard methods were used throughout (Standard Methods for the Experimenting of Water and Wastewater, 12th Edition, 1965). Studies made and planned on the various testing procedures are given below:

1. Suspended Solids - It was found that the drying time in the usual procedure for suspended solids was often insufficient. This was solved by resorting to the more rigorous laboratory practice of reweighing everything to constant weight. This greatly improved the reliability of results.

2. Phosphates - Because of color interference in the waste stream, a modification was devised involving bleaching out the color with chlorine and removing the available chlorine with heat. In addition to the normal total phosphate determination run on filtered effluent a determination is also made on the unfiltered effluent. This was known as "Nutrient" phosphate and is based on the idea that undissolved phosphates are also available to the microbiological life.

3. Nitrate - A simple modification has not been found to enable routine nitrate testing, mainly because of high color and chloride contents. A rather complicated scheme has been developed which allowed some limited nitrate testing. The chemical methods were found to be too lengthy; therefore, a nitrate sensitive electrode was purchased and used, thus providing a simpler method.

4. Sulfates - A sulfate procedure has been studied but has not been perfected.

5. BOD - A BOD procedure was used which eliminated interference from the spent sulfite liquor in the waste. Dissolved oxygen was determined by the Winkler method on the original saturated sample before incubation as well as on the test sample after the usual 5-day incubation. This assumes that the same interference is present before and after incubation, thus canceling the error. BOD's of various durations other than five days were run to show that oxygen uptake was quite constant and free from any toxicity effects.

6. COD - Chloride interference was removed by the mercury complexing method. This has been shown to give results equal to those corrected by the Mohr titration for chloride.

7. Foam - A lengthy study of foaming characteristics has provided a test method which relates foaming tendency to concentration of a standard foaming agent.

Neutralization

The Hammermill wastes, as presently discharged, have a pH of about 3. Therefore, they must be neutralized to be amenable to biological treatment. Laboratory and pilot scale tests were performed to determine alkali requirements, as well as neutralization techniques. These studies revealed that the pH of the waste must be initially adjusted to about 8.5 to compensate for a backsliding effect of the waste; two to four hours after neutralization to 8.5, the pH adjusts to 6.5 to 7.0 and remains at that level. No acid conditions were experienced at the pilot plant once Hammermill wastes were adjusted to a pH of 8.5 by lime.

Color

The characteristic color of the Hammermill wastes will not appreciably change after treatment by the activated sludge process, except for the effect of dilution with the municipal waste.

The removal of color has been studied by Hammermill for some two years. Laboratory studies have included the use of lime precipitation, alum precipitation, activated carbon adsorption, chlorine bleaching and in-plant bleaching process modification. Each scheme was tried singly and in combination with others. These methods of color removal proved to be most uneconomical. The costs associated with removal of color are exorbitant and could well be as great as the cost of providing secondary treatment.

Color Removal

In the cooking operation, lignins and extractives are solubilized, appearing in the waste liquor and subsequent washes. Nearly two-thirds of the color generated comes from cooking. Most of the rest of the color load results from the chlorine and extraction stages of the bleaching sequence, in which additional lignin is solubilized. The small amount of color generated in wood handling and paper-dyeing operations makes up the remainder of the color load (less than 1% of the total).

It should be noted that the dissolved materials which create color are almost completely non-biodegradable. Thus, the color problem is entirely one of appearance of the receiving water and has no relationship to oxygen demand or marine life in any way.

The deep well disposal system removes over half of the color produced by cooking, or about one-third of all generated color. The remainder is carried by the sewer system.

It has been of interest to Hammermill to remove some of the color from the pulp mill sewer stream. Research work was undertaken in the spring of 1965 and has been pursued almost continuously up to the present. Following is a brief description of the major studies made and their conclusions:

METHOD	COLOR REMOVAL	COST
Lime Precipitation	Maximum 70%	Equivalent to combined primary & secondary treatment costs
Alum Precipitation	70% +	Same as lime precipitation
Other Precipitation Processes	No success (ferric salts, silica gel, polyelectrolytes)	
Activated Carbon	All plus BOD	Triple combined primary and secondary treatment costs
Lime & Carbon in Series	All plus BOD	No advantage over activated carbon
Hypochlorite Oxidation	50% ±	Same as lime precipitation
Lime & Chlorine in Series	50% +	No advantage over lime precipitation
Membrane Processes	Most + BOD	Greater than activated carbon
Other Bleaching Processes	(Many studied, nitric acid extensively - technical and by-product marketing problems too great)	

METHOD	COLOR REMOVAL	COST
Deep Well Disposal	All	Volume too great for deep wells
In-plant Modifications	30%-40%	More favorable than lime precipitation but color reduction inadequate.

Corrosion

Samples of cast iron, low carbon steel and stainless steel Types 304, 316, 316L and 440 were placed in the aeration tanks at the pilot plant to determine the degree of corrosion. At the end of 38 days the samples were removed, inspected, weighed and then returned to the tank.

After 58 days, the samples were removed, inspected, weighed and measurements taken to determine the volume and surface area. From these data, the average surface erosion in mils per year was calculated, as shown in the following tabulation:

	Initial Weight	Final Weight	Weight Lost	Weight Lost	Thickness Loss mil/year	Reference
Cast Iron	31.5016g	31.3451g	0.1565g	0.49	1.6	(1)
Low Carbon Steel	128.5196	128.1900	0.3296	0.27	1.6	(2)
Stainless #304	89.2888	89.2865	0.0023	0.0026	0.018	(3)
Stainless #316	86.5863	86.5711	0.0152	0.017	0.12	(4)
Stainless #316L	86.8768	86.8609*	0.0159*	0.018*	0.18	(5)
Stainless #440	84.3191	84.2921	0.0270	0.032	0.40	(6)

*After 38 days. Other samples 58 days.

(1) Surface pitted and oxide particles on surface
(2) Surface pitted; oxide particles easily removed
(3) No visible surface or weld change
(4) Some surface corrosion visible; no weld damage obvious

(5) No visible surface or weld change
(6) Large areas of surface corroded; no visual weld damage.

Additional samples, using brass, bronze, and copper were run for the first 38 days; however, these samples were lost prior to the termination of the test because of their light weight and strong agitation in No. 3 tank.

On the basis of the results shown in the tabulation, all samples tested should be satisfactory for the application, with certain qualifications. Their suitability for use is based on the fact that, in each case, the loss due to erosion and chemical attack was less than 2 mils per year.

The fact that the cast iron and low carbon steel surfaces were pitted, would indicate the possibility of greater attack than calculated because of the formation of cathodic and anodic areas in the vicinity of and within the pits. To obtain more meaningful data, it will be necessary to plot a weight loss curve vs. time based on a test of longer duration than 58 days. It is recommended that such long-duration tests be conducted prior to the design of the combined treatment plant.

Foaming Tendencies

There has been some tendency of the combined wastes to foam with aeration, and defoamer was periodically added to control this condition. It should be noted that pilot plant aeration tanks were not equipped with water sprays. Water sprays could have alleviated most of the foam problems experienced at the pilot plant.

Hammermill effluent presently contains large quantities of defoamer; this, plus lime neutralization, and flowing in an intercepting sewer to a joint treatment plant, should suppress the foaming tendencies of the pulp wastes.

It is believed that a well-designed foam spray system could suppress most, if not all, the foam which may occur on the aeration tanks for the joint plant.

XI

SIGNIFICANCE FOR DESIGN

Primary Treatment

When handled separately, any or all of the Hammermill wastes appear less amenable to treatment by primary sedimentation than does municipal sewage alone. However, when the combined Hammermill waste is neutralized and mixed with sewage in the proportions of 1 to 1, the resulting mixture is effectively treated by primary sedimentation. The percentage reductions in suspended solids of the mixed wastes are quite similar to those obtained by primary sedimentation of municipal sewage alone. In pilot plant operations such reductions were generally in the order of 76%.

Primary treatment also effected 25 to 30 per cent reductions in the BOD and COD of the mixture of the Hammermill wastes and municipal sewage. While these reductions are not as high as those obtained by primary sedimentation of municipal sewage alone, the difference is attributed to the fact that the Hammermill wastes contained higher concentrations of soluble COD or BOD than municipal sewage.

The pilot plant was operated at a constant flow. The rate of inflow to municipal plants varies widely from hour-to-hour, day-to-day and season-to-season. This variation in flow, even though smoothed some in a joint plant by a relatively constant flow from Hammermill, will fluctuate widely and joint primary treatment will not be as effective as the pilot plant primary unit.

Provision for retention in the primary unit of a joint plant for 1.5 hours and a surface overflow rate of 1,000-1,100 gal/sq ft/day should result in the removal of 25% of the incoming BOD and 60% of the suspended solids.

The consistency of the sludge resulting from the primary treatment of the mixed wastes appeared to be quite similar to that of normal municipal primary sludge. However, repeated analyses proved this appearance to be misleading. The sludge withdrawn from the pilot plant primary settling tank generally contained only about 1.5% solids, whereas normal municipal primary sludge may be expected to contain at least 4 to 6 percent solids. The pilot plant sludge was also materially higher in volatile matter. On a dry basis, it averaged approximately 80% volatile, whereas municipal primary sludge normally contains less than 70% volatile matter.

