BIO-PROCESSES OF THE OXIDATION DITCH WHEN SUBJECTED TO A SUB-ARCTIC CLIMATE

by

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Report NO. IWR-27 May 1972

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INTRODUCTION

Alaska's far northern area is sparsely populated primarily because of a severe climate which varies from northern temperate to Arctic. Construction and power costs are high. Skilled operating personnel are scarce and expensive, if available. Receiving streams are said to be delicate, particularily in the winter, when little possibility for reaeration exists due to a total ice cover. The oxidation ditch modification of the extended aeration activated sludge process appears to be well suited for the treatment of wastes in this environment. Past operating data on a plant of this type located in Interior Alaska (near Fairbanks) indicated it may be well suited to treat small volumes of domestic waste economically, with low sludge production, and minimal sensitivity to low temperatures.

Grube and Murphy (1969) reported data on this ditch at a time when it was hydraulically underloaded by fifty percent. The data indicated some sludge deposition in the ditch proper, although the removal of biochemical oxygen demand (BOD) was consistently greater than ninety percent. Since arctic engineering practice dictates deep ditches to minimize heat losses, the sludge deposition problem, being proportional to depth, becomes an important design parameter. To add to the deposition problem, the ditch under study was used as a dumping station by septic tank pumping services, severely adding to the solids load carried in the system.

The plant was operating at design loading when this project was performed. This, together with the much greater solids loading, made the plant well suited for study. The project was performed with the following primary objectives:

(1) to evaluate the process performance in a sub-arctic climate at design capacity;

(2) to compare treatment efficiencies under both winter and summer conditions;

(3) to evaluate the solids carried in the ditch as they are affected by (a) rotor type, (b) waste loads, (c) season, and (d) ditch configuration.

A number of ancillary studies were performed to aid in evaluating the above. Poor quality effluent occasionally was produced. The mechanism or mechanisms causing this were sought. The nature of the sludge in this system, the effect of the extreme cold ambient temperatures on it, and any changes in sludge concentration were studied. Methods for determining the allowable solids loading on the settling tank were explored. The significance of the very low Sludge Volume Index (SVI) was analyzed and discussed. Areas of excess sludge deposition were located *in situ*. A comprehensive literature review on the oxidation ditch process is presented. The possibility of avoiding excess sludge deposition by use of an alternate rotor is discussed. The suitability of this process, or modification thereof, is presented in the discussion and conclusion.

BASIC PRINCIPLES AND BACKGROUND

Pasveer developed the oxidation ditch process in an attempt to find a method to treat small volumes of sewage at minimum cost. The design is a modification of the extended aeration activated sludge process. Pasveer (1960) summarized important aspects of the process as follows:

(1) the energy required for oxygenation is greater than for conventional activated sludge plants because the sewage is not presettled, making the exerted BOD higher (this is true of any extended aeration process, not just the oxidation ditch);

(2) every class of waste able to be treated by biological oxidation can be treated in this process;

(3) the high suspended solids level renders the process quite insensitive to peak loads;

(4) due to the large volume of the aeration tank, it is less sensitive to sudden increases in toxic constituents should they be introduced;

(5) the treatment efficiency of the plant will be less susceptible to the influence of low temperature than conventional activated sludge, which is relatively insensitive.

The process differs from conventional extended aeration in its physical configuration, not the biological process effecting treatment. Detailed discussions of the biological principles will not be presented in this volume unless they have a direct bearing upon the findings. Complete reviews of the theory and practice are available in the open literature. The only factors different in the oxidation ditch are the aeration tank shape and the method of oxygen transfer and mixing.

The basic form of the aeration tank is an oval ditch, usually having a trapazoidal cross section. Materials of construction vary from earth to concrete linings. A detention time of 24 hours, in conformance with established extended aeration criteria, is normally specified.

A cage rotor is used for aerating the activated sludge. This is merely a mechanical aerator. The rotor also provides circulation and turbulence so the mixed liquor suspended solids (MLSS) do not settle and are able to pass under the rotor at frequent intervals for reaeration. Various configurations of ditches and rotor placement are presented elsewhere in this report.

Existing Practice

Kountz and Forney, as reported by Eckenfelder (1966), have shown that approximately twenty-three percent of the biological solids produced in the extended aeration process are relatively inert to further degradation and accumulate in the system. On the other hand, the active mass of organisms in the system is relatively constant, being a function of the loading rate of biodegradable material (BOD) applied. Table 1, "Reported Oxidation Ditch Loading Rates," presents some data from the literature on existing facilities. The normal loading varies from 10-14 pounds of BOD applied to the plant per day per thousand cubic feet of aeration capacity (lbs BOD/day/1000 cu. ft.). This figure is relatively standard for all extended aeration processes. All of the data shown resulted in ninety percent or greater BOD removals. Of extreme importance is the level of MLSS carried in the system. Solids loading rates are a function of this value and not necessarily a function of the aeration tank volume. The normal

TABLE 1: Reported Oxidation Ditch Loading Rates

LOCATION	DITCH LOADINGS		SOURCE
	Volumetric (1)	Solids (2)	
Netherlands	10.5	--	Pasveer (1960)
Ontario	13.0	0.052	Guillaume (1964)
Minnesota	12.2	--	Anon. (1965)
Summer	--	0.027	
Winter	--	0.042	
West Virginia	13.5	--	Burchinal & Jenkins (1969)
Ohio	12.5	--	Kaneshige (1970)

(1) lbs BOD applied per day per 1000 cu.ft. aeration capacity
(2) lbs BOD applied per day per lb MLSS under aeration

design value for these plants is approximately 0.052 pounds of BOD applied per day per pound of mixed liquid suspended solids under aeration. A disregard for the solids level, and/or designing for the distant future, can result in low BOD loadings, which in turn can cause poorly settling sludge and/or its loss in the effluent. A better means of expressing loading would be in terms of volatile suspended solids rather than total suspended solids, although even this has certain disadvantages depending upon the age of the sludge. Eckenfelder (1970) has presented equations to determine the required MLVSS in the extended aeration process. Since this is a rather standard approach in the design of such systems, further explanations will be not considered in this report.

The activated sludge floc produced in the extended aeration process generally settles rapidly. Lawrence (1963) reported on the very short times required to settle the sludge at many plants in Canada. He attributed the phenomena to the low energy level of the organisms. The food to microorganism ratio is small in the extended aeration process since the organisms are in the endogenous phase of metabolism; hence their low energy level. The quick and easy settleability of the solids is evidenced by the low Sludge Volume Index (SVI) encountered in most oxidation ditch plants reported in the literature. The settling tank should be designed by considering the sludge settling characteristics, since settling may indeed be the most important single item to be considered in the total process. Dick (1970) reported the solids sludge curve method used for design of settling tanks. Dick (1969) also discussed the value of Sludge Volume Index and stated that it is only a single point on the settling curve, and great significance should not be attached to it. American engineers have long used the SVI as a critical parameter, many plants being operated with this value in mind. In fact, most state standards specifically refer to this value in their operating procedures. Kalbskopf (1970) reported that SVI does indeed have a decisive influence on the permissable solids loading on settling tanks, but suggested a new design parameter which he calls "sludge volume loading." The sludge volume loading is obtained by multiplying the Sludge Volume Index, in cubic meters per kilogram, by the solids loading, in kilograms per square meter per hour. He suggested that values exceeding 0.300 cubic meters per square meter hour should not be used. Based upon the literature and the data accumulated on this project, it follows that in the oxidation ditch system, with its inherently low Sludge Volume Index, higher solids loading than conventional process should be considered in design. Pasveer (1960) indicated SVI values ranging from 44 to 55 for the ditch at Noordwijk. Ford (1970) reported SVIs of 80 to 200 for conventional activated sludge plants treating domestic wastes.

This information signifies that the sludges developed in the oxidation process may indeed be different than conventional activated sludge. In fact, they may even be somewhat different than sludges from other types of extended aeration modifications of the conventional activated sludge process.

Aeration and Mixing Devices

The so called cage rotors are used to aerate and circulate the activated sludge within the oxidation ditch proper. Baars (1962) stated that the required velocity of the material should be between 25 and 30 cm/sec (0.82 and 0.98 ft/sec). Pasveer (1960) demonstrated that a velocity of 30 cm/sec would not exceed the critical value needed to prevent erosion of various European soils, and that an excavated and unlined ditch could be used in nearly any soil.

Design criteria has been established for ditch volume per foot of rotor as well as the ratio of the length of rotor to the ditch width. Baars (1962) recommended 150 cubic meters of aeration tank volume per meter length of rotor (12,079 gallons per foot). Burchinal and Jenkins (1969) used a value of 16,000 gallons per foot of rotor in the design for the plant at Cameron, West Virginia. Guillaume (1964) concluded that adequate circulation could be provided with 16,000 gallons per foot in a concrete lined ditch, and 13,000 gallons per foot for an unlined ditch.

The velocity achieved in the ditch is a function of the immersion depth of the rotor and the total depth of the liquid in the ditch. For example, Kaneshige (1970) reported the average velocity at Somerset, Ohio to be 1.55 fps at 4 inches immersion, 1.65 fps at 6 inches immersion, and 1.92 fps at 9 inches immersion. The ditch was concrete lined and designed at 13,000 gallons per foot of rotor. As would be expected in any open channel, the velocities at the bottom of the ditch, and at the sides, were significantly lower than those in the top one third.

The primary purposes of maintaining the aforementioned velocity are threefold: (1) to provide intense aeration to the waste every 4 to 10 minutes, which approximates the complete mixing concept as advanced in the more recent literature by McKinney and others; (2) to provide a velocity sufficient to keep the activated sludge floc in suspension and to prevent unwanted sedimentation; and, (3) to fully homogenize the incoming waste with the contents of the ditch. In many cases the controlling factor is the rotor length necessary for propulsive power to induce circulation rather than the oxygenating capacity or the turbulence. Burchinal and Jenkins (1969) and Zeper and De Mann (1970) showed an adequate suspension of the floc can be maintained in an oxidation ditch even though the SVI is below 60 as long as the velocity is maintained between 25 and 30 cm/sec. These ditches were of trapazoidal cross-section. The ditch upon which this study was based has a rectangular cross-section.

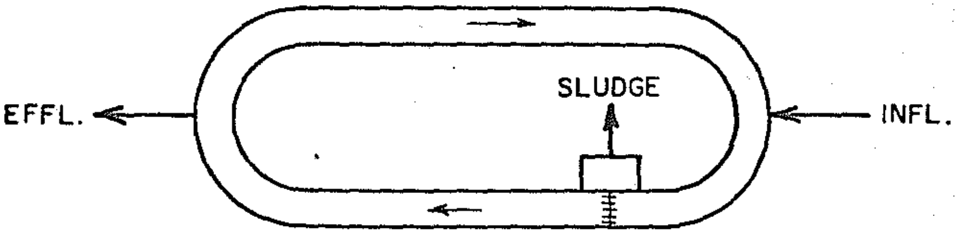
Pasveer (1960) used an oxygenation capacity to BOD load factor of 2 for designing cage rotors. Guillaume (1964) came to the same conclusion that two pounds of oxygen per pound of BOD applied must be transferred to the solution. Beck (undated) reported performance curves (done by others) at different depths of immersions for the rotors marketed by the Lakeside Equipment Corporation. This data have been adopted for design criteria in North America. Beck (undated), in the same publication, described the possible flexibility in operation by changing the immersion depths according to BOD load. Baars (1962) commented as follows on Beck's work:

> *"If the ditch capacity selected is greater than necessary for the actual load with a view to possible needs in the remote future, it might be supposed that even with the slight depth of immersion that is needed to give this low oxygen supply, the mixed liquid would circulate at the desired speed. This, however, is not the case. When conditions become too extreme the ditch has to be built for the actual load and enlarged afterwards. On the other hand, when sewage with a very high BOD has to be treated and large quantities of oxygen supplied, great depth of immersion is necessary or required. Under such circumstances the circulation velocity in the ditch may become too high, reducing the difference between the speed of the rotating aerator blades and the water. Special measures then must be taken to lessen the speed of the latter by means of perforated baffles."*

