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Extended Aeration Sewage Treatment in Cold Climates

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EXTENDED AERATION SEWAGE TREATMENT
IN COLD CLIMATES

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ABSTRACT

In an effort to develop design criteria for biological treatment of low temperature domestic sewages, the Arctic Environmental Research Laboratory has designed and operated two parallel low temperature extended aeration units near Fairbanks, Alaska.

The two units had exposed aeration basins utilizing submerged aerators and were differentiated by type of clarifier. One unit had a conventional horizontal flow clarifier while the other had a modified upflow clarifier with tube settlers. The liquid temperatures varied from 0°C to 19°C. In addition, a 0.5 MGD subarctic, oxidation ditch and low temperature bench scale units were studied.

Organic loading was the parameter most seriously affected by the low temperatures. It was found that BOD removals above 80 percent at liquid temperatures below 7°C could generally be maintained at loadings of 0.08 Kg BOD/Kg MLSS/Day or less.

As in warmer climates, intentional sludge wastage was found to be required. Low temperature solids accumulation rates indicated that the standard wastage criteria of 0.5 Kg SS/Kg BOD is usually adequate.

Other parameters investigated and reported were:

1. aeration for oxygen transfer and mixing.

2. comparative clarifier performance.

3. nutrient and total coliform removals.

This report was submitted in fulfillment of Project Number 16100, by the Arctic Environmental Research Laboratory. Work was completed December 1973.

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ACKNOWLEDGEMENTS

The foresight and initiative of the Arctic Environmental Research Laboratory's first Waste Treatment Research Director, Mr. Sidney E. Clark, provided the impetus for a viable waste treatment research program, of which this report is a summary of the work on extended aeration. His contribution is acknowledged with sincere thanks.

The Alaska Air Command, Headquarters, Civil Engineering Division, has provided most of the support in the initial construction of the Eielson Air Force Base pilot plants. Their assistance is acknowledged with sincere thanks.

The 5010th Civil Engineers of Eielson Air Force Base, and especially Mr. Jack Howard and the waste plant operators, have given their continued assistance in maintaining, operating, and sampling the Eielson Air Force Base pilot plants. Their contribution is acknowledged with sincere thanks.

The College Utilities Corporation has provided the unpublished data on their oxidation ditch. Their contribution is acknowledged with sincere thanks.

SECTION I

RECOMMENDATIONS

The conventional extended aeration sewage treatment process can provide secondary treatment with low temperature sewage under subarctic conditions if the two following recommendations are followed:

1. Facility Design: The required degree of protection against freezing must be determined by proper heat transfer calculations.

2. Process Design: (a) Organic loading should not exceed 0.08 Kg BOD/ Kg MLSS/Day at MLSS temperatures below 7°C. (b) An effluent polishing system, such as a lagoon, sand filter, or microscreen, should be used if separate sludge wastage facilities are not installed.

SECTION II

SUMMARY AND CONCLUSIONS

Waste water treatment research and development activities in Alaska have been primarily directed toward adapting the biological processes for use in cold climates. The feasibility of the extended aeration process as an economical and effective means of secondary waste treatment has been demonstrated in the laboratory and in the field. However, the process requires more consistent operation and maintenance than many lagoon systems in an area where costs are high and skilled operators are extremely scarce.

FACILITY DESIGN

Additional long-term experience should further demonstrate economical and efficient operation of cold operating temperatures. Cold temperature process design criteria must be used if systems with mixed liquor temperature less than 10°C are to reach optimum efficiency. An obvious key to successful operation of an extended aeration system at any temperature is the solids separation process. Additional study is needed to determine optimum mixed liquor dissolved oxygen levels for the separation and thickening process.

The heat transfer characteristics of each component in the treatment system from collection and transport through each unit process should be carefully considered in any cold climate project. Present thermal design is based largely on empirical methods which are not necessarily economical.

Utilization of exposed aeration chambers for the extended aeration process is practical. Earthen basins are feasible where economic and construction conditions warrant, provided impervious liners are utilized. Provision of a stable sidewall surface that can tolerate mixing velocities, wave action, freeze-thaw cycles, extreme temperatures and ice movement is very important. Otherwise vertical sidewall construction should be utilized to promote better mixing. Reinforced concrete block and/or concrete grout should be considered as economical liner materials where the design permits.

When basins with low sloping sidewalls construction are utilized, the aeration devices should be clustered in the center of the basin for best mixing. For heat economy, consideration should be given to mounting the clarifiers within the aeration basin. When utilizing exposed basins, heat loss effects must be evaluated in conjunction with detention time to avoid potential freezing problems. The detention time available before icing occurs is a function of sewage temperature, ambient air temperature, and aeration basin configuration. For interior Alaska, the following maximum detention times at the corresponding sewage temperatures should provide an adequate margin of safety:

Detention Days	Sewage Temperature °C
1	5
2	10
4	20

Vulnerable equipment such as pretreatment units, pumps, and flow measurement devices should be located in a heated enclosure. Secondary sedimentation basins also need to be enclosed but may not need heating.

Some protection against freezing should be provided for aeration equipment with minimum heat enclosures for compressors and unheated housing for oxidation ditch rotors. Exposed surface aerators require excessive maintenance in cold climates and, therefore, should not be considered. Warmer temperature criteria are adequate for sizing submerged aeration equipment. Air piping should not pass through the exposed water surface because it may freeze shut during a power failure.

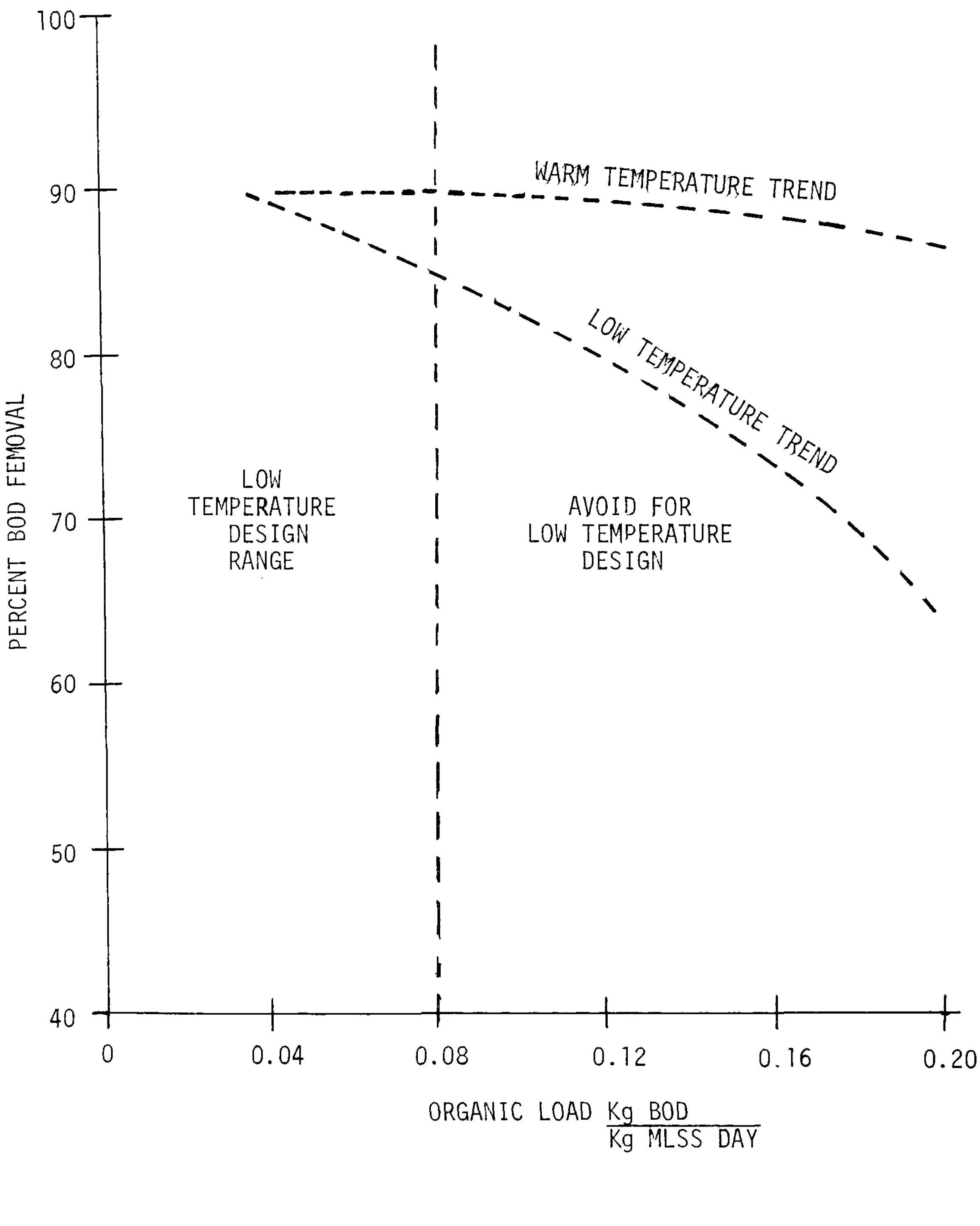
Extensive icing on an aeration basin can be a problem in an extended aeration process. Suspended solids entrainment in the ice may cause failure of the process. However, solids captured in surface ice may prove to be an excellent method for concentrating and removing solids from an exposed aerobic digestion basin because sludge that has been frozen dewaters vary easily. This technique needs to be demonstrated before its economics in cold climate areas can be defined.

Air lifts for sludge return have been proven to be satisfactory in many smaller extended aeration units.

ORGANIC LOADING

The process parameter most seriously affected by the low temperature was organic loading. The normal warmer temperature design loading range for extended aeration is 0.01 to 0.1 Kg BOD/Kg MLSS/Day, but in actual practice some plants operate efficiently at loadings approaching 0.2 Kg BOD/Kg MLSS/Day. At low temperatures, the performance decreases rapidly as organic loading is increased (see chart below).

TEMPERATURE EFFECTS OF LOADING ON PERFORMANCE



For sewage temperatures of 7°C or less, no extended aeration plant should be designed to operate at an organic loading above 0.08 Kg BOD/Kg MLSS/Day.

Pilot extended aeration units treating domestic sewage at less than 8°C operated satisfactorily at a MLSS concentration up to 4000 mg/l. Levels above this value have been reported by other investigators.

SOLIDS SEPARATION

Solids separation is dependent upon both the biological and physical aspects of the system. Sludge, although it may bulk and lead to separation problems, can be developed which will perform efficiently and produce non-turbid effluent at temperatures <1°C. A turbid effluent at cold temperatures, as at higher temperatures, is caused by an unacclimated sludge or an organic loading rate which is too high. Under these conditions, a less stabilized sludge develops with a corresponding relative decrease in numbers of stalked ciliates and an increase of free swimming organisms which contributes to turbidity. High loading at low temperatures affects the separation process resulting in poor performance.

Tube settlers can provide effective solids separation for sludges with sludge volume index (SVI) ranging up to 250 at temperatures above 10°C. They can also be considered as a device for improving effluent quality during upsets in the biological process or during peak flow rates. Cleaning of the tubes is necessary on a routine basis during normal operation with high MLSS concentration or bulking sludges. If a regular turnover of sludge in the tubes is not maintained by frequent cleaning, denitrification at temperatures greater than 8°C can cause sludge to rise in the tubes and overflow in the effluent. Tube settlers also make it difficult to determine sludge blanket depth.

The performance of the upflow clarifier with tubes was comparable to the horizontal flow clarifier at the EAFB pilot units. Clarifier overflow rates should be held below 12 lit/sq m/min (0.3 gal./sq ft/min) at low operating temperatures on an average daily flow basis and 20 lit/sq m/min (0.5 gal./sq ft/min) at peak flows.

SLUDGE WASTING

Careful attention to sludge wasting and disposal in cold climates for the extended aeration process is a necessity. As the process temperature decreases, the excess sludge production increases and may reach 0.6 Kg SS/Kg BOD applied below 7°C. The standard wastage criteria of 0.5 Kg SS/Kg BOD applied is adequate if 0.1 Kg SS/Kg BOD applied can be tolerated in the effluent. MLSS levels appear to be cyclic, thereby causing widely fluctuating effluent suspended solids levels. At low temperatures, this auto-induced sludge wastage in the effluent can be expected to be more severe. Sludge wasting and disposal facilities or a polishing lagoon for effluent discharge should be provided where necessary to protect receiving waters. Larger extended aeration units lacking wastage facilities should have a sand filter or microscreen for effluent filtration.

NUTRIENTS AND COLIFORM REMOVAL

At low temperatures, 6°C or less, there was no significant nitrogen removal in the pilot extended aeration units. Phosphorus removal was also insignificant, but appeared to be independent of temperature. Total coliform reduction at low temperatures, 10°C or less, was from 90-98 percent; similar to warmer temperature expectations.

SECTION III

INTRODUCTION

GENERAL

Alaska is the largest of the 50 United States. It has varied climate including arctic and subarctic zones where temperatures less than -45°C (-50°F) are common in winter. The population is small and widespread with 302,000 people (based on the 1970 census) inhabiting 586,000 square miles of land area. Settled areas requiring domestic sewage treatment include large municipalities, military installations, remote sites and villages, each of these having different requirements and presenting different problems.

Construction and power costs in Alaska are very high and excessively so in remote areas. Skilled personnel for operation and treatment plants are scarce or nonexistent. Costs of shipping to Alaska are also very high and increase with the degree of remoteness.

With increased development, population growth, and a greater awareness of environmental considerations, the problem of waste disposal in Alaska is assuming larger and larger proportions. The effect of man's waste on the arctic and subarctic ecosystems has received little attention in the past and is not well understood. Because of recent increased interest in these areas, some information is now becoming available on man's possible impact. For example, in the winter, dissolved oxygen (DO) of ice-covered Alaskan rivers may reach extremely low levels of 3 mg/l or less under natural conditions. Because of the retarded ability of Alaskan streams to replenish dissolved oxygen during the long winter period, it becomes essential that the natural balance is not upset by man. Under these conditions, the best available waste treatment must be provided.

In discussing biological waste treatment processes, Alter (2) states, "In view of present technology, aerobic processes appear to offer the greatest promise for cold region sewage treatment." The anaerobic process is severely retarded at colder operating temperatures. One of the major advantages of biological processes is that the greatest portion of the energy required for treatment is supplied by the biological system itself, thereby reducing shipping costs, etc., associated with materials required for chemical treatment. Aerated lagoons have proven suitable for facilities where minimum attention is a requirement and sufficient and suitable land area is available. Extended aeration may be used where greater sophistication can be tolerated, suitable land area is not available, or greater process control is required and appears to have great potential for reliable and economical secondary treatment in Alaska.

SCOPE AND PURPOSE

This report describes investigations conducted on bench scale units at the Arctic Environmental Research Laboratory; at a pilot plant located 22 miles

S.E. of Fairbanks, at Eielson AFB and; at the College oxidation ditch. The research was concerned primarily with adapting methods developed in the contiguous United States to the extreme climates found in Alaska, and included investigations in the following areas:

1. low temperature process performance

2. low temperature solids separation

3. degree of environmental protection required for equipment and processes

4. aeration chamber mixing

5. waste sludge production

The purpose of these research efforts was to develop adequate waste treatment methods and design criteria for use under the extreme climatic conditions found in the subarctic. These methods would hopefully provide the basis for facilities that were economical to construct, simple to operate, and require as little maintenance as possible, while providing the desired degree of treatment.

BASIC PROCESS DESCRIPTION

Stewart (3) defines activated sludge wastewater treatment as involving "physical and biological processes in a system having special configuration and operation such that the wastewater is substantially purified and rendered less reactive." The basic activated sludge system includes an aeration tank and settling tank, as shown in Figure 1. Untreated wastewater enters the aeration tank where biologically degradable materials are stabilized by microorganisms (activated sludge). The aeration tank mixture (mixed liquor) is displaced to the settling tank where the activated sludge settles to the bottom and is returned to the aeration tank. The treated wastewater leaves the process as overflow from the settling tank. Excess cell material produced is removed from the system either by deliberate wasting of sludge or unintentional wasting of suspended solids in the settling tank overflow.

Many variations in the activated sludge process are possible and most of these are described by Stewart (3). Discussion here will be limited to the extended aeration process which is a long detention form of the activated sludge process. In extended aeration the aeration tank detention may vary from 1/2 to 3 days but is usually 1 day.

The design of activated sludge waste treatment processes basically requires knowledge of three factors: organism growth rate or process reaction time; cell yield or excess sludge production; and endogenous respiration or auto-oxidation rate. Organism growth rate generally does not enter into design considerations for the conventional or extended aeration activated sludge treatment at normal temperatures because it is not a limiting factor in the process. Cell yield and auto-oxidation rate are utilized in the growth kinetics equation as follows:

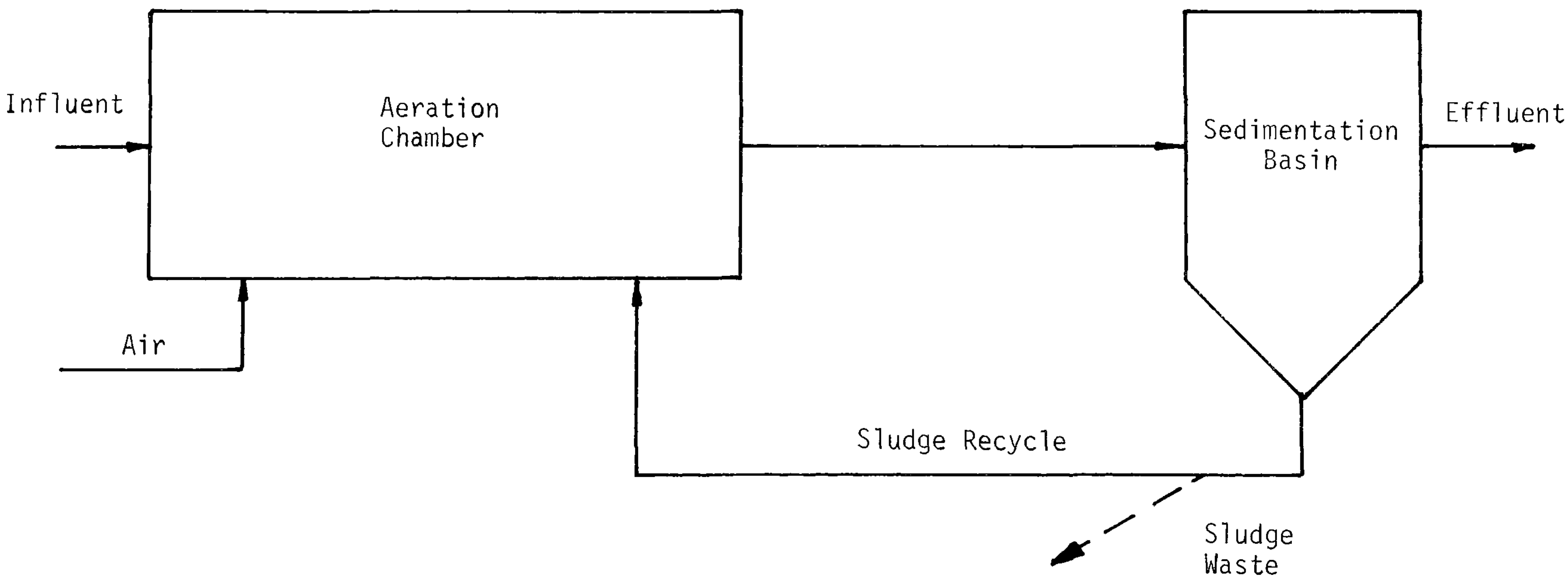


FIGURE 1

BASIC ACTIVATED SLUDGE TREATMENT PROCESS

$$\frac{\text{Kg excess volatile sludge}}{\text{day}} = \frac{c(\text{Kg BOD removed})}{\text{day}} - k(\text{Kg volatile sludge})$$

Net Growth = New Growth - Endogenous Increase

The cell yield (c) represents the ratio of new cells produced per unit weight of biochemical oxygen demand (BOD) removed from the wastewater. The endogenous respiration rate (k) represents the decrease in cell tissue in the process due to self-destruction of cellular material. The volatile sludge present in a system is generally measured by the weight of volatile suspended solids (VSS).

An important parameter in biological treatment of wastewater is the food to microorganism ratio (Kg BOD/Kg MLVSS Day) which varies considerably for the different variations in the activated sludge process. The conventional activated sludge process operates at an organic loading factor varying from 0.2 to 0.5 Kg BOD/Kg MLVSS Day, with a volumetric loading factor of about 0.56 Kg BOD/Day cubic meter (35 lb BOD/Day 1000 cubic feet) of aeration tank capacity. Excess sludge disposal for normal domestic sewage is about 1.5 percent of influent flow and BOD removal efficiencies are 80 percent or better.

The extended aeration process operates at loading factors ranging from 0.05 to 0.2 Kg BOD/Kg MLVSS Day, or about 0.32 Kg BOD/Day cu m (20 lb BOD/Day 1000 cu ft) of aeration tank capacity. Extended aeration BOD removal efficiencies approach those of conventional activated sludge when sludge wasting is practiced. When excess volatile sludge, produced in the extended aeration system, is allowed to go out with (wasted in) the process effluent, percentage BOD removals are lower, ranging upward from 50 percent.

SECTION IV

FACILITIES AND METHODS

COLD ROOM BENCH SCALE REACTORS

Controlled temperature laboratory studies, using bench scale activated sludge units were conducted at the Arctic Environmental Research Laboratory from 1969 to 1971.

Initial activated sludge studies were carried out on a laboratory scale using two cone reactors, manufactured by the Pope Scientific Company. The 5 1/2-liter units consisted of two concentric cones and a center tube as shown in Figure 2. Aeration and mixing were supplied by porous ceramic diffusers which caused the mixed liquor to circulate around the inner cone. Effluent rose through the center tube, 25 cm (10 in.) in length, where solids separation took place. The reactors were modified slightly to replace the original vacuum effluent drawoff design with an overflow device as shown. Effluent was collected in plastic containers. Holter Perfusion Roller Pumps were used for feeding. The feed rate of these pumps could be varied from 0.33 to 1600 ml/min with a full scale accuracy within $\pm$ 1 percent. These units had two pumping tubes which permitted simultaneous pumping from two sources.

The reactors were fed from 76-liter (20-gal.) plastic containers as shown and the feed kept uniformly mixed with a paddle-type mixer. The desired mixed liquor temepratures were maintained by placing the equipment in refrigerated, walk-in, constant temperature rooms.