Activated Sludge Treatment

After primary treatment the mixture from Hammermill wastes and municipal sewage proved to be quite amenable to treatment by the activated sludge process, and the addition of supplemental nutrients, i.e. nitrogen or phosphorun, appeared unnecessary to effect good BOD reduction. Throughout pilot plant operations the organic plus ammonia nitrogen content of the feed generally ranged between 3 and 5 percent of its 5-day BOD, while the phosphate (PO_4) content generally ranged from 2 to 4 percent.

High sludge volume indices were encountered in both the bench scale plant and the pilot plant throughout much of the time they were in operation. Microscopic examination of the pilot plant sludge revealed the presence of heavy filamentous growths, which no doubt contributed to the sludge bulking. It is possible that had the ratio of nitrogen to BOD in the feed been higher, and the BOD to volatile solids loading been lower, the development of filamentous growths might have been retarded or prevented. However, further protracted pilot plant operations under varying temperature conditions would be required to prove the truth of this statement. Even if the use of supplemental nitrogen were to curtail such growths, its use as a method of control is questionable, not only because of the cost involved, but because the nitrogen content of the final effluent would be increased if the nitrogen feed to the process was greater. An effluent high in nitrogen would contribute to the eutrophication of the Lake and defeat one of the purposes and inherent benefits of joint treatment of Hammermill wastes with municipal sewage.

If a joint treatment plant is to be considered, it should be designed to operate successfully at a sludge volume index of at least 200. It appears that if still higher indices are to be avoided, the volatile content of the activated sludge must be prevented from materially exceeding 80% and that this may best be done by the use of long solids aeration periods and relatively low BOD to volatile suspended solids loadings. The means of controlling sludge volume indices has not been completely explored in the operation of the bench scale continuous flow plant. Based on pilot plant operations only, it appears that if the volatile content of the activated sludge is to be kept from exceeding 80%, the quotient of the BOD loading expressed in pounds per day per 100 pounds of volatile suspended solids under aeration divided by the solids aeration period should not exceed 6.

Early operation of the pilot plant indicated that effective BOD removals could be obtained over short periods of time at BOD loadings as high as 50 to 55 lb. per day per 100 lb. of volatile suspended solids under aeration, but did not demonstrate that such loadings could be continually maintained without encountering excessively high volatile contents and high sludge volume indices in the activated sludge. Those early studies were all made during August to October, inclusive, when mixed liquor temperatures ranged between 18° and 24° C. The pronounced effect of temperature variations upon the process did not become apparent until much later.

Pilot plant operations definitely established the fact that a 10° C. change in mixed liquor temperature effected a fourfold change in reaction rates when treating the 50-50 mixture of Hammermill waste and municipal sewage. This fact is firmly established and is perhaps the most significant conclusion thus far drawn from pilot plant operation. It has a tremendous bearing on the oxygen requirements of the process, upon the build-up of excess biological floc and upon the degree of BOD reduction that can be reasonably expected from the process.

The rate of endogenous respiration varies directly with the "K" value and thus, high oxygen requirements and only a minimum of floc build-up will be encountered at high temperatures, while the reverse is true at low temperatures.

BOD removal by the activated sludge process is a function of the reaction rate ("K"), the length of the mixed liquor aeration period, and the concentration of volatile solids in the mixed liquor. Therefore, low temperatures and resulting low "K" values can, within limits, be compensated for by increasing mixed liquor solids and aeration times. This means that conventional operation, i.e. straight mixed liquor aeration without the use of sludge reaeration, is the process best suited to cold weather operation and judging from pilot plant performance, the only one that can effect reasonable BOD reductions. Even then, BOD loadings per 100 lb. of volatile suspended solids must be quite low. However, drastic reductions in both the mixed liquor solids concentrations and aeration periods are an absolute necessity at higher temperatures if extremely high oxygen requirements are to be avoided.

Therefore, much shorter mixed liquor aeration periods and much lower mixed liquor solids concentrations are essential during warm weather to keep oxygen requirements within bounds. Hence, BOD loadings per pound of volatile suspended solids must increase. At first it might appear that this could be accomplished by simply taking mixed liquor aeration tanks out of service, but if this were all that was done, the BOD to volatile solids loading would soon become so high, and the solids aeration period so short, that their ratio would materially exceed the limiting value of 6, causing the volatile content of the sludge and its sludge volume index to increase so rapidly that the process would become uncontrollable. For this reason, sludge reaeration must be an essential feature of the plant during warm weather operation. In cold weather, when higher concentration of solids in the return sludge are permissible, and when longer mixed liquor aeration periods are required, it is recommended that the practice of sludge reaeration be discontinued and that all aeration tanks be used for mixed liquor aeration.

The fact that short-circuiting occurred in some spiral flow tanks has been known for decades, but the recent work of the FWPCA group working out of the Robert S. Kerr Water Research Center, has shed a new light on the seriousness of that problem. By the use of radioactive tracers, they measured the actual times of flow through the aeration tanks at several different plants and found that actual detention time ranged from 16% to 89% of the theoretical detention time, with a higher length to width ratio apparently improving the actual detention time.

At present Erie has five aeration tanks, each of which is a two-pass tank with a length to width ratio of 12. It seems probable that their actual detention period is less than 80% of their theoretical displacement period. If so, it would appear that unless the present tanks are modified, aeration periods contemplated in the design of the joint plant should be increased over those recommended from pilot plant studies by about 25%.

It is not practical to convert the existing Erie aeration tanks to completely mixed tanks. However, an approach to such a conversion and the elimination of short-circuiting, might be accomplished by: (1) converting the five two-pass tanks to ten single-pass tanks, and (2) replacing the existing method of aeration with turbine type dispersers, equally spaced along the length of the tanks. Turbine type gas dispersers have a much higher oxidation efficiency than do porous diffuser tubes. An arrangement such as suggested above would make it possible to supply more oxygen to a given tank and hence increase the BOD loading on that tank over what it could be if porous diffuser tubes were used for aeration. It would also reduce air requirements and the number or size of the blowers required. In calculating aeration tank capacity for the joint treatment of Hammermill wastes and Erie sewage, it was assumed that any additional aeration tanks required would be of similar design and capacity.

Preliminary aeration tank design calculations were made for the 20° C. temperatures expected in summer months and for the cold weather operation at a 10° C. temperature. In the calculations, return sludge flows of 50, 75, 100 and 150 per cent of the average daily waste flow were used. The calculations for a 100% return sludge flow will be used to illustrate the calculations made for 20° C. temperatures.

The five-day BOD of the mixture of Hammermill wastes and sewage at 1985 volumes will be 280 mg/l. With a 25% BOD reduction in primary treatment the primary effluent would have a 210 mg/l five-day BOD. The BOD of the final effluent would be 28 mg/l for a plant removing 90% of the incoming five-day BOD. The influent to the aeration tanks will be a mixture of primary effluent and returned sludge. With a sludge return of 100% the BOD of the mixture would be $\frac{210 + 28}{2} = 119$ mg/l. The BOD remaining in the final effluent as a per cent of incoming BOD would be $\frac{28 \times 100}{119} = 23.5\%$ with a 100% sludge return.

Work reported earlier showed that a K of 0.73×10^{-3} is expected for sludge reaeration at 20° C. Going to figure 9 a Sat $\times 10^{-3}$ of 4.4×10^{-3} is the value for 23.5% remaining BOD. Using trial calculations, a mixed liquor tank volume can be selected which will fit into a logical plant design. For the proposed Erie joint plant, a total mixed liquor aeration volume equal to 23.6% of the daily waste flow was selected for 100% sludge return. This volume would give a mixed liquor aeration time of $\frac{0.236 \times 24}{1+1} = 2.83$ hrs. and the mixed liquor volatile solids (Sa) would be $\frac{4.4 \times 10^{-3}}{2.83} = 1,560$ mg/l. The volatile suspended solids content of the return sludge would be 3,120 mg/l. With a volatile content of 80% the total solids would be $\frac{3,120}{.8} = 3,900$ mg/l - approximating the 4,000 mg/l maximum solids concentration deemed permissible in return sludge during warm weather.

Solids reaeration should be used in summer months. Through trial calculations a total sludge reaeration volume was selected which gave a ratio of less than 6 when the total BOD loading per 100 pounds of solids was developed by the total solids aeration time. A sludge reaeration volume amounting to 10.3% of the total daily waste flow was selected. This gave a sludge reaeration time of $1 \times .103 \times 24 = 2.49$ hrs. making a total solids aeration time of 5.32 hrs. The total volatile solids in the activated sludge system would be $(1.560 \times .236) + (3.120 \times .103) = 690$ mg. for each liter/day of primary effluent with a five-day BOD of 210 mg/l. The BOD loading per 100 units of volatile solids divided by the solids aeration time gives $\frac{210 \times 100}{690 \times 5.32} = 5.72$ which is below the 6 set as an upper limit.

Similar calculations for 50, 75, 100 and 150 per cent sludge return showed that the total aeration volume was approximately the same for sludge returns of 75 and 100 per cent. Lower or higher sludge returns would require a larger aeration tank volume and it was recommended that a total aeration tank volume equal to 34% of the expected average daily mixed waste flow be used. With this volume the BOD loading per 1,000 cubic feet of aeration capacity would be approximately 39 pounds per day. The piping should be arranged so all tanks could be used for mixed liquor aeration and at least 1/3 could be used for sludge reaeration.