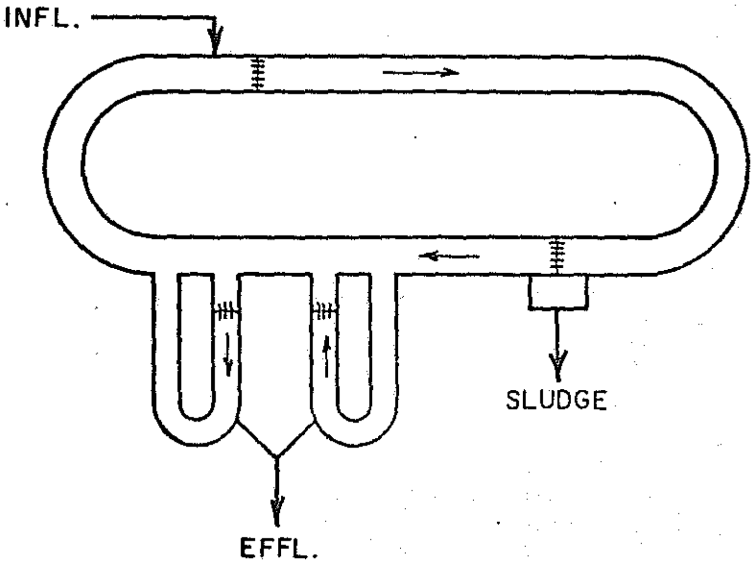
Naturally, if a significant difference in the tangential velocity of the rotor and the horizontal velocity of the water is not maintained, an adequate velocity will be created, but sufficient turbulence will not be induced to transfer the necessary oxygen. Zeper and De Mann (1970) attributed the restriction on the maximum depth of the oxidation ditch of 1.5 meters to the fact that the cage rotors have effective grip only on the surface layers. Hence, they concluded that the depth of the Pasveer ditch is limited by the conventional cage rotor. If the normal wide dividing strip is replaced by a thin wall in order to minimize heat loss, the problem becomes more severe. Ironically, in subarctic and arctic climates, both conditions are advantageous. To reduce the surface area, to conserve heat, and to reduce construction costs, deep ditches with a single dividing wall are logical in the far north. It follows that the cage rotor is not the most efficient means to satisfy these conditions. Zeper and De Mann (1970) did describe a low cost aeration device of high oxygen transfer efficiency which can generate the required flow even in deep ditches. The reported new aeration device, the so called "Carrousel," is a surface aerator which imparts centrifugal movement to the upper layers in the tank as well as a rotating movement along the vertical axis. They reported a uniform turbulent flow over the entire cross-section of the tank with this aerator. Le Compte and Mandt (1971) reported the use of jet aerators to propel and aerate the mixed liquid in very deep ditches. They reported this device to be a much better flow inducer and aerator than the cage rotor. Unfortunately, only sparse data is presently available on this latter system, although it is felt by the authors it may be a significant advance for the oxidation ditch configuration.

Ditch Configuration

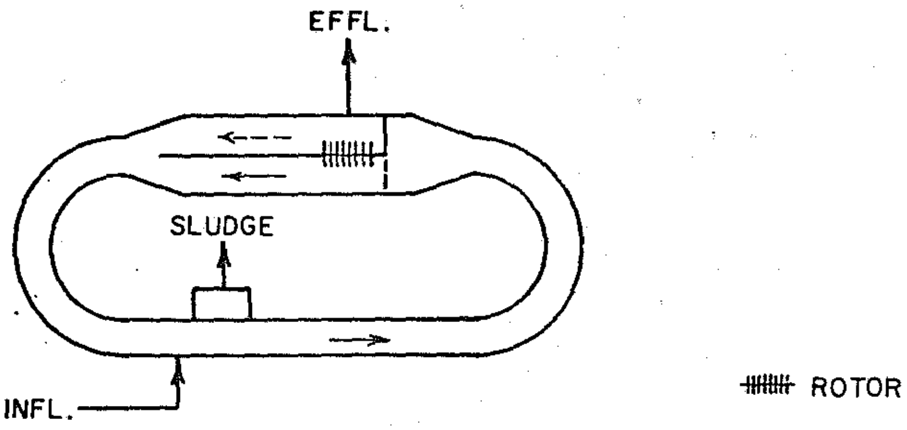
Pasveer originally envisioned the oxidation ditch as an earthen ditch with a trapazoidal section and some form of bank protection near the liquid level. The original process was a fill and draw device in which the incoming waste was allowed to enter the ditch. The rotors were turned off intermittently and the activated sludge was allowed to settle, after which the effluent was drawn off. The median strip was designed so that its radius of curvature was not so sharp as to increase the frictional resistance or retard the liquid flow. Median strips are recommended over the alternative single baffle wall since the latter can cause eddy currents which disrupt the flow pattern at the ends of the ditch. A number of configurations for the oxidation ditches have been put forth in the literature. Figures 1 and 2 are the sketches of some of these. Figure 3 shows the plan and details of the ditch studied at College, Alaska and reported on herein. A fair amount of discussion can be found in the literature concerning the ideal size and shape of oxidation ditches. However, the fundamental considerations of hydraulics and sedimentation clearly point to the fact that the configuration is limited and that good design practices must be used. The construction materials specified have varied from soil to concrete lined, as well as concrete block, ditches. The selection of material depends upon the climate where the unit will be used as well as local economics. For instance, an earthen ditch with an impermeable membrane has been used, but experience with PVC liners indicate they are not feasible for use in cold climates since the material is very susceptable to damage at low temperatures due to brittleness. Ice formation often



(a) Voorschoten Type

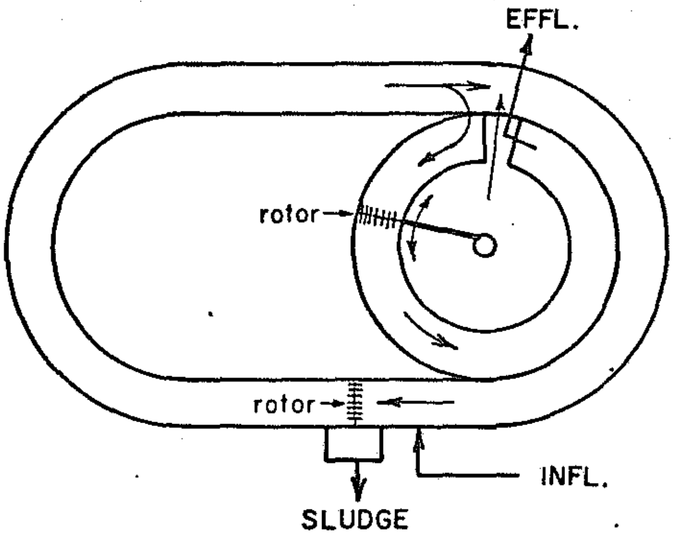


(b) Noordwijk Type

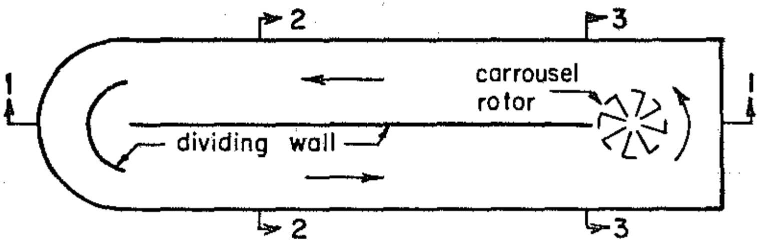


(c) Berkel Type

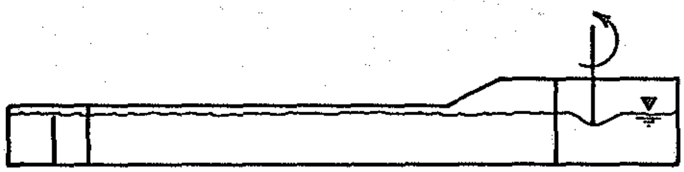
Figure 1 Some Typical Oxidation Ditch Configurations



(a) Circular Settling Tank



Plan View



Section 1-1

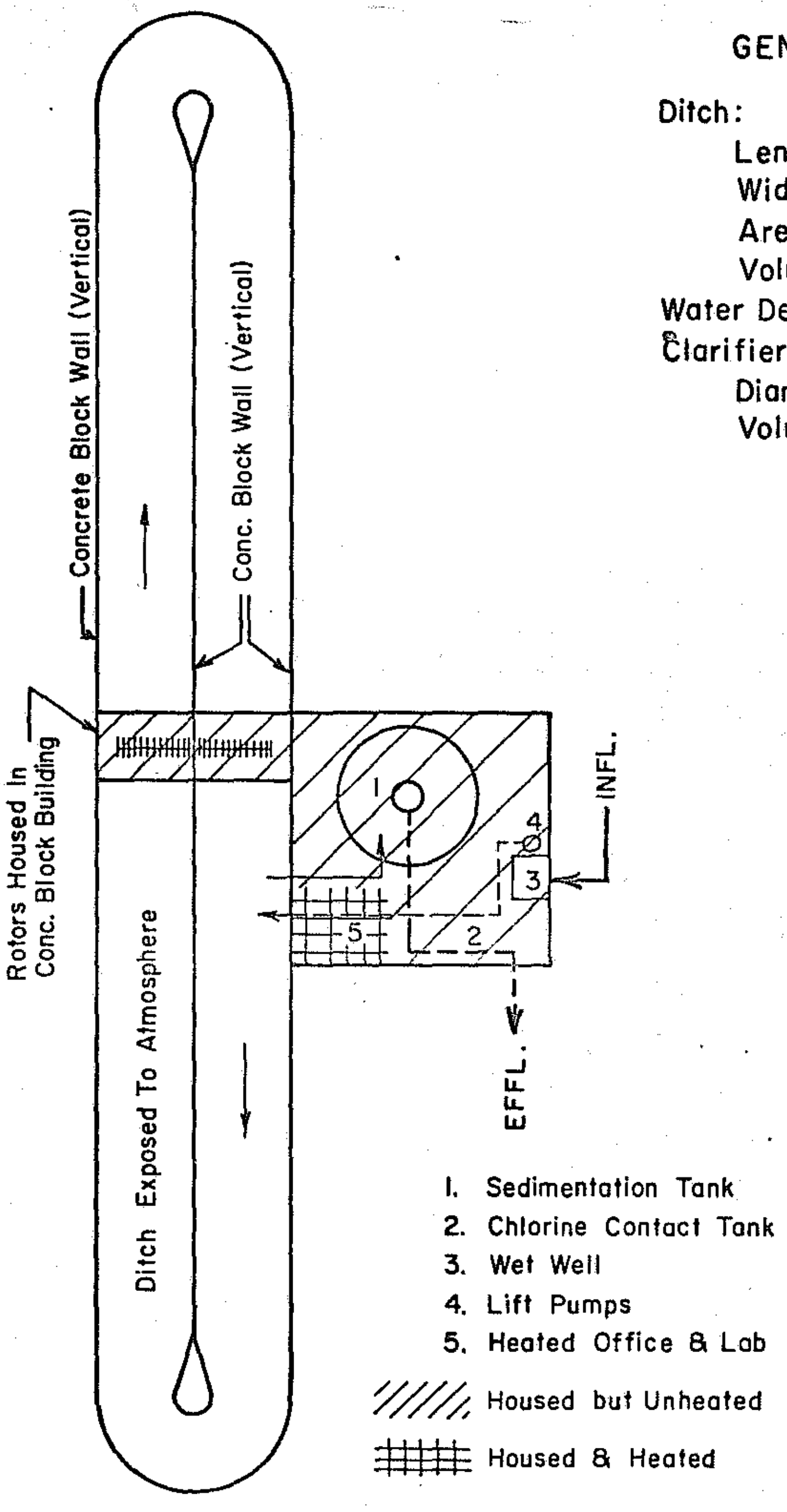
Section 2-2 *Section 3-3*

(b) "Carrousel" Configuration

Figure 2 Newer Variations of Oxidation Ditches

GENERAL DIMENSIONS

Ditch:	
Length	305.3 ft.
Width	19.75 ft.
Area	10,348 sq. ft.
Volume	333,000 gallons
Water Depth	4.33 ft.
Clarifier:	
Diameter	30 ft.
Volume	54,000 gallons



1. Sedimentation Tank
2. Chlorine Contact Tank
3. Wet Well
4. Lift Pumps
5. Heated Office & Lab

▨ Housed but Unheated

▦ Housed & Heated

Figure 3 College Utilities Corp. Oxidation Ditch Details can cause breaks in the lining. Of course, aging, and exposure to sun light, increase its susceptability to damage. Like any engineered construction, the choice of material used for the walls and subsurface will be dictated by local conditions, economics, and soils.

Ditch Capacity

The maximum size of an oxidation ditch is restricted by the large surface area required, since the liquid depth should be limited to 5 feet or less when using conventional rotors. The quantity of surplus sludge that can be handled economically is a factor that must be considered. Elaborate sludge disposal schemes could easily make the process equally or more expensive than conventional activated sludge. One must be aware that the energy requirements of the oxidation process are approximately 25 kilowatt hours per population equivalent per year as compared to the conventional activated sludge process which requires approximately 12 kilowatt hours per population equivalent per year (Zeper, 1969). If the Carrousel type aerator, which is said to enable one to design for depths of 2.5 meters, is feasible, or the ejectors reported by Le Compte and Mandt (1971), these factors would be changed. It must be remembered that the oxidation ditch was originally developed for small communities, making it difficult to extrapolate its usefulness for large population centers because of the cost of land and power, which can be overcome by processes using shorter detention times.

On the other extreme, very small plants create different problems. For example, in a 10,000 gallon per day plant having pronounced diurnal loadings, there is a possibility that during certain periods continuous aeration without sufficient food could cause the activated sludge to become dispersed, subsequent settling being rendered difficult. Thus, small plants operated intermittantly may be most suitable in some cases. However, such systems are prone to short circuiting and methods of preventing this should be considered. Holding tanks and other appurtenances have met with some success.