A 33.7-liter (8.9-gal.) activated sludge reactor, as shown in Figure 3, was fabricated to study settling characteristics of settling tubes (clarifiers) at controlled temperatures. The Neptune Microfloc Company developed tube settlers for use in water treatment and has conducted studies to evaluate them for use in activated sludge separation (4). A schematic of the reactor and associated equipment is shown in Figure 4. Two settling tubes were provided, each 5 cm (2 in.) square and 1.2 m (48 in.) long and inclined at an angle of 60 degrees. Each tube also had an effluent drawoff. The reactor was designed to provide a circulation pattern sweeping down in front of the tubes to carry the settled sludge away. A tank of approximately 230 liters (60 gal.) was constructed for feeding the reactor and the contents kept completely mixed with a circulating pump, drawing from near the bottom of the tank and returning to the bottom of the hopper, as shown. During periods when the cold room temperatures were increased above 4°C, the feed tank contents were kept cool with a Blue M refrigeration unit. Holter pumps were used for feeding the reactor and for controlling the effluent flow from the settling tubes.

A second reactor of 47.1 liters (12.5 gal.) was fabricated to further study tube settler characteristics and is shown in Figures 5 and 6. The settling portion of the reactor consists of one 10 cm x 8.9 cm x 1.8 m (4 in. x 5 in. x 70 in. long) tube with an individual drawoff and two

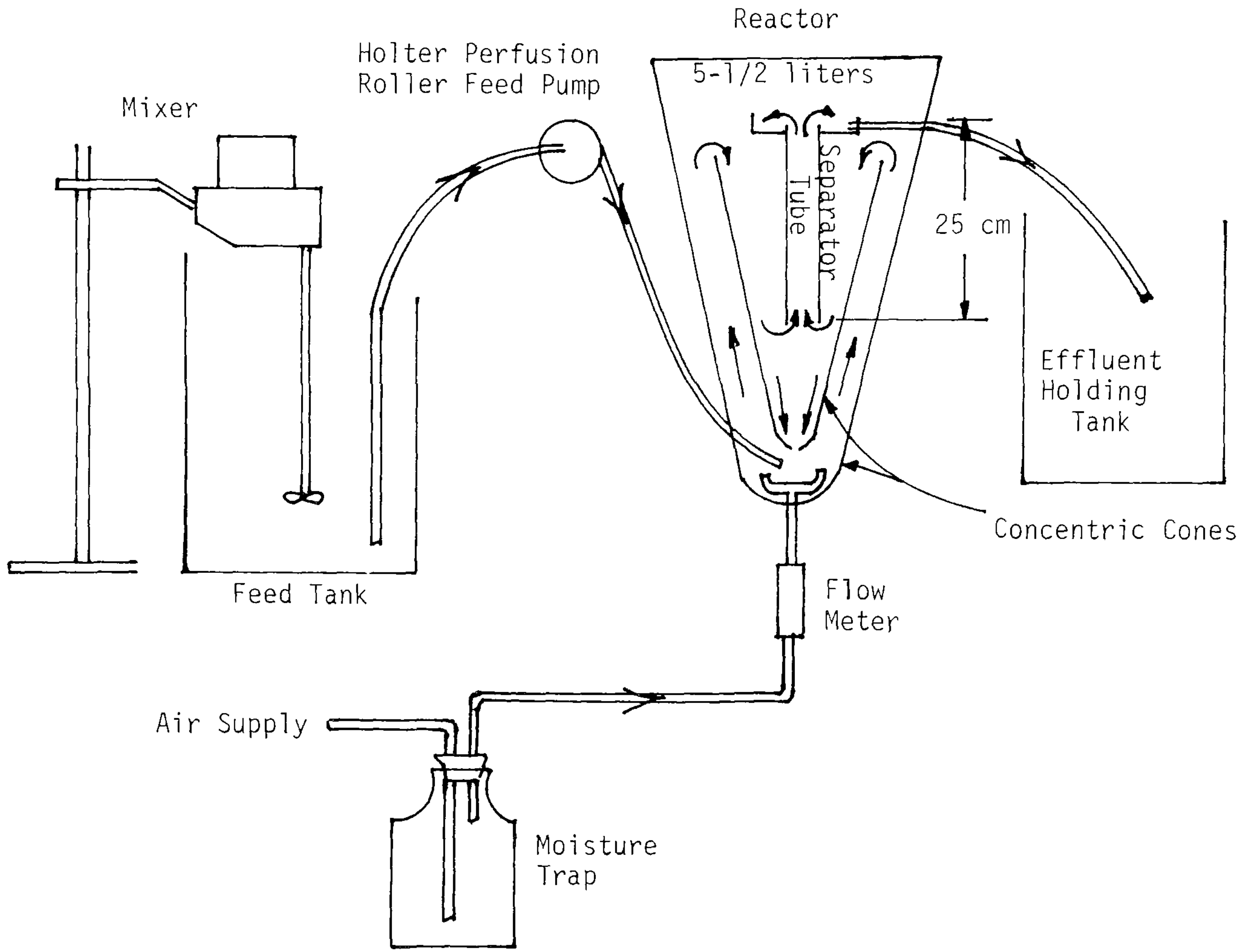


FIGURE 2

CONE REACTORS*
SCHEMATIC OF APPARATUS

*As manufactured by Pope Scientific

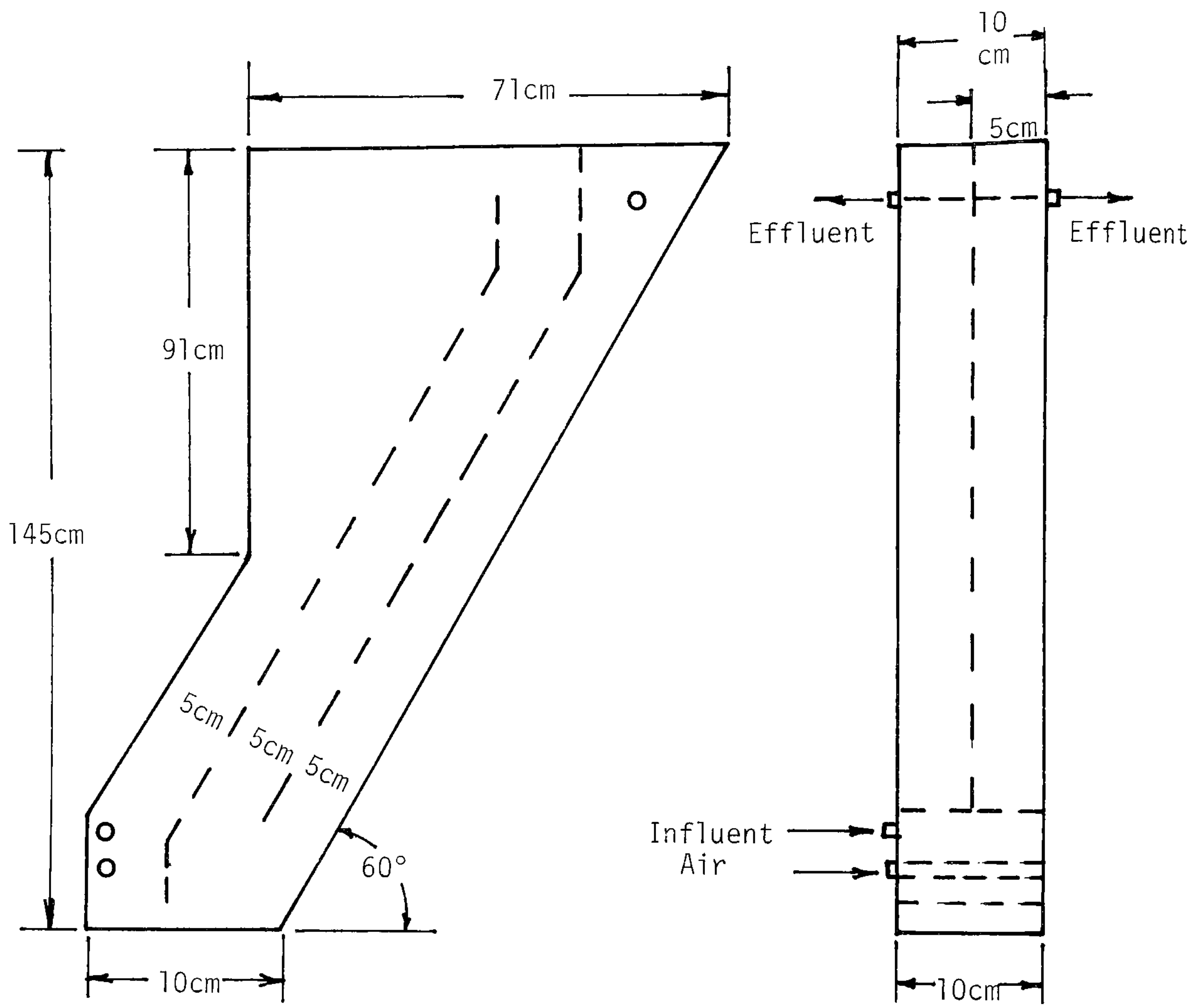


FIGURE 3

33.7-LITER (8.9-GALLON) REACTOR DETAILS

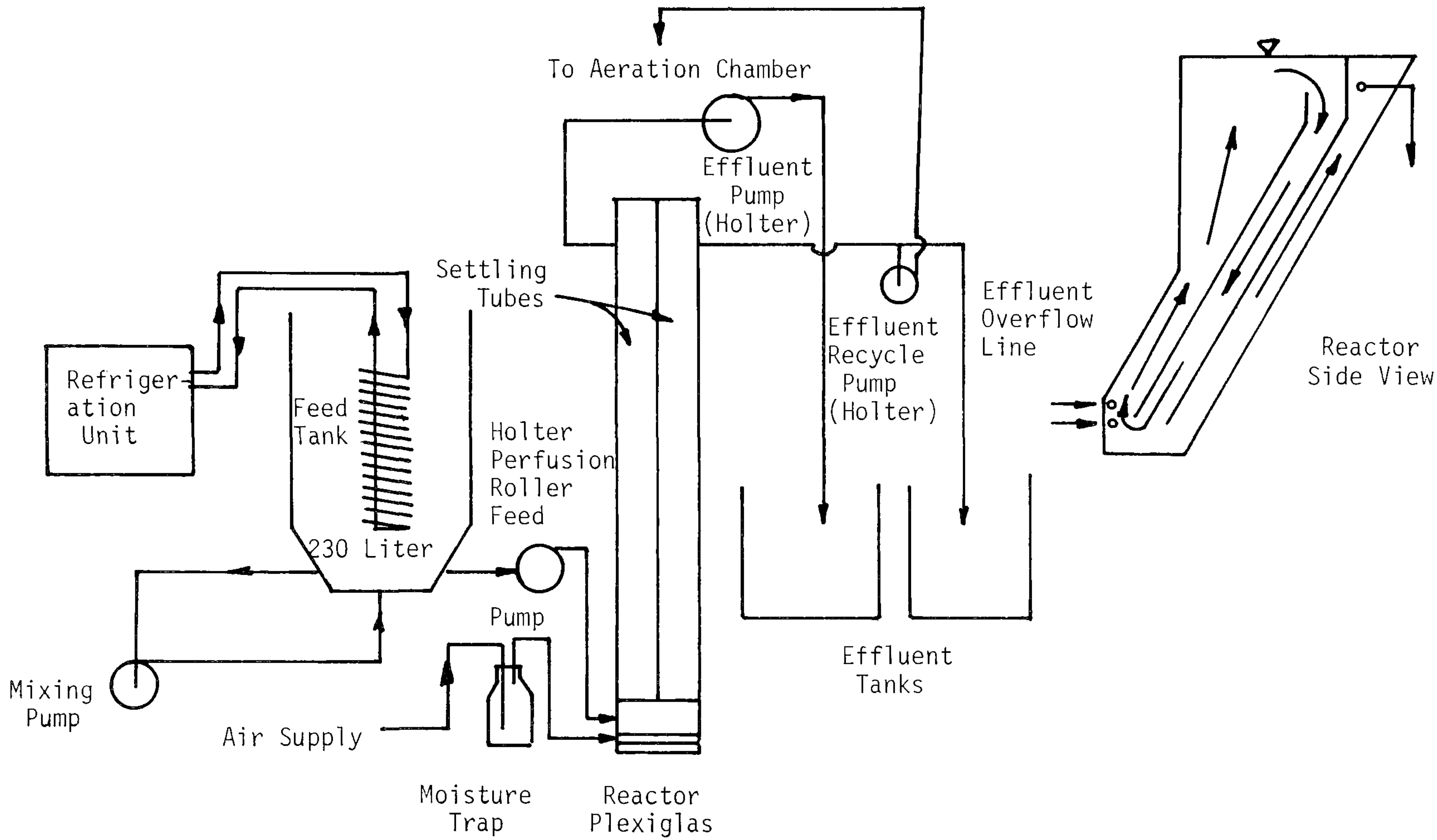


FIGURE 4

33.7-LITER (8.9-GALLON) REACTOR
SCHEMATIC OF APPARATUS

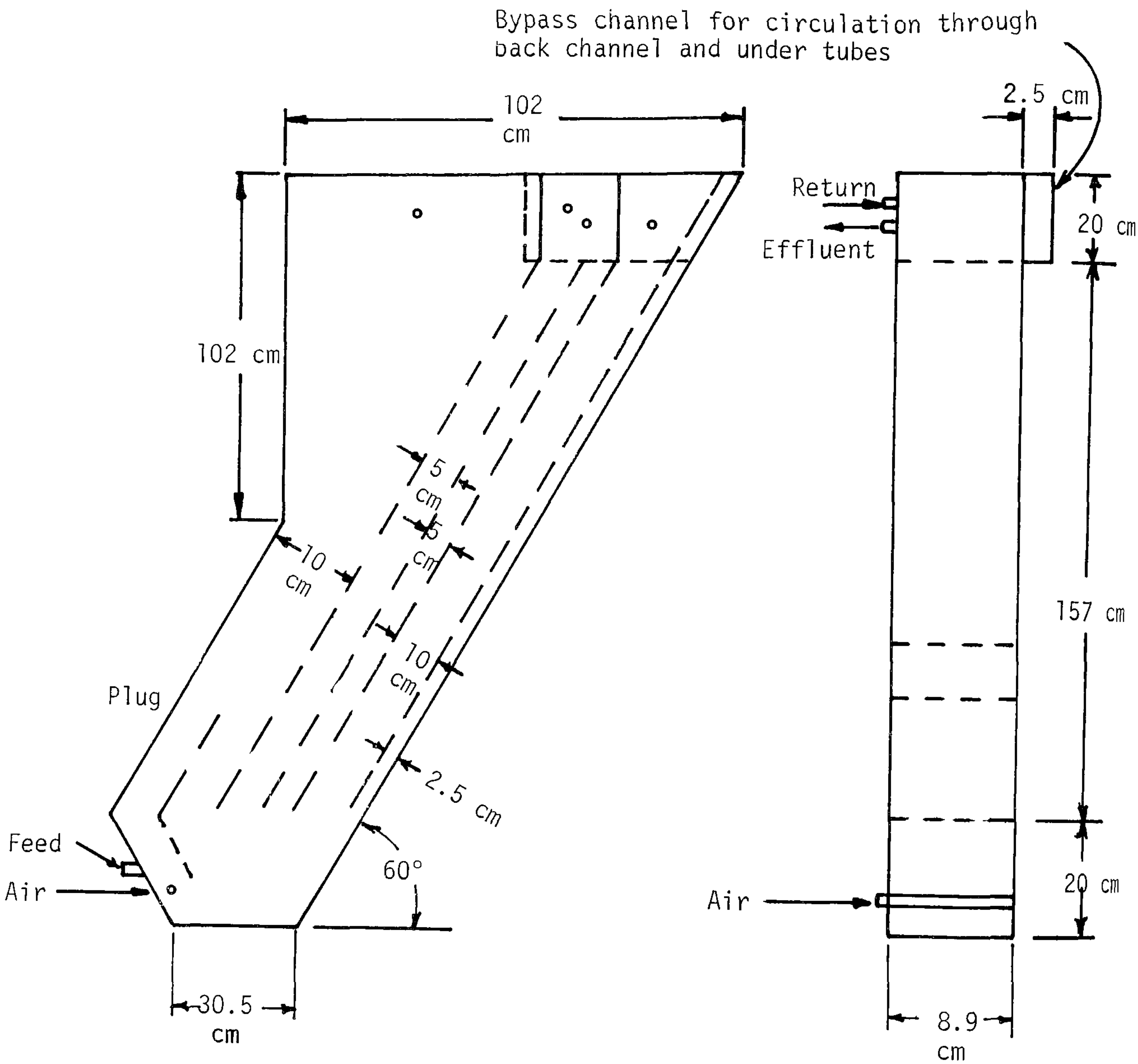


Figure 5

47.1-LITER (12.5-GALLON) REACTOR DETAILS

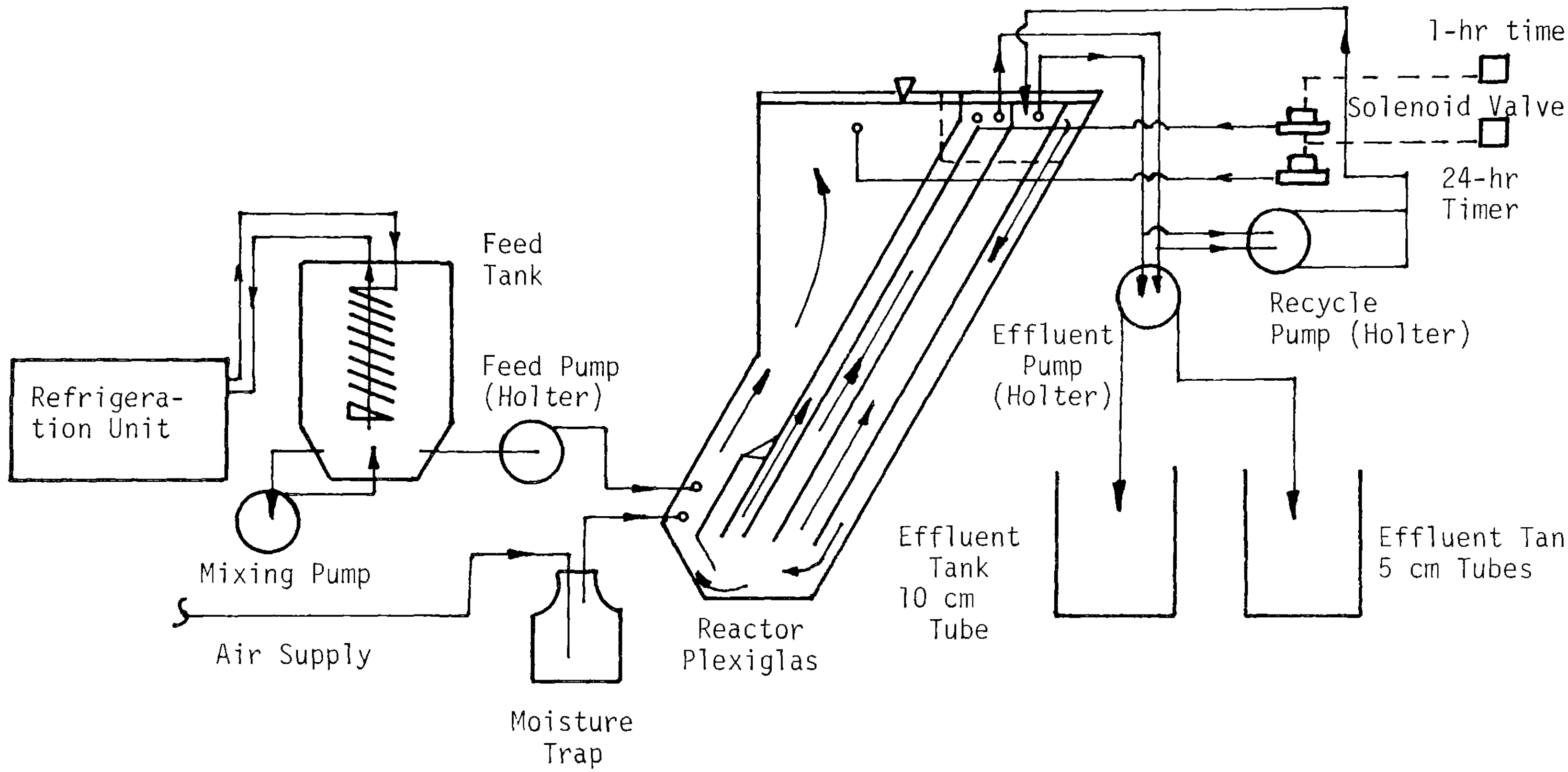


FIGURE 6

47.1-LITER (12.5 GALLON) REACTOR
SCHEMATIC OF APPARATUS

5 cm x 8.9 cm x 1.8 m (2 in. x 3.5 in. x 70 in.) long tubes with a common effluent drawoff. This reactor was fed in parallel with the other tube settler reactor from the same feed tank. Holter pumps were used for feed and to control the effluent rates.

The cone reactors were monitored primarily for biokinetic information and samples collected on Monday, Wednesday and Friday. Routine analyses included influent and effluent BOD's, mixed liquor and effluent suspended solids (SS), and volatile suspended solids (VSS). Nutrient analyses were made on the influent and effluent samples on a weekly basis during the second half of the study period and included ammonia, nitrite, nitrate, and organic nitrogen, and total and orthophosphates.

Feed consisted of effluent from the Eielson Air Force Base primary treatment plant. The feed was brought to the Laboratory in 19-liter (5-gal.) containers and held in the constant temperature room overnight before feeding. Samples were taken of the feed tank contents immediately after feeding, again before the next feeding, and the two results averaged to provide influent data for the sampling period. Effluent was collected in the plastic containers and samples taken at the end of the sampling period.

Essentially, the same procedures were followed with the tube settler reactors as with the cone reactor units with the exception that sampling was done on a daily basis. Feed consisted of effluent from the Eielson Air Force Base primary plant which was brought to the laboratory in 57-liter (15-gal.) containers and held overnight in a cold room at 1°C before feeding. Samples were collected 7 days per week at the beginning of the study and reduced to 5 days per week later. BOD and COD analyses were run routinely on the influent and effluent samples and Tuesdays and Thursdays on the reactor mixed liquor samples. Suspended solids and volatile suspended solids were performed daily on the influent and mixed liquor samples. Suspended solids analyses only were performed on the effluent because of difficulty in obtaining reliable VSS figures at low concentrations. Total solids and total volatile solids analyses were done on the mixed liquor only. Effluent for each sample period was collected in 114-liter (30-gal.) plastic containers. After sampling, the effluent containers were emptied and collection for the next sample period begun.