Calculations were made for cold weather operation (10° C.) using all aeration tanks for mixed liquor aeration. It was assumed that the return sludge would contain the maximum permissible concentration of suspended solids of 6,500 mg/l or 1.3 times the sludge density of a mixed liquor having a sludge volume index of 200. This time using a 75% sludge return to illustrate the calculations, the mixed liquor total solids would be $\frac{0.75 \times 6,500}{1 + .75} = 2,790$ mg/l and if 80% volatile the volatile solids would be 2,230 mg/l. With a mixed liquor aeration volume available of 34% of waste flow, (established by summer calculations) the mixed liquor aeration time would be $\frac{0.34 \times 24}{1.75} = 4.66$ hours. The Sat $\times 10^{-3} = 2.23 \times 4.66 \times 10^{-3} = 10.4$ and then using a K of 0.114×10^{-3} (conventional operation) and reading from the curve in figure 6 the BOD remaining in the effluent would be 46%. Then to establish the final effluent BOD the equation $\frac{1.75 \text{ EFFBOD}}{210 + .75 \text{ EFFBOD}} = .46$ or 68 mg/l. The per cent BOD overall reduction is $\frac{280 - 68 \times 100}{280} = 76\%$. The reduction with the same volume and 100% sludge return is 78%. The volatile solids under aeration would be $2.230 \times 34 = 760$ mg. per liter for 75% sludge return. The BOD loading per 100 units of volatile solids divided by the aeration time is $\frac{210 \times 100}{760 \times 4.66} = 5.93$ which is just under 6. It is also under 6 for 100% sludge return indicating that sludge reaeration is not needed during the winter months. Average daily oxygen requirements can be calculated by formula (6) and the probable build-up of excess biological floc by use of formula (7)

	Sludge Return	
	75%	100%
Average oxygen requirements - pounds/million gallons mixed waste		
20° C.	1,750	1,910
10° C.	920	1,020
Excess biological floc-pounds/ million gallons mixed waste		
20° C.	370	300
10° C.	510	540

The most economical design for 20° C. operation is an aeration tank volume equal to 34% of the daily mixed waste flow and with return sludge rates of 75% to 100%. It is felt that sludge return facilities should be designed to permit peak rates of return of 125% and preferably 150% of daily waste flow. At least 1/3 of the tanks should be piped so they can be used for mixed liquor aeration or sludge reaeration.

During extreme cold weather, the overall BOD reduction may be only 78% even when the rate of sludge return is 100% of the waste flow. Even during extreme cold weather it may be possible to maintain a "K" value considerably higher than the 0.114×10^{-3} used in the calculations. It may be entirely possible to maintain a "K" value of 0.183×10^{-3}, or even higher. With such a value, overall BOD reductions in the order of 85% could be obtained.

Mixed liquor temperatures may at times be as high as 23° to 25° C. and under such conditions, oxygen requirements will materially exceed those prevailing at 20° C.

By the use of formulae (6) and (7), it was calculated that under such conditions the oxygen needs of the process would average 2,810 lb/million gallons of mixed waste and the build-up of excess biological floc would be only 149 lb/day/million gallons of mixed waste.

Bulking may become serious if the inventory of volatile solids is reduced unless the hot spell were of short duration and filamentous growths were completely absent. Therefore, the sizing of turbines and blowers should be based on an oxygen need of 2,810 lb. per day per million gallons of waste flow.

During the period the pilot plant was in operation, the reduction in phosphate by the activated sludge and the phosphate content of the final effluent varied from day to day over wide limits. Average percentage reductions in phosphate for various periods of operation ranged from 30 to 43 per cent. During the same periods the phosphate concentration in the final effluent ranged from 3 to 7 mg/l. There seems to be some correlation between the concentration of phosphates in the final effluent and the amount of phosphate in the applied waste when that amount is expressed as a percentage of the applied BOD. If such is the case, then it is obvious that the addition of supplementary phosphates should be avoided except under emergency conditions.

Although occasional phosphate removals in the general order of 80% were observed, it is questionable if the activated sludge process can be depended upon to consistently effect such removals and still maintain satisfactory performance as regards BOD reduction, sludge volume indices and suspended solids removal. Our recommendation would be that the activated sludge process be designed and operated in such a manner as to effect good overall BOD and solids performance and that supplemental treatment be provided, if additional phosphate removal is required.

Final Settling Tanks

In general the removal of suspended solids by the pilot plant activated sludge process has been somewhat disappointing and much inferior to its removal of BOD. This phenomenon is not peculiar to the pilot plant or the mixture of Erie sewage and Hammermill waste. Other plants utilizing the activated sludge process to treat various types of paper mill wastes have experienced similar difficulties in the removal of suspended solids. A careful review of pilot plant performance has indicated no correlation between the sludge volume index of the mixed liquor and the suspended solids content of the final effluent.

Full-scale sedimentation is one of the most difficult processes to simulate in pilot plant operation, since of necessity, the ratio of area to depth of pilot plant sedimentation units must be very materially less than that of conventional full-scale settling tanks. If a joint treatment plant were constructed and properly operated it should produce a final effluent of lower suspended solids content than was produced in the pilot plant. It is probable that even a full-scale plant could not consistently produce a final effluent averaging less than 40 mg/l of suspended solids. The detention period in the final settling tanks should be approximately 1.9 hours based on mixed liquor flow, or 3.8 hours based on waste flow. The settling rate, based on the flow of mixed liquor, would be 1,140 gallons per square foot per day. Overflow rates based on raw waste flow, would be only about 7,300 gallons per day per linear foot of effluent weir.

The aforestated design criteria are ultraconservative. However, they are warranted in view of the apparent difficulty of obtaining effective suspended solids reduction and the likelihood that mixed liquor sludge volume indices in the order of 200 may be encountered much of the time.

Suction type sludge collection equipment should be used in all of the final settling tanks and it must be of special design in order to permit operation at the high rates of sludge return recommended. In addition, studies should be conducted to determine if the clarifiers should contain a flocculator type center well to enhance solids settling.

Sludge Thickening

Thickening is generally accomplished in continuous flow units which operate at low surface and high solids loadings. In municipal practice it has been found that the thickening of mixtures of primary and excess activated sludge can best be accomplished when the mixed sludges are fed to the thickener at a low solids concentration and a nominal liquid retention time of some 2.5 hours. Solids are generally stored in the bottom of such thickeners for at least one and preferably two days and when this is done, the underflow generally contains from 4 to 8 per cent solids.

It was not possible to simulate a continuous flow gravity thickener in pilot plant operations of the size installed by Hammermill at the Erie Treatment Plant, because of the impossibility of simulating area to depth ratios that prevail in conventional gravity thickeners. Therefore, continuous flow tests of gravity thickening were not conducted at the pilot plant. Numerous batch settling tests indicated that when the mixed primary and excess activated sludge from the pilot plant was subjected to 2 to 2.5 hour sedimentation periods and solids retention on the order of one day, the resulting sludge contained 2 to 2.5 per cent total solids. By increasing the settling period to 3 hours or more and sludge holding periods to over one day, concentrations in the order of 3% total solids were obtained. Overflow rates of 600 gallons per square foot per day and sludge holding periods in excess of a day are indicated for gravity thickeners.

Unlike gravity thickening, air flotation may be conveniently and reliably studied on a pilot plant scale. Such studies were conducted on a 1 square foot pilot flotation unit. The results indicated that air flotation could be depended upon to produce a sludge containing approximately 3% solids when handling either excess activated sludge alone, or a mixture of primary and excess activated sludge together. To accomplish such results with activated sludge alone, the loading on the unit should not exceed 24 lb. of solids, or 1,000 gallons per day per square foot. If a combination of primary and waste activated sludge was to be concentrated, the corresponding loadings could be 48 lb. of solids, or 600 gallons per square foot per day.

At many plants where air flotation has been used, the use of polymeric flocculants has proved beneficial. However, such was not the case with the pilot plant sludges. Nevertheless, if air flotation is to be used, it would be prudent to incorporate facilities for feeding such aids as a part of the installation.

The cost of operating and maintaining air flotation units is considerably higher than that of operating and maintaining gravity thickeners. In this instance, air flotation has specific advantages over gravity thickening, which stems from the fact that the solids are retained in the air flotation unit for a much shorter time than they are in the gravity thickening unit, and there is believed to be sufficient oxygen in the vicinity of the sludge to prevent anaerobic conditions which are conducive to the release of phosphates. Therefore, little or no phosphates are released, there is far less chance of objectionable odors being released, and the returned liquid is highly aerated.

These advantages may be offset by the higher power requirements. At Erie a rigorous analysis might indicate that a combination of flotation and gravity thickening would be the preferable process.

Sludge Digestion

After concentration, the sludge in municipal plants is frequently subjected to anaerobic digestion and then dewatered for ultimate disposal. However, at several of the larger plants, anaerobic digestion is omitted. The concentrated sludge is dewatered and then disposed of by incineration.

Our studies indicate that even after concentration, the sludge from the joint treatment of sewage and Hammermill waste will contain only 2-1/2 to 3 per cent solids, which means that even if there were no increase in the total amount of solids to be disposed of, the volume of sludge to be digested would be twice that now handled.