A series of small oxidation ditches of approximately 30,000 gallon per day capacity (at 24 hour detention time) have been constructed between the City of Fairbanks and the Brooks Range in northern Alaska for the construction camps to be used for the Trans-Alaska Pipeline System. These ditches seem to be perfectly suitable for operation, and there is no reason why they should not work. No long term data is available on these (Murphy, 1972) because the loading factors have been extremely low since the population has been only at a caretaker level, thus making them over designed for this load by a factor of approximately 20.

Types of Waste Amenable to Treatment

Adema (1967) reported a ditch treating wastewater from two coking plants with very high efficiency. A shortage of phosphorus was reported on these plants but was alleviated. Dairy wastes have been treated, as reported by Pasveer (1960), and phenol (Baars, 1962), as well as data showing a considerable tolerance for peak loads and/or shock loads. Ditches have been installed to treat animal waste, slaughter house waste, cannery waste, and industrial waste containing organic chemicals (Hikes, 1971). The use of oxidation ditches as an intregal part of animal housing units have been extensively reported in the literature (Hart, 1970). The literature is replete with information indicating that the oxidation ditch process is very suitable for the treatment of industrial waste, since it can tolerate peak loads of toxic components much better than the conventional activated sludge process. This fact is borne out when one realizes that the oxidation ditch is simply a form of a nearly complete mixed extended aeration plant.

EXPERIMENTAL PROCEDURE

The oxidation ditch studied at College, Alaska is presented as Figure 3. The basic dimensions of this plant are shown therein. Two cage rotors, 27-1/2 inches in diameter and 13 feet long, are mounted at the center of the ditch. They are each driven by a 7.5 horsepower motor at 89 rpm with an immersion depth of 6 inches. The rotors and driving motors are located inside a concrete block housing which has been used to prevent freezing of the spray during the winter periods.

The influent waste flow is from the University of Alaska, a few adjacent subdivisions, and a grammar school, thus making the raw waste essentially domestic sewage. The raw waste enters the plant through a bar screen from which it goes to a wet well and is intermittantly pumped to the ditch by 800 gallon per minute Smith and Loveless pumps. During the study period, the return sludge was drained into the wet well by gravity and pumped with the raw waste into the ditch. The settling tank, 30 feet in diameter with a volume of 54,000 gallons, is peripherally fed, with a center weir for discharge. Effluent passes through a 12 inch Parshall Flume and then is chlorinated in a contact chamber, from which it is discharged into the Chena River, a small river in the Tanana River basin. Raw waste was sampled from a manhole immediately ahead of the wet well. All effluent samples were taken at the Parshall flume immediately downstream from the sedimentation tank. No flow measuring devices have ever been installed in the effluent line and the flow through the plant was estimated from measurements at the Parshall flume. The mixed liquor samples were taken at the point where they enter the inlet channel to the settling tank. The suspended solids and dissolved oxygen in the ditch proper could be determined only on one side of the rotor since the other side was inaccessible due to a chain-link fence. A D.O. sampler was used for collecting all samples within the ditch proper.

Methods of Analysis

All analyses were performed as delineated in Standard Methods for the Examination of Water and Wastewater (1965). Many of the dissolved oxygen values in the ditch were determined with a Beckman DO analyzer, as were the oxygen uptake rates. The climatological data presented are those observed at the Fairbanks International Airport, located approximately 2 miles from the treatment facility.

Insignificant ambient temperature differences were noted between the airport and the ditch. During the period of study the treatment plant was operating at very near design capacity. As was pointed out previously, an atypical situation occurred throughout a great part of the study as the owner of the oxidation ditch, College Utilities, Inc., provided as a service to the local septic tank pumpers the availability of the ditch to dump their tankage. The number of loads of septic tank waste and their volume and strength were unable to be determined throughout the test period. Therefore, it is known that a greater amount of BOD and suspended solids (over figures for the influent) were added to the system throughout the study, but quantitative values are not known. However, as one will notice upon the examination of the results which follow, the plant operated quite effectively, and, if the reported numbers are in error, they are conservative.

The results which follow in the next section have a two fold purpose: (1) to present a large amount of data taken throughout a long study period which gives a basic evaluation of the oxidation ditch as a treatment device; and (2) some specific studies concerned with the sludge deposition and a sludge balance, as well as dissolved oxygen concentrations in various locations in the ditch and studies on aerobic stabilization of the sludge. The overall efforts serve the purpose of giving an overview of the oxidation ditch process for relatively small treatment plants in the Far North and some specific studies related to this ditch and some of the operating parameters.

Much of the data is presented graphically. Additional data used in the analysis is reported in the appendix.

RESULTS AND DISCUSSION

Influent Characteristics

The BOD and suspended solids of the influent were determined on a regular basis over an eight month period. Probability plots of influent BOD and suspended solids are presented in Figure 4. The BOD was less than or equal to 200 mg/l and suspended solids less than or equal to 175 mg/l 50 percent of the time. These data were obtained from grab samples, except for two days (3/22 and 7/7). Table A-1 (Appendix) lists these parameters as well as the volatile fraction and pH. The diurnal variation of influent suspended solids and BOD were also determined for this plant and are shown in Figure 5. As would be expected, both parameters had peaks in the mid-morning and early evening, with a minimum during the early morning hours. The flow through the plant, as measured by the effluent flow in the Parshall flume, is depicted in Figure 6 for both summer and winter conditions. The peaks and valleys coincide with BOD and suspended solids, indicating that the influent to the plant was very weak at the time.

The sewage temperatures for both summer and winter conditions versus time for typical days are presented in Figure 7. Surprisingly little difference in temperature between the two seasons was measured. This is attributed to the fact that many sewers in the area served by this facility are located in utilidors (all at the University of Alaska). Thus, the fairly high temperatures of the incoming waste may be one reason for the good performance of the ditch. In the winter, the daytime low flow temperature was 8°C compared to the high of 19°C. Figure 8 shows the maximum and minimum average daily ambient air temperatures during the study period.

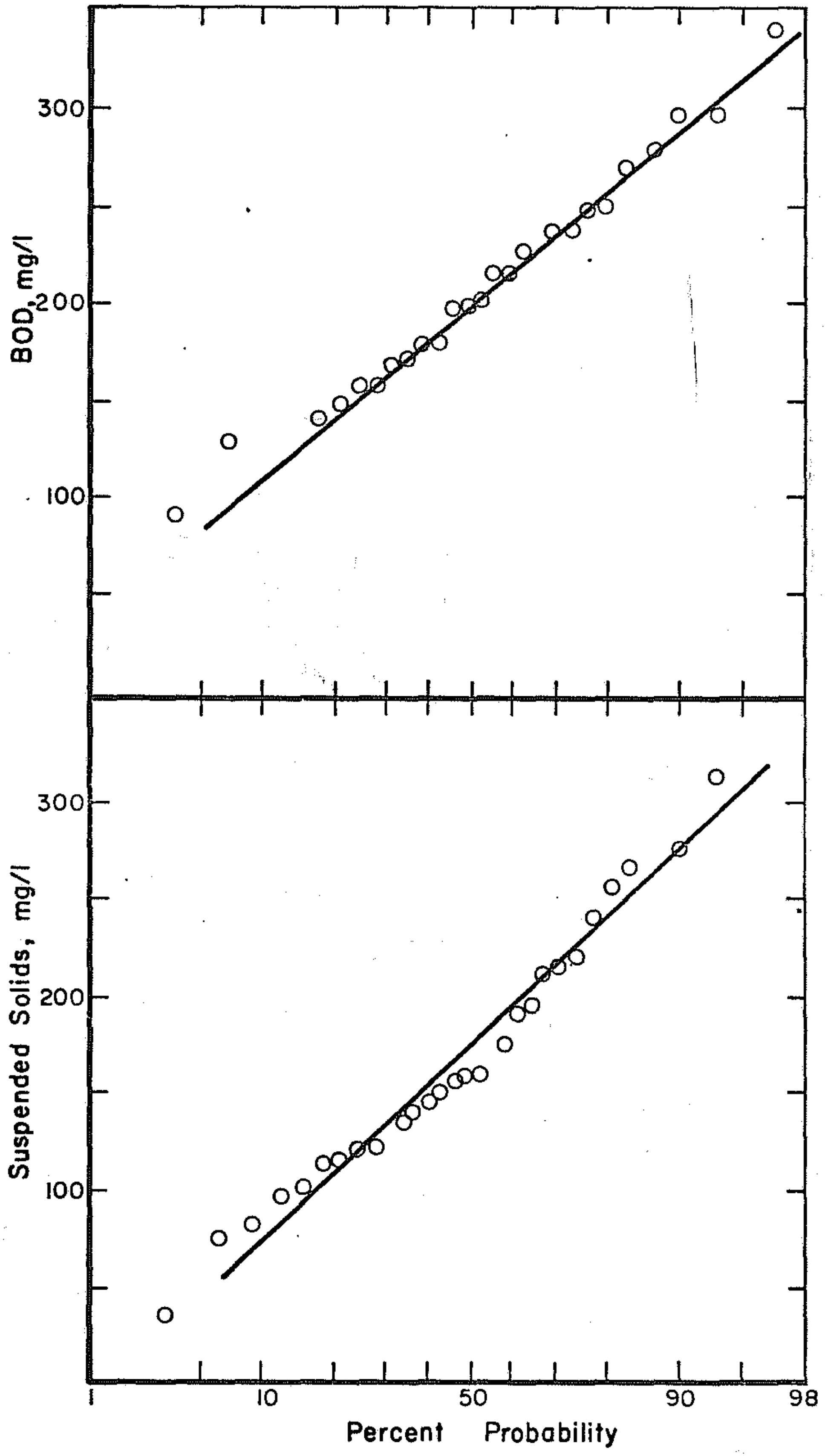
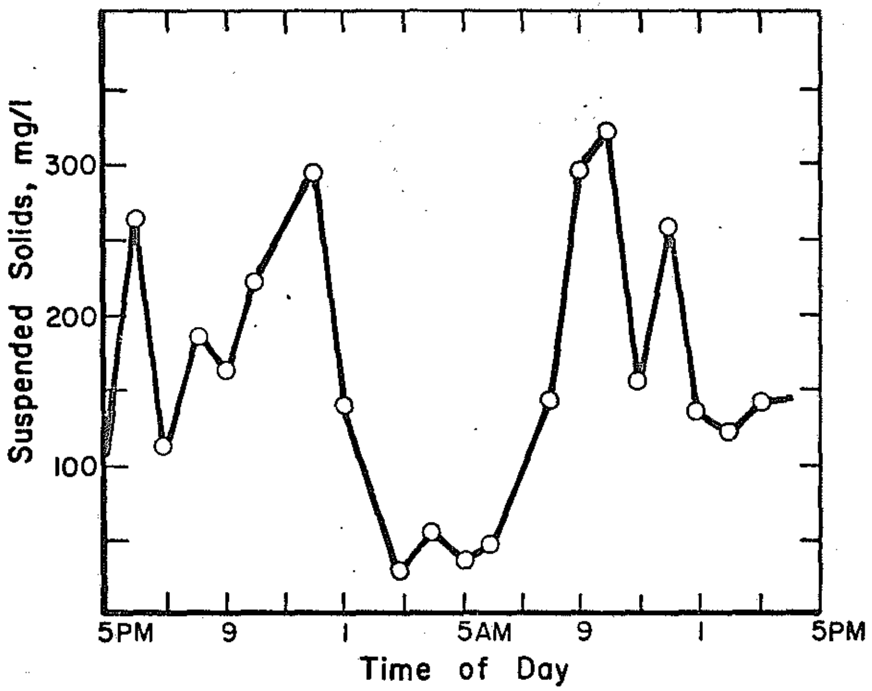