A limited number of nutrient and coliform determinations were made on the influent and effluent samples at times consistent with the study schedules of the reactors. Microscopic examinations of the reactor contents were made on irregular basis at times when apparent or suspected changes in the mixed liquor had occurred. The examinations consisted of general observations on the relative quantities of protozoa present and the degree of activity. BOD, COD, and solids analyses were done in accordance with <u>Standard Methods</u> procedures (5). Coliform counts were made by the membrane filter method as described in <u>Standard Methods</u> and nutrient analyses made in accordance with Federal Water Quality Administration Standards (6).

EIELSON AIR FORCE BASE PILOT PLANTS

In cooperation with the Alaskan Air Command, the Arctic Environmental Research Laboratory constructed and operated a pilot waste treatment facility at Eielson Air Force Base (EAFB). The facility included an aerated lagoon and an extended aeration basin. The purpose of this facility was to increase the knowledge of biological waste treatment at cold temperatures and to develop design criteria.

EAFB is located 35 Km (22 miles) southeast of Fairbanks and has a similar subarctic climate. The mean annual temperature at Fairbanks is approximately 4°C (25°F) with a minimum and maximum recorded temperatures of 55°C (66°F) and 38°C (+99°F), respectively (7). The area has approximately 200 days per year with temperatures below freezing (0°C).

The initial extended aeration pilot plant studies conducted at EAFB were performed in a 570-cu m (∿150,000-gal.), inverted, truncated pyramidal basin with low sloping sidewalls. The side slope ratio was 1:2 (8). Two submerged tube settler modules, 1.2 x 1.5 m (4 x 5 ft) surface area, were used as the sludge separation and return devices. Because of extreme subarctic winter conditions, tube settler modules were much undersized in comparison to the aeration basin. Operating these settler modules at an overflow rate of 20 lit/sq m/min (0.5 gal/sq ft/min) limited the hydraulic detention to a minimum of approximately 5 days, causing excessive icing problems in a basin with such a large exposed surface-to-volume ratio. Because of the many operational problems associated with this system, it was decided to use a more conventional configuration for pilot extended aeration units.

A large, concrete, vertical wall tank, 9 x 9 x 4.6 m (30 x 30 x 15 ft) deep nominal dimensions, was divided into two equal-size pilot extended aeration treatment units (Figure 7). The units were sized to operate any nominal detention from 1/4 to 4 days, and were differentiated by the clarifier design. The south unit had a conventional horizontal flow type clarifier. The north unit, hereafter called the up side, had a rectangular upflow type clarifier with tubes. Aeration in the up side was provided by 27 Walker process (W.P.) "monospargers." The monospargers were set up in such a way (Figure 7) that either 1/3, 2/3 or all could be operated at any one time. Sludge return was accomplished by means of 10-cm (4-in.) and 15-cm (6-in.) air lifts. Suction for the 10-cm air lift was taken from the bottom of the hoppers in the clarifier, one hopper per each airlift. The 15-cm auxilary airlifts which did not have suction manifolds were provided to remove any heavy sludge concentrations below the tubes. The flow pattern in the up side (Figures 7, 8 and 9) was such that the mixed liquor flows over the surface of the clarifier in three horizontal troughs, down behind the tube section in a downflow channel, exiting just below the tubes but above the hoppers. Heavy suspendeds immediately fall into the hoppers and effluent flows up through the tubes. Sludge that falls into the hoppers is collected by the airlifts and returned to the aeration basin. Above the tubes, effluent is collected in a submerged manifold. The section above the tubes was divided into three parts for the purpose of backwashing the tubes, 1/3 at a time. During a backwash cycle, approximately 1 hour per day, effluent is drawn through 2/3 of the tubes to backwash the other 1/3.

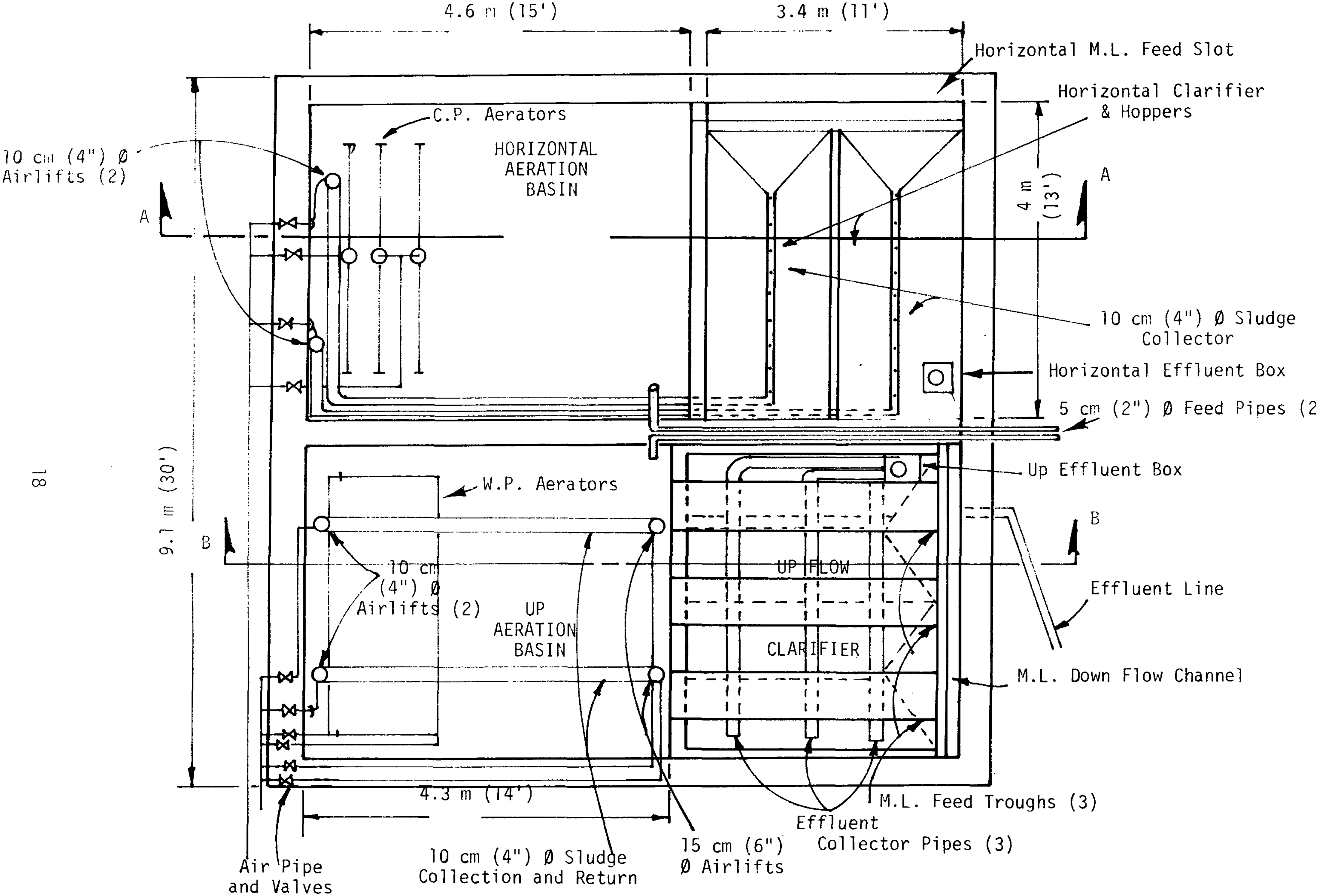
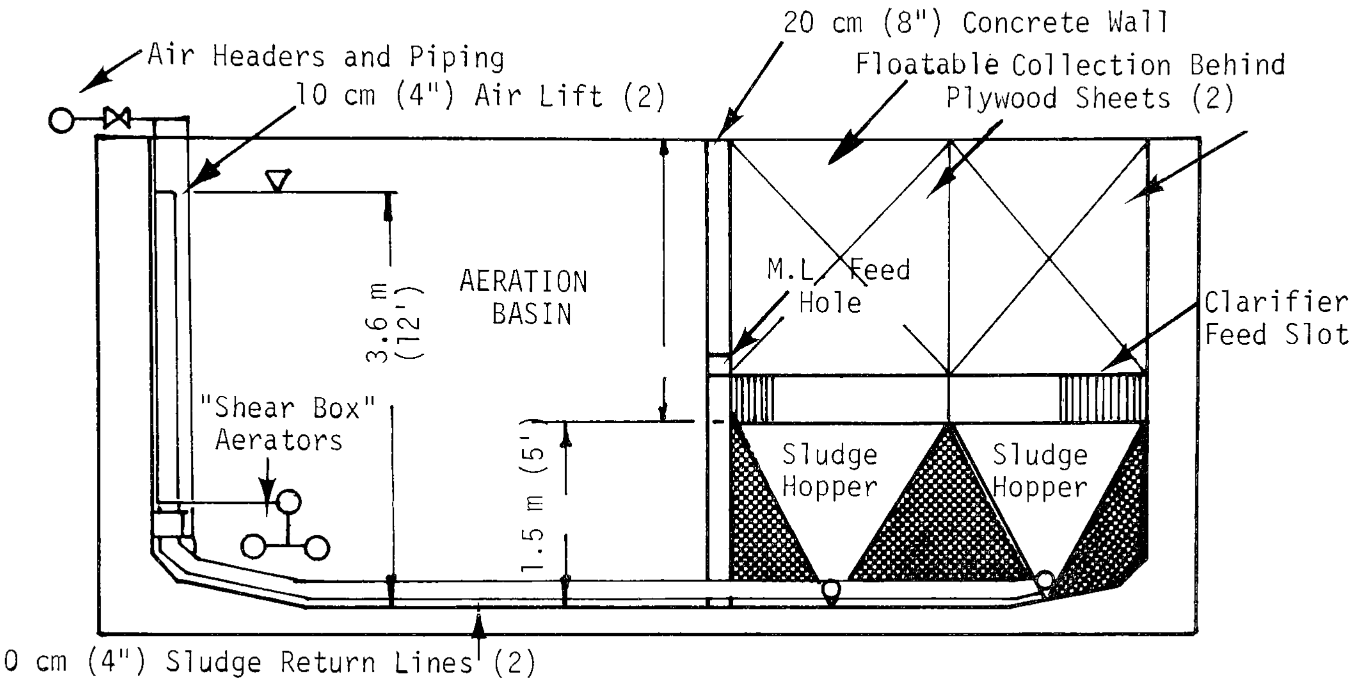
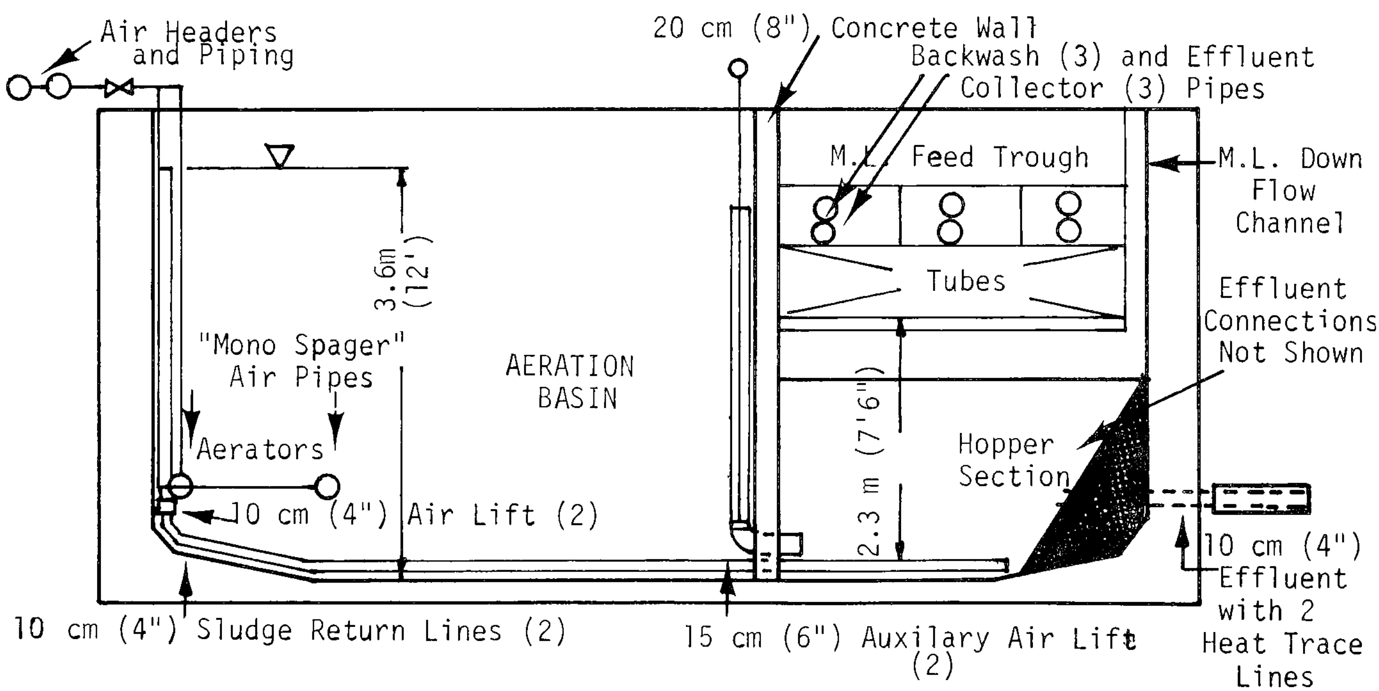


FIGURE 7. EIELSON AIR FORCE BASE EXTENDED AERATION PILOT PLANTS

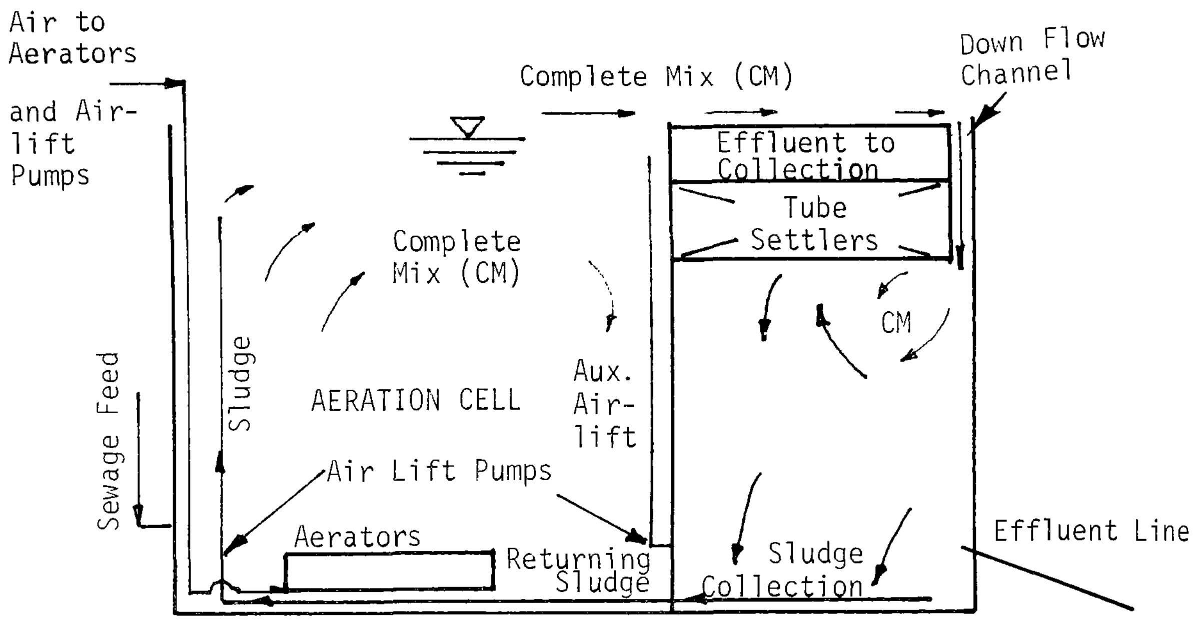


HORIZONTAL SIDE SECTION AA



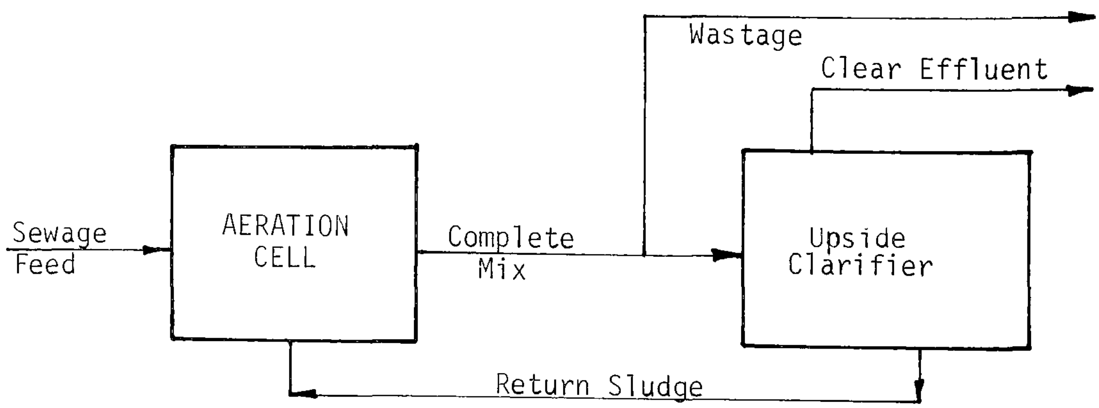
UP SIDE SECTION BB

FIGURE 8. EIELSON AIR FORCE BASE EXTENDED AERATION PLANTS--SECTIONS



AERATION CELL WITH TUBE SETTLER CLARIFIER

PROCESS FLOW SECTION



FLOW SCHEMATIC

FIGURE 9

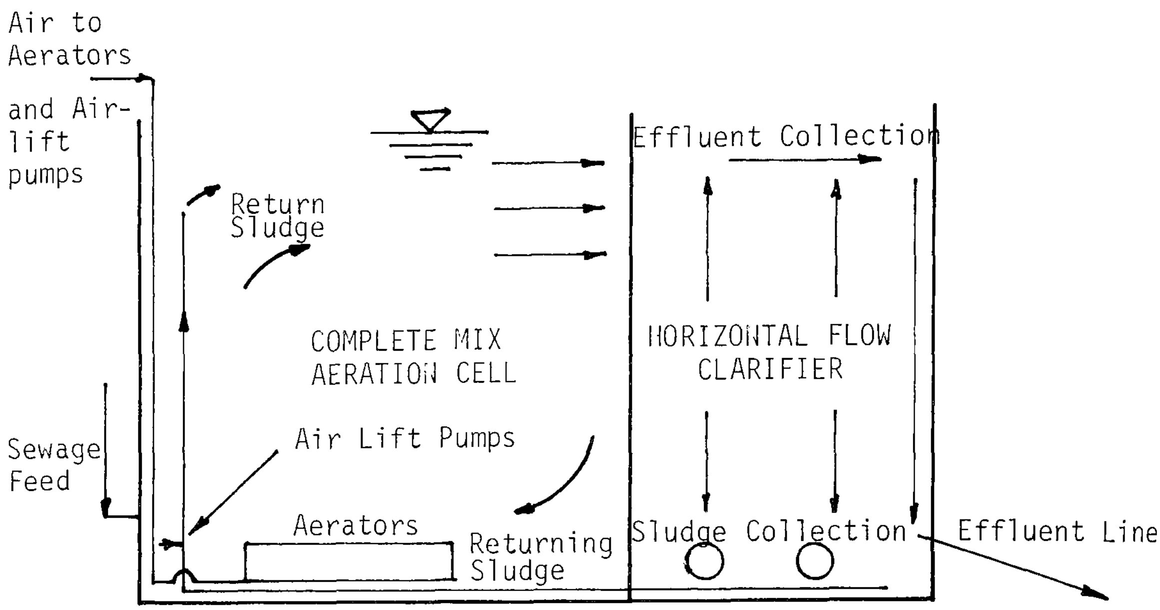
UPSIDE EXTENDED AERATION PILOT UNIT

Feed rates were held constant. To create an artificially high overflow rate, effluent was taken from the clarifiers and pumped back into the aeration basin. The artificial overflow rate plus the effluent rate equalled the total overflow rate.

Initially, raw sewage was used as feed to the extended aeration units. Two 5-cm (2-in.) trash pumps pumped from the aerated grid chamber of the Air Base's existing primary plant to a flow equalizer cooling pond. From the cooling pond, the sewage was pumped at a constant rate with variable speed pumps to the extended aeration units. A cooling pond level control activated the 5-cm trash pumps in the sewage plant. In late October 1971, due to considerable trash pump clogging and down time caused by the raw sewage feed, it was decided to use primary effluent as feed. The trash pumps were then moved to the end of the primary plant's clarifiers. In late December 1971, it was realized that the cold air did not have enough heat absorption capacity to cool the sewage down to 5°C at flow rates through the feed equalizer cooling pond. A spray system was added to this pond which caused considerable ice masses but kept the feed temperature at 5°C or below. Feed (cooled primary effluent in this case) was introduced into the complete mix aeration basins (Figure 7) near the common corner of the basins and clarifiers. Flow rates to the units were varied from 76 to 150 cu m/day (20,000 to 40,000 gal./day). Flow splitting, control and monitoring were accomplished with valves and venturi meters.

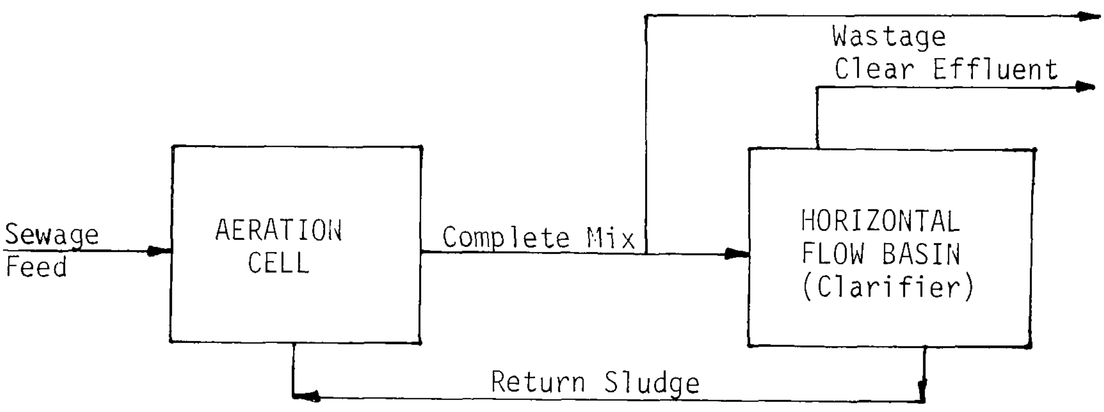
In the horizontal flow side mixed liquor was circulated by the aerators and flowed into the horizontal flow clarifier (Figures 7, 8 and 10) through the horizontal mixed-liquor feed hole and slot. Sludge was collected by a 10-cm (4-in.) manifold in the bottom of each of the two hoppers and returned to the aeration basin by 10-cm airlifts. Effluent and artificial overflow was collected near the surface at the end of the horizontal flow clarifier. Artificial overflow was created in the same manner as for the upflow section. Aeration in the horizontal side aeration section was accomplished by means of 30 Chicago Pump (C.P.) shearfuser aeration boxes which were divided into 2/3 and 1/3 sections such that the air rate would be varied over a wide range. As can be seen in Figures 7 and 10, the aeration basins and clarifiers shared common walls. The basin walls were reinforced concrete. All air lift sludge returns were mounted in the aeration basins, the end of their discharge pipes terminated just at water level. Air lines were steel pipes while sludge and airlift pipes were plastic. The 60° sludge hoppers were sheet metal. Dead volume between hopper and concrete walls was filled with sand. The horizontal flow clarifier feed slot, as shown in Figure 8, is about 3.05 decimeters (1 ft) high and consists of vertical 2.5 x 15 cm (1 x 6 in.) wood slats placed 5 cm (2 in.) on center.