The sludge digestion studies conducted in the Hammermill Laboratory indicate that the mixed sludge from the joint treatment of Hammermill wastes with municipal sewage is amenable to anaerobic digestion, but that to be effective, the digester should provide about a 40-day retention period and should not be loaded in excess of 0.1 lb. of volatile solids per day per cubic foot. From this it was calculated that approximately one million cubic feet of digestion capacity would be required as a minimum, i.e. some four times the volume of the existing sludge digestion tanks. Furthermore, those studies revealed that even at such loadings, considerable lime would be required to maintain suitable alkaline conditions in the digestion tanks and the resulting gas would be somewhat lower in methane and B.t.u. content than the gas resulting from the digestion of typical municipal sewage. For these reasons, we conclude that anaerobic digestion will not be practical or desirable at a joint treatment plant.

Sludge Dewatering Prior to Thermal Decomposition

It is recommended that after concentration by air flotation, the mixed primary and excess activated sludge solids be dewatered and then disposed of by incineration.

Pilot studies were conducted by using both a centrifuge and a vacuum filter as a means of sludge dewatering. Those studies indicated that with either type of equipment, a cake containing approximately 20% solids could be produced. The pilot studies showed that vacuum fillers should have a yield of 3.5 lb/sq ft/hr with 20% TS in the cake when operating on a mixed sludge with 3% TS and using a 1% polymeric flocculant dosage. The optimum rate for the Sharples p-660 centrifuge used in the studies appeared to be 2 gpm feed containing 3% TS and a polymeric flocculant dosage of 2% to obtain a cake with 20% TS. The capture of solids by vacuum filtration was far superior to that obtained with the centrifuges and the dosage of polyelectrolyte required by vacuum filtration appeared to be less than that required for reasonably successful operation of the centrifuges.

The studies seemed to indicate that with careful control of solids feed and polyelectrolyte usage, it should be possible to obtain a vacuum filter cake containing as much as 25% instead of 20% solids, but there appeared little likelihood that a cake containing more than 20% solids could be obtained from the centrifuges. The cost of incinerating a 25% solid cake would be materially less than the cost of incinerating a 20% solid cake. For these reasons, we recommend that a vacuum filtration be adopted as the means of dewatering sludge ahead of incineration.

Thermal Decomposition of Sludge

No pilot studies of incineration were possible. However, approximate and ultimate analyses of the sludge are contained in the main body of the report and are believed to provide sufficient information for sizing incineration equipment. The foregoing recommendation that sludge be concentrated by vacuum filtration prior to incineration is predicated on the assumption that incineration would be accomplished in multiple hearth furnaces, or fluidized bed furnaces.

Annual cost of operating the incinerator would be dependent upon the demands of regulatory agencies. For example, if a gas outlet temperature of 900° F. is acceptable for the control of odors (our experience and that of others indicate that it is reasonable), then the sludge would be auto-combustible and no auxiliary fuel will be required during burning. At Erie an allowance of say $10,000 per year for the gas required for warm-up, etc., should be more than adequate. If, for example, the incinerators must operate with a gas outlet temperature of 1400° F., then the annual cost of auxiliary fuel would approach $300,000. If the high temperature is required, then there would be an incentive to investigating means of removing additional moisture from the cake by the use of some type of screw press, or similar equipment. Very limited studies indicate that additional dewatering by this method may be feasible. The benefits to be derived by an increase in total solids of the filter cake from 20% to 25% are quite great in view of the fact that a 40% reduction in fuel cost would result.

XII

COSTS

Preliminary order of magnitude construction cost estimates were prepared by two consulting firms for the additions to the Erie City Waste Treatment Plant to obtain capacity to handle 53 mgd of municipal sewage and 27.5 mgd of pulping and papermaking wastes. One estimate was made of the construction costs of facilities to handle 53 mgd of sewage and no Hammermill wastes. The estimates were based on an Engineering News Record construction cost index of 1300 and are before any possible federal participation. As was to be expected with this type of rough estimate, there was a substantial spread, \$18,000,000-\$24,000,000, for total project cost. The allocation of the cost attributable to Hammermill introduces additional complications since there is no one correct method. The use of incremental costs is one method. The costs could also be allocated in relation to flow, BOD and suspended solids of the respective wastes. Using \$21,000,000 for a total project cost the allocation of \$16,000,000 to Hammermill is a reasonable figure for illustrative purposes, although not necessarily the figure which would be arrived at through negotiations.

Distributing the \$16,000,000 used as the Hammermill allocation on a flow basis - considerations of BOD and suspended solids eliminated for simplicity - indicates that construction costs would be approximately \$37,000 per ton of daily pulp production and \$4,600 per ton of daily packed paper productions.

The total annual operating costs were estimated, incorporating the use of the NH_3-Cl_2 mixture for disinfection, at \$1,200,000 at a flow of 67.5 mgd in 1971. This gives a cost of \$.049 per thousand gallons for the mixed wastes. Allocation of operating costs is as difficult as the allocation of construction costs. There is no one right answer and the problem would have to be solved by negotiations. Using \$600,000 a year for processing 27.5 mgd of Hammermill wastes, the cost would be about \$.06 per thousand gallons. The \$600,000 a year cost would give a cost of \$4.00 per ton of pulp produced plus \$0.45 per ton of packed paper.

Before embarking on the construction of a joint treatment plant a more definitive total construction cost estimate would have to be prepared. A method of allocating construction costs and operating costs would have to be established.

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Mr. Walter Lyon, Chief of the Division of Sanitary Engineering of the Pennsylvania Department of Health, suggested an investigation of joint treatment of Erie City Municipal and Hammermill Erie Division wastes.

Mr. W. Zabban, Mr. A. F. Lisanti and Mr. T. R. Haseltine of The Chester Engineers, Pittsburgh, Pennsylvania, who with their associates, directed the design of the pilot plant and guided the operation of the plant. Mr. Haseltine (now retired) did many of the calculations, evaluated the collected data, and wrote a major share of an initial report which was the basis for this report.

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REFERENCES

1. Eckenfelder, W. W. and Weston, R. F., "Kinetics of Biological Oxidation," Chapter 1-2, Biological Treatment of Sewage and Industrial Wastes, Reinhold Publishing Company, 1956.

2. Brown, R. W. and Spalding, C. W., "Deep Well Disposal of Spent Hardwood Pulping Liquors," Journal of Water Pollution Control Federation, Volume 38, No. 12, 1916-1924. (December 1966).

3. Cohway, R. A. and Kumke, G. W., "Field Techniques for Evaluating Aerators," Journal of the Sanitary Engineering Division of the American Society of Civil Engineers, 92 (SA2 No 4257), 21-42 (April 1966).

4. Laws, R. L. and Burns, D. B., "Recent Developments in the Application of the Activated Sludge Process for the Treatment of Pulp and Paper Mill Wastes," Technical Bulletin No. 138, National Council for Stream Improvement (March 20, 1961).

5. Weston, R. F. and Rice, W. D., "Contact-Stabilization Activated Sludge Treatment for Pulp and Paper Mill Waste," TAPPI, Volume 45, No. 3, 223-237 (March 1962).

6. Schlenz, H. E., "Standard Practice in Separate Sludge Digestion," Proceedings ASCE, 63, 114 (1937).

7. "Sewage Treatment Plant Design," FSIWA, Manual of Practice No. 8, 214 (1959).

8. Sawyer, C. N. and Schmidt, H. E., "High Rate Digestion," Journal ASCE, 42 (1955).

OTHER REFERENCES

McKinney, R. E., "Complete Mixing Activated Sludge," Water and Sewage Works, 107, 70-71 (February 1960).

Haseltine, T. R., "A Rational Approach to the Design of Activated Sludge Plants," Chapters 3-1, Biological Treatment of Sewage and Industrial Wastes, Reinhold Publishing Company, 1956.

Haseltine, T. R., "Sludge Reaeration in the Activated Sludge Process - A Survey," Journal WPCF, 33, 946 (September 1961).

Haseltine, T. R., "The Activated Sludge Process at Salinas, California with Particular Reference to Causes and Control of Bulking," Sewage Works Journal, 4, 461 (May 1932).

Keefer, C. E., "Relationship of Sludge Density Index to the Activated Sludge Process," Journal WPCF, 35, 1166 (September 1963).

Haseltine, T. R., "Some Recent Advances in the Design of Activated Sludge Systems," presented at meeting of California Water Pollution Control Association (April 1962).

Heukelekian, H., Orford, H. E., and Manganelli, R. M., "Factors Affecting the Quantity of Sludge Production in the Activated Sludge Process," Sewage and Industrial Wastes, 23, 945 (1951).

Eckenfelder, W. W., "Activated Sludge," Advances in Sewage Treatment Design, Sanitary Engineering Division, Metropolitan Section ASCE, Manhattan College, New York (May 1961).

Haseltine, T. R., "Activated Sludge Plant Operation," Sewage and Industrial Wastes, 24, 1533 (December 1952).

Haseltine, T. R., "Suggested Design Criteria for the Activated Sludge Process," Advances in Sewage Treatment Design, Sanitary Engineering Division, Metropolitan Section ASCE, Manhattan College, New York (May 1961).

Thomas, H. A. Jr. and McKee, J. E., "Longitudinal Mixing in Aeration Tanks," Sewage Works Journal, 16, 42 (January 1944).

Helmers, E. N., et al, "Nutritional Requirements in the Biological Stabilization of Industrial Wastes, I Experimental Method," Sewage and Industrial Wastes, 22, 1200 (September 1950).

Helmers, E. N., et al, "Nutritional Requirements in Biological Stabilization of Industrial Wastes, II Treatment with Domestic Sewage," Sewage and Industrial Wastes, 23, 884 (July 1951).