Figure 4 Occurrence Probability of Influent BOD and Suspended Solids



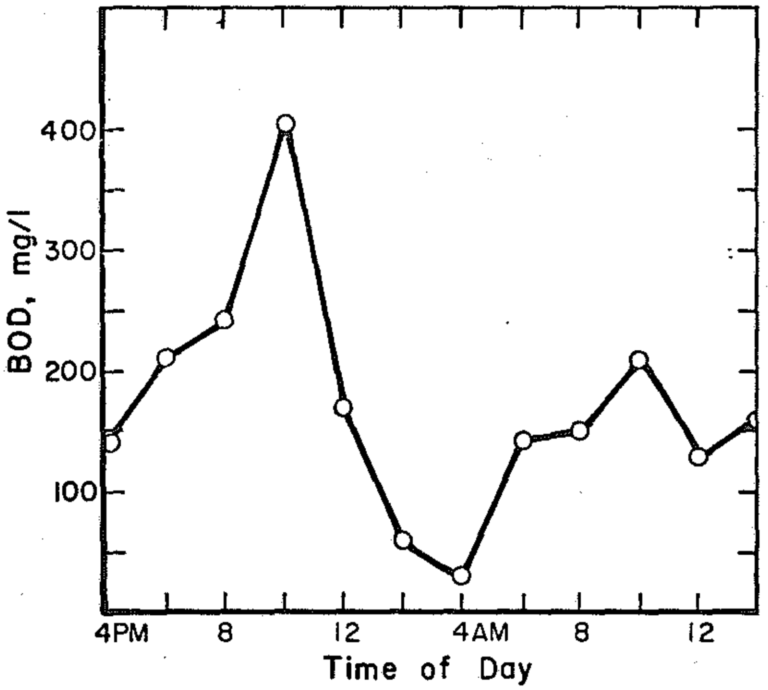
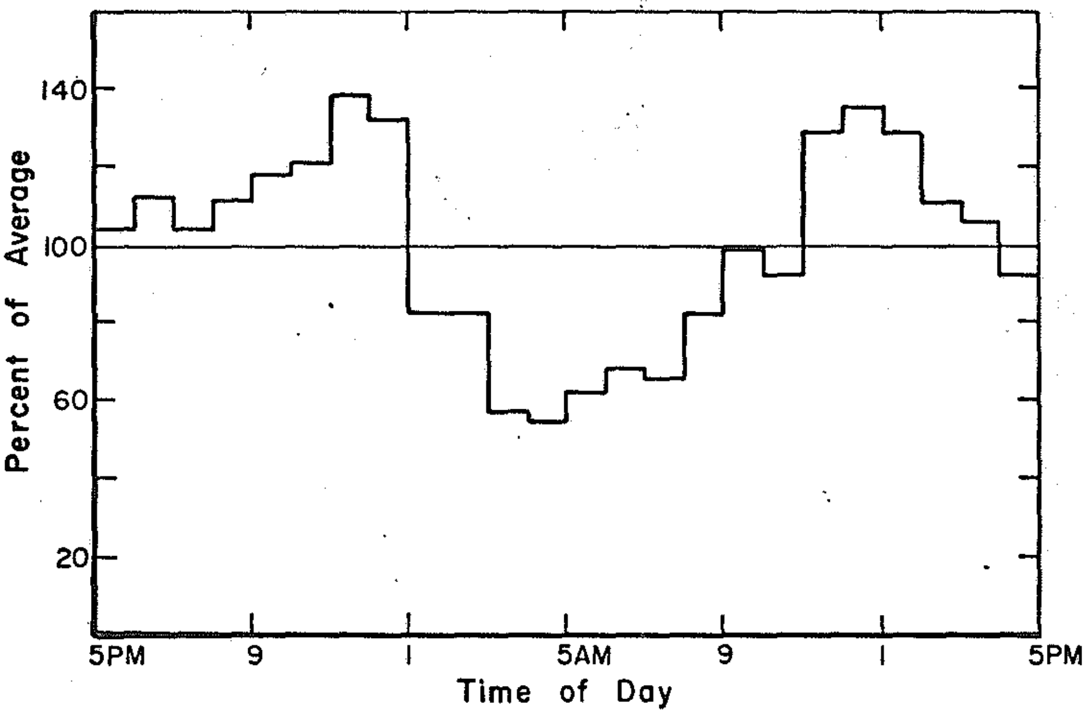
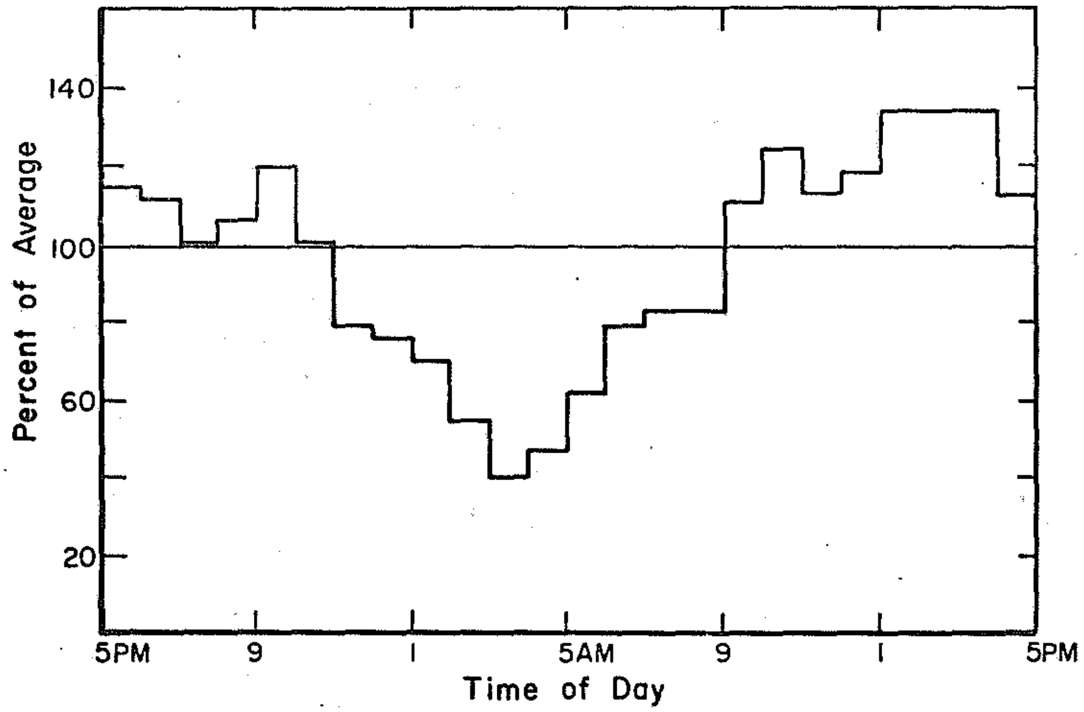


Figure 5 Influent BOD and Suspended Solids Concentrations Versus Time of Day



(a) Winter Flow



(b) Summer Flow

Figure 6 Diurnal Plant Flows as Measured in Effluent Parshall Flume

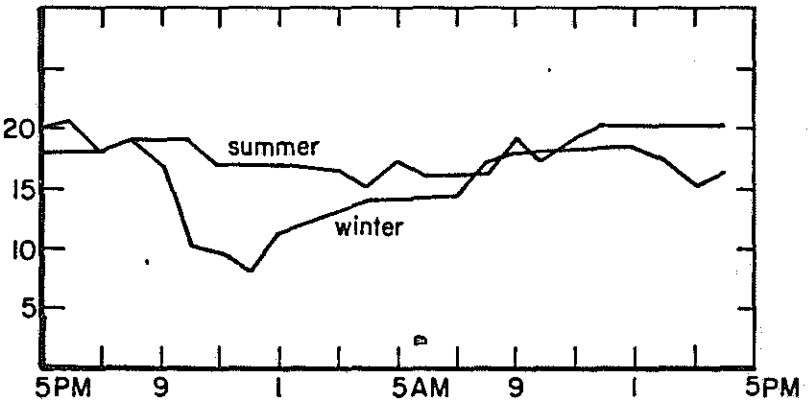


Figure 7 Diurnal Influent Temperatures in Winter and Summer

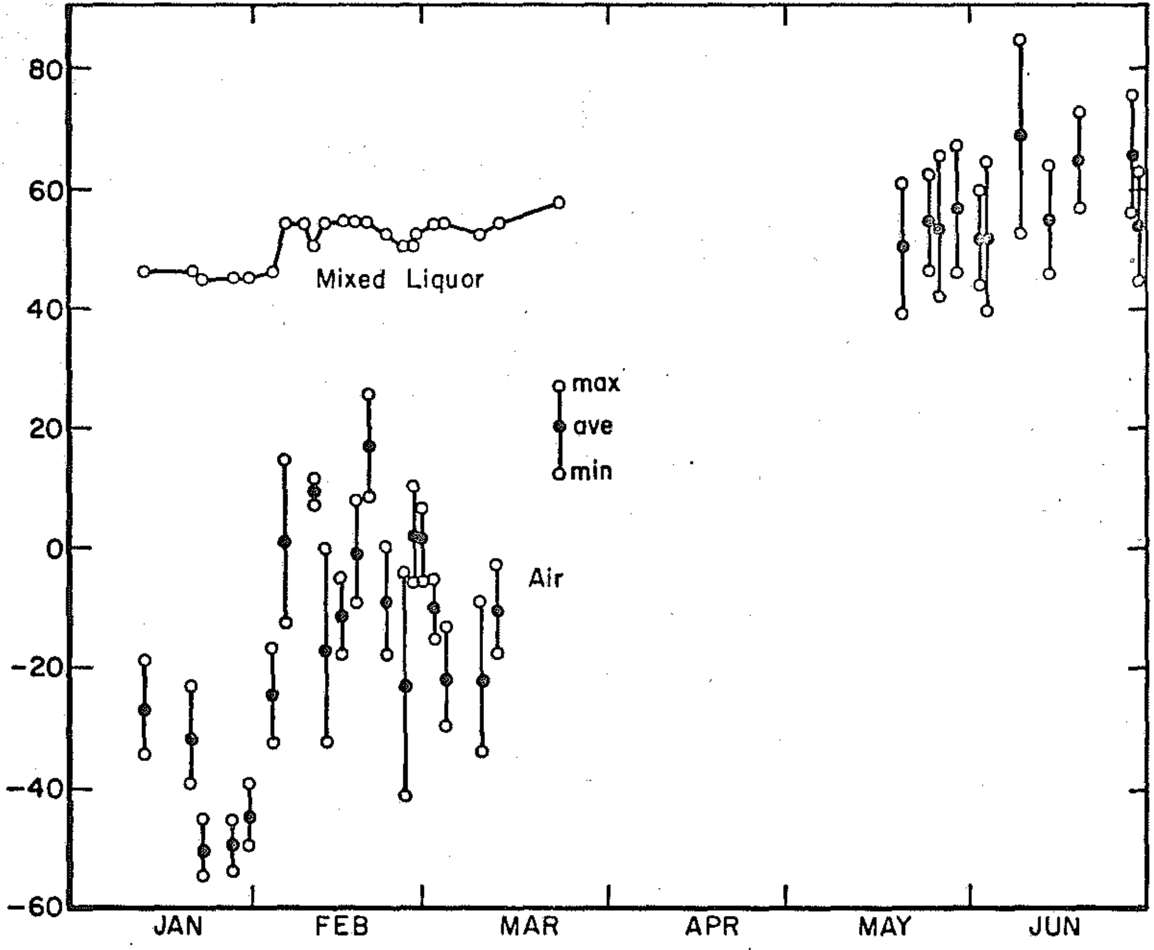


Figure 8 Seasonal Mixed Liquor and Ambient Air Temperatures During Study Period

Although the air temperatures are extreme, the lowest temperature is found during the period of maximum flow, which is also the time when temperatures are highest in the utilidors. The steam lines which are installed in the utilidors are carrying their maximum load to heat the various buildings at the University.

Effluent Characteristics

Probability plots of the effluent BOD and suspended solids concentrations are presented in Figure 9. The BOD was less than or equal to 29 mg/l 50 percent of the time. The occasionally high suspended solids and BOD which occurred were due to the return sludge line clogging, thus overloading the sedimentation tank. Removal of return sludge by gravity will always be prone to such problems. The owners of the plant, cognizant of the problem, are in the process of remedying the situation (1972). The frequent unpredictable loss of solids in the effluent due to the above reason, along with the normal auto-induced sludge wasting typical of extended aeration plants, as well as the daily introduction of septic tank sludge, masked any attempt to define and measure the sludge growth in the system. Table A-2 (Appendix) lists these parameters as well as the volatile fraction and pH.