The aeration basins of both units were exposed to the environment. The clarifier sections were housed in an insulated, unheated A-frame building. During extreme cold periods (<-40°C or °F), limited heat was applied to prevent freezing of the sampling systems. The A-frame was an equilaterial triangle covering both clarifiers, approximately 3.7 x 9.2 m long (12 x 30 ft). The A's were 5 x 15 cm x 3.7 m, 0.6 m on centers (2 x 6 in. x 12 ft, 24 in. on centers). Roof panels were of sandwich construction with



AERATION CELL WITH HORIZONTAL FLOW CLARIFIER

PROCESS FLOW SECTION



FLOW SCHEMATIC

HORIZONTAL FLOW EXTENDED AERATION PILOT UNIT

Figure 10

5 cm (2 in.) of urethane foam between two 1.2 x 2.4 m (4 x 8 ft) plywood sheets.

Feed and effluent samples were 24-hour composites, composited on the basis of time and flow. Mixed liquor suspended solids were always grab samples. From start-up in September to early November 1971, the BOD and COD analyses were run once per week and suspended solids run once or twice per week. Starting in November 1971, COD and suspended solids analyses were run three times per week. BOD's were always run once per week. In December 1971, the mixed liquor suspended solids were run daily and effluent suspended solids were also run daily shortly thereafter. Starting the week of January 10, 1972, feed and effluent COD's were taken daily and frozen on the site. BOD's and volatile suspended solids were run only on Wednesdays. Effluent BOD's and percent removals for all weekdays except Wednesdays were based upon daily COD's and the COD/BOD ratio as calculated weekly from the Wednesday's samples. The following parameters were measured daily: 2-liter settlometer tests at 5, 15, 30 and 60 minutes; outside ambient temperatures; airflow and pressure; and sludge wastage pump rates. Feed rates were recorded and adjusted daily. Rhodamine (R-HB) dye was injected with the feed to qualitatively define flow patterns.

BOD and solids analyses were begun within 4 hours of sample collection. COD samples were usually frozen until enough samples were accumulated for economical analysis. All analyses were performed in accordance with Standard Methods (5) and/or FWPCA-Methods for Chemical Analysis of Water and Wastes (6).

The analytical data for the EAFB pilot units are summarized in a computer printout which may be obtained by contacting the author. This printout contains listings, daily in some cases, from September 1971 to May 1972, of process parameters and chemical analyses. The tabulated parameters are: feed strength: total coliforms, BOD, and COD; organic loading and detention: mass BOD/mass MLSS/day and days; mixed liquor; solids temperature, DO, settling rate, age, and wastage; clarifier loadings, lit/sq m/min.; effluent strength and removals: total coliform, BOD, COD, and solids. Weekly COD to BOD ratios and major perturbations are also listed.

OXIDATION DITCHES

There is only one oxidation ditch in Alaska for which any performance data are available. This ditch, owned and operated by College Utilities Corp., is 4 miles west of Fairbanks and serves the University of Alaska, an elementary school, and a residential area. This ditch is exposed to the environment and has a volume of 1200 cu m (0.3 MG) at a depth of 1.3 m (4.3 ft). The clarifier is enclosed in an unheated building and has a sludge return, but no wastage system. A housing has been provided over the two rotors. A diagram of this oxidation ditch is shown in Figure 11.

Performance data for this ditch were extracted from the reports of Grube and Murphy (9) and Murphy and Ranganathan (10). Their analytical methods

DIMENSIONS

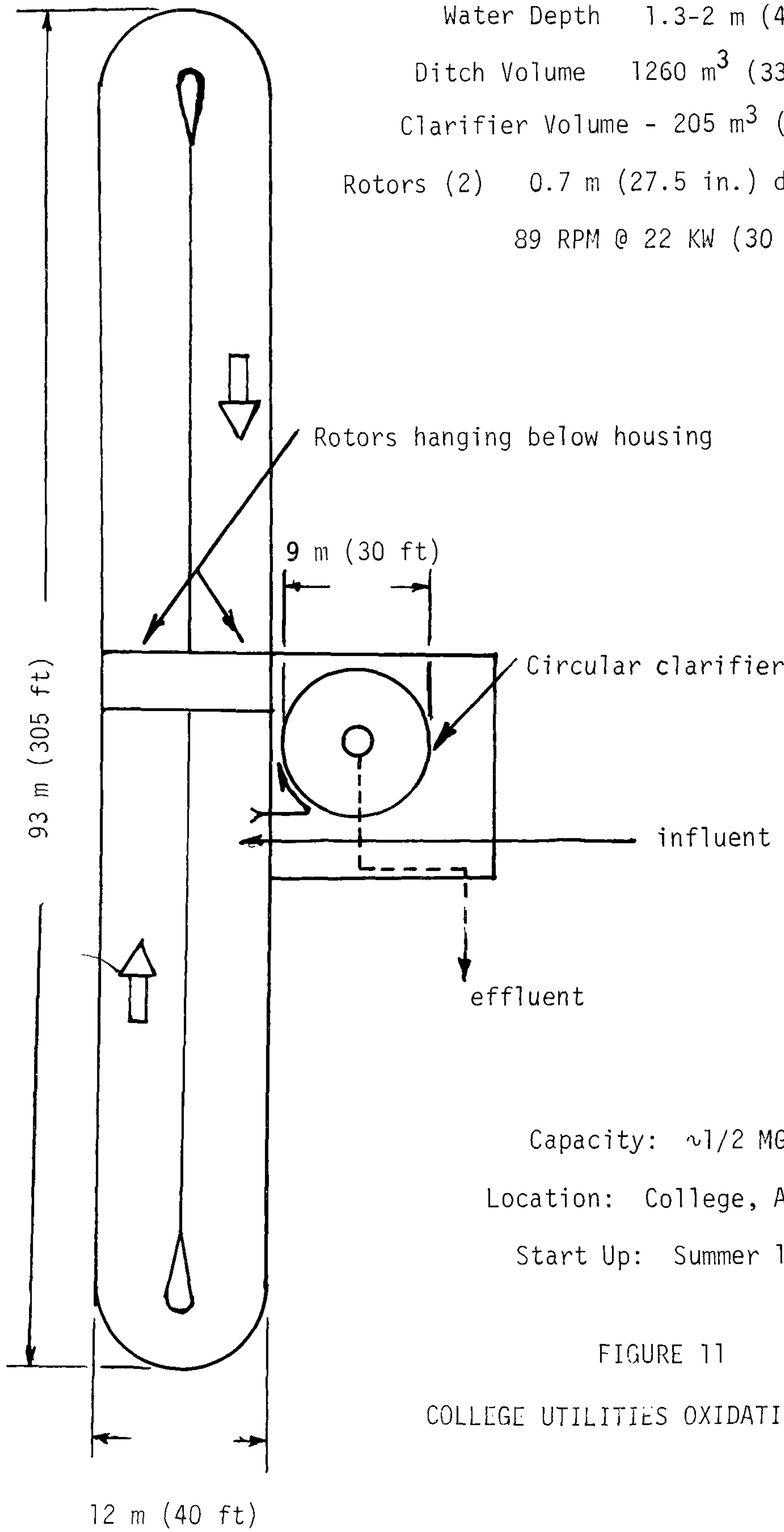
Water Depth 1.3-2 m (4.3-6 ft)

Ditch Volume 1260 m^3 (333,000 gal.)

Clarifier Volume - 205 m^3 (54,000 gal.)

Rotors (2) 0.7 m (27.5 in.) dia x 4 m (13 ft)

89 RPM @ 22 KW (30 HP)



Capacity: ~1/2 MGD

Location: College, Alaska

Start Up: Summer 1965

FIGURE 11

COLLEGE UTILITIES OXIDATION DITCH

were performed in accordance with Standard Methods procedures (5), and with the use of an electronic DO instrument.

The Minnesota Department of Health has reported on an oxidation ditch under cold temperature conditions. This ditch serves the city of Glenwood which is located about 120 miles northwest of Minneapolis. The ditch loop was build in a horseshoe shape; total loop length was about 386 m (1265 ft). The ditch was 3.8 m (12.5 ft) wide at the bottom and 5.6 m (18.5 ft) wide at the surface at the nominal 0.9 m (3 ft) operating depth. Total capacity at operating depth was 1700 cu m (0.44 MG).

Performance data for this ditch were extracted from the Department of Health report (11).

SECTION V

OPERATION AND PERFORMANCE

COLD ROOM REACTORS

Results of operation of the bench scale cone reactors are summarized in Tables 1 and 2. Filtered effluent represents the effluent sample run through a filter pad (used in separation of membrane filter pads in packaging) which was coarse enough to leave bacteria for seed in BOD determinations yet reduce the suspended solids to essentially zero. BOD determinations on the filtered effluent samples were performed to obtain a rough determination of the amount of dissolved organic material removed.

Both biological sludges were relatively easy to establish. The 6.5°C reactor had been operating for approximately 6 months before this series of sampling was begun. The reactor, operating at 1.3°C, was placed in operation approximately 6 weeks before sampling began and seeded with material that had been aerated in the cold room in a 19-liter (5-gal.) container which was batch fed periodically with domestic sewage. The reactor runs were started with the longest detention time first and the times decreased in chronological order. The 1.3°C reactor did not become stabilized until the shorter detention times were reached, as evidenced by the MLSS buildup as time progressed.

There was apparently little difference in the biological activity at the two temperatures; however, operation of the reactor at 6.5°C was more erratic. These reactors were operated with a clarifier overflow rate less than 7.1 lit/sq m/min (0.17 gal./sq ft/min). Both reactors generally practiced "autoinduced sludge wasting" in the same manner as the College Utilities oxidation ditch as described by Grube and Murphy (1). The MLSS would build up to a point and begin to pass solids for 1 or 2 days and then repeat the cycle. The cycle was repeated with 2 to 3 weeks as opposed to the monthly occurrences reported by Grube and Murphy.

The reactors differed in their manner of passing solids, with the 1.3°C reactor generally having a much more turbid effluent and the 6.5°C reactor having a relatively clear effluent. Heavy solids passed from the 6.5°C reactor by rising in the settling tube as a solid mass. As the concentration of solids in the mixed liquor increased, the level of solids in the settling tube would rise until spilling over into the effluent tank. After passing an undetermined amount of solids, the cycle would be repeated. A gradual drop in pH was noted in the 6.5°C unit as the suspended solids began to build before discharging. The pH dropped from slightly above 7 to values of 6.6 to 6.7. The pH of the 1.3°C unit consistently remained around 7.4.

The 6.5°C effluent solids settled to the bottom of the effluent tank leaving a clear liquid above; whereas, the 1.3°C effluent solids did not settle out to any degree. As the 1.3°C reactor became more stabilized,

TABLE 1

DATA SUMMARY

1.3°C Cone Reactor
Feed: Primary Plant Effluent

Detention Time (hrs)	21	15	13	9
Influent BOD (mg/l)	111	170	201	184
Reactor				
Susp. Solids (mg/l)	1074	1561	2657	2926
Volatile Susp. Solids (mg/l)	890	1324	2212	2402
Filtered Effluent				
BOD (mg/l)	37	11	20	14
% BOD Removal	66	93	90	92
Unfiltered Effluent				
Susp. Solids (mg/l)	29	43	38	82
BOD (mg/l)	40	62	28	44
% BOD Removal	64	64	86	76
Loading Factor $\frac{\text{Kg BOD Feed}}{\text{Kg MLVSS-DAY}}$	0.14	0.21	0.17	0.20
Clarifier Overflow rate liter/m^2 min (gal/ft^2 min)	3.0 (0.074)	4.1 (0.10)	4.9 (0.12)	6.9 (0.17)

TABLE 2

DATA SUMMARY

6.5°C Cone Reactor
Feed: Primary Plant Effluent

Detention Time (hrs)	17	15	13	9
Influent BOD (mg/l)	139	132	153	155
Reactor				
Susp. Solids (mg/l)	2346	1885	1880	2285
Volatile Susp. Solids (mg/l)	1915	1563	1587	1801
Filtered Effluent				
BOD (mg/l)	51.3	16.3	13.3	11.7
% BOD Removal	63	88	91	92
Unfiltered Effluent				
Susp. Solids (mg/l)	11	69	96	45
BOD (mg/l)	53	36	31	33
%BOD Removal	62	73	80	79
Loading Factor $\frac{\text{Kg BOD Feed}}{\text{Kg MLVSS Day}}$	0.10	0.14	0.18	0.23
Clarifier Overflow rate Liter/m^2min	3.7	4.1	4.9	6.9
(gal/ft^2 min)	(0.091)	(0.10)	(0.12)	(0.11)

the effluent became less turbid and the MLSS began to increase. The 6.5°C reactor operation was less stable, with the maximum level of MLSS generally not rising above 2300 mg/l as opposed to 3000 mg/l for the 1.3°C reactor.

Overall results of operation of the 33.7-liter and the 47.1-liter tube settler reactors are presented in Tables 3 and 4. These reactors were operated at 12 and 24 hour hydraulic detention times with daily sludge wasting to maintain the MLSS at 4000 mg/l. Sludge wasting was accomplished by drawing off the required amount of mixed liquor, a portion of which was used for a solids analysis to determine the exact amount of solids removed. Loading and wastage values are approximate since they do not reflect the variable quantity of solids in the clarifier. Clarifier overflow rates were varied from 4 to 35 lit/sq m/min (0.1 to 0.8 gal./sq ft/min) by pumping some of the effluent back into the mixed liquor.

Effluent BOD and COD values of 9 to 21 mg/l and 46 to 96 mg/l, respectively, indicate that a considerable amount of biological activity takes place at low operating temperatures. Effluent organics were well stabilized as indicated by the high COD/BOD ratios which varied from 7.7 to 3.7. These compared with influent COD/BOD ratios of 1.8 to 1.5. Amounts of sludge wasted varied from 0.42 mg suspended solids/mg BOD removed at the low temperatures to 0.14 at 10.5°C and 24-hour detention time. The pH of both reactors ranged from 7.2 to 7.6 during the sample periods reported.

EIELSON AIR FORCE BASE UNITS

Organic removal performance of the EAFB extended aeration units is summarized in Figure 12 for the horizontal flow clarifier, and Figure 13 for the upflow clarifier side. These graphs, percent BOD removal, and temperature vs. date, include a running account of the operational perturbations to which the systems were subjected. The data are broken down into three periods: a high and low temperature range at a high organic loading, and a low temperature range at a low organic loading.

These data periods were selected to arbitrarily exclude unsteady state conditions due to startup, and the changing of major operational parameters such as detention time and temperature. Rhodamine-B dye, which was injected to define flow patterns, tended to upset the system. Most of the dye poison data, when effluent BOD was greater than feed BOD, was excluded in the period III summary for the up side.

The dates of the time periods for steady state analyses are:

Period/temperature/loading	Horizontal side	Up side
I/7-19°C/High	10-25-71 to 12-21-71	10-25-71 to 12-21-71
II/2-9°C/High	1-20-72 to 2-26-72	2-1-72 to 2-26-72
III/1-8°C/Low	3-23-72 to 5-1-72	3-20-72 to 4-20-72

TABLE 3

SUMMARY OF RESULTS OF 33.7-LITER REACTOR AND 47.1-LITER REACTOR AT 12 HR DETENTION

Feed: Primary Plant Effluent

	REACTOR TEMPERATURE (AVG°C)			
	0.6	2.9	3.8	8.0
Reactor MLSS (mg/l)	4160	4097	4076	3737
% VSS	80	80	81	80
BOD	2489	2503	1477	1299
COD	5648	5788	5260	4705
Loading: $\frac{\text{Kg Infl. BOD}}{\text{Kg MLVSS-Day}}$	0.12	0.10	0.10	0.14
Sludge Wasted: $\frac{\text{mg MLSS}}{\text{mg BOD Removed}}$	0.42	0.33	0.32	0.33
Unfiltered Effluent				
Suspended Solids (mg/l)	18	3	12	5
BOD (mg/l)	21	13	17	9
BOD Removal (%)	89	92	90	96
COD (mg/l)	78	46	67	96
COD Removal (%)	76	73	78	83
COD/BOD Ratio				
Influent	1.7	1.7	1.8	1.5
Effluent	4.2	4.3	4.0	6.3
Reactor	2.3	2.3	3.6	3.6

TABLE 4

SUMMARY OF RESULTS OF 33.7-LITER REACTOR
AT 24-HOUR DETENTION

	REACTOR TEMPERATURE (AVG°C)		
	1.9	6.8	10.5
Reactor MLSS (mg/l)	2595	3872	3896
% VSS	83	83	82
BOD	1693	2105	1808
COD	3712	5019	5178
Loading: $\frac{\text{Kg Infl. BOD}}{\text{Kg MLVSS-Day}}$	0.09	0.07	0.07
Sludge Wasted: $\frac{\text{mg MLSS}}{\text{mg BOD Removed}}$	0.42	0.16	0.14
Unfiltered Effluent			
Suspended Solids (mg/l)	3	4	6
BOD (mg/l)	14	10	10
BOD Removal (%)	93	95	95
COD (mg/l)	51	53	69
COD Removal (%)	83	84	80
COD/BOD Ratio			
Influent	1.5	1.5	1.6
Effluent	3.7	5.3	7.7
Reactor	2.2	2.4	2.9

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The high loading rate was achieved by use of a 1/2-day hydraulic detention. Operating temperatures fluctuated from about 18°C to 7°C from October 4, 1971, to January 3, 1972, depending upon ambient temperature and cooling pond efficiency. After converting to a spray-type cooling pond, the aeration basin temperatures ran from 2-9°C at the higher loading, period II, and from 1-8°C at the lower loading, period III.

For period I (Figures 12 and 13) performance of both units is about comparable and averages above 80 percent BOD removal. Intentional wastage of mixed liquor suspended solids (MLSS) in early November seems to have improved performance. Starvation (lack of feed) and lower mixed liquor temperatures in late December appeared to reduce performance on both sides.

For period II, data from January 1 to about January 23, 1972, are considered to be transitional (unsteady state). The up side 15 cm air lifts were not working during the transition period. For the rest of period II, the up side performance is very poor as compared to the horizontal side; in fact, the up side effluent BOD was usually larger than the influent; i.e., losing activated sludge.

The feed rate was reduced by approximately 1/2 on February 26, 1972, but not until March 20, did the performance for both sides improve. From then on, the performance ranged from 75 to 96 percent BOD removal except for dye poisoning. The horizontal side performed slightly better, probably due to the ability of its clarifier to retain a higher MLSS.

Figures 14 and 15 are chronological plots of mixed liquor and effluent suspended solids. Intentional wastage of MLSS is indicated on these graphs.

The mixed liquor suspended solids fluctuated more widely than did the BOD removal. The drops in biomass population (MLSS) were due to the intentional wastage of the mixed liquor or to autoinduced wastage out of the clarifier. The bacterial population seems to follow the conventional sigmoidal ecological cycle, where the population (activated sludge biomass) increases until some force triggers its decline. Starvation may also alter biomass settleability.

After intentional wastage of mixed liquor (November 1-5), the biomass usually recovered quickly, as can be seen in Figure 14. The up side MLSS did not appear to recover as well as shown in Figure 15. After the December wastage, the MLSS for the horizontal side did not recover for the rest of period II. Autoinduced wastage kept the MLSS $\leq$3,000 mg/l.

The effect of the auxillary 15-cm airlift is shown in the data for the up side on Figure 15. The airlift was off (air line frozen) from about January 1 to January 23, 1972, and the aeration basin mixed liquor suspended solids during that time dropped to less than 300 mg/l. Essentially, all the MLSS was stored beneath the tubes. The airlift problem was the reason period II data analysis for the up side did not start until February 1.

After switching to the 1-day detention (period III) on February 25, 1972, it took approximately 3-4 weeks for the horizontal side mixed liquor suspended

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solids to build up to a good operating level of about 3,000 mg/l as shown in Figure 14. It took a longer time for the up side biomass to reach that level, Figure 15.

The upflow clarifier did not appear to perform as well as the horizontal flow clarifier in period III and was sporadically passing solids causing effluent suspended solids levels to vary from 20 to 100 mg/l. For the horizontal flow side, Figure 14, the effluent suspended solids were generally below 40 mg/l.

In late April, the effect of autoinduced sludge wastage is apparent in the up side, Figure 15. This wastage may have been triggered by the Rhodamine-B dye which was injected on April 6 and April 16. Both units were shut down on May 1, 1972.

OXIDATION DITCHES

Grube and Murphy (9) reported consistent removal efficiencies exceeding 90 percent at liquid temperatures of 2°C and air temperatures ranging down to -49°C (-58°F) for the College oxidation ditch. Detention time in the clarifier was established at 5 hours through a dye study. Retention times in the ditch averaged 2.3 days. No ice cover was reported at any time except during mid-January and early February when transient skim ice formed ahead of the rotor. Ice formation on the rotors did become a problem but was eliminated by hanging rubber mats from the rotor housing to 5 cm (2 in.) above the liquid surface. Influent temperatures averaged 16.6°C with a minimum of 7.5°C.

Monthly autoinduced sludge wasting was reported with the MLSS of the ditch increasing gradually for 3-4 weeks with the effluent suspended solids remaining low. At an undefined maximum mixed liquor concentration, a large mass of solids was discharged for 1 to 2 days and the cycle repeated. Discharged solids showed good settleability and produced no odor. The cause of the discharge was not known.

All reported information for this ditch is summarized in Table 5. Apparently sampling from 1967 through 1969 and 1972 did not catch the effluent when solids were being passed due to autoinduced wastage or operational upsets. The 1969 data are unpublished and supplied by the Institute of Water Resources, University of Alaska. They are from grab samples that were collected from one to six times per month, but in most cases, weekly. The 1972 data was unpublished data supplied by College Utilities Corporation and are from grab samples that were collected, generally once every other week.