Helmers, E. N., et al, "Nutritional Requirements in Biological Stabilization of Industrial Wastes, III Treatment with Supplementary Nutrients," Sewage and Industrial Wastes, 24, 496 (April 1952).

Helmers, E. N., et al, "Nutritional Requirements in Biological Stabilization of Industrial Wastes, IV Treatment on High Rate Filters," Sewage and Industrial Wastes, 25, 596 (May 1953).

Torpey, Wilbur N., "Concentration of Combined Primary and Activated Sludges in Separate Thickening Tanks," Proc. ASCE, 80, 443 (May 1954).

Katz, W. J. and Geinopolis, A., "Sludge Thickening by Dissolved Air Flotation," Journal WPCF, 39, 946-957 (June 1967).

Baker, H. A., "Archives of Microbiology," 7, 404-420 (1936).

Langford, L. L., "Digester Volume Requirements," Water and Sewage Works (December 1960).

Nash, Norman and Chasick, A. H., "High Rate Digester Performance at Jamaica," Journal WPCF, 526-537 (May 1960).

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Chronology of Operations

A brief chronological summary is given below to show the major phases of operation in the pilot plant schedule.

June 30	Construction was completed.
July 5	An initial start-up was attempted. Some mechanical features were found to need correction, necessitating a shutdown.
July 18	A successful start-up was accomplished, running an influent of 20 gpm of City sewage. Initial seeding was obtained with activated sludge from the City treatment plant. The mode was conventional activated sludge. Return sludge was 40%.
July 26	The operation was changed to sludge reaeration with equal volumes of reaerated sludge and mixed liquor. Flow rates and total detention were unchanged.
July 31	Hammermill waste addition was begun at 1 gpm and gradually increased daily to replace sufficient City flow to achieve a 50-50 blend.
August 1	Sludge return was increased to 100%.
August 7	A 50-50 mixture of Hammermill and City waste was attained.
August 15	The second in a series of loadings to be studied was attained.
September 6	The highest loading of the series was reached. It required some time and some special measures to resume a reasonable rate of solids buildup.
September 22	The aeration solids were built up to a high level so that the operation could be maintained at one-half the former aeration volume. Both aeration tank levels were lowered by inserting float pumps. These float pumps destroyed the flocculation ability of the sludge, producing a severe solids carryover which forced the temporary abandonment of this phase of the experiment.

September 25	Operation was changed to conventional activated sludge at 3.6 hours aeration time (mixed liquor basis). A sludge bulking and flotation condition still persisted.
September 30	Addition of nitrogen nutrient was begun to compensate for the unusually high influent BOD's experienced. Some changes in aeration time and sludge return rate improved sludge settleability.
October 2	The raw flow was cut to 15 gpm to aid final clarifier performance.
October 4	Beginning of occasional addition of defoamer to combat foam on aeration tanks.
October 5	The raw flow returned to 20 gpm and heavy sludge wasting in an effort to improve high sludge volume index (SVI) problem.
October 6	Nutrient changed to aqueous ammonia to keep phosphate concentrations at level to permit removal studies.
October 12	The raw flow and return rate cut to 15 gpm to study effect detention time has on SVI.
October 15	Return sludge rate cut to 7.5 gpm.
October 20	Return sludge rate varied daily in relation to sludge density index (SDI), to keep rate of return at the minimum necessary to prevent sludge buildup in final clarifier.
October 28	Conventional activated sludge was established using 1-1/2 aeration tanks. Flow was 18 gpm with 67% sludge return. Detention time 5.6 hr.
November 3	Ammonia nutrient addition stopped.

November 10	Sludge reaeration started at same influent and sludge return rates.
November 19	Changes in influent lowered the loadings well below desired 50 lb of Biochemical Oxygen Demand (BOD) per 100 lb of volatile suspended solids (VSS); therefore, heavy wasting of solids to rectify this condition.
November 26	The primary flow was increased to 24 gpm, of which 6 gpm was bled off to acclimate "Surfpac" unit for future inclusion into the total treatment scheme.
December 1	"Surfpac" included in the system between primary and aeration tanks as a roughing filter. Aeration changed to conventional using only 1/2 tank. Influent 18 gpm with 67% return. Aeration time 1.9 hr; "Surfpac" loading some 200 lb BOD/1000 cu ft/day.
December 4	Flow to "Surfpac" and aeration lowered to 9 gpm, sludge return 100%. Excess flow after primary wasted out of system. Aeration period 3.2 hr., filter loading some 130 lb BOD/1000 cu ft/day.
December 15	"Surfpac" removed from system, returned to sludge reaeration at 18 gpm flow, 67% return using 1-1/2 tanks; 3.8 hr mixed liquor, 4.7 hr reaeration detention times.
December 22	Hammermill flow discontinued for a period of 12 days to simulate a long term plant shutdown. Plant received 9 gpm sewage with 83% sludge return (minimum pump setting). No sludge wasted. Detention times were 7.5 hr reaeration and 6.9 hr mixed liquor; loading 10 - 15 lb BOD/100 lb VSS.
January 3	Hammermill wastes returned and conditions returned to those of December 15.
January 7	Hammermill waste was discontinued for a one day period due to freezing problem at collection facilities.
January 8	System switched to conventional with 18 gpm influent and 100% return. Detention time became 4.7 hr.

January 13	Return rate reduced to 83%, changing detention time to 5.1 hr.
January 22	The pilot plant was shut down.

Activated Sludge Performance
August 8 to September 5, inclusive

	No. of Days Observed	Average of Daily Observation	Median Value	High Quatril	Low Quatril	High Decil	Low Decil
Flow, gpm							
Primary Effluent	29	20.1	20	20	20	20	20
Return Sludge	29	20.0	20	20	20	20	20
Total Suspended Solids							
Primary Effluent, mg/l	27	75	66	86	54	118	42
Final Effluent, mg/l	27	50	49	60	30	82	29
% Removed	27	18*	34	48	20	55	-81
5 Day BOD							
Primary Effluent, mg/l	23	220	219	262	189	324	163
Final Effluent, mg/l	23	38	36	46	27	55	21
% Removed	23	83*	83	86	81	89	79
COD							
Primary Effluent, mg/l	22	867	800	930	735	1272	623
Final Effluent, mg/l	22	549	540	657	430	785	414
% Removed	22	35*	35	41	28	49	22
Phosphate as PO_4							
Primary Effluent, mg/l	23	9	8	10	5	18	5
Final Effluent, mg/l	21	6	6	9	4	10	2
% Removed	21	22*	20	50	0	60	-13
Organic & Ammonia Nitrogen							
Primary Effluent, mg/l	24	7	7	8	5	9	5
Final Effluent, mg/l	24	3	4	4	2	5	1
% Removed	24	56*	57	75	50	83	20
% BOD in Primary Effluent	13	3.3*	3.3	3.9	2.7	4.5	2.5
Mixed Liquor							
Aeration Period, hr	29	2.75	2.75	2.75	2.75	2.75	2.75
Dissolved Oxygen, mg/l	29	3.4	3.4	3.6	2.9	3.9	2.6
TSS, mg/l	27	982	941	1196	818	1690	740
TSS, % Vol.	27	72	73	76	68	78	60
S.V.I.	27	101	101	111	87	174	73
Sludge Reaeration							
Aeration Period, hr	29	5.8	5.8	5.8	5.8	5.8	5.8
Dissolved Oxygen, mg/l	29	3.3	3.6	4.2	3.1	4.5	2.6
TSS, mg/l	28	2100	1923	2214	1729	3737	1571
TSS, % Vol.	28	73	73	77	71	83	61
Return Sludge							
% of Waste Flow	29	100	100	100	100	100	100
TSS, mg/l	26	2008	1967	2160	1783	3610	1437
TSS, % of MLSDI	26	20	19	24	16	31	14
Air Used							
1,000 cfd	29	9.8	9.2	10.6	8.6	12.7	7.9
cu ft/lb BOD applied	23	198	185	239	160	286	133
cu ft/lb TSS under air	27	57	54	61	49	84	43
BOD Loadings							
lb/1000 cu ft aeration vol.	23	29	28	32	24	43	21
lb/100 lb TSS under air	22	29	31	36	23	43	17
lb/100 lb VSS under air	21	43	43	48	32	64	27
Final Clarifier Loading, G/SF/D							
Waste inflow only	29	750	750	750	750	750	750
Mixed Liquor	29	1500	1500	1500	1500	1500	1500

*Percent removal in Tables IV through X are the average of all the daily averages.