The plant efficiency is a function not only of the biological reactions, but to an equal or greater degree, of the settling and return of the activated sludge. In addition to poor effluent quality occurring during the loss of the solids mentioned above, the active mass from the system is lost, which affects the biological efficiency. Efficient return of the sludge is a small maintenance and operation factor considering its effect

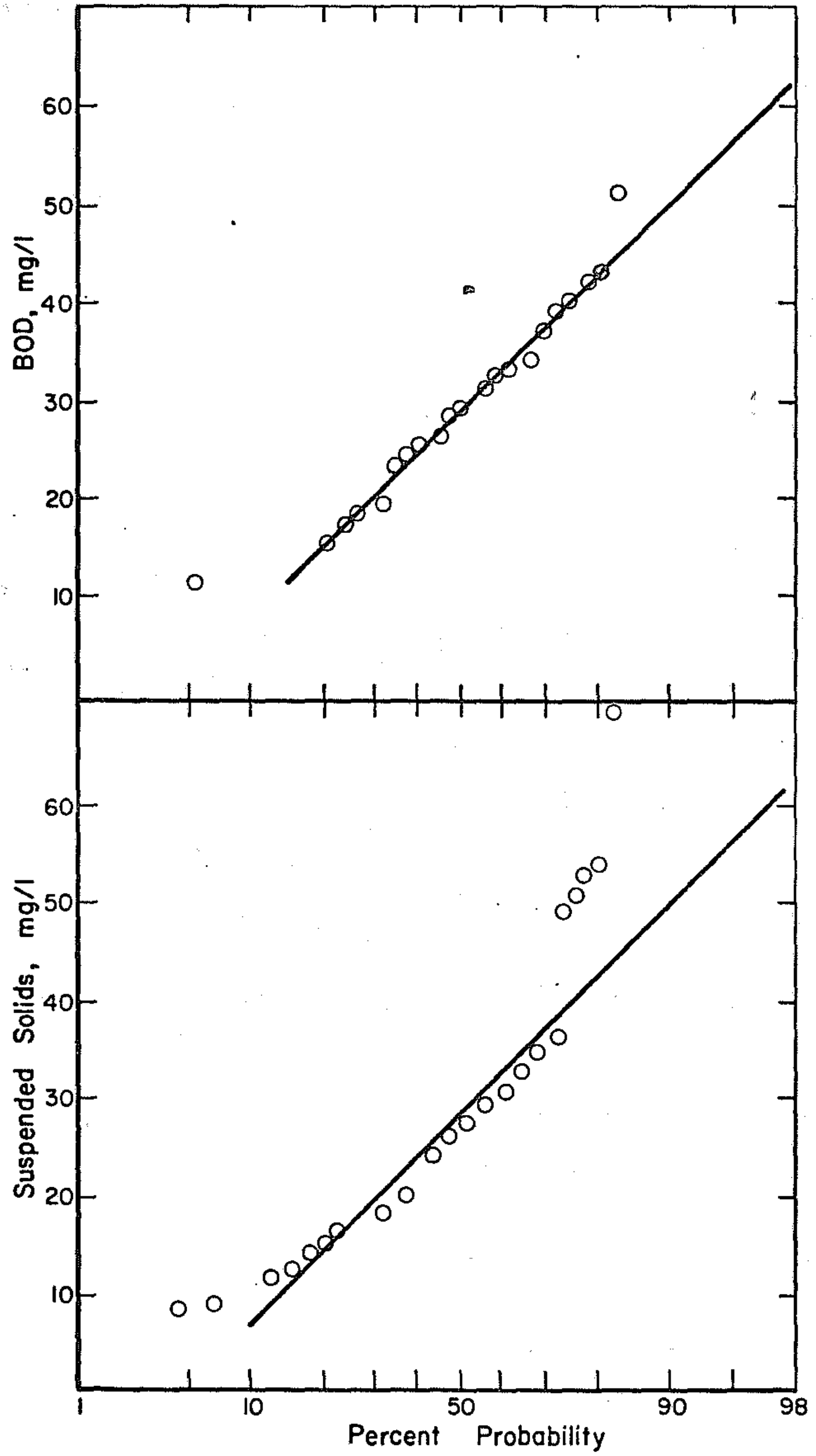


Figure 9 Occurence Probability of Effluent BOD and Suspended Solids

on the total system.

Table A-3 (Appendix) lists the BOD:COD ratios of both the plant influent and effluent during the period of the study. The influent had a range between 0.38 and 0.80, and the effluent between 0.18 and 0.57. The lower BOD_5 to COD ratio in the effluent compared to the influent in any waste treatment process may be due either to the concentration of non-removable refractory materials accounting for a larger portion of the COD in the effluent than in the raw waste, or due to the larger BOD reaction rate of the raw waste compared to the treated effluent. In the treated effluent, most of the oxygen consumption is at the slower endogenous rate yielding a lower mean BOD reaction rate compared to the untreated waste water. Thus, the BOD_5 to COD ratio becomes less throughout the process. In the case of domestic waste, the fraction of refractory compounds may not be significant, and the lower BOD reaction rate of the effluent probably has the most pronounced effect on the BOD to COD ratio. Clark, et al. (1970), reported that the BOD to COD ratio varied between 0.13 to 0.27 for the effluent and between 0.55 and 0.66 for the influent in the case of an experimental extended aeration plant situated 20 miles south of Fairbanks treating domestic waste.

Overall Process Efficiency

The removal efficiencies of both BOD and suspended solids are listed in Table 2. Except for those days in which the solids were being discharged in the effluent, the BOD removal ranged between 77 and 97 percent, and the suspended solids removal between 75 and 93 percent. The removal efficiency

TABLE 2: BOD and Suspended Solids Process Removal Efficiencies

DATE	REMOVAL EFFICIENCIES - % BOD	REMOVAL EFFICIENCIES - % S.S.	DATE	REMOVAL EFFICIENCIES-% BOD	REMOVAL EFFICIENCIES-% S.S.
1/13	87	79	3/22-23	83	83
2/2	90	90	5/18	89	93
2/4	84	90	5/24	91	95
2/11	89	82	5/26	90	93
2/16	81	86	6/2	92	92
2/18	84	85	6/3	79	92
2/20	78	75	6/5	87	77
2/23	77	82	6/9	73	52
2/26	16	--	6/14	--	90
3/2	86	90	6/29	88	88
3/4	93	91	7/6	97	92
3/10	90	85	7/7-8	89	86
3/13	93	85	7/27	93	93

All data presented in Tables A-1 and A-2 (Appendix).

was generally higher during the summer. The BOD removals based on the 24 hour composite samples of March 22, 23 and July 7, 8 were 83 and 89 percent respectively. Efficiency on other days, based on grab samples, have limited interpretive significance except that they are indicative of the overall state of the plant. The organic loading rates on March 22, 23 and July 7, 8 were 14.5 lbs BOD/1000 cu.ft./day (0.12 lbs BOD/lb MLVSS/day) and 7.1 lbs BOD/1000 cu.ft./day (0.026 lbs BOD/lb MLVSS/day) respectively. The latter loading could lead to poor settling sludge, although this was not the case, probably due to the large BOD load in the form of septic tank sludge introduced into the system. On July 7, 8, eight trucks of septic tank sludge were discharged into the ditch, and on March 22, 23, two truck loads were discharged into it.

Goodman (1972) stated "We are only getting 60 to 75 percent removal of biodegradable waste from the average well run treatment plant in our country." He went on to mention that this was not necessarily attributable to poorly designed plants, or undertrained operating personnel. He added that upgrading the conscientiousness of plant personnel could make up for a multitude of sins in design of present plants. He further stated: "We not only have the technological ability to clean up 90 percent of the waste in municipal effluents, we have the production capability." His figures were based upon the fact that samples are not always taken at the worst times of the day or during a plant upset. The operators are usually much too busy attempting to remedy the situation to devote large amounts of effort to routine analytical testing. Based upon these figures, it appears that the oxidation ditch, which is ostensibly operating under very severe conditions, is doing quite well and can be said to be equal to or better than the national average. Without considering any of the other factors involved, the performance of the ditch was not affected by low temperatures. It was possible, however, that contact stabilization might have been occurring in the influent wet well when the activated sludge came into contact with the influent. This is an interesting conjecture, but because of the physical nature of the plant, definitive data on this point was impossible to obtain.

Oxidation Ditch Mixed Liquor Characteristics

The mixed liquor suspended solids and the Sludge Volume Index (SVI) were determined throughout the study period and are presented in Table 3

TABLE 3: Mixed Liquor Suspended Solids Characteristics

DATE	MLSS mg/l	MLVSS mg/l	%VSS	SVI	pH	DATE	MLSS mg/l	MLVSS mg/l	%VSS	SVI	pH
1/7	1152	798	70	39	7.9	3/13	960	670	70	203	7.0
1/9	844	560	66	57	7.6	3/23	3436	2268	66	55	--
1/13	1160	790	69	47	7.6	5/18	5770	2700	47	38	7.1
1/21	3460	2480	72	35	7.4	5/20	4130	1950	47	35	7.2
1/28	3130	2150	69	--	--	5/22	5310	2530	48	38	7.2
1/30	1685	1165	69	--	7.2	5/24	5120	2350	47	43	7.2
2/2	1440	1352	94	49	7.3	5/26	4410	2140	49	39	7.2
2/4	380	275	72	53	7.2	5/28	2850	1400	49	35	7.2
2/6	1740	1260	72	55	--	6/2	3990	1920	48	--	7.2
2/11	1000	630	63	50	7.3	6/3	4810	2330	48	42	7.2
2/13	1780	1210	67	62	7.1	6/5	2920	1470	50	48	--
2/16	2480	1720	70	36	7.0	6/9	5830	2990	51	55	7.1
2/18	2300	1600	70	40	7.0	6/14	4090	1970	48	55	--
2/20	1290	880	68	120	7.1	6/18	3560	1740	49	--	--
2/23	2160	1520	70	70	7.1	6/28	4060	2040	50	--	--
2/26	1030	870	84	75	7.0	6/29	2080	950	46	--	--
2/27	730	500	68	--	7.4	7/1	930	510	55	32	--
2/28	910	600	67	--	7.5	7/6	3840	1990	52	34	--
3/2	1250	830	67	--	7.4	7/7-8	8075	4415	55	37	--
3/4	1480	940	64	--	7.3	7/16	8330	4450	54	--	--
3/10	990	660	67	111	7.2	7/27	5260	2820	54	--	--

together with the pH and volatile suspended solids. As can be seen, the SVI values were very low, consistent with values expected for low energy systems. It follows that if the settling tank loading was to be based on the criteria suggested by Kalbskopf (1970) in terms of sludge volume loading, higher solids loadings on the settling tank serving the ditch are possible. The fluctuation in solids level was attributed to storage of sludge in the settling tank due to the clogging of the return sludge line, or to the loss of solids in the effluent. This rather large fluctuation in the ditch proper is quite significant and can be attributed to operational problems rather than process problems.

The data of Table 3 indicates that as the Sludge Volume Index decreased, a proportional decrease in the volatile suspended solids fraction took place, although this was not consistant. A significant reduction in the VSS fraction from about 70 to 50 percent occurred during the study period. A definitive reason for this reduction is not clear, although it is thought to have been due to the high fixed solids in the septic tank sludge which would accumulate with time. This change also coincided with the release into the ditch of a frozen sheet of solids about 60 to 70 feet long, the width of the ditch, and more than 1 foot thick. The reason the ditch froze, and some of the implications, are described below. The large increase in the solids level during the summer survey was attributed to the above release. The mixed liquor solids had a high fraction of non-biodegradable volatile solids as evidenced by a very low oxygen uptake rate. The discussion of this information is presented elsewhere in this report.

Freezing in Ditch

A sheet of ice ten feet long was noticed just ahead of the south turn of the ditch in the latter part of January. Its formation was originally due to foam generated by the rotors. As is well documented in the literature, foaming problems increase at lower temperatures, predominantly due to the fact that protein has a tendency to foam under turbulent conditions as the temperatures decrease. The foam, once it was formed, had a very large surface area and would quickly freeze on the ditch surface. In the process, some solids would become enmeshed within the frozen lattice. When the material floated down the ditch and reached the bend it would tend to become jammed and cause the section behind to be covered with greater amounts of foam. This action appeared to cause a constriction of the surface velocity which prevented complete mixing. The liquid underneath the foam layer therefore was able to freeze. The length of the frozen sheet gradually increased toward the rotor, and, in the middle of April, it was approximately 70 feet long, the width of the ditch, and a foot thick. A large amount of solids was caught in this frozen sheet. The low solids level of the mixed liquor during the winter survey and the increase in the summer survey was probably caused by the solids release when the ice was manually broken-up at the end of April and subsequently melted, releasing large quantities of solids.