For the January through March 1971 data, 2 of the 23 sampling dates have effluent BOD's greater than feed (raw sewage) BOD's. Three of the 17 effluent BOD's are greater than corresponding feed BOD's for the May through July 1971 data.

All the sample sets except two were grab. Sludge return line plugging and anaerobic activity in the ditch may have been responsible for the poor May

TABLE 5

OXIDATION DITCH--COLLEGE, ALASKA

AVERAGE PERFORMANCE DATA

Date: Mo/Yr	Ditch Detn. Days	Liquid Temp. °C	%BOD Removal	MLSS mg/l	Percent Volatile	Overflow Liter/m^2 min ($gal/ft^2/day$)	Effluent SS mg/l
(1) 10/67-3/68	2.0±	10-11	92	1700	--	6.8 (240)	21
(2) 4/69-12/69	----	11-20	91 (5)	2800	--		18
(3) 1/71-3/71	1.0±	8-14	52 (4,5)	1600	71	13 (470)	222 (4)
(3) 5/71-7/71	1.8±	16-20	9 (4,5)	4500 (6)	50	7.3 (260)	588 (4)
(7) 6/72-11/72	0.9±	14-19	82 (5)	4260	--	15± (530±)	35

(1) Grube, G. A. (1)

(2) Unpublished Data, compliments of Institute of Water Resources, University of Alaska

(3) Ranganathan, D. R., and Murphy, R. S. (10)

(4) Data included when activated sludge was passing into effluent

(5) Septic tank sludge not included in influent BOD

(6) Solids in quiescent sections of ditch have exceeded 20,000 mg/l

(7) Data compliments of College Utilities Corporation

through July 1971 performance. Murphy and Rangathan (10) indicated excessive sludge deposition (SS<20,000 mg/l) in quiescent sections of the ditch. A sludge return pump was installed in June 1972. One period of autoinduced sludge wastage into the effluent was noticed between two August 1972 sample dates, but effluent samples were apparently not collected during the suspended solids loss.

The Glenwood, Minnesota oxidation ditch (11) was studied in late January 1965. At the time of the study, the ditch was operating at ∿40 hours detention time with an actual loading of 1.0 Kg BOD/cu m/min (6 lb BOD/1000 cu ft/day) or about half the design loading. The settling tank overflow rate was 15 lit/sq m/min (0.37 gal./sq ft/min), opposed to the design overflow rate of 23 lit/sq m/min (0.57 gal./sq ft/min). During the winter sampling period, the air temperature ranged from -4°C (25°F) to -33°C (-27°F). Mixed liquor temperature in the ditch ranged from 0.°C (32°F) to 2°C (36°F) and averaged 1°C (34°F). Raw sewage temperature ranged from 4°C to 10°C (40° to 50°F). The greatest ice formation occurred during windy weather and covered approximately 75 percent of the ditch with 1.3 to 2 cm (1/2 to 3/4 in.) thick ice which gradually dissipated during calm weather. BOD removals averaged 92 percent over a 4-day sampling period.

SECTION VI

MAJOR FACTORS AFFECTING PERFORMANCE

ORGANIC LOADING EFFECTS

Cold room bench scale data tends to shown that for low organic loads, 0.14 Kg BOD/Kg MLSS/Day or less, temperature has little effect as long as clarifier overflow rate is kept very low, less than 8 lit/sq m/min (0.2 gal./sq ft/min. At loadings less than 0.1, there were no sludge bulking problems. Low temperature performance of the larger field units was much more sensitive to loading.

All the Eielson Air Force Base 1971 and 1972 data, and the 1971 data for the College oxidation ditch are summarized in Table 6--Subarctic Alaska Extended Aeration Units. Of all the parameters affecting low temperature performance, organic loading is the most significant.

For this paper, organic loading (food to mass ratio) is defined as mass of BOD input per day divided by mass of MLSS. It can also be expressed as Feed BOD (mg/l)/MLSS (mg/l)/detention (days). Because the EAFB units had oversized clarifiers in comparison to most extended aeration units, part of the MLSS in the clarifiers was included in the organic loading calculation. Suspended solids in the clarifier sludge blanket varied from 100 to 200 percent of the MLSS concentration; 125 percent was taken as the average ratio.

The following formula was used to calculate the loading on a daily basis:

$$\text{Organic Load} = \frac{\text{mg/l BOD input}}{\left[MLSS_{AB} + 1.25 MLSS_{AB} \frac{(2.7-DS)}{2.7} \frac{Vc}{V_{AB}}\right] D.T.}$$

Where:

MLSS = Aeration basin MLSS, mg/l

DS = distance (meters), sludge blanket surface to water surface in clarifier.

actual measurement in horizontal flow clarifier.

unmeasurable (under tubes) in upflow clarifier; therefore, assumed to be 2.1 m.

The clarifiers were effectively 2.7 m deep; therefore, the fraction filled with sludge is $\left(\frac{2.7-DS}{2-7}\right)$

Vc = volume of clarifier, cubic meters.

TABLE 6

SUBARCTIC ALASKA EXTENDED AERATION UNITS
AVERAGE PERFORMANCE DATA

Period	Location	Clarifier Flow Pattern	Major Liquid Temp. Range °C	% BOD Removal	Loading BOD/ MLSS Day	MLSS mg/l	Percent Volatile	Overflow Liter/m^2 min (gal/ft^2 day)	Effluent SS mg/l
I	EAFB	Rect. Hz (1)	7-17	81	0.10	2330	82	20 (710)	36
II	EAFB	Rect. Hz (2)	2-9	10	0.14	1710	84	9.3 (330)	134
III	EAFB	Rect. Hz (3)	1-8	84	0.03	3360	78	12 (420)	17
I	EAFB	Rect. Up (1)	7-19	82	0.12	2370	80	20 (710)	99
II	EAFB	Rect. Up (2)	2-7	-30	0.11	2750	83	10 (370)	122
III	EAFB	Rect. Up (3,6)	1-8	76	0.04	2740	79	12 (420)	50
1971	College Oxidation Ditch	Circular Up (4,5)	8-20	84	0.05	3000	60	8.7 (310)	28

(1) From October through December 1971, period I average feed BOD = 173 mg/l.

(2) For February 1972, average period II feed BOD = 143 mg/l.

(3) For March to May 1972, average period III feed BOD = 128 mg/l.

(4) Ranganathan, K. R., Murphy, R.S., (10) Institute of Water Resources, University of Alaska, Report #IWR-27, May 1972. Septic tank sludge not included in influent BOD. Solids in quiescent sections of ditch have exceeded 20,000 mg/l.

(5) Not including data when solids were being wasted into effluent; i.e., effluent BOD >influent BOD.

(6) Rhodamine-B Dye poisoning data excluded.

V_{AB} = volume of aeration basin, cubic meters.

D.T. = detention time, days.

For each period, the loading could be converted to a volatile mass basis by dividing the loading by the average volatile fraction of the MLSS; i.e., MLVSS/MLSS.

Organic loading is usually reported in terms of mixed liquor volatile suspended solids, MLVSS. This was not done with the EAFB data since it was desired to compare loadings from other reports (12)(13) in which volatile fractions were not always reported.

In period I for both sides, the BOD removal averaged 81 to 82 percent. For period II at the same feed rate, the performance dropped to less than 20 percent removal. Aeration basin temperature was the only operational variable that could effect the drastic reduction in performance. Temperatures averaged 12°C for period I and 4°C for period II. Decreasing the average clarifier overflow from 20 to about 9.9 ±0.6 lit/sq m/min (0.49 to 0.24 ±0.01 gal./sq ft/min) did little to compensate for the temperature effects. It was felt that the systems for period II had not yet reached equilibrium but would continue to lose efficiency. In period II solids passing through the clarifier reduced the MLSS which increased the organic loading, thereby forcing the process to self-destruction.

Period III data further illustrates that loading is the main temperature sensitive variable. During this period, performance recovery was excellent even though it took 3 to 4 weeks to attain steady state. The 3 to 5 week equilibrium state is not enough time to make accurate predictions of long-term performance. The removal for the horizontal flow side averaged 84 percent at an average loading rate of 0.03, even though the total overflow was increased from period II to 12 lit/sq m/min (0.3 gal./sq ft/min). The up side did not perform as well at the same temperatures and overflow rate even though performance data were excluded when there were indications that Rhodamine-B dye injections were poisoning the system.

It should be noted that the EAFB system was operated using primary effluent as feed. If raw sewage was used as feed, it is estimated that the percent BOD removal would be up to 5 percent higher assuming the detention time would be increased to keep the loading down.

For the EAFB units, the volatile fraction of the MLSS decreased, as expected, with increased detention time. The College oxidation ditch, due to its low bottom velocity, tends to accumulate partically digested activated sludge as indicated by the low volatile fraction. Information presented for ditch removals exclude data when solids were being discharged into the effluent.

Overall temperature effects of loading on performance for many other extended aeration units is shown in Figure 16. Most of the warm 12-25°C temperature data were extracted from the 1960 U.S.P.H.S. survey of several extended aeration plants (12). Some of the plotted data represents more than five performance analyses and some represent only one or two. The

TEMPERATURE EFFECTS OF LOADING ON PERFORMANCE

EFFLUENT SS LIMITED TO LESS THAN 100 mg/l

DATA FROM EIELSON AIR FORCE BASE AND REFERENCES (10 & 12)

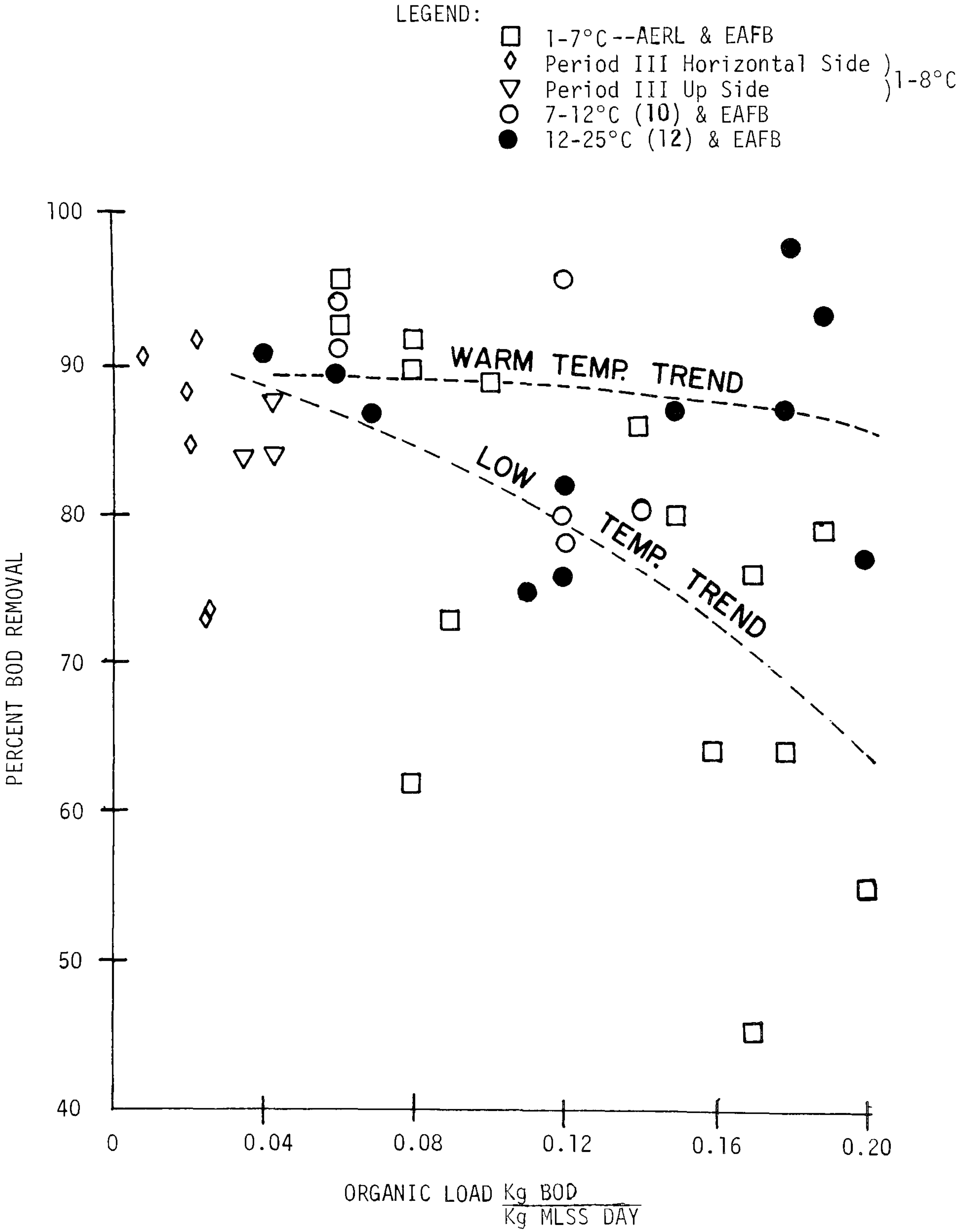


FIGURE 16

7-12°C data are from the College oxidation ditch (10), AERL cold room reactors, and the EAFB units. The 1-7°C data were obtained from the cold room reactors and the EAFB units. Weekly average data from EAFB were plotted for period III. For this graph, all data with effluent suspended solids greater than 100 mg/l were excluded since it is felt that proper intentional wastage of excess activated sludge would limit effluent suspended solids to less than 100 mg/l. This graph is then based only on expected performance when intentional wastage separate from effluent is practiced.

Notice in Figure 16, as loading increases, BOD removal drops off quite rapidly at low temperatures (below 5 to 8°C). For warmer temperatures (above 12°C), loss of performance with load is moderate.

Wuhrman (14) also presented data which show that, as loading increases, performance decreases; more so at temperatures less than 11°C than for temperatures greater than 13°C. His data are more in the activated sludge range; i.e., loadings greater than 0.2.

SOLIDS LEVELS AND SEPARATION

In startup of an extended aeration plant, performance is usually low until enough biomass (MLSS) has been built up for adequate bioadsorption. Generally speaking, a low MLSS concentration also represents a high organic loading which might tend to force the process to self-destruction were it not for the clarifiers which, at startup, are underloaded in terms of solids handling. A typical curve of performance vs. the product of MLSS and detention is shown in Figure 17. The upper curve is from the National Sanitation Foundation observation of 10 package extended aeration units (13). Summarized EAFB data is plotted on this graph. The EAFB period I data would not have appeared better than the NSF package plant data if the abscissa was in units of MLSS only. The NSF data is for temperatures greater than 11°C. The comparative poor performance of period III data is attributed to the low temperature and the fact that the feed was primary effluent.

Extensive surface icing on an aeration basin should be avoided because it may rob the basin of its MLSS. In discussing 1970 EAFB experience (Clark, et al. (8) stated that the sludge accumulated in the growing ice, reducing the suspended solids level in the pond from approximately 2,500 mg/l to less than 200 mg/l.

Solids removal plays a very important part in the efficiency of the activated sludge treatment process. The degree of sludge separation directly influences the quality of effluent from wastewater treatment plants with higher concentrations of effluent solids contributing to higher effluent BOD.

In activated sludge operation, solids separation is the most important physical process contributing to overall process performance. Clarifier performance can usually be met by design, whereas, performance of biochemical-adsorption usually cannot. Reed and Murphy (15) conducted an

PERFORMANCE VS. SOLIDS DETENTION

EIELSON AIR FORCE BASE EXTENDED AERATION UNITS

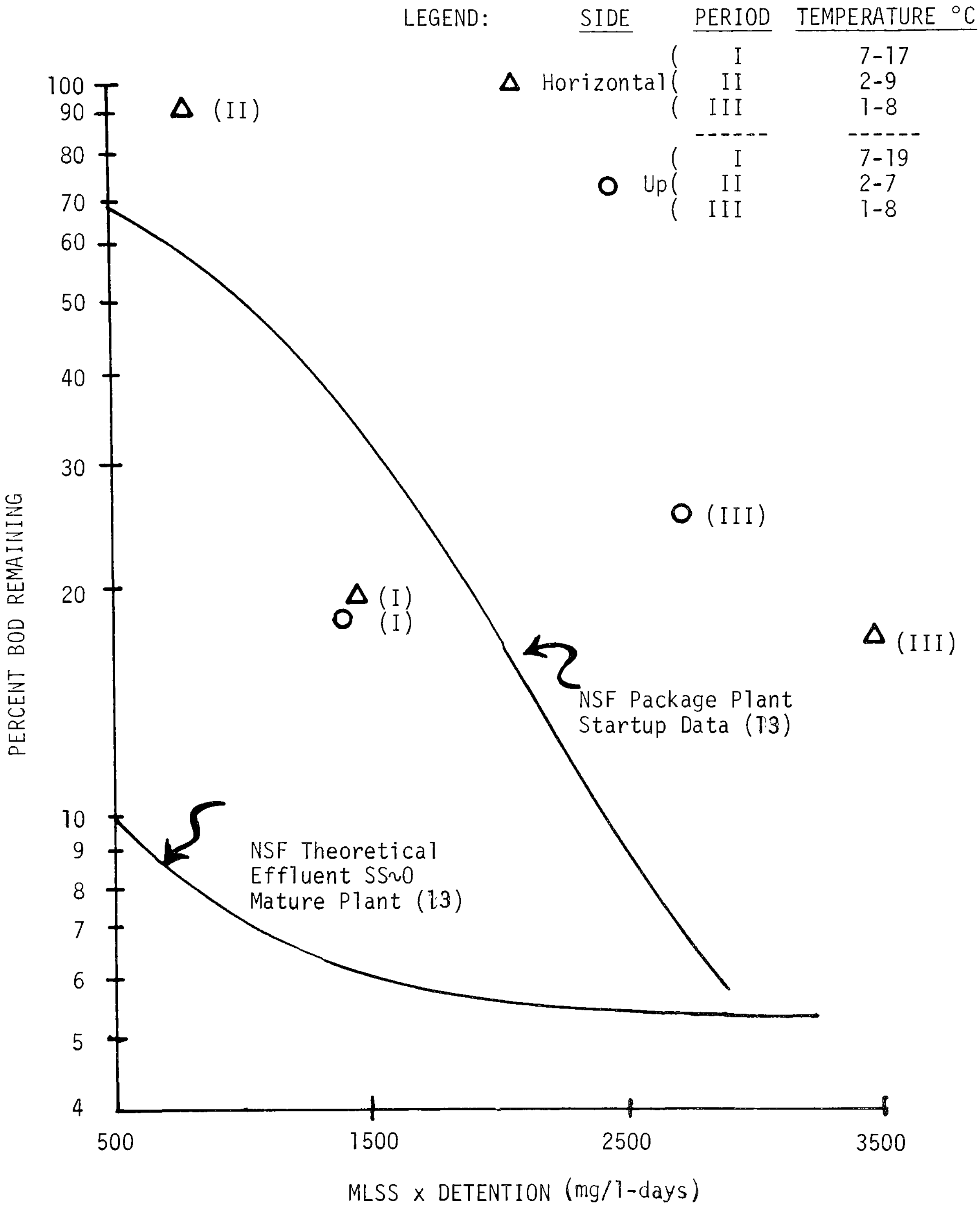


FIGURE 17

investigation of settling characteristics of activated sludge at temperatures ranging from 1.1° to 23.4°C and found that the influence of temperature on settling velocity decreased as the concentration increased. They developed an equation for zone settling based on experimental data. They also suggested upflow sludge blanket clarifiers as having greater potential for cold regions application. Benedict (16) suggested that effects of sludge settleability on gross COD removal was magnified at low temperatures and as loading rates were increased.

Solids separation is a function of both biological characteristics of the sludge and physical parameters of the settling unit. Cold room experience indicates that turbid effluent is not necessarily due to failure of the sedimentation unit and may be eliminated by building up a well-acclimated activated sludge population. This will require operation at a relatively low biological loading rate in order to obtain the degree of organic stabilization necessary for low turbidity (17). The cone reactor operating at 1.3°C did produce a turbid effluent at loadings of around 0.2 Kg BOD/Kg MLVSS/Day, but with a very low clarifier overflow rate (Table 1).

Indications are that sludge bulking may be a problem in the activated sludge process at the cold operating temperatures. This problem was reported by Ludzack (18). Bulking sludges have not been reported in cold temperature oxidation ditch studies (1, 10, 11); however, these ditches were operated at much longer detention times (1 to 2.3 days) which may be a factor. Although bulking sludges have not been a problem with the College oxidation ditch, floating solids have. Raganathan and Murphy (10) reported, "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."

The circular upflow clarifier for this oxidation ditch was evaluated in terms of solids flux; lbs dry solids in clarifier feed per day per sq ft of clarifier separation area (10). Solids flux may be controlling in clarifier design for high MLSS values and low SVI's. The oxidation ditch MLSS usually had low SVI--less than 100 most of the time.

Hansen and Culp (19) reported on experiments with a method of solids separation which successfully employed shallow depth sedimentation theory. The settling unit consisted of small diameter tubes (2.5 cm) inclined at 5° and 0.6-1.2 meters in length. Detention times were very low; however, backwashing was necessary for removal of accumulated solids. Hansen, et al. (20), also reported on the use of steeply inclined tubes (60°) which permit solids depositing in the tubes to continuously slide down by gravity. Plant scale applications of the steeply-inclined settling tube concept have been reported by Conley and Slechta (4). They concluded that for primary clarification, complete removal of settleable solids and 40-60 percent of suspended solids can be achieved with 0.6-m (2-ft) long settling tubes 5 cm (2 in.) in depth at an overflow rate of 122 lit/sq m/min (3 gal./sq ft/min). They indicated that until methods are developed to continually control the biological process, tube settlers in the activated sludge process should be considered as a device for improving effluent quality during upsets in the biological process or peak flows. Flow rates should not exceed 41 lit/sq m/min (1.0 gal./sq ft/min), which should provide effluent with 20-40 mg/l suspended solids under present biological conditions and 5-20 mg/l under normal conditions. They stated that material will collect on top of the tubes and that routine cleaning is required to maintain effluent quality. Pohl (21) investigated tube settlers in the laboratory and found his best results at room temperature; however, he felt the tubes occasionally passed excessive colloidal solids.

Tube settlers were evaluated as a possible alternate means of providing solids separation and return. Initial data were obtained from the 33.7-liter reactor with 5 cm x 5 cm (2 x 2 in.) settling tubes. These results are summarized in Table 7 and are based on continuous flow without an on-off or backwash cycle. A plot of effluent suspended solids vs. overflow rates is shown in Figure 18.