Activated Sludge Performance
September 6 to September 20, inclusive

	No. of Days Observed	Average of Daily Observation	Median Value	High Quatril	Low Quatril	High Decil	Low Decil
Flow, gpm							
Primary Effluent	15	18.6	20	20	15	20	15
Return Sludge	15	19.3	20	20	20	20	17
Total Suspended Solids							
Primary Effluent, mg/l	12	63	66	79	45	84	30
Final Effluent, mg/l	14	64	63	86	35	126	27
% Removed	12	-38	5	45	-31	53	-107
5 Day BOD							
Primary Effluent, mg/l	15	271	273	300	220	397	195
Final Effluent, mg/l	15	51	54	64	39	68	21
% Removed	15	86	82	87	71	90	71
COD							
Primary Effluent, mg/l	11	1046	955	1210	874	1260	869
Final Effluent, mg/l	11	663	687	765	544	768	525
% Removed	11	36	37	44	30	46	22
Phosphates as PO_4							
Primary Effluent, mg/l	7	10	9	9	10	14	8
Final Effluent, mg/l	7	7	7	9	5	9	5
% Removed	7	39	40	44	29	44	29
Organic & Ammonia Nitrogen							
Primary Effluent, mg/l	8	7	6	8	5	9	4
Final Effluent, mg/l	7	3	3	2	3	4	2
% Removed	7	40	50	78	25	85	-21
% BOD in Primary Effluent	8	2.8	2.2	2.6	1.7	3.0	1.4
Mixed Liquor							
Aeration Period, hr	15	2.90	2.75	3.13	2.75	3.43	2.75
Dissolved Oxygen, mg/l	15	3.4	3.5	3.8	3.1	4.0	3.0
TSS, mg/l	14	978	880	1387	725	1617	706
TSS, % Vol.	13	76	80	81	71	82	71
S.V.I.	14	66	63	75	57	93	55
Sludge Reaeration							
Aeration Period, hr	15	6.0	5.8	5.8	5.8	6.8	5.8
Dissolved Oxygen, mg/l	15	3.6	3.5	4.1	3.0	4.4	2.8
TSS, mg/l	15	1760	1447	2352	1266	2921	1200
TSS, % Vol.	14	78	79	81	77	85	73
Return Sludge							
% of Waste Flow	15	105	100	100	100	133	100
TSS, mg/l	15	1826	1651	2442	1256	2937	1217
TSS, % of MLSDI	14	12	9	18	8	27	7
Air Used							
1,000 cfd	15	12.4	10.8	16.2	9.4	19.4	8.8
cu ft/lb BOD applied	15	208	216	231	181	265	156
cu ft/lb TSS under air	15	68	67	80	58	82	53
BOD Loadings							
lb/1000 cu ft aeration vol.	15	34	33	39	24	50	21
lb/100 lb TSS under air	15	35	34	47	24	52	21
lb/100 lb VSS under air	15	56	52	71	40	88	32
Final Clarifier Loadings							
G/SF/D							
Waste Inflow only	15	700	750	750	750	750	560
Mixed Liquor	15	1430	1500	1500	1320	1500	830

Activated Sludge Performance
October 1 to October 27, inclusive

	No. of Days Observed	Average of Daily Observation	Median Value	High Quatril	Low Quatril	High Decil	Low Decil
Flow, gpm							
Primary Effluent	27	16.2	15	20	15	20	15
Return Sludge	27	14.6	15	20	8.5	20	7.5
Total Suspended Solids							
Primary Effluent, mg/l	26	71	67	86	58	92	46
Final Effluent, mg/l	26	64	54	84	43	98	32
% Removed	26	9	13	42	-13	50	-48
5 Day BOD							
Primary Effluent, mg/l	25	266	260	310	230	330	210
Final Effluent, mg/l	25	43	32	50	22	93	17
% Removed	25	80	86	91	81	92	66
COD							
Primary Effluent, mg/l	19	1122	1040	1280	1020	1320	890
Final Effluent, mg/l	19	689	660	820	550	990	500
% Removed	19	39	42	45	30	49	16
Phosphates as PO_4							
Primary Effluent, mg/l	18*	7	7	8	5	10	3
Final Effluent, mg/l	18*	4	4	5	3	7	3
% Removed	18*	40	41	57	28	75	0
Organic & Ammonia Nitrogen							
Primary Effluent, mg/l	24	13	13	15	12	16	11
Final Effluent, mg/l	24	6	6	6	5	10	4
% Removed	24	57	58	64	50	71	38
% BOD in Primary Effluent	23	5.2	5.4	6.3	4.1	6.8	3.5
Mixed Liquor							
Aeration Period, hr	27	3.3	3.7	4.9	2.75	4.9	2.75
Dissolved Oxygen, mg/l	26	3.5	3.5	4.1	3.1	4.2	3.0
TSS, mg/l	26	2630	2345	2980	2250	3653	2055
TSS, % Vol.	24	84	84	85	83	86	80
S.V.I.	26	191	190	216	158	248	129
Return Sludge							
% of Waste Flow	27	89	100	100	175	118	50
TSS, mg/l	26	5046	5121	5380	4517	6215	4149
TSS, % of MLSDI	26	96	95	114	74	129	69
Air Used							
1,000 cfd	27	8.85	9.15	10.2	7.0	10.8	6.5
cu ft/lb BOD applied	25	181	176	194	147	250	120
cu ft/lb TSS under air	25	62	63	73	53	76	49
BOD Loadings							
lb/1000 cu ft aeration vol.	25	58	57	63	48	70	42
lb/100 lb TSS under air	25	36	36	41	30	57	22
lb/100 lb VSS under air	25	42	44	51	35	60	26
Final Clarifier Loadings							
B/SF/D							
Waste Inflow only	27	608	560	750	560	750	560
Mixed Liquor	27	1250	1110	1500	840	1500	840

*October 1 to 6 omitted because of phosphate additions on October 1 to 5 inclusive.

Activated Sludge Performance
October 28 to November 10, inclusive

	No. of Days Observed	Average of Daily Observation	Median Value	High Quatril	Low Quatril	High Decil	Low Decil
low, gpm							
Primary Effluent	14	17.8	18	18	18	18	16.7
Return Sludge	14	11.9	12	12	12	12	11.2
otal Suspended Solids							
Primary Effluent, mg/l	13	71	72	92	47	103	41
Final Effluent, mg/l	12	78	83	91	72	200	71
% Removed	13	-8	-18	9	-35	36	-375
Day BOD							
Primary Effluent, mg/l	12	248	245	270	230	278	210
Final Effluent, mg/l	12	57	58	71	49	131	46
% Removed	12	77	75	81	72	83	45
OD							
Primary Effluent, mg/l	10	988	975	1065	895	1128	852
Final Effluent, mg/l	10	703	665	900	645	760	630
% Removed	10	28	31	42	21	36	7
hosphates as PO_4							
Primary Effluent, mg/l	12	7	6	7	4	8	5
Final Effluent, mg/l	12	4	4	5	3	6	2
% Removed	12	31	32	40	0	83	0
rganic & Ammonia Nitrogen							
Primary Effluent, mg/l	13	10	11	12	7	13	6
Final Effluent, mg/l	13	4	5	6	4	6	3
% Removed	13	51	55	68	33	71	7
% BOD in Primary Effluent	12	4.1	4.1	4.6	3.2	6.1	2.5
ixed Liquor							
Aeration Period, hr	14	5.61	5.55	5.55	5.55	5.55	5.98
Dissolved Oxygen, mg/l	14	4.2	4.0	4.2	3.6	4.8	3.3
TSS, mg/l	13	1530	1571	1634	1403	1723	1232
TSS, % Vol.	13	81	82	82	81	83	80
S.V.I.	13	151	144	162	140	175	135
eturn Sludge							
% of Waste Flow	14	67	67	67	67	67	67
TSS, mg/l	13	3400	3430	3558	3256	3974	2782
TSS, % of MLSDI	13	51	50	54	48	58	48
ir Used							
1,000 cfd	14	8.4	8.7	10.4	6.3	10.3	5.1
cu ft/lb BOD applied	12	151	151	175	119	195	111
cu ft/lb TSS under air	12	63	66	77	49	79	40
OD Loadings							
lb/1000 cu ft aeration vol.	12	40	40	43	37	44	34
lb/100 lb TSS under air	12	42	40	45	37	53	34
lb/100 lb VSS under air	12	50	50	55	45	64	42
inal Clarifier Loading /SF/D							
Waste Flow Only	14	666	675	675	675	675	623
Mixed Liquor	14	1110	1125	1115	1110	1125	1045

Activated Sludge Performance
November 11 to November 30, inclusive

	No. of Days Observed	Average of Daily Observation	Median Value	High Quatril	Low Quatril	High Decil	Low Decil
Flow, gpm							
Primary Effluent	20	17.4	18	18	18	18	17.3
Return Sludge	20	12.0	12	12	12	12	12.0
Total Suspended Solids							
Primary Effluent, mg/l	20	59	60	70	52	86	42
Final Effluent, mg/l	19	79	77	94	63	100	54
% Removed	19	-33	-28	-4	-62	+20	-90
5 Day BOD							
Primary Effluent, mg/l	20	241	240	275	210	295	175
Final Effluent, mg/l	19	105	122	129	80	127	169
% Removed	19	56	56	64	51	66	48
COD							
Primary Effluent, mg/l	14	989	1025	1155	810	1195	735
Final Effluent, mg/l	14	718	800	895	600	995	590
% Removed	14	20	22	26	18	28	5
Phosphates as PO_4							
Primary Effluent, mg/l	20	5	5	5	5	7	3
Final Effluent, mg/l	20	3	3	4	2	5	1
% Removed	20	36	40	53	22	71	0
Organic & Ammonia Nitrogen							
Primary Effluent, mg/l	20	8	8	9	7	11	5
Final Effluent, mg/l	18	5	4	5	4	8	4
% Removed	18	34	43	50	20	56	0
% BOD in Primary Effluent	20	3.3	3.2	3.7	2.8	4.5	2.3
Mixed Liquor							
Aeration Period, hr	20	3.75	3.66	3.66	3.66	3.76	3.66
Dissolved Oxygen, mg/l	20	4.0	4.1	4.5	3.5	5.0	3.1
TSS, mg/l	20	1125	1098	1283	968	1350	916
TSS, % Vol.	20	83	82	84	81	88	80
S.V.I.	20	153	141	170	138	177	134
Sludge Reaeration							
Aeration Period, hr	20	5.1	5.1	5.1	5.1	5.1	5.1
Dissolved Oxygen, mg/l	20	4.4	4.4	5.3	3.4	6.3	3.0
TSS, mg/l	20	2483	2531	2688	2163	2957	2095
TSS, % Vol.	20	82	82	84	81	85	81
Return Sludge							
% of Waste Flow	20	67.5	67	67	67	69.5	67
TSS, mg/l	20	2398	2435	2562	2125	2345	1931
TSS, % of MLSDI	20	32	36	41	31	45	29
Air Used							
1,000 cfd	20	3.4	3.1	3.8	2.2	5.1	2.2
cu ft/lb BOD applied	20	67	59	73	47	116	39
cu ft/lb TSS under air	20	24	22	29	19	36	15
BOD Loadings							
lb/1000cu ft aeration vol.	20	43	44	50	37	53	31
lb/100 lb TSS under air	20	39	43	48	28	53	24
lb/100 lb VSS under air	20	47	51	57	31	63	29
Final Clarifier Loading G/SF/D							
Waste Flow Only	20	654	675	675	675	675	650
Mixed Liquor	20	1118	1125	1125	1125	1125	1100