Sludge Deposition in the Ditch

The configuration of the College Utilities Corp. oxidation ditch was previously mentioned as being prone to creating eddy currents. Many of these were observed throughout the period of study and intensive sampling procedures were instituted to determine their areal extent and the concentration of various parameters within and below the eddy. The easily settleable sludge of the process resulted in heavy sludge deposition in many of these eddy currents. Figure 10 delineates the areas where sampling was performed on the south half of the ditch. The data obtained during these procedures is tabulated on subsequent pages. Table 4, "Solids Concentration at Ditch Section Midpoints," clearly demonstrates a strong suspended solids gradient does not exist at the center of the ditch as

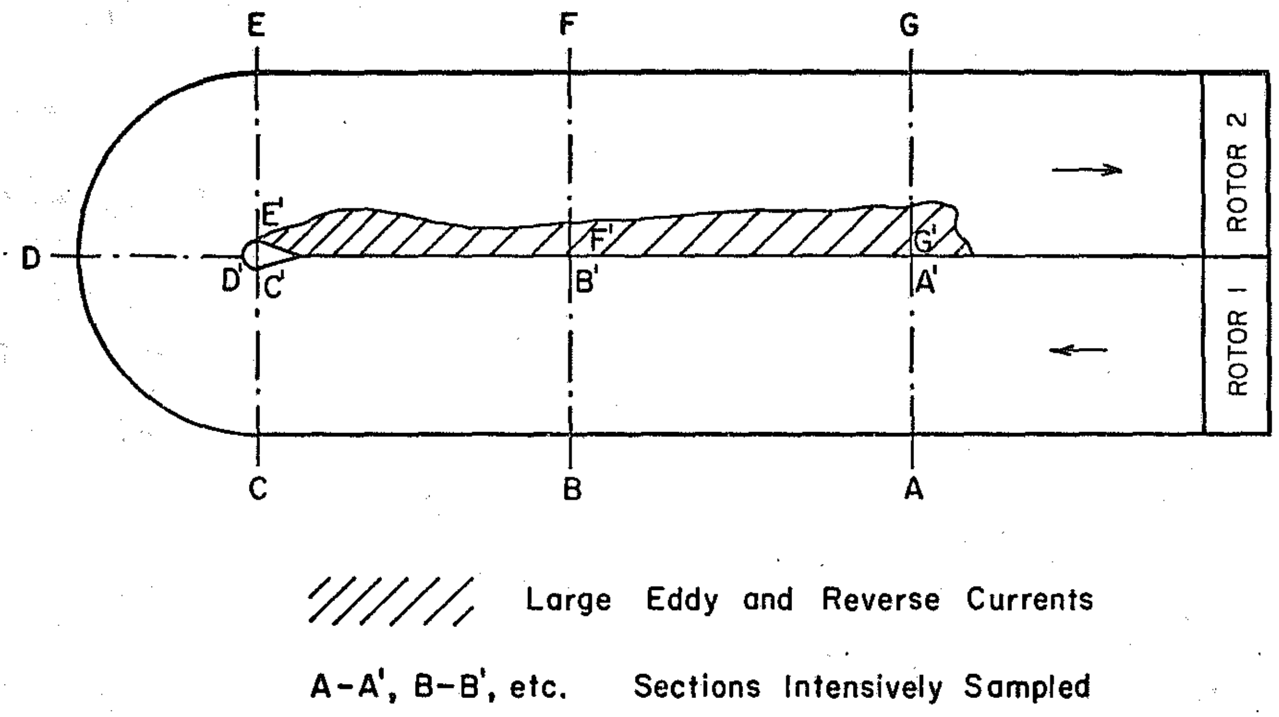


Figure 10 Sampling Stations for Sludge Deposition Studies

TABLE 4: Solids Concentrations at Ditch Section Midpoints

SECTION	DEPTH ft.	MLSS mg/l	AVERAGE mg/l
A-A'	0.5	1220	3010
	1.5	2470	
	3.0	5340	
C-C'	0.5	2050	2490
	1.5	2770	
	3.0	2640	
E-E'	0.5	2490	2796
	1.5	3080	
	3.0	2820	
F-F'	0.5	2510	2860
	1.5	3060	
	3.0	3000	
G-G'	0.5	3240	3350
	1.5	2890	
	3.0	3920	

Ditch effl. S.S. = 2,250 mg/l
Data obtained on 4/13

as one proceeds around the circuit. This is consistent with the fact that the velocity would be at its maximum at this point, sufficient to carry the solids in suspension. Table 5 presents data obtained at Section A-A' on two separate days (4/17 and 4/20). This information, although not easily correlated from day-to-day, clearly shows a solids gradient increasing from the center to the sides of the channel as well as with depth. Section A-A' should be the least prone to sludge deposition as it is immediately downstream from a constantly operating rotor. Thus, if a solids gradient is evident at Section A-A', sections further away from the rotor will most probably be unable to hold the material in suspension.

TABLE 5: Suspended Solids Distribution at Section A-A' on Two Days.

LOCATION*	DEPTH, FT.	MLSS, mg/l	MLVSS, mg/l	%VSS	D.O. mg/l	pH
		Sampled on 4/17				
I	0.5	5040	2830	56		6.4
	1.5	7210	4350	60		7.0
	3.0	10670	6420	60		7.0
II	0.5	3970	2220	56		7.0
	1.5	4340	2520	58		7.1
	3.0	4000	2300	58		7.0
III	0.5	4100	2370	58		7.1
	1.5	4250	2500	59		7.0
	3.0	6410	3920	61		7.1
		Sampled on 4/20				
I	0.5	5270	2820	54	3.89	6.6
	1.5	5730	3040	53	3.84	7.0
	3.0	6740	3870	58	3.68	7.0
II	0.5	5400	2890	54	3.95	7.1
	1.5	3770	2000	53	3.78	7.2
	3.0	7260	4420	61	3.78	7.0
III	0.5	4290	2280	53	4.21	7.0
	1.5	5770	3170	55	4.21	7.0
	3.0	4660	2440	53	4.1	7.0

* I is 3 ft. from outer edge of A-A'
II is at midpoint of A-A'
III is 3 ft. from inside edge of A-A'

The data of Table 5 indicates the volatile fraction of the suspended solids was approximately the same, as a percentage of the total, in all vertical sections. It can thus be concluded that the total mass of sludge was settling uniformly rather than some more dense fraction of it, as was originally suspected at the onset of this testing.

Dissolved oxygen values were obtained on the second day of testing in Section A-A' and are presented in Table 5. The D.O. varied between 3.68 and 4.21 mg/l in this cross-section. These values are within expected limits and significant conclusions can not be drawn from the data except for the fact that their magnitude indicates sufficient oxygen transfer is taking place.

Table 6 presents further solids data for Sections D-D' and G-G'. D. O. values are also shown. This information clearly demonstrates the serious deposition problem occurring at Section G-G', which is in the end of the shaded "deposition area" outlined in Figure 10. Additional complications to process efficiency are characterized by the low D.O. concentrations found at Section G-G'. This information definitely demonstrates the rather extreme internal sedimentation problem taking place in this particular oxidation ditch. Additional information on dissolved oxygens and pHs was taken during the study and is presented as Table A-4 (Appendix).

The indications of this data are significant in that a large amount of solids deposition was shown. Apart from this, it was observed during the period of study, by using a probe, that there was considerable bottom deposits all along the ditch bottom, particularly near the sides and under the areas of eddy and reverse currents (see Figure 10). At Sections G-G' and D-D', the sampler was imbedded in the deposited sludge, which was quite dense in nature. In order to determine whether the solids themselves were of a biodegradable nature, oxygen uptake rate studies were made on

TABLE 6: Suspended Solids and D.O. Distribution at Section D-D' and G-G'.

LOCATION*	DEPTH, ft.	D.O., mg/l	MLSS, mg/l	MLVSS, mg/l	%VSS
Section D-D', sampled 5/14					
	0.5	1.0	3490	1670	48
I	1.5	1.0	4460	2130	48
	3.0	0.8	6850	4110	60
	0.5	0.8	5100	2420	48
II	1.5	0.8	5430	2570	47
	3.0	0.8	4670	2220	48
	0.5	0.8	5100	2510	49
III	1.5	0.8	3060	1510	49
	3.0	0.6	3630	1810	50
Section G-G', sampled 5/14					
	0.5	0.3	6540	3220	49
IV	1.5	0.3	21620	10160	47
	3.0	0.2	20920	10400	50

* I is 3 ft. from outer edge of D-D'
II is at the midpoint of D-D'
III is three feet from inner edge of D-D'
IV is one foot from inner edge of G-G'

samples taken at Section G-G'. The results are shown in Figure 11. As can be seen from the figure, the greatest oxygen uptake rate was at a three foot depth in the area of eddy currents, while the smallest oxygen uptake rate was at the 1.5 foot depth at the mid-point. This data is indicative of a highly biodegradable material within the sludge deposits which could have a significant bearing upon the operation of the plant. The Glenwood, Minnesota plant (Anon., 1965) reported significant sludge deposition, as did Pasveer (1960), but he claimed it caused little or

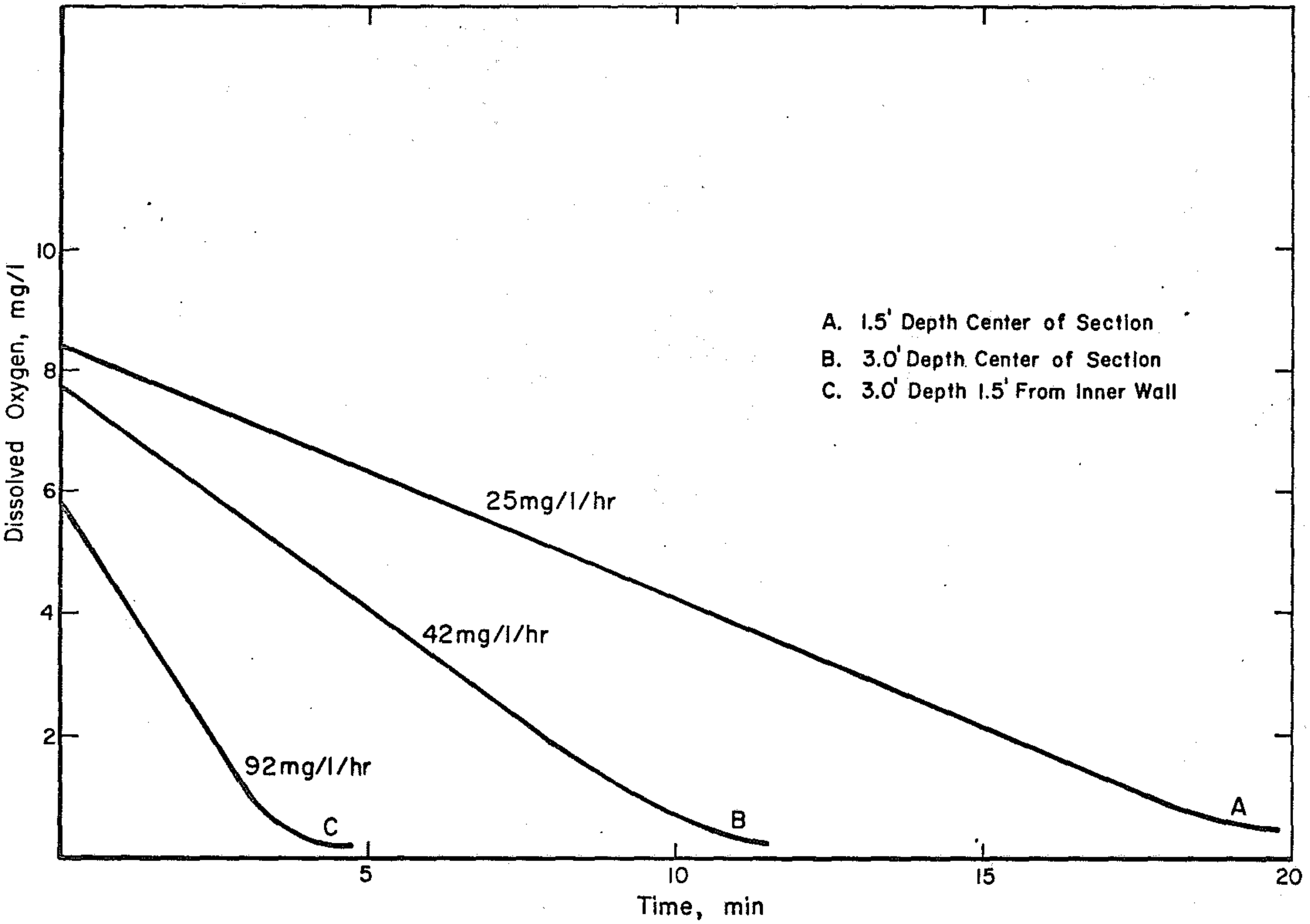


Figure II   Oxygen Uptake Rates of Sludges Taken From Section G—G' no reduction in the process efficiency.

Gas bubbles rising from the bottom layer were seen during the late summer, at which time pH values at the three foot depth were lower than those just below the liquid surface, particularly near Section G-G', where the pH was 6.6 (Table A-4). The 19°C temperature during the test was suitable for anaerobic decomposition of the deposited layer. In the late summer, the whole ditch became covered with a mat of floating solids, which were thought to have originated from the anaerobic activity, raising the sludge deposit from the bottom of the tank. These solids, if carried to the settling tank, would not easily settle, most being lost in the effluent, lowering its quality. Thus, the sludge deposition problem could be quite serious during the warm summer months, even in the sub-arctic environment of Fairbanks, Alaska. Further, it would be expected that some of the products of the anaerobic decomposition would in themselves exert a BOD during a period when the oxygen levels are critical, any additional BOD exertion being detrimental to the process. It thus appears that the rectangular configuration and the aerators used in this plant are unsuitable for keeping the floc in suspension. Other types of prime movers should be investigated for rectangular deep ditches without wide median strips.

Further aerobic stabilization studies were performed and the results are presented in Table A-5 (Appendix). The oxygen uptake rates were determined on the mixed liquor over a period of 5 days, 20 hours with continuous aeration. The initial uptake rate was 0.114 pounds of oxygen per pound

MLVSS per day. This rate was lower than that of the endogenous respiration rates determined by Symons and reported by Eckenfelder (1966) for mixed cultures developed from simple substrates. These values were found to be 0.36 pounds of oxygen per pound MLVSS per day. The low uptake rate indicates a high nonbiodegradable volatile content in the sludge. This, in turn, signifies the active mass fraction of the VSS was low and that if periodic sludge wasting was not accomplished, the percentage would continue to be low. During the period of this study, intentional sludge wasting was not practiced. At the end of the aeration period, a total suspended solids oxidation of 22 percent, and volatile solids destruction of 31 percent, were obtained. The significance of this result is two-fold. First, it does indicate the relatively low active mass being carried in the system, and secondly, the use of aerobic digestion for sludge conditioning should be considered as a unit process in the oxidation ditch configuration.