Effluent overflow rates were varied by utilizing two pumps, one to provide recycle and one for effluent, as shown in Figure 5. A desired overflow rate (less than the feed rate) was set with the effluent pump on one of the tubes while the remaining feed was forced to flow through the second tube to the overflow line. The desired flow rate through the second tube could then be obtained by utilizing a recycle pump.

During operation, sludge rose in the tubes until it reached a level at which it was in equilibrium with the effluent flow. Action in the tube consisted of a rolling motion in which solids were being carried up along the top side of the tube in a mass with the effluent, as shown in Figure 19. The mass gradually settled toward the bottom side of the tube where it entered a current moving downward caused by the weight of the solids. During normal operation, solids in the tube are constantly being replaced at a relatively high rate (<3 hrs). This fact was confirmed by placing Rhodamine-B dye in one of the 33.7-liter reactor tubes while the sludge was at a high level of approximately 1.3 m (50 in.) and timing the rate of descent along the bottom of the tube. Figure 20 shows a plot of sludge level in the 5 cm x 5 cm (2 x 2 in.) tubes at various continuous overflow rates.

As an illustration of the tendency of the sludge to reach a certain level in the tubes in equilibrium with the effluent flow, a plot of sludge rate of ascent vs. sludge height at a given overflow rate is presented in Figure 21. This curve was obtained by shutting off the effluent flow until the sludge settled to a low height in the tube. The overflow rate was then set and the sludge height recorded at specific time intervals. As can be seen, the rate of sludge rise markedly decreases as the sludge height increases.

During this period of operation, the SVI's of the mixed liquor ranged around 230 without hindering operation of the reactor. During the previously described erratic cold room operation, while trying to reach an 8°C reactor temperature, the mixed liquor SVI increased to around 260 and the sludge took on a fluffy snowflake appearance. The rolling action of the sludge in the tubes stopped and the sludge height began to rise, eventually spilling out with the effluent. Cutting the effluent flow rates back to less than 8 lit/sq m/min (0.2 gal./sq ft/min) resulted in lowering the DO in the effluent tubes to zero, further complicating the problem.

TABLE 7

33.7-LITER (8.9-Gallon) REACTOR
RESULTS OF OPERATION WITH VARYING EFFLUENT
OVERFLOW RATES ON THE SETTLING TUBES

	INFLUENT			REACTOR		EFFLUENT					
Reactor[1] Temp. °C	Susp. Solids (mg/l)	BOD (mg/l)	COD (mg/l)	Susp. Solids (mg/l)	SVI	Overflow Rate liter/min-m^2 (gpm/ft^2)	Solids (mg/l)	BOD (mg/l)	% BOD Removal	COD (mg/l)	% COD Removal
0.35 (.3-.5)	95	244	292	3973	238	16 (.4)	10	12	95	69	76
0.7 (.4-.9)	112	253	370	4237	238	12 (.3)	8	22	91	71	79
						24 (.6)	20	29	89	87	77
4.2 (2.8-6.4)	94	193	229	4147	---	12 (.3)	10	17	91	60	74
						24 (.6)	14	20	90	70	69
3.8 (3.5-4.1)	77	142	283	4067	229	20 (.5)	10	14	90	62	78
						33 (.8)	13	20	86	69	76

(1) Values in parentheses are minimum and maximum for that period.

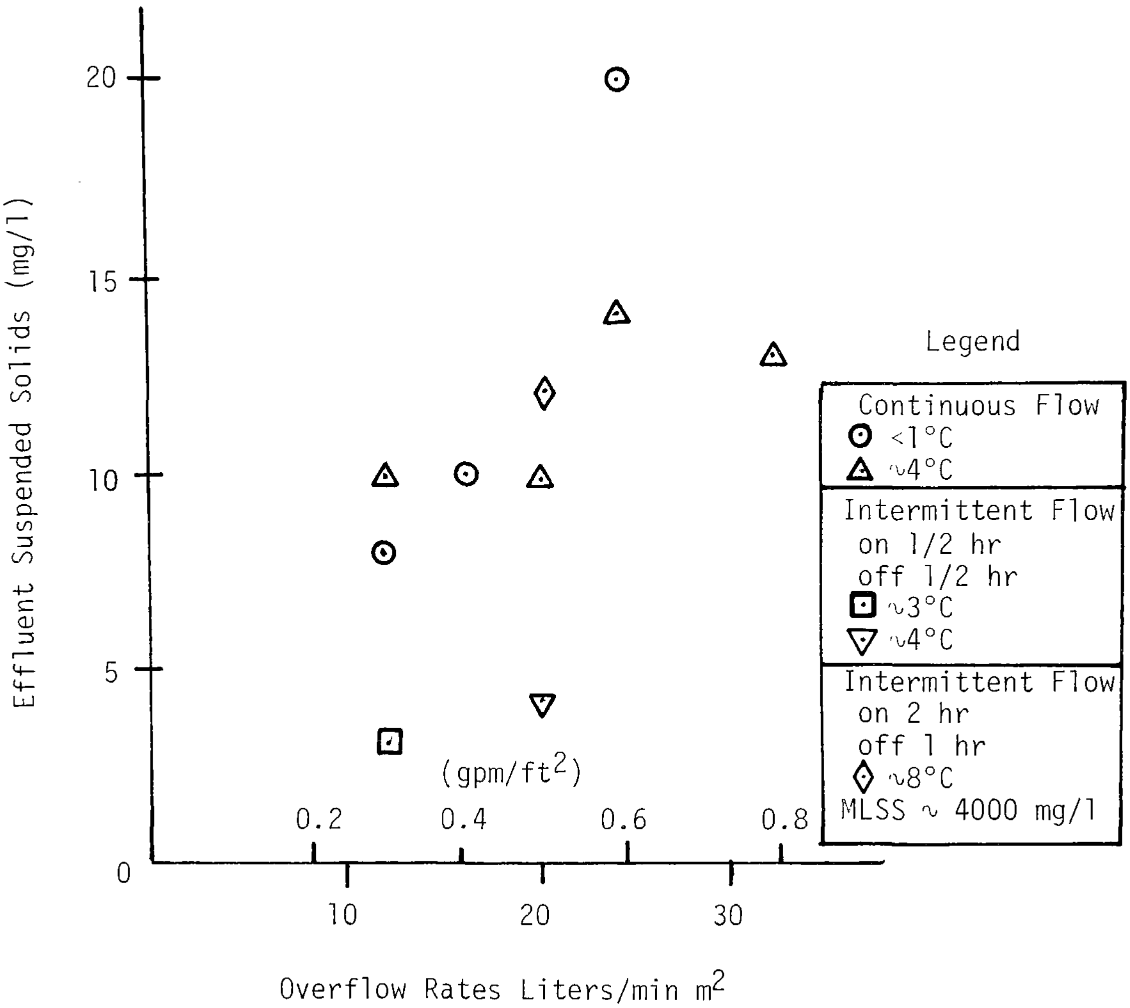


FIGURE 18

33.7-LITER AND 47.1-LITER REACTORS
EFFLUENT SUSPENDED SOLIDS
VS.
OVERFLOW RATES AT VARIOUS TEMPERATURES

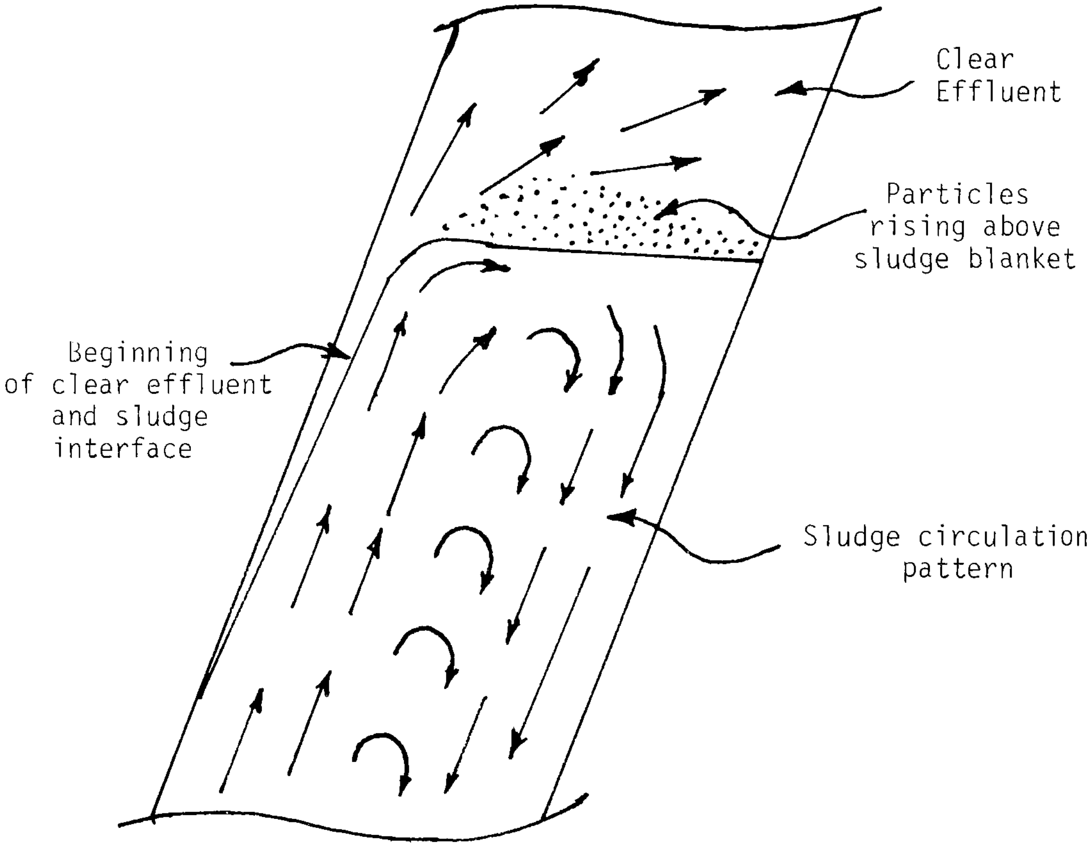


FIGURE 19. SLUDGE ACTION IN SETTLING TUBES

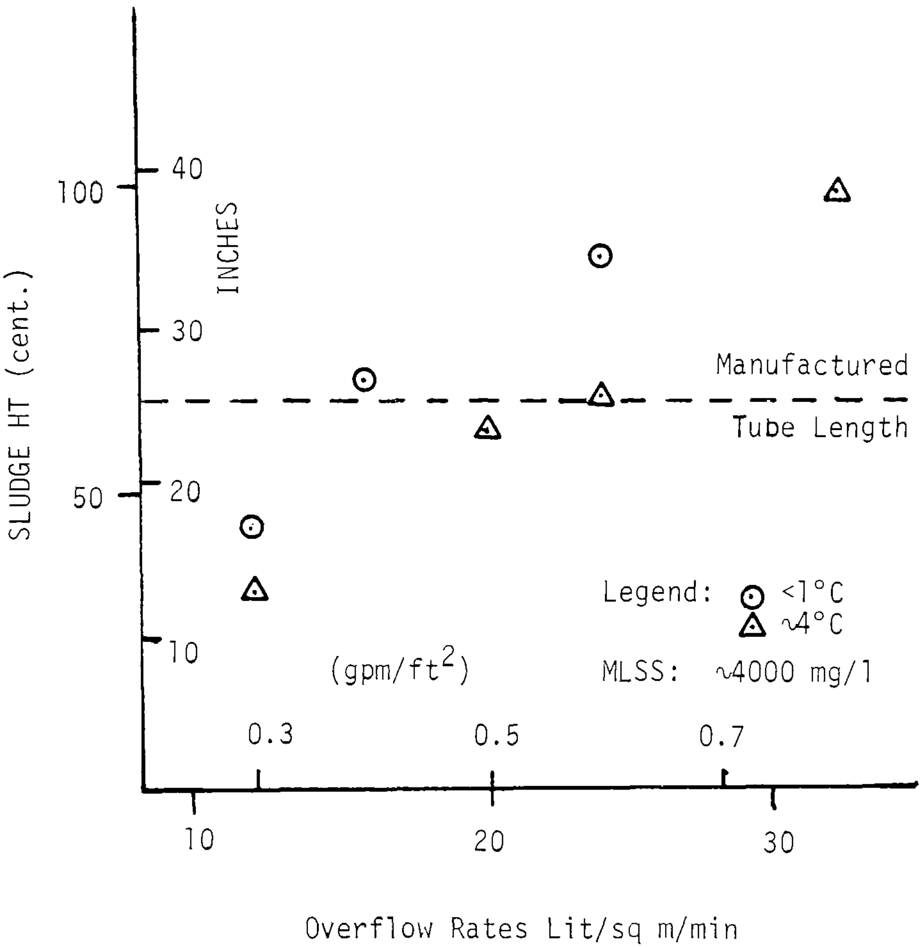


FIGURE 20

33.7-LITER REACTOR
SLUDGE HEIGHTS IN EFFLUENT TUBES
VS.
EFFLUENT OVERFLOW RATES WITH CONTINUOUS FLOW THROUGH TUBES

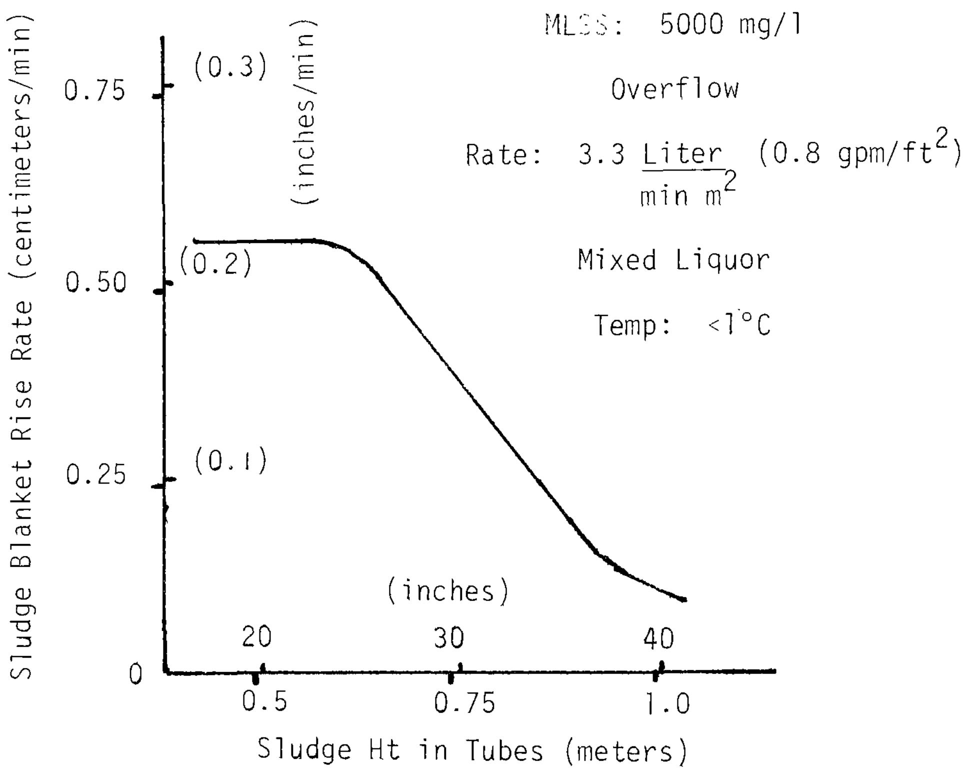


FIGURE 21. RATE OF SLUDGE RISE IN TUBES VS. SLUDGE HEIGHT

At a later date, the 47.1-liter reactor was placed in operation. This reactor was constructed with two tube sides, one 10 cm deep by 8.9 cm wide, and two 5 cm deep by 8.9 cm wide, as shown in Figure 5. This reactor also had a channel running down behind the tubes to permit circulation of mixed liquor under the tubes for removal of settled sludge.

This reactor was operated for a period of time with a very low continuous overflow rate and then increased to an average rate of 20 lit/sq m/min (0.5 gal./sq ft/min) with an alternate on-off cycle. In other words, with overflow for 1/2 hour and no overflow for 1/2 hour as a cycle, the actual flow then was 40 lit/sq m/min (1 gal./sq ft/min) for 1/2 hour.

A summary of results for this reactor is shown in Table 8 and the corresponding maximum and minimum sludge heights in the tubes presented in Table 9. As indicated, the SVI's again ranged above 200 with very consistent solids removals. Effluent solids concentrations are very low for the whole range of studies. The longer on-times for the on-off cycle (2-1/2 hours as opposed to 1/2 hour) did indicate that longer cycles may result in higher effluent solids concentration. The data were inconclusive, however, because of the few sets of data and the fact that the change in temperature may have been a contributing factor in the higher effluent solids at 7.8°C.

Neither the 5 cm x 8.9 cm tubes or the 10 cm x 8.9 cm tube appeared to have an advantage as far as solids removal are concerned. There was a significant difference between the maximum sludge heights reached within the tubes, however, which is a very important consideration. Lengths of the tubes will be limited in actual application because of space requirements and economic reasons.

As indicated in Table 9, the maximum sludge heights reached in the smaller cross-section tubes were considerably less than those reached in the larger tube. This may be attributed to the fact that the two smaller tubes provided twice the surface area at the top side of the tubes which significantly reduced the effluent flow along these surfaces. Consequently, the upward force on the sludge in the tubes was reduced resulting in lower sludge heights.

An observation of sludge heights in the tubes during backwash operations was also recorded. Introduction of the backwash cycle did significantly reduce the maximum sludge heights by forcing the sludge blanket back down the tubes. Backwashing provides a definite advantage in that it prevents a bulky sludge from becoming stagnant in the tubes as occurred when the 33.7-liter reactor operation failed at 8°C. Cold room experience indicated that clarifier backwashing in conjunction with low overflow rates was successful in overcoming problems associated with bulking sludge.

Organic loading rates also affected sludge settleability as shown in Figure 22, which is a graph of settling rate--0 to 5 min rate in a 2-liter settlometer vs. MLSS for different detention times and temperatures for the horizontal side, EAFB pilot units. Generally, the settling velocity decreased with decreasing temperature and increasing MLSS concentration. The data should be interpreted with caution for they do not suggest that one would not be able to hold a MLSS concentration greater than 3000 mg/l at an overflow greater than 12 lit/sq m/min (0.30 gal./sq ft/min).

TABLE 8

47.1-LITER (12.5-GALLON) REACTOR
RESULTS OF OPERATION WITH VARYING EFFLUENT OVERFLOW
RATES ON THE SETTLING TUBES

	INFLUENT			REACTOR		EFFLUENT						
Reactor[(1)] Temp. °C	Solids (mg/l)	BOD (mg/l)	COD (mg/l)	Susp. Solids	SVI	Overflow[(2)] Rate (gpm/ft^2) liter/m^{2}min	Tube Size	Solids (mg/l)	BOD (mg/l)	% BOD Removed	COD (mg/l)	% COD Removed
2.4 (1.4-3.5	77	177	303	3957	---	8 (0.2) (continuous)	2 x 3.5	2	19	89	35	88
							4 x 3.5	2	19	89	39	87
2.9	86	185	275	4157	214	12 (0.3) (on 1/2 hr-	2 x 3.5	4	12	94	50	82
						off 1/2 hr)	4 x 3.5	3	10	95	52	81
4.4	93	223	321	4095	235	20 (0.5) (on 1/2 hr-	2 x 3.5	4	12	95	55	83
						off 1/2 hr)	4 x 3.5	5	12	95	69	79
7.8	87	194	313	4504	209	20 (0.5) (on 2 hr-	2 x 3.5	12	20	90	69	78
						off 1 hr)	4 x 3.5	14	23	88	64	80

(1) Values in parentheses are minimum and maximum for that period.
(2) Notes in parentheses indicate the time cycle of effluent flow through the tubes.

TABLE 9

47.1-LITER REACTOR
SLUDGE LEVELS IN TUBES AT
VARIOUS EFFLUENT OVERFLOW RATES

Overflow Rate[1] Liter/(m^2 min) (gpm/ft^2)	Temp (°C)	Reactor Susp. Solids (mg/l)	SVI	10 x 8.9 cm Tube(2) Sludge Hts cm (in.)		5 x 8.9 cm Tubes(2) Sludge Hts cm (in.)	
				High	Low	High	Low
1.2 (.3) [on 1/2 hr off 1/2 hr]	4	4407	185	86 (34)	58 (23)	61 (24)	28 (11)
2.0 (.5) [on 1/2 hr off 1/2 hr]	4	4253	223	119 (47)	58 (23)	76 (30)	20 (8)
2.0 (.5) [on 2-1/2 hr off 1/2 with backwash]	8	4023	232	58 (23)	0	38 (15)	0

[1] Notes in brackets indicate the type cycle of effluent flow through the tubes

(2) High and low points represent the maximum heights which the sludge reached in the tubes during effluent flow and the minimum levels reached during the off cycle or backwash cycle

2-LITER SETTLOMETER TEST, 0-5 MINUTE RATE

EIELSON AIR FORCE BASE PILOT EXTENDED AERATION PLANT

Horizontal Side

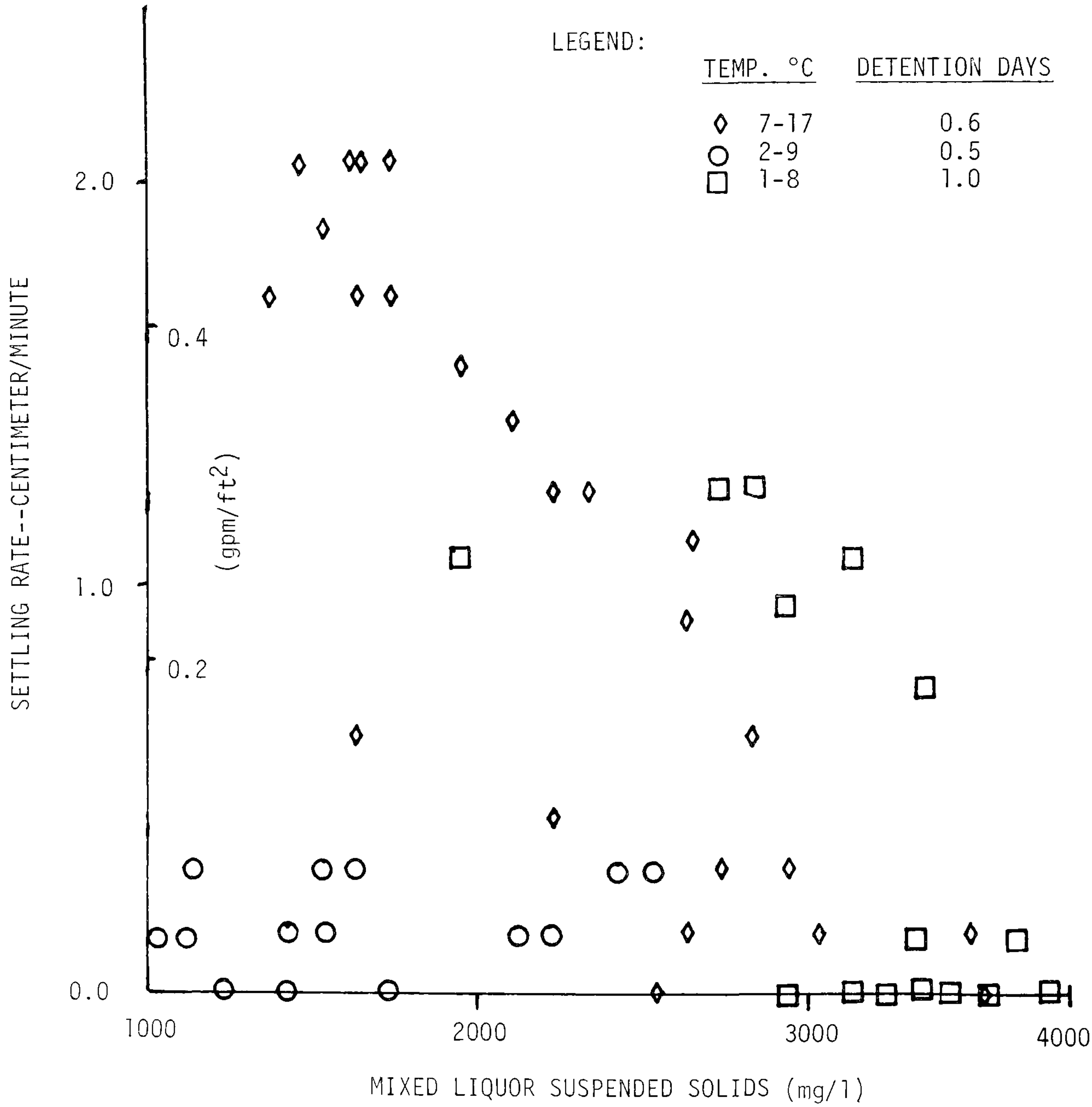


FIGURE 22

The residence time in clarifiers is much greater than 5 minutes and the clarifier geometry usually favors better solids separation. For normal sludges, the 0 to 5 minute rate was the highest settling rate. The 0 to 5 minute rate was not always the highest settling rate for bulking sludges.