Activated Sludge Performance
December 1 to December 14, inclusive

	No. of Days Observed	Average of Daily Observation	Median Value	High Quatril	Low Quatril	High Decil	Low Decil
Flow, gpm							
Surfpac Effluent	14	13.0	9	18	9	18	9
Return Sludge	14	9.8	9	11	9	12	9
Total Suspended Solids							
Surfpac Effluent, mg/l	14	71	78	84	62	95	54
Final Effluent, mg/l	14	47	47	54	34	79	20
% Removed	14	35	36	54	19	57	2
5 Day BOD							
Surfpac Effluent, mg/l	13	180	190	200	155	245	110
Final Effluent, mg/l	14	72	70	80	61	99	49
% Removed	13	58	61	66	50	73	38
COD							
Surfpac Effluent, mg/l	10	949	940	1070	770	1290	610
Final Effluent, mg/l	10	649	710	825	430	1020	545
% Removed	10	21	20	28	16	29	11
Phosphates as PO_4							
Surfpac Effluent, mg/l	1	3	3	-	-	-	-
Final Effluent, mg/l	14	3	3	4	2	6	1
% Removed	1	67	67	-	-	-	-
Organic & Ammonia Nitrogen							
Surfpac Effluent, mg/l	1	7	7	-	-	-	-
Final Effluent, mg/l		4	4	4	3	4	2
% Removed	1	57	57	-	-	-	-
Mixed Liquor							
Aeration Period, hr	14	2.50	3.07	3.07	1.94	3.07	1.84
Dissolved Oxygen, mg/l	14	4.0	3.9	4.4	3.6	5.3	2.9
TSS, mg/l	14	2298	2208	2679	2097	3220	1430
TSS, % Vol.	14	85	85	86	84	89	83
S.V.I.	14	316	308	379	261	412	218
Return Sludge							
% of Waste Flow	14	75	100	100	67	100	61
TSS, mg/l	14	4583	4635	5450	3887	6030	2884
TSS, % of MLSDI	14	143	155	171	120	182	73
Air Used							
1,000 cfd	14	2.6	2.4	3.3	2.1	3.9	1.5
cu ft/lb BOD applied	13	102	104	114	75	182	54
cu ft/lb TSS under air	14	43	40	45	34	77	27
BOD Loadings							
lb/1000 cu ft aeration vol.	13	65	54	78	52	97	45
lb/100 lb TSS under air	13	45	37	58	33	81	25
lb/100 lb VSS under air	13	52	44	69	37	96	29
Final Clarifier Loading G/SF/D							
Waste Flow Only	14	487	386	675	386	675	386
Mixed Liquor	14	830	675	1065	675	1125	675

Activated Sludge Performance
January 8 to January 21, inclusive

	No. of Days Observed	Average of Daily Observation	Median Value	High Quatril	Low Quatril	High Decil	Low Decil
Flow, gpm							
Primary Effluent	14	17.9	18	18	18	18	18
Return Sludge	14	15.7	15	17.5	15	18	13.9
Total Suspended Solids							
Primary Effluent, mg/l	13	56	54	62	48	72	42
Final Effluent, mg/l	13	57	32	76	26	104	22
% Removed	13	-5	42	47	-11	63	-231
5 Day BOD							
Primary Effluent, mg/l	13	201	190	230	180	245	165
Final Effluent, mg/l	13	57	49	63	40	95	40
% Removed	13	71	76	78	68	81	47
COD							
Primary Effluent, mg/l	13	795	770	860	735	945	625
Final Effluent, mg/l	13	542	550	590	480	660	440
% Removed	13	31	33	36	26	46	16
Phosphates as PO_4							
Primary Effluent, mg/l	12	6	5	7	5	7	4
Final Effluent, mg/l	12	5	4	7	3	7	2
% Removed	12	18	0	40	0	60	0
Organic & Ammonia Nitrogen							
Primary Effluent, mg/l	13	10.5	11	11	10	12	10
Final Effluent, mg/l	13	5	3	6	3	10	3
% Removed	13	55	67	71	46	73	-1
% BOD in Primary Effluent	13	5.3	5.3	5.8	4.7	6.5	4.1
Mixed Liquor							
Aeration Period, hr	14	5.0	5.1	5.1	4.7	5.3	4.7
Dissolved Oxygen, mg/l	14	4.1	3.6	4.4	3.2	5.6	2.7
TSS, mg/l	12	2206	2198	2292	2146	2425	2040
TSS, % Vol.	12	81	81	81	80	82	77
S.V.I.	12	224	214	241	201	280	191
Return Sludge							
% of Waste Flow	14	87	83	97	83	100	82
TSS, mg/l	13	4130	4097	4289	3831	5015	3579
TSS, % of MLSDI	12	94	94	109	82	113	72
Air Used							
1,000 cfd	13	3.9	3.6	4.0	2.4	8.5	1.7
cu ft/lb BOD applied	12	96	72	100	62	217	49
cu ft/lb TSS under air	11	21	19	22	15	41	10
BOD Loadings							
lb/1000 cu ft aeration vol.	13	32	30	37	29	39	26
lb/100 lb TSS under air	12	23	22	26	21	30	18
lb/100 lb VSS under air	12	29	27	32	26	41	22
Final Clarifier Loading G/SF/D							
Waste Flow Only	14	668	675	675	675	675	675
Mixed Liquor	14	1265	1240	1335	1240	1355	1205

"Surfpac" Data

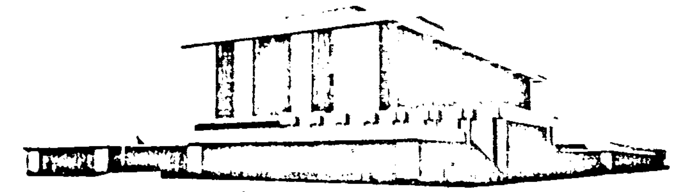
Date	Flow GPM	pH Inf.	pH Eff.	COD Inf.	COD Eff.	COD Reduction %	BOD Inf.	BOD Eff.	BOD Reduction %	S.S. Inf.	S.S. Eff.	V.S.S. Inf.	V.S.S. Eff.	Temp. Inf.	Temp. Eff.	PO_4 Inf.	PO_4 Eff.	Total Nitrogen Inf.	Total Nitrogen Eff.
12/1	18	7.5	7.9	-	-	-	180	120	33	72	84	44	53	-	-	-	-	-	-
12/2	18	7.4	7.7	-	-	-	200	170	15	38	54	24	42	-	-	-	-	-	-
12/3	18	8.7	8.3	940	880	6	220	190	14	18	28	-	-	52	50	-	-	-	-
12/4	15	7.5	7.7	920	850	8	210	170	19	86	80	-	-	51	49	-	-	-	-
12/5	9	7.3	7.4	980	890	9	240	190	21	44	54	-	-	53	53	T=total PO_4 N=nutrient PO_4		-	-
12/6	9	7.3	7.5	1590	1510	5	310	290	7	50	66	-	-	54	54	T=4	T=3 N=3	8	7
12/7	9	7.5	7.6	1090	990	9	270	200	26	68	80	-	-	55	54	-	-	-	-
12/8	9	-	-	-	-	-	-	-	-	68	92	50	72	54	53	-	-	-	-
12/9	14	7.6	7.5	-	-	-	230	180	22	68	78	50	74	54	52	-	-	-	-
12/10	9	7.3	7.4	1100	1010	8	250	200	20	74	84	-	-	52	49	-	-	-	-
12/11	0	6.9	7.3	1210	1070	11	260	190	27	72	60	-	-	52	49	-	-	-	-
12/12	9	7.1 7.2*	7.3 7.2*	1150 1150*	1070 1030*	7 10	260 280*	200 200*	23 29	88 82*	98 76*	-	-	52	50	-	-	-	-
12/13	9	7.4 7.3*	7.5 7.3*	810 850*	690 770*	15 9	190 200	140 150	26 23	62 44*	78 54*	-	-	52	48	-	-	-	-
12/14	18	7.3 7.4*	7.3 7.5*	610 590*	530 540*	13 8	140 140	100 97	28 31	64 36*	62 42*	-	-	51	47	-	-	-	-
Average	13			1056	949	9	269	182	22	67	77	-	-	52.7	50.7	-	-	-	-

*After 2 hour settling time.