Settling Tank Analysis

Periods of intensive study were performed to determine the sedimentation tank characteristics. The data is presented in Table 7 for diurnal load variations, loading rates, SVI, and return sludge concentrations. The decline in solids levels from 7:00 p.m. to 8:00 a.m. was due to only one rotor operating, a practice which was used to conserve power during much of the year. Paranthetically, both rotors were put into operation during periods of high BOD inflow. During the low flow periods, one rotor was turned off. The solids concentration increased at 10:00 a.m., when the other rotor was started. The return sludge concentration varied between

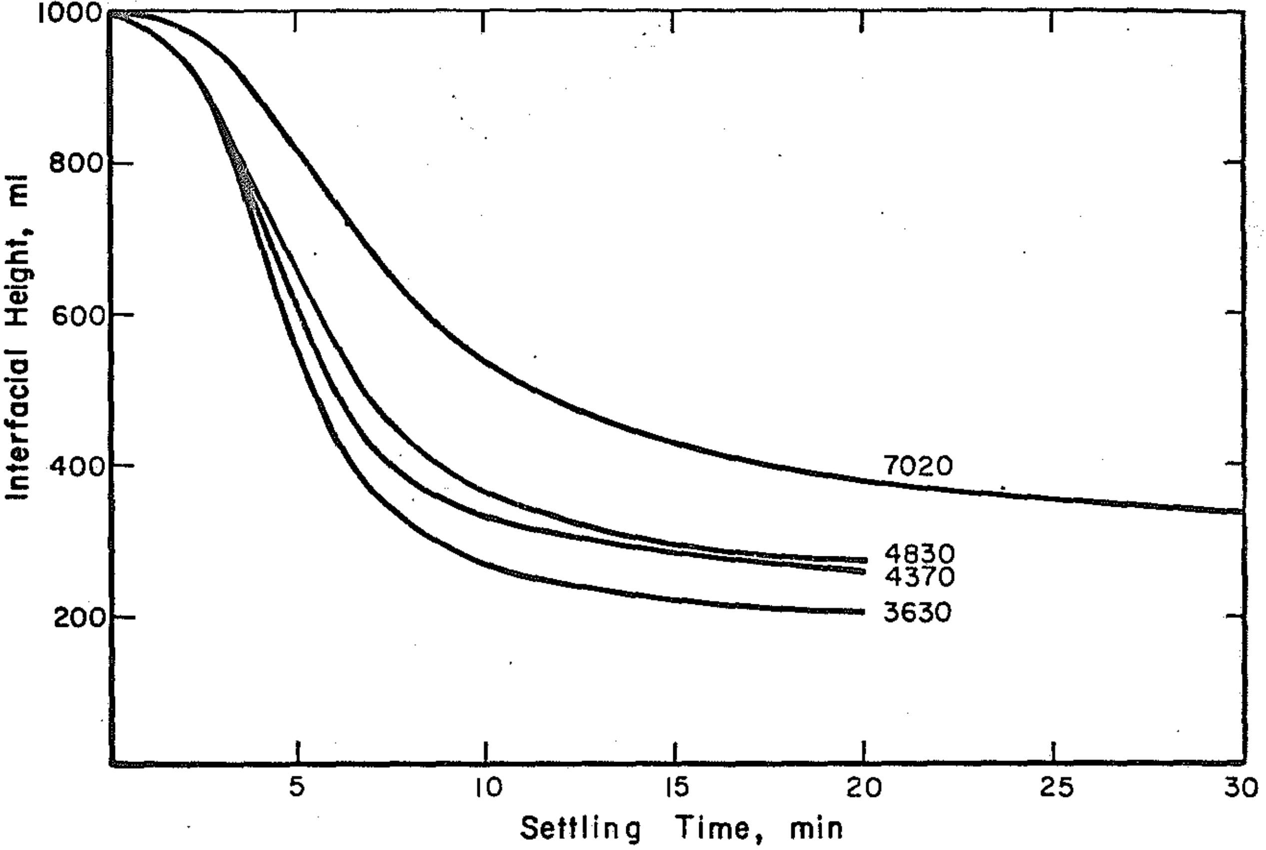
TABLE 7: Settling Tank Hydraulic and Solids Loadings

DATE: 7/20-21

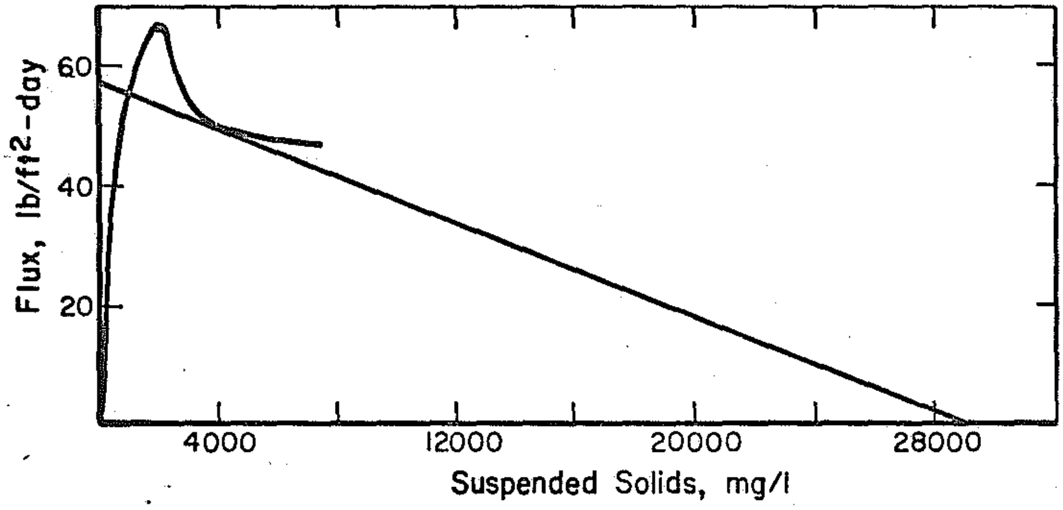
TIME OF DAY	HYDRAULIC LOADING gal/hr	MLSS mg/l	SVI	RETURN SLUDGE mg/l	TIME OF DAY	HYDRAULIC LOADING gal/hr	MLSS mg/l	SVI	RETURN SLUDGE mg/l
3 pm	16,580	6,250	48	28,720	3 am	9,330	--	--	--
4	16,580	5,880	49	25,580	4	10,150	5,000	--	28,400
5	16,580	5,910	51	28,980	5	9,220	--	--	--
6	16,580	6,480	46	29,920	6	8,510	4,910	--	28,040
7	14,080	5,900	51	29,860	7	11,300	4,440	--	--
8	11,300	5,860	46	28,700	8	11,300	4,310	--	--
9	15,600	5,610	46	29,440	9	15,600	--	--	--
10	15,600	4,960	52	28,620	10	16,150	5,380	--	--
11	11,790	5,210	50	30,300	11	16,150	--	--	--
12	9,950	5,070	49	30,360	12	16,580	5,280	--	--
1 am	9,220	--	--	--	1 pm	16,580	--	--	--
2	8,510	4,950	49	28,360	2	16,580	5,920	--	--

25,580 mg/l and 30,360 mg/l (Table 7). At the maximum flow of 16,580 gph and a solids concentration of 6,250 mg/l, the dry solids loading was 29.3 pounds per square foot per day. This is a very high loading, but the settling tank was able to handle it efficiently. The sludge volume loading for the above data, in cu.m/sq.m/hr as suggested by Kalbskopf (1970), was 0.286. The upper limit given by Kalbskopf was 0.3 cu.m/sq.m/hr. Hence, it is clear that due to the low SVI encountered in the oxidation ditch system, a high solids loading on the settling tank will result, and is efficient.

Dick (1969) questioned the capability of SVI to indicate the settling characteristics of activated sludge. He demonstrated that two sludges of entirely different settling characteristics can have the same SVI values. In order to determine whether Dick's approach was significant for the College Utilities plant, settling characteristics were obtained for four concentrations of the sludge and are shown in Figure 12(a). The settling velocities obtained are presented in Table A-6. From this data, a solids flux curve was constructed as shown in Figure 12(b), based on the same data. It can be seen that for solids loadings as high as 56.5 lbs/ft^2/day, the settling tank can return sludge effectively at a concentration of 29,000 mg/l at an SVI of 47. The limiting value using the sludge volume loading approach would allow only 30.8 lbs/ft^2/day at this SVI. It thus can be concluded that the settling velocity is the deciding factor in the design, and that SVI has only limited application. It is not suggested, however, that solids loadings as high as 56.5 lbs/ft^2/day are always possible in an oxidation ditch system, since the sludge evaluated was not an ideal activated sludge.



(a) Sludge Settling Curves for Various Initial Concentrations



(b) Solids Flux Plot

Figure 12 Settling Characteristics of MLSS

CONCLUSIONS

The previous section of this report discussed the findings of this study. The most significant ones are listed below.

(1) Arctic and sub-arctic climates dictate deep oxidation ditches as the most logical choice because of heat loss considerations.

(2) The oxidation ditch studied produces an effluent better than normally found for activated sludge plants in the temperate areas of North America.

(3) The effluent produced by this process is good, but many design refinements could be made based upon the results presented herein.

(4) The applicability of using this process for small installations is as good as for any other extended aeration process, particularly if fill and draw operation is specified.

(5) The rectangular cross-section and thin dividing wall incorporated in the plant studied must be considered a poor design as it creates large areas of very concentrated sludge deposits.

(6) The cage rotor is not capable of maintaining all the activated sludge in suspension in the ditch under consideration. The accepted U. S. design criteria of 16,000 gal/ft of rotor length is insufficient.

(7) Changing the 16,000 gal/ft criteria will not solve the problem for this ditch in that insufficient oxygen could be transferred.

(8) The sludge in the oxidation ditch process is characteristically easy to settle out and hence a very high solids loading in the settling tank is possible. Loadings as high as 50 $lbs/ft^2/day$ may be in order.

(9) Greater attention must be paid to the process of sludge settling in the operations of settling tanks in order to improve the overall process efficiency.

(10) The high sludge content normally found in the oxidation ditch is quite amenable to aerobic digestion.

REFERENCES

Adema, D. (1967) The Largest Oxidation Ditch in the World for the Treatment of Industrial Waste. *22nd Industrial Waste Conference Purdue University, Lafayette, Indiana.*

Anonymous (1965) Report on Operation of Oxidation Ditch Sewage Treatment Plant, Glenwood, Minnesota. *Department of Health, Division of Environmental Heatlh, Section of Water Pollution Control.*

Baars, J. D. (1962) The Use of Oxidation Ditches for Treatment of Sewage from Small Communities. *W.H.O. Bulletin,* V.26.

Beck, W. L. Theory, Operation and Cost of the Oxidation Ditch Process. *RAD-90.* Made available through Lakeside Engineering Corporation, Chicago, Ill.

Burchinal, J. C. and Jenkins, C. R. (1969) Ditches Provide Efficient Treatment. *Environmental Science and Technology,* Vol.3, No. 11, pp 1170-1173.

Clark, S.E.,et al.(1970) Design Considerations for Extended Aeration in Alaska. *Proc. Int. Symp. for Cold Regions Water Pollution Control,* Environmental Protection Agency Research Series 16100 EXH11/71, pp 213-236.

Dick, R. I. (1969) Sludge Volume Index - What is it. *Jrnl. Water Poll. Control Fed.*, Vol.41, No.7, pp 1285-1291.

Dick, R. I. (1970) Role of Activated Sludge Final Settling Tanks. *Jrnl. of the Sanitary Engineering Div., ASCE,* Vol. 96, No. SA2, Proc. Paper 7231, pp 423-436.

Eckenfelder, W. W. (1966) *Industrial Water Pollution Control.* McGraw Hill, New York.

Eckenfelder, W. W. (1970) *Water Quality Engineering for Practicing Engineers,* Barnes and Noble, Inc. New York.

Ford, D. L. (1970) General Sludge Characteristics, *Water Quality Improvement* (Edited by E. F. Gloyna and W. W. Eckenfelder), Univ. of Texas Press, Austin, pp 341-357.

Goodman, Brian (1972) Remarks presented at the Ecodyne Corp. "Editors Roundtable" Lenexa, Kansas.

Grube, G. A. and Murphy, R. S. (1969) Oxidation Ditch Works Well in Sub-Arctic Climate. *Water and Sewage Works*, July, pp 267-271.

Guillaume, F. (1964) *Evaluation of the Oxidation Ditch as a Means of Wastewater Treatment in Ontario,* The Ontario Water Res. Comm., Div. of Res., Publication No. 6.