Downing (22) (Figure 23) shows that settleability is improved by longer detention times (10 hours) and very short detention times (4 hours) when operating an activated sludge plant at warm temperatures. The EAFB horizontal side data shows somewhat better settleability than Downing indicated, but his data may be based on much higher MLSS data. He did not specify temperatures. The EAFB low temperature long detention data (period III) brackets his general curve.

A solids flux analysis was not performed for the EAFB units because it was felt that solids flux has little meaning when SVI's are above 100. The two EAFB clarifiers were operated at similar total overflows for direct comparison. Table 10 is a listing of total overflow and effluent SS for the two types of clarifiers operated at the same temperature and same sludge settling (0 to 5 min) rate, cm/min. The table should be considered only as showing a trend even though each value listed is an arithmetic average of from 2 to 9 daily points. For the 1/2-day detention periods, the upflow clarifier was operating at an overflow rate 13 percent above the horizontal flow clarifier. But the up side effluent averaged only 6 percent richer in suspended solids. The horizontal clarifier performance appears superior, 28 percent less SS, for the 1-day detention period when the mixed liquor temperatures were 6° and 2°C, while the up side was at 3°C. The above data isn't consistent enough to show any strong trend, but it could be interpreted to mean that the up flow with tubes clarifier has no advantage over conventional clarifiers at low temperatures. To hold reasonable effluent SS levels using the data presented in Figure 18 through 22 and Tables 6 through 10, it appears that the maximum low temperature (<10°C) clarifier design overflow rate should not be above 12 lit/sq m/min (0.3 gal./sq ft/min) based on average flow. There was no diurnal flow fluctuation at the EAFB facility or in the cold room reactors; therefore, a peak flow criteria was not determined. But in acknowledging the solids hysteresis effect (solid flow damping effect) of clarifiers one would probably be safe in allowing peak overflow rates to reach 20 lit/sq m/min (0.5 gal./sq ft/min).

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) has also investigated the use of tube settlers in low temperature extended aeration units (23, 24). They have found that home-made (5 cm diameter pipe) tube settlers perform satisfactorily.

SOLIDS ACCUMULATION AND WASTAGE

Little information is available on solids accumulation for biological treatment process design for temperatures less than 5°C. Ludzack (18) and Hunter et. al. (25), have observed that excess MLSS accumulation increases with decreasing temperature. Cell yield and auto-oxidation rate are utilized in the growth kinetics equation as defined in Section III.

VOLUME PERCENT OF ACTIVATED SLUDGE VS. DETENTION TIME

EIELSON AIR FORCE BASE EXTENDED AERATION PLANT

HORIZONTAL FLOW SIDE - 2 LITER SETTLOMETER

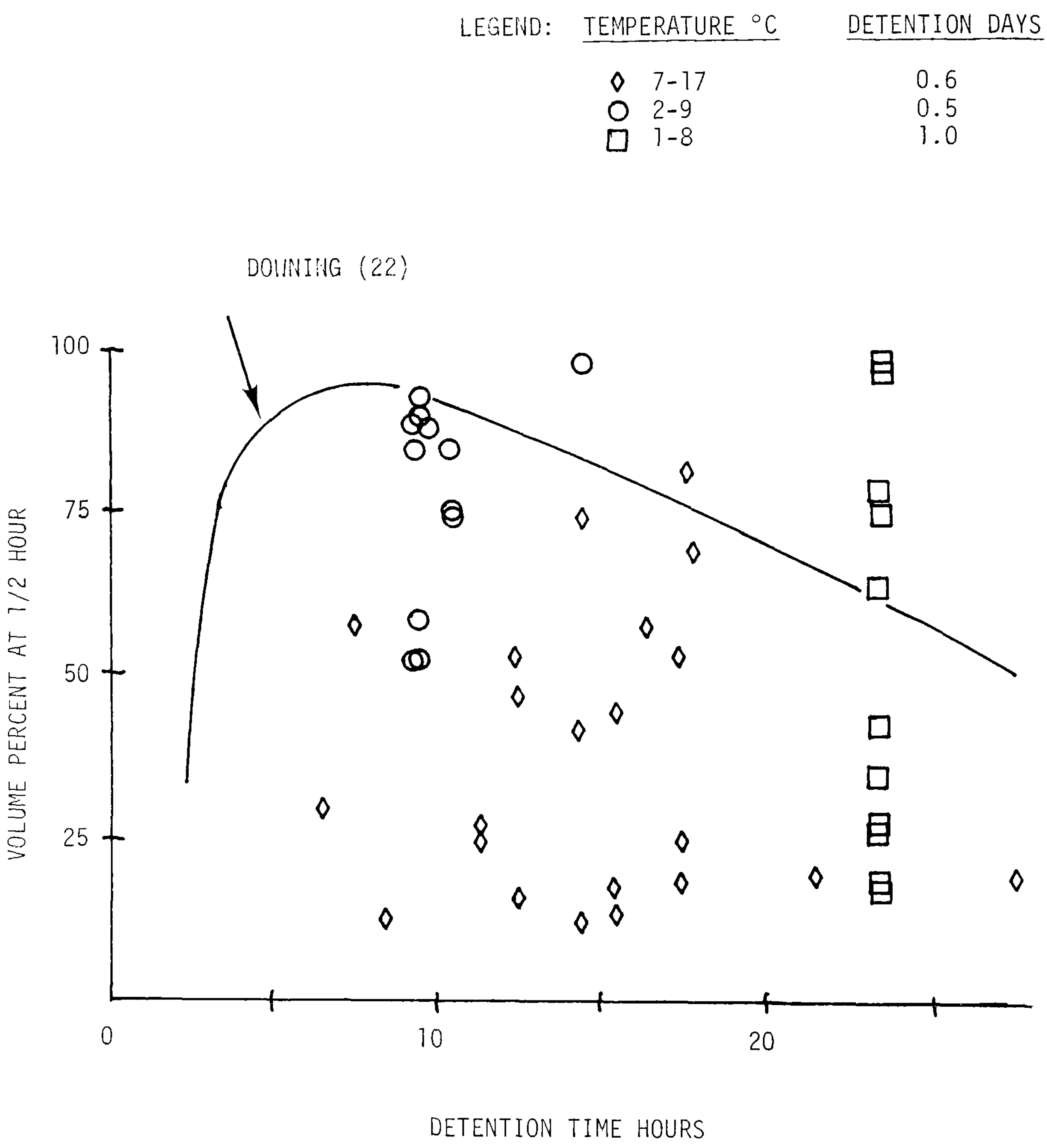


FIGURE 23

COMPARISON OF UP SIDE WITH TUBE AND

HORIZONTAL FLOW CLARIFIERS

MLSS		HORIZONTAL FLOW		UPSIDE	
Temp. °C	Settlometer Rate Both Sides cm/min	Total Overflow liter/min m^2	EFF. SS mg/l	EFF. SS mg/l	Total Overflow liter/min m^2
1/2 Day Detention					
13	0.2	16	43	51	18
13	0.3	19	94	169	23
11	1.3	21	18	40	22
3	0.2	8.5	282	111	11
6 & 5	0.3	9.3	53	151	9.3
1 Day Detention					
6 & 3	0.2	12	26	27	12
2 & 3	1.1	12	17	33	12

Cell yield (c) increases with increasing temperature because it is believed a larger portion of BOD removal is utilized for energy at low temperatures than at high temperatures (26). The rate of endogenous respiration is depressed at low temperatures (more so than cell yield); therefore, the quantity of excess sludge produced is increased. Benedict (16) reports values for c and k (endogenous rate) at 4°C of 0.42 mg/mg COD and 0.0132/day respectively.

In discussing small extended aeration treatment plants, an Alaskan Department of Health and Welfare report (27) indicates that, since the effluent will usually be discharged into a small stream, it must be well treated. The report also states that, in most cases, to produce a good effluent, sludge wasting must be practiced.

Morris (28) studied the effects of effluent discharges to streams by two extended aeration plants having no provision for intentional sludge wasting, and stated that plant efficiency is directly related to the amount of solids lost in the effluent. He indicated sludge discharges occur similar to those described by Grube and Murphy (1) with solids depositing on the stream bed, creating nuisance potential.

Statements such as the above should be considered along with the fact that excess solids production increases with decreasing treatment plant temperatures. In view of this observation, sludge wasting and disposal in cold climates must be given special consideration. Based on cold room data, Tables 3 and 4, it would appear that provision should be made for wasting 0.5 Kg solids per Kg of BOD removed at colder operating temperatures (<5°C) and at organic loadings of 0.1 Kg influent BOD/Day/Kg MLVSS.

Different results were obtained at EAFB extended aeration units where the solids accumulation is defined as:

$$\text{Solids accumulation (SA)} = \Delta\text{MLSS} + \text{Solids Lost (EFFLUENT + WASTAGE)}$$

Solids accumulation is calculated as a ratio of SS to input BOD. The following formula is used to calculate the solids accumulation from a computer printout of data from the EAFB pilot plant:

$$SA = \frac{(\Delta\text{MLSS})\ (\text{DETENTION TIME})}{(\text{Avg Feed Bod})\ (\text{Data Period})(\text{Days})} + \frac{\text{TOTAL SS LOST}}{\text{Avg Feed BOD}}$$

Where: ΔMLSS = MLSS at end of data period - MLSS at start of data period.

The EAFB data points for the six periods are plotted in Figure 24, Solids Accumulations, along with the NSF package plant data (13). Some of the EAFB data indicates that excess solids were accumulating at rates greater than 0.6 Kg SS/Kg BOD applied. Excess solids are suspended solids above those required to maintain a constant MLSS level. Under normal operations, some SS is wasted into the effluent. Assuming an SA of 0.6, applied (feed) BOD equal to 200 mg/l and an effluent SS of 20 mg/l, then the separate (exclusive of effluent) wastage requirement would be reduced by 0.1 Kg SS/Kg BOD; yielding 0.5 Kg SS/Kg BOD to be wasted. The 0.5 figure then seems

SOLIDS ACCUMULATION

EIELSON AIR FORCE BASE EXTENDED AERATION UNITS

Kg MLSS/Kg BOD APPLIED

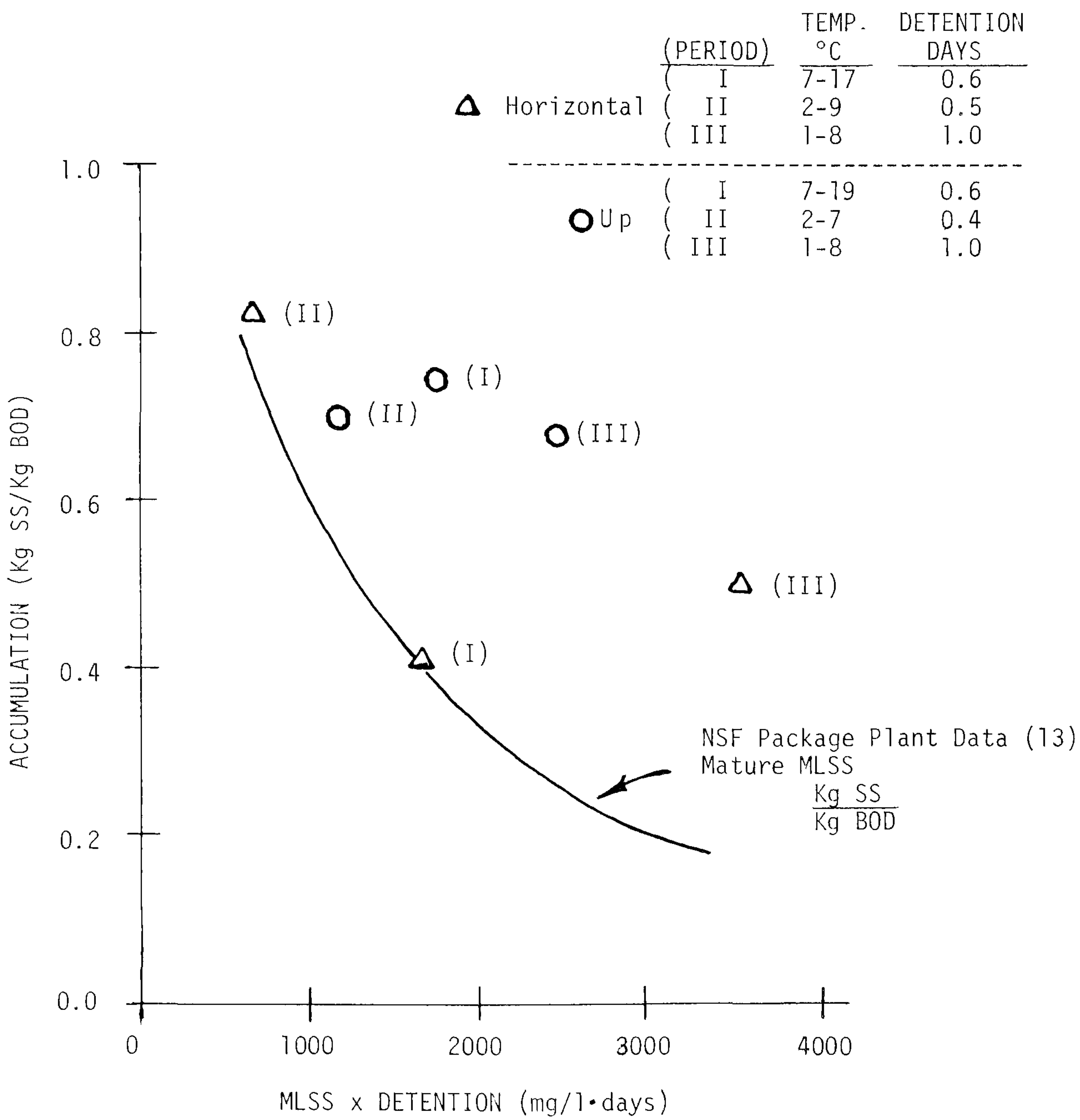


FIGURE 24

adequate for low temperatures at low organic loadings $\leq$0.08 Kg BOD/Kg MLSS/Day. High loadings at low temperatures is of course impracticable as shown earlier. The EAFB influent SS to BOD ratio varied from 0.6 to 0.9. If one is designing for a higher feed ratio, then the wastage facility capacity might have to be increased.

Under normal conditions without intentional wastage, the MLSS will build up to a certain high level (limited by settling characteristics and system operation), then considerable SS will pass into the effluent in a short time, reducing the MLSS to a more optimum level. This self-wastage has been called "autoinduced wastage" (9). Between the wastage periods, the effluent SS has always been less than 100 mg/l for extended aeration units in stable equilibrium. Intentional wastage should also always keep the effluent SS less than 100 mg/l.

At EAFB, intentional wastage was practiced only in period I. In period II both sides were losing MLSS. During period III, it was attempted to find the maximum MLSS the system would hold before autoinduced wastage occurred. The horizontal side reached ∿4100 mg/l and the up side ∿3300 mg/l before autoinduced wastage was triggered at the low mixed liquor temperatures.

Separate intentional wastage has not been practiced at the College oxidation ditch which caused some of the poor 1971 performance (Table 5). The 1972 performance appears much better, because autoinduced wastage periods and recovery probably occurred between the every-other-week sampling periods. Observation of the ditch effluent between some of the September and October sampling periods showed it to be very rich in SS. The MLSS concentration, as sampled, was observed to slowly drop from 5820 mg/l on August 2, 1972, to 2570 mg/l on October 25, 1972.

The above discussion points out the necessity of obtaining 24-hour flow proportioned composite samples for characterizing any short detention (less than 10 days) biological waste treating system. In the opinion of the author, separate intentional wastage would prevent sludge banks from forming downstream of any secondary sewage treatment plant.

When separate wastage is practiced, disposing of the wasted sludge then becomes a problem. Sludge digestion and disposal methods present a problem at colder temperatures due to added heat requirements and poor drainability. Ludzack (18) indicates that sludge development at cold temperatures may require digestion at higher temperatures before disposal. Thomas (26) indicates the freeze-thaw cycle may be taken advantage of in cold climates to increase drainability. Clark, et al. (8), have shown that sludge can be concentrated in ice forming on an exposed aeration (digestion) basin. The Sewage Commission of the City of Milwaukee (29) reports that freezing is an excellent method of activated sludge conditioning. But they also reported that capital and operating costs (refrigeration) were appreciably higher for the freeze method than for the chemical method. In the lower 49 states, freezing sludge is expensive, but in cold climates, it does not require refrigeration facilities. Space to store wasted sludge during the short summers is not usually expensive unless land values are high.

DISSOLVED OXYGEN LEVELS

The major winter difference between the oxidation ditch and the EAFB units was in the activated sludge characteristics. The oxidation ditch MLSS reached ∿5800 mg/l with SVI less than 100, while the EAFB units limited themselves to about 4100 mg/l with SVI's usually greater than 100. A major cause for this difference may have been the mixed liquor DO levels. The oxidation ditch subsurface DO was usually less than 1 mg/l, while the DO of the EAFB pilot units was usually greater than 1.5 mg/l with no gradient due to depth. At EAFB, lower DO activated sludges appeared to settle faster. Murphy (10) indicated that the cage rotors at the College utilities oxidation ditch were not capable of transferring sufficient oxygen under prevailing conditions.

For extended aeration, the oxygen requirements are much higher than for conventional activated sludge due to the endogenous respiration and nitrification requirements. For temperate climates, air requirement values of 100-130 cubic meters/Kg BOD (1500-2000 SCF/lb BOD) have been quoted (30, 31). Oxygen requirement is lower for low temperature operation because of less nitrification and a lower wet oxidation (endogenous respiration) rate.

The following equation has been used to define the temperature effect of oxygen transfer rates:

$$K_1 = K_2\theta^{(T_1 - T_2)}$$

where:

K_i = rate at T_1

θ = temperature coefficient

Eckenfelder and O'Connor (32) state that the temperature coefficient θ, when applied to oxygen transfer efficiencies, has been reported to vary from 1.016 to 1.047 and that studies on bubble aeration indicate a temperature coefficient of 1.02 applies. Effects of temperature on stream reaeration have been studied under controlled experiments in the laboratory and a θ value of 1.0241 found for the temperature range of 5 to 30°C (33).

Terashima, et al. (34), indicated the mass of oxygen transferred is more affected by increasing the saturated dissolved oxygen concentration than by decreasing the overall oxygen transfer coefficient and concluded low water temperatures are not detrimental to oxygen transfer. In other words, the increase in driving force (higher saturation) at lower temperatures more than compensates for the increase in diffusion resistance. They found θ equal to 1.017 in the temperature range of 5-25°C.

For oxygen transfer, the minimum air rate (to maintain 1/2 mg/l DO) into 5°C, 2000 mg/l MLSS was found to be 63 cubic meters/Kg BOD (1000 SCF/lb BOD) at the EAFB units. The transfer efficiency (including surface effects) with the open-type aerators (monospargers and shearboxes, both underloaded) was approximately 4 percent at 3.4 m (11 ft) depth and 1/2 mg/l DO.

UPSETS

The EAFB extended aeration units were relatively insensitive to starvation or temporary lack of oxygen. As noted on Figures 12 and 13, the feed was off for as long as 3 consecutive days in October with very little effect upon performance. A white surface foam formed on the aeration basin indicating the starvation condition. Due to temporary unbalance in the aeration system, the air to one side or the other was off for many hours (overnight in a few cases) with no noticable effect upon performance.

The effect of Rhodamine-B dye poisoning is noted on Figure 12 for period III. Dye strength was estimated to be from 2 to 7 mg/l in the aeration basins. The high concentration was used to qualitatively define the basin's flow patterns without the use of a fluorometer. The dye-induced wastage did not occur until 4 to 6 days after injection into the low temperature mixed liquor. Apparently, the inhibitory effects took 3 to 5 days to develop.

SECTION VII

MINOR FACTORS AFFECTING PERFORMANCE

MIXING

Results from the qualitative dye study at EAFB indicated that there was complete mixing in the aeration basin but that the minimum system flow-through time was very short. For instance, the horizontal side, Rhodamine-B dye (~1 liter 40% solution) was injected into the feed and in less than 5 minutes, the aeration basin was completely colored. A colored upwelling under the clarifier effluent trough was noted at 35 minutes. The liquid 1 meter down in the center of the horizontal flow clarifier had not developed any color by the time the dye was beginning to pass out with the effluent at about 45 minutes. This indicates that it would be most wise to locate the effluent weir away from any wall or baffle when density currents could cause upwelling. Mixing time to color the up side aeration basin was also less than 5 minutes, but the dye appeared above the tubes (settler) in 25 minutes and was passing into the effluent at 1/2 hour.