Appendix IX

Bench Scale Plant Performance on 100% Hammermill Waste

From	9-21	10-13	10-23	10-30	11-5	11-13	11-22	11-27	12-6	12-12	12-17
To	10-12	10-20	10-29	11-4	11-8	11-21	11-26	12-5	12-11	12-16	12-20
Flow											
Mixed Liquor, gal/hr	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Primary Effluent, gal/hr	0.85	0.86	0.86	0.89	0.93	0.93	0.92	0.90	0.84	0.87	0.89
Return Sludge, gal/hr	0.65	0.64	0.64	0.61	0.57	0.57	0.58	0.60	0.66	0.63	0.61
Return Sludge, %	76	75	75	69	61	61	63	67	79	72	69
Suspended Solids											
Primary Effluent, mg/l	256	325	338	276	458	221	356	370	344	256	277
Final Effluent, mg/l	64	57	138	109	65	42	47	55	51	30	24
% Removed	75	85	60	64	81	81	86	84	85	88	91
COD											
Primary Effluent, mg/l	2700	2570	2600	2495	2330	1860	2160	2320	2260	2135	1550
Final Effluent, mg/l	1750	1640	1770	1770	1565	1200	1300	1435	1395	1390	870
% Removed	35	36	32	29	33	35	40	38	38	35	44
BOD											
Primary Effluent, mg/l	550	460	515	494	420	343	482	464	425	394	318
Final Effluent, mg/l	76	59	81	118	83	40	33	42	34	31	15
% Removed	89	89	85	76	80	89	93	91	94	92	95
lb applied per 100 lb MLVSS	42	36	41	42	32	29	43	41	37	34	36
Ammonia Nitrogen added as N											
mg per liter	26	21	19	15	13	19	21	22	22	21	20
% of applied BOD	4.7	4.6	3.7	3.0	3.1	5.5	4.4	4.7	5.2	5.3	6.3
Phosphate added as PO_4											
mg per liter	177	143	129	102	88	20	16	12	9	5	3.5
% of applied BOD	32	31	25	21	21	5.8	3.3	2.6	2.1	1.3	1.1
Mixed Liquor											
Dissolved oxygen, mg/l	4.1	3.9	4.4	4.1	4.3	4.8	4.6	4.5	4.5	4.4	4.2
Total Susp. Solids, mg/l	5000	4617	4170	4322	4760	4235	3990	3910	4010	3600	2980
Total Susp. Solids, % Vol.	84	83	85	84	85	85	79	83	82	85	80
SVI	115	111	149	164	166	136	144	221	240	269	324
Return Sludge											
Total Susp. Solids, mg/l	9800	9415	6318	9918	-	-	8300	7353	-	-	-
Total Susp. Solids, % Vol.	86	85	86	84	-	-	80	82	-	-	-
BOD Loadings per 100 lb VSS											
Hr of solids aeration	8.4	7.2	8.2	8.4	6.4	5.8	8.6	8.2	7.4	6.8	7.2
Sludge Age, Days	7.4	5.6	5.1	5.1	5.2	5.1	5.0	4.8	4.1	4.2	4.4
Length of Period, Days	22	8	7	6	4	9	5	9	6	5	4



Municipal Building

CITY OF ERIE

PENNSYLVANIA

Office of Mayor Louis J. Tullio *Joseph J. Robie, Executive Assistant*

June 20, 1968

Joe G. Moore, Jr., Commissioner
Federal Water Pollution Control Administration
U.S. Department of the Interior
Washington, D. C. 20242

Dear Mr. Moore,

Re: WPRD-223-01-68

Enclosed are the completed original copies of the material forwarded with your letter of May 22, 1968. We are pleased to accept the offer of a Research and Development Grant. Our acceptance of the conditions and assurances set forth in the document is shown by the signing of the documents.

We believe that the project will contribute significantly to the joint treatment of domestic sewage and pulp and paper mill wastes and will serve as a useful demonstration.

Sincerely yours,

Louis J. Tullio
Mayor

LJT/pl

Enclosures

UNITED STATES
DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
WASHINGTON, D.C. 20242

MAY 2 2 1968

Re: WPRD 223-01-68

Dear Mr. Tullio:

We are pleased to offer you a Research and Development Grant for the project titled, "Joint Treatment of Domestic Sewage and Pulp and Paper Mill Waste," as described in your application of January 19, 1968.

The Grant Offer is $88,230 or 75% of eligible project costs, whichever is less, subject to the conditions and assurances set forth in the enclosed Section I of the Offer and Acceptance document and attachments.

Acceptance of this offer must be made by completing the enclosed material, including the Section II of the Offer and Acceptance document, and returning the original copies of the material within the next thirty (30) days.

We are hopeful that this project will contribute significantly to advancement of the Administration's Water Pollution Control Program by assisting in the development of research and demonstration projects for prevention of pollution by industry. The importance of this and other projects in serving as useful demonstrations, having wide application, cannot be overemphasized.

Should you have questions concerning this Grant Offer, please contact our Office of Research and Development.

Sincerely yours,

John T. Barnhill for

Joe G. Moore, Jr.
Commissioner

Mr. Louis J. Tullio
Mayor - City of Erie, Pa.
Municipal Building
Erie, Pennsylvania 16501

Enclosure

Department of the Interior
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
Office of Research and Development

WPRD-223-01-68
Project Number

OFFER AND ACCEPTANCE OF FEDERAL GRANT FOR RESEARCH AND DEVELOPMENT
UNDER 33 U. S. C. 466 et. seq.

SECTION I

A. Location of Project (State, County, City)
Pennsylvania, Erie, Erie

B. Legal Name and Address of Applying Authority (herein called the "Applicant")
The City of Erie
Municipal Building
Erie, Pennsylvania 16501

C. Project Financing Under Terms of this Offer

Total estimated project cost. $333,674

Estimated project cost eligible for Federal participation . $117,641

FEDERAL GRANT OFFERED. . . . . $ 88,230 or
75% of eligible project costs whichever is less.

D. Description of Project

Title of Project: "Joint Treatment of Domestic Sewage and Pulp and Paper Mill Waste."

Project Objectives: Determine the technical success of joint secondary treatment, the economic factors involved and the nutrient removal which may be obtained.

Grant Period: Six months

"The Commissioner of the Federal Water Pollution Control Administration acting in behalf of the United States of America, pursuant to Section 6 of The Federal Water Pollution Control Act, as amended, hereby offers to the Applicant named herein a grant to assist in the accomplishment of the project described herein, provided the Commissioner receives from the Applicant the assurances in the attached Rules and Regulations, a completed Section II of this form, and provided that Acceptance is made within thirty (30) days of the Offer, and subject to the following special conditions:

1. Eligible costs for this grant are limited to those of preliminary studies and reports and post construction studies and reports conducted subsequent to April 14, 1967 until completion of the project.

2. A detailed plan of operation shall be submitted within thirty (30) days for approval by the FWPCA Project Officer.

For the United States of America
Federal Water Pollution Control Administration

May 22, 1968 — (Date)

Joe G. Moore, Jr. — (Commissioner)

(Page 2)

ACCEPTANCE

SECTION II

On behalf of City of Erie
(Legal Name of Applicant)

I, the undersigned, being duly authorized to take such action, as evidenced by the attached CERTIFIED COPY OF AUTHORIZATION BY THE APPLICANT'S GOVERNING BODY, do hereby accept this Offer and make the assurances contained in the Rules and Regulations attached thereto.

June 20, 1968
(Date)

Louis J. Tullio
(Signature of Representative)

Louis J. Tullio, Mayor
(Name and Title of Representative - Type or Print)

(Page 3)

BIBLIOGRAPHIC:

The City of Erie, Pennsylvania and Hammermill Paper Company, Joint Municipal and Semichemical Pulping Waste Treatment, FWPCA Publication ORD-1

ABSTRACT:

The City of Erie, Pennsylvania and Hammermill Paper Company made a study of the joint treatment of domestic sewage and pulp and papermaking wastes. A pilot plant was constructed and operated in a series of controlled experiments. Supplemental studies were conducted in the Hammermill laboratories including the operation of a bench-scale activated sludge plant.

It was demonstrated that a joint treatment plant could effectively treat a mixture of domestic sewage and pulp and paper mill wastes from Hammermill's Erie Division. A full-scale joint treatment plant should obtain a BOD removal of approximately 90% in summer months and 80%-85% in winter months. Primary treatment

ACCESSION NO.

KEY WORDS:

Pilot Plants
Pulp Wastes
Municipal Wastes
Sewage Treatment
Activated Sludge
Sludge Disposal
Oxygenation
Disinfection
Annual Costs

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should achieve a 25% reduction in BOD and a 60% reduction in suspended solids. Treatment of mixed wastes by the activated sludge process will require a long solids aeration period and a relatively low BOD to volatile solids loading to avoid high sludge volume indicies. The activated sludge process does not reduce the color of the mixed wastes and the final effluent will have about 40 mg/1 of suspended solids. The chlorine demand of the final effluent averaged over 60 mg/1. A NH_3-Cl_2 mixture added at a level of 2.61 ppm NH_3 and 15-17 ppm Cl_2 showed promise as a disinfectant with coliform counts generally below 1,000/100 ml.

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