Hart, S. A. (1970) Animal Manaure Lagoons - A Questionable Treatment System, paper presented at the *2nd International Symposium for Waste Treatment Lagoons,* Kansas City, Missouri, June 23-25.

Hikes, Burd (1971) Private Correspondence, Lakeside Engr. Corp., Chicago, Illinois.

Kalbskopf, K. H. (1970) European Practices in Sedimentation, *Water Qual. Improvement by Phys. and Chem. Processes.* (Edited by E. F. Gloyna and W. W. Eckenfelder) Univ. of Texas Press, Austin, pp 92-103.

Kaneshige, H. M. (1970) Performance of the Somerset, Ohio, Oxidation Ditch. *Jrnl. Water Pollution Control Fed.* Vol. 42, No. 7, pp. 1370-1378.

Lawrence, N. A. (1963) *Mechanical Aeration is a Logical Development for Sewage Lagoons in Western Canada.* Canadian Municipal Util., made available through Lakeside Engr. Corp.

Le Compte, A. R., and Mandt, M. G. (1971) A Case Study of Effluent Treatment by Channel Aeration Propelled and Oxygenated with Ejectors, paper presented at the *44th Annual Conference, Water Pollution Control Federation,* San Francisco, Oct. 3-8.

Murphy, R. Sage (1972) Personal Observation.

Pasveer, A. (1960) Developments in Activated Sludge Treatment in the Netherlands, paper presented at *Conference on Biological Waste Treatment,* Manhattan College, made available through Lakeside Equip. Corp., Chicago, Ill.

Standard Methods for the Examination of Water and Wastewater (1965) 12th Ed., Amer. Public Health Assn., New York.

Zeper, J. (1969) Large Size Oxidation Ditch, Carrousel (R), paper presented at *Aquateck 69 Congress,* location unknown.

Zeper, J. and De Mann, A. (1970) New Developments in the Design of Activated Sludge Tanks with low BOD Loadings, paper presented at the *5th International Water Pollution Research Conf., Prague.*

APPENDIX

TABLE A-1: Influent BOD, Suspended Solids, and pH.

DATE	BOD mg/l	SS mg/l	VSS mg/l	%VSS mg/l	pH	DATE	BOD mg/l	SS mg/l	VSS mg/l	%VSS mg/l	pH
1/13	238	158	128	81	7.5	5/18	142	265	150	57	7.6
2/2	270	490	360	73	7.3	5/20	92	115	50	44	7.5
2/4	158	312	256	82	7.4	5/24	169	220	85	39	7.4
2/11	180	145	85	59	7.3	5/26	159	160	110	69	7.4
2/16	182	140	90	64	7.8	5/28	--	210	150	72	7.9
2/18	204	150	70	47	7.4	6/2	149	120	110	92	7.8
2/20	198	215	140	65	7.7	6/3	129	96	56	58	7.5
2/23	174	175	112	64	7.6	6/5	142	35	35	100	--
2/26	298	100	67	67	7.6	6/9	142	75	65	82	7.8
2/27	248	155	110	71	7.8	6/14	--	135	90	67	--
2/28	--	135	118	87	7.8	6/18	240	240	120	50	--
3/2	227	275	210	76	7.9	6/29	297	255	130	51	--
3/4	217	195	125	64	7.7	7/1	281	83	65	78	--
3/10	200	114	80	70	7.8	7/6	342	275	230	84	--
3/13	216	122	78	64	7.6	7/7-8	210	190	150	79	--
3/22-23	238	175	120	69	--	7/27	252	190	150	79	--

TABLE A-2: Effluent BOD, Suspended Solids, and pH.

DATE	BOD mg/l	SS mg/l	VSS mg/l	%VSS mg/l	pH
1/7	--	16	13	80	7.8
1/9	--	18	16	89	7.6
1/13	30	34	24	71	7.6
1/21	27	48	34	71	7.3
1/28	35	70	56	80	--
1/30	43	88	38	43	7.1
2/2	26	50	34	68	7.2
2/4	25	32	22	69	7.4
2/6	29	52	44	85	--
2/11	20	26	18	70	7.4
2/13	33	28	20	71	7.4
2/16	34	20	12	60	7.1
2/18	32	23	10	44	7.3
2/20	44	53	38	72	7.1
2/23	40	32	21	66	7.4
2/26	250	775	610	79	7.2
2/27	473	1250	860	69	7.2
2/28	--	2370	1610	68	7.2
3/2	32	28	23	82	7.4
3/4	16	18	11	61	7.4
3/10	20	17	11	65	7.3
3/13	16	18	14	78	7.2
3/22-23	41	30	24	80	--
5/18	16	20	10	50	7.4
5/20	177	1080	540	50	7.2
5/22	16	12	10	83	7.4
5/24	16	11	7	64	7.4
5/26	16	11	8	73	7.3
6/2	12	9	9	100	7.1
6/3	27	8	6	75	7.4
6/5	18	8	8	100	--
6/9	38	36	26	72	6.9
6/14	--	14	9	64	--
6/18	1012	4870	2470	51	--
6/28	52	25	15	60	--
6/29	35	30	22	73	--
7/1	1380	1400	720	51	--
7/6	12	23	21	91	--
7/7-8	24	26	26	100	--
7/27	19	13	5	38	--
8/13	--	2990	1170	39	--

TABLE A-3: BOD/COD Ratios of Influent and Effluent

DATE	INFLUENT BOD mg/l	INFLUENT COD mg/l	INFLUENT BOD/COD	EFFLUENT BOD mg/l	EFFLUENT COD mg/l	EFFLUENT BOD/COD
2/2	270	600	0.45	26	78	0.33
2/11	180	432	0.42	20	112	0.18
2/16	182	324	0.56	34	93	0.36
2/18	204	456	0.45	32	70	0.47
2/20	198	525	0.38	44	173	0.25
2/23	174	324	0.54	40	154	0.26
3/2	227	510	0.45	31	78	0.40
3/4	217	496	0.44	16	68	0.23
3/10	200	416	0.48	19	68	0.28
3/13	216	484	0.45	16	60	0.21
3/22-23	238	424	0.56	41	120	0.34
5/18	142	270	0.52	16	64	0.25
5/24	169	312	0.54	16	28	0.57
5/26	159	286	0.55	16	55	0.29
6/3	129	256	0.50	27	64	0.42
6/29	297	372	0.80	35	92	0.38
7/6	342	468	0.73	12	52	0.23
7/27	252	424	0.59	19	40	0.47

TABLE A-4: D.O. and pH Values at Various Ditch Cross-Sections.

Sampled 9/9

SECTION	D. O., mg/l	
	Rotor I in use	Rotor I & II in use
at Rotor I	1.3	1.5
A	0.5	0.9
C	0.3	0.3
F	0.4	0.1
G	0.3	0.2

Sampled 1 ft. from dividing wall at 1 ft. depth.

Sampled 8/17

SECTION	DEPTH IN FT.	pH
A	3	7.3
C	3	7.3
E	3	7.4
G	3	6.6
B	Just below surface	7.6
before entry to settling tank	--	7.55

TABLE A-5: Aerobic Stabilization Studies

Date 7/27 - 8/2

TIME SINCE STARTING-Hrs.	OXYGEN UPTAKE RATE lbs/day[1]	OXYGEN UPTAKE RATE mg/hr[2]	SS mg/l	VSS mg/l
0	.114	13.7	5,170	2,870
31.5	.092	11.1	5,460	2,890
44.5	.066	7.8	5,500	2,810
58	.085	10.8	5,960	3,040
69	.058	7.2	5,780	2,960
80	.029	4.8	6,990	3,900
105	.032	5.4	8,040	4,040
130	.022	6.0	13,900	6,520
140	.053	7.2	6,590	3,240

STABILIZATION

	INITIAL	FINAL
Volume of mixed liquor, ml	900	550
SS, mg/l	5,170	6,590
VSS, mg/l	2,870	3,240
SS, mg	4,650	3,620
VSS, mg	2,580	1,780
Percent SS oxidation	22	
Percent VSS destruction	31	

1 - lbs. oxygen per lb. MLVSS per day
2 - mgs. per liter per hour

TABLE A-6: MLSS Settling Velocity and Solids Flux

SUSPENDED SOLIDS CONCENTRATION, mg/l	SETTLING VELOCITY ft./min.	SOLIDS FLUX lb/ft^2-day
1,500	.464	62.6
2,000	.368	66.2
2,500	.268	60.3
3,000	.188	50.6
3,630	.145	--
4,000	.136	49.0
4,370	.132	--
4,830	.115	--
5,000	.108	48.5
7,000	.076	47.8
7,020	.076	--
8,000	.064	46.0
10,000	.044	39.6

TABLE A-7: Occurrence Probability of Influent BOD

BOD mg/l	m	$\frac{m}{n+1}$	PERCENT OCCURRENCE	BOD mg/l	m	$\frac{m}{n+1}$	PERCENT OCCURRENCE
92	1	0.0345	3.45	204	15	0.5175	51.75
129	2	0.0690	6.90	216	16	0.5520	55.20
142	5	0.1725	17.25	217	17	0.5865	58.65
149	6	0.2070	20.70	227	18	0.6210	62.10
158	7	0.2415	24.15	238	20	0.6900	69.0
159	8	0.2760	27.60	240	21	0.7245	72.45
169	9	0.3105	31.05	248	22	0.7590	75.90
174	10	0.3450	34.50	252	23	0.7935	79.35
180	11	0.3795	37.95	270	24	0.8280	82.80
182	12	0.4140	41.40	281	25	0.8625	86.25
198	13	0.4485	44.85	297	26	0.8970	89.70
200	14	0.4830	48.30	298	27	0.9315	93.15
				342	28	0.9660	96.60

TABLE A-8: Occurrence Probability of Influent Suspended Solids

SS mg/l	m	$\frac{m}{n+1}$	PERCENT OCCURRENCE	SS mg/l	m	$\frac{m}{n+1}$	PERCENT OCCURRENCE
35	1	0.0313	3.13	158	16	0.5000	50.00
75	2	0.0625	6.25	160	17	0.5313	53.13
83	3	0.0938	9.38	175	19	0.5938	59.38
96	4	0.1250	12.50	190	20	0.6250	62.50
100	5	0.1563	15.63	195	21	0.6563	65.63
114	6	0.1875	18.75	210	22	0.6875	68.75
115	7	0.2188	21.88	215	23	0.7188	71.88
120	8	0.2500	25.00	220	24	0.7500	75.00
122	9	0.2813	28.13	240	25	0.7813	78.13
135	11	0.3438	34.38	255	26	0.8125	81.25
140	12	0.3750	37.50	265	27	0.8438	84.38
145	13	0.4063	40.63	275	29	0.9063	90.63
150	14	0.4375	43.75	312	30	0.9375	93.75
155	15	0.4688	46.88	490	31	0.9688	96.88

TABLE A-9: Occurrence Probability of Effluent BOD

BOD mg/l	m	$\frac{m}{n+1}$	PERCENT OCCURRENCE	BOD mg/l	m	$\frac{m}{n+1}$	PERCENT OCCURRENCE
12	2	0.054	5.4	34	23	0.621	62.1
16	8	0.216	21.6	35	25	0.675	67.5
18	9	0.243	24.3	38	26	0.702	70.2
19	10	0.270	27.0	40	27	0.729	72.9
20	12	0.324	32.4	41	28	0.756	75.6
24	13	0.351	35.1	43	29	0.783	78.3
25	14	0.378	37.8	44	30	0.810	81.0
26	15	0.405	40.5	52	31	0.837	83.7
27	17	0.459	45.9	177	32	0.864	86.4
29	18	0.486	48.6	250	33	0.891	89.1
30	19	0.513	51.3	473	34	0.918	91.8
32	21	0.567	56.7	1012	35	0.945	94.5
33	22	0.594	59.4	1380	36	0.972	97.2

TABLE A-10: Occurrence Probability of Effluent Suspended Solids

SS mg/l	m	$\frac{m}{n+1}$	PERCENT OCCURRENCE
8	2	0.0488	4.88
9	3	0.0732	7.32
11	5	0.1220	12.20
12	6	0.1464	14.64
13	7	0.1708	17.08
14	8	0.1952	19.52
16	9	0.2196	21.96
17	10	0.2440	24.40
18	13	0.3172	31.72
20	15	0.3660	36.60
23	17	0.4348	43.48
25	18	0.4592	45.92
26	20	0.5080	50.80
28	22	0.5568	55.68
30	24	0.6056	60.56
32	26	0.6544	65.44
34	27	0.6788	67.88
36	28	0.7032	70.32
48	29	0.7276	72.76
50	30	0.7520	75.20
52	31	0.7764	77.64
53	32	0.8008	80.08
70	33	0.8252	82.52
88	34	0.8496	84.96
775	35	0.8740	87.40
1080	36	0.8984	89.84
1250	37	0.9228	92.28
1400	38	0.9472	94.72
2370	39	0.9716	97.16
4870	40	0.9960	99.60