The velocity profile for the EAFB extended aeration basins was determined using a vertical vane, magnetic head, velocity meter. This instrument indicated only the horizontal component of the velocity. Surface velocities were measured by timing a floating wood block. The velocities at various depths are listed in Table 11.

All velocities except those near the surface were consistently less than the generally recommended 0.3 meters (1 ft) per second but there was no excessive sludge accumulation in the bottom of either basin. It should be remembered, however, that both units were fed with primary effluent. Operation with air inputs as low as 5 cmm/10^6 liters (0.7 SCFM/1000 gal.) had caused some MLSS to settle in the aeration basin.

For weaker sewage, mixing may require more air than does oxygen transfer. For adequate mixing in vertical wall tanks with 3.4 m (11 ft) aerator submergence, the air requirement is 7 to 14 cmm/10^6 liters (1 to 2.0 SCFM/1000 gal.).

Grube (9) reported surface velocities on the College Utilities oxidation ditch to be about 0.3 m per second. Murphy (10) later reported excessive sludge deposition and said, "...it thus appears that the rectangular configuration and the aerators used in this plant are unsuitable for keeping the floc in suspension."

BIOLOGICAL CHARACTERISTICS

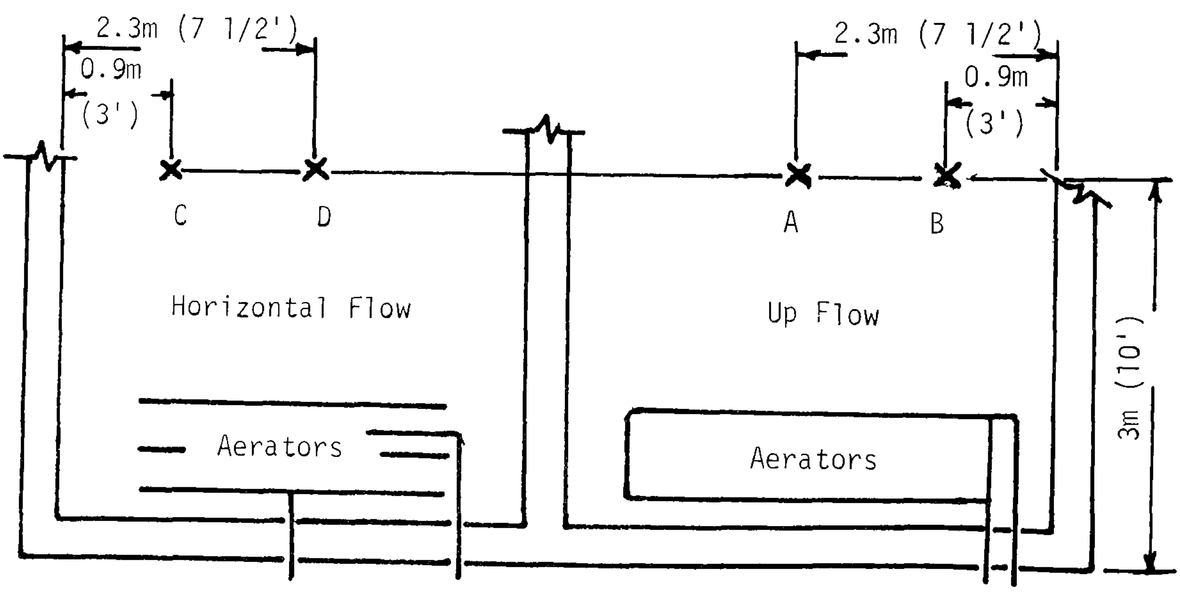
Poor settling sludges were developed during the operation of the cold room bench scale reactors with the Sludge Volume Index (SVI) consistently ranging above 200. The sludge produced appeared to be of a zoogeal type

Table 11. EIELSON AIR FORCE BASE EXTENDED AERATION BASINS
HORIZONTAL VELOCITY COMPONENTS

Velocities in Meters/second (ft/second)

	Location in Aeration Basins							
	Horizontal Flow				Up Flow			
Depth m (ft)	C		D		A		B	
Surface	----	---	0.37	(1.2)	0.30	(1.0)	----	---
0.3 (1)	0.15	(0.5)	0.30	(1.0)	0.27	(0.9)	0.12	(0.4)
1.0 (3)	0.06	(0.2)	0.09	(0.3)	0.18	(0.6)	0.12	(0.4)
1.5 (5)	0.09	(0.3)	0.06	(0.2)	0.03	(0.1)	0.09	(0.3)
2.1 (7)	0.06	(0.2)	0.09	(0.3)	0.06	(0.2)	0.09	(0.3)
2.7 (9)	0.03	(0.1)	0.06	(0.2)	0.09	(0.3)	0.12	(0.4)
3.4 (11)	0.06	(0.2)	0.06	(0.2)	0.12	(0.4)	0.18	(0.6)
Liquid Depth	----	---	3.7	(12ft)	3.7	(12ft)	----	---

Air lifts off; using 3.4 cubic meter/min (cmm) compressor;
bleeding approximately 1.4 cmm



Plan
Front 2/3 of Aeration Basins

similar to that reported by Heukelekian and Wiesburg (35) who found a direct correlation between increasing SVI and increasing bound water for this type of bulking. Very little evidence of Sphaerotilus was noted during microscopic examination. Ludzack (18) also reported a poor settling sludge at low temperatures (5°C) with very poor drainability.

Because of the differences noted in operation of the cone reactors at 1.3°C and 6.5°C, it was decided to raise the 33.7-liter reactor temperature gradually, first to 4°C and then to 8°C, letting the reactor stabilize at each temperature. This was done in an attempt to determine the changing sludge characteristics with temperature changes from 4° to 8°C.

Reactor temperature was first raised to 4°C from less than 1°C over a period of 2 days with no noticeable effects. After stabilizing at 4°C, reactor temperature was again raised. However, at the same time, the coils of the cold room refrigeration unit began to freeze due to excessive mositure condensation and the cold room operation became very erratic. Reactor temperature went from 4°C to 10°C, back to 6.5°C, and finally stabilized at around 8°C within about 5 days. The SVI jumped from around 230 to 260 with the sludge changing from a granular matrix to a fluffy, snowflake appearance. The reactor began to pass heavy solids concentrations in the effluent 3 days after the erratic cold room operation began. Noticeable microscopic changes during this period were an obvious reduction in quantity and activity of protozoa.

Reactor operation was maintained at 8°C for approximately 10 days during which time it did not return to its normal state. It was subsequently returned to the colder operating temperatures and the feed cut off for 12 days in an attempt to improve the settling qualities of the sludge. The SVI's returned to around 230 but few other changes took place with negligible decrease in suspended solids or percent volatile suspended solids. The quantity and activity of protozoa did begin returning to their former state at about the time the reactor temperature was returned to the lower level.

The significance of protozoa in an efficiently operating activated sludge process, as reported by McKinney (17), was observed during operation of the reactors even at the coldest temperatures. The 47.1-liter reactor was started at temperatures <2°C with return sludge seed from an oxidation ditch treating domestic sewage. Initially, the effluent was very turbid as the sludge was acclimating itself to the new conditions. The decreasing turbidity of the sludge as acclimation progressed corresponded to increasing numbers of protozoa, generally Paramecium and Vorticella. As reported by McKinney, a very well stabilized activated sludge system will have few stalked ciliates and no other protozoa because of relatively few bacteria; whereas, a somewhat less stabilized system will have greater numbers of free swimming ciliates because of greater numbers of free swimming bacteria. He states that the presence of stalked ciliates indicated an activated sludge system with a low BOD effluent. Vorticella was present in both reactors after initial startup except for one period in the 47.1-liter reactor as described below.

After stable operations at temperatures of <2°C and ∿4°C, the 47.1-liter reactor temperature was increased to 8°C over a period of 6 days. Effluent suspended solids increased from approximately 5 mg/l before the temperature change to approximately 18 mg/l during the change and to a maximum of 46 mg/l 3 days after reaching 8°C. During this period, the effluent became very turbid with very few solids settling out in the effluent tank. Protozoa became very reduced in numbers and very inactive. Again, the return to normal operation corresponded to an increase in the number of Vorticella and Paramecium present in the sludge. Coliform removals also directly correspond to the numbers of protozoa present, dropping from 99.8 percent removals before the upset to less than 80 percent during the period of reduced protozoa.

Aside from temperature change, the only other parameter measured, which could explain the sudden change in reactor performance, was an increase in dissolved solids for over a one day period. Dissolved solids ranged from 250 to 360 mg/l prior to the sharp increase to 450 for one day and a subsequent decrease to ∿360 mg/l. This could be evidence of toxic material in the feed. Ten days after returning to stable operation at 8°C, the sludge was exhibiting the same characteristics as with the 33.7-liter reactor. That is, the SVI's were ranging around 250 and the floc exhibited a fluffy snowflake appearance. Reactor operation was not impaired under these conditions because of the backwash cycle added to the settling apparatus.

EQUIPMENT HOUSING AND PROCESS EXPOSURE

At EAFB the unheated A-frame clarifier provided sufficient protection even though it was not totally sealed at the clarifier surface or around a polyethylene film curtain door. During low liquid temperature operation, thin ice formed on the surfaces of the clarifiers but did not affect the operation other than to make manual removal of floatables difficult. During cold weather, 40°C and colder, a 38,000 K cal/hr space heater (150,000 BTU/hr) was set at about 4°C and aimed at the sampling equipment to assure operation and liquid samples. It is obvious that freeze protection is necessary anywhere aqueous fluids are exposed.

Grube and Murphy (9) indicated a thick ice formation on the concrete block oxidation ditch-clarifier building interior due to condensation. The ice did not create any problems, however. They reported the building temperature remained relatively constant at 1.7°C.

At the Glenwood, Minnesota oxidation ditch (11) only the rotors had any climatic protection. They were covered with a structure similar to that at the College oxidation ditch.

In subarctic climates, if sufficient care is used in the design of extended aeration units, there is no reason to house the aeration basin. Ranganathan and Murphy (10) reported that the College oxidation ditch accumulated a sheet of surface ice approximately 6 m (20 ft) wide, 30 cm (1 ft) thick and 21 m (70 ft) long by mid-April of 1971. Solids concentration in the ice was probably much higher than in the mixed liquor. They reported that when the ice melted it released large quantities of solids.

Clark, et al. (8) have stated "When utilizing exposed basins, heat loss effects must be evaluated in conjunction with detention time determinations to avoid potential freezing problems. Solids entrainment in ice can cause failures of an activated sludge process." Concentrating waste sludge by this method was discussed in Section VI.

During March of 1972, the sewage feed temperature for the EAFB units was less than 4°C. With a hydraulic detention of 1 day, a thin sheet of ice formed on all basins except directly over aerators and air lift sludge returns. Based upon the author's experience, the following maximum exposed aeration basin (housed clarifiers) detentions should not be exceeded where the average January temperature is less than -23°C (-10°F):

Detention, Days	Sewage Temperature, °C
1	5
2	10
4	20

It is possible to operate with longer detentions at lower temperatures but operating problems will increase exponentially.

SECTION VIII

OTHER PERFORMANCE CRITERIA

NUTRIENTS

Nutrient removal (N and P) is an important consideration in establishing performance criteria. In 1968, Grube (9) reported limited nitrogen data (four samples) for the College oxidation ditch. He said, "The test results indicate that nitrification during periods of low temperature (<12°C), is almost nonexistent." No phosphorus data has been published for the College oxidation ditch.

Results of nutrient analysis for cold room Pope reactors are presented in Table 12. As expected, there was not a great deal of activity at the lower temperature. There was an insignificant change in nitrate and total nitrogen at 6.5°C when going from 9 to 13 hours detention time. This was also true at 1.3°C to a lesser degree. There was a greater reduction in ammonia nitrogen and a greater increase in nitrate nitrogen at 6.5°C than at 1.3°C. Total nitrogen removals were much higher at 6.5°C than at 1.3°C with little detention time effects.

Additional studies were undertaken at a later time using the 47.1-liter reactor in an attempt to determine the effect of denitrification on bulking conditions. Sampling points included influent, effluent, reactor mixed liquor and stations along the settling tube as shown in Figure 25. Samples were anlayzed for solids (TS, TVS, SS, VSS) and nitrogen (NH_3, NO_2, NO_3, Kjeldahl). Dissolved oxygen levels were determined at the points sampled using a polarographic probe. Reactor temperature during these studies was ∿11°C and detention time 12 hours.

Samples were taken on six different days with results for a typical day presented in Figure 26. Sludge level in the tube was just above the T-4 sample point during sampling for this day. Denitrification was obviously taking place. Ammonia-nitrogen dropped from 21 mg/l in the influent to 2 mg/l in the reactor mixed liquor while the nitrate-nitrogen increased to 15 mg/l. The DO level dropped from 6 mg/l in the reactor to 1.5 mg/l at the lower end of the tube which was enough to cause a decrease in the nitrate-nitrogen level for denitrification to begin. The DO concentration continued to drop slightly to the top of the sludge height in the tube. Denitrification continued while the ammonia and nitrite levels remained the same. The DO level increased again at the top of the tube and in the effluent with reaeration due to the configuration of the reactor. As a result, denitrification ceased and the ammonia and nitrite-nitrogen were converted to a nitrate. There is little doubt that the low DO level in the tubes and the resultant denitrification contributed to the deterioration of sludge settling characteristics as the reactor temperature was raised from 4° to 8°C. This fact does not explain the initial bulking conditions, though less severe, at temperatures below 8°C since nitrification should not be expected to occur to any significant degree below 5°C (36).

TABLE 12

CONE REACTORS

RESULTS OF NUTRIENT ANALYSIS

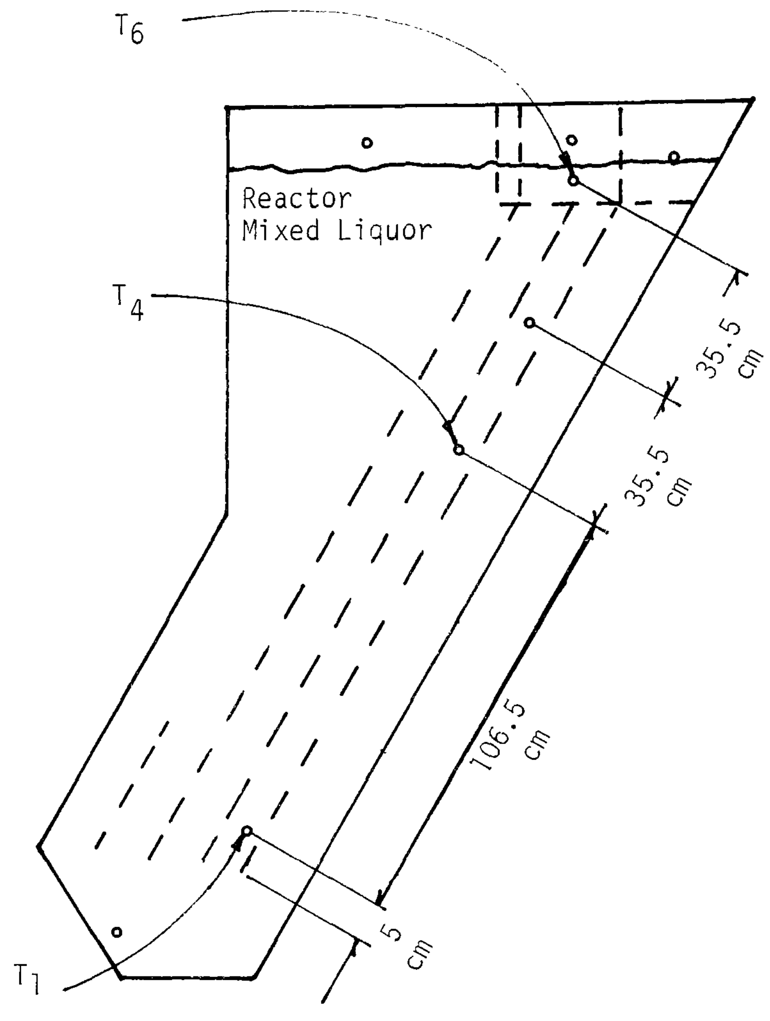
13 Hour Detention Time

	1.3° REACTOR			6.5°C REACTOR		
	Influent	Filtered Effluent	Unfiltered Effluent	Influent	Filtered Effluent	Unfiltered Effluent
NH_3-N (Ammonia)	22	19	18	19	1	1
NO_2-N (Nitrite)	.13	.09	.05	.11	.13	.15
NO_3-N (Nitrate)	.13	2.13	2.02	.21	9.17	12.13
Kjeldahl-N (Nitrogen)	41	28	29	37	3	3
Total Nitrogen	41	30	31	37	12	15
Total Nitrogen Removals (%)	-----	27	24	-----	67	59
O-PO_4 (Ortho-Phosphate)	20	18	18	19	18	18

9 Hour Detention Time

	1.3°C REACTOR			6.5°C REACTOR		
	Influent	Filtered Effluent	Unfiltered Effluent	Influent	Filtered Effluent	Unfiltered Effluent
NH_2-N (Ammonia)	21	19	19	21	1	1
NO_2-N (Nitrite)	.06	.03	.03	.06	.14	.12
NO_3-N (Nitrate)	.11	.68	.54	.07	8.03	14.45
Kjeldahl-N (Nitrogen)	36	26	27	35	3	3
Total Nitrogen	36	27	28	35	11	18
Total Nitrogen Removals (%)	-----	26	24	-----	68	50
O-PO_4 (Ortho-Phosphate)	17	14	15	19	18	16

(1) Total nitrogen results reported are the sum of the nitrite, nitrate and Kjeldahl nitrogen analysis.



DENITRIFICATION STUDY SAMPLE STATIONS

FIGURE 25

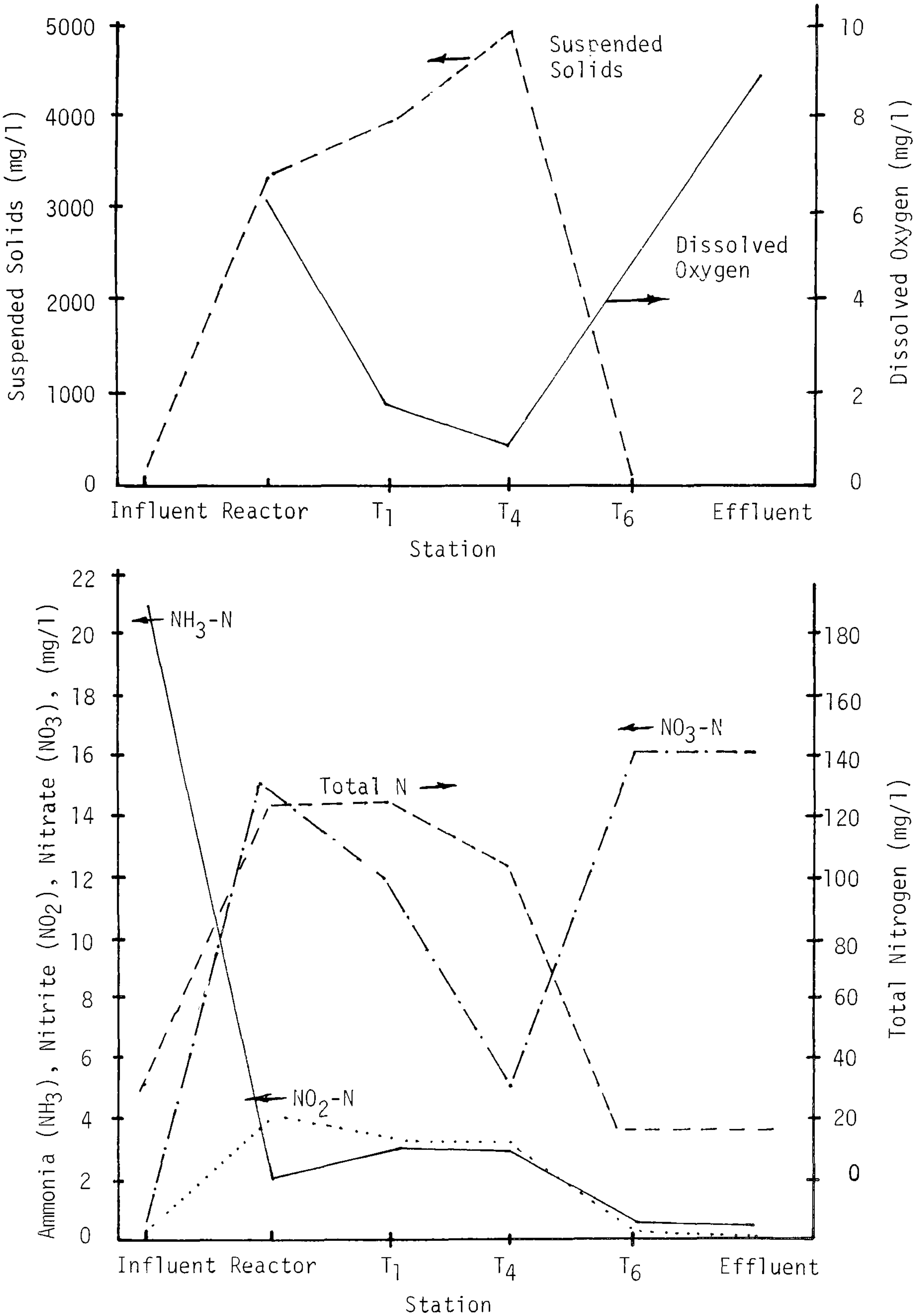


FIGURE 26

DENITRIFICATION STUDY, TUBE SETTLER NITROGEN PROFILE

The EAFB nitrogen data is listed in Table 13. Nitrogen removal was accomplished only at mixed liquor temperatures of 8°C or above. Apparently, at 8°C, the sludge age $\left(\frac{\text{Mass of MLSS}}{\text{Mass of SS Lost Per Day}}\right)$ must be above 13 days for denitrification to occur. At temperatures of 5°C or below, there was no significant nitrification even with sludge ages of 100+ days. It can be surmised from the data on Table 13, that denitrification, i.e., nitrogen gas formation, was not contributing to the bulking (SVI>100) conditions in period III.

The phosphorus data on Table 14 shows less than 10 percent removal which is to be expected with the conventional extended aeration process. One would not think that phosphorus removal would be affected by low temperatures.

TOTAL COLIFORMS

The percent total coliforms remaining before chlorination at the EAFB pilot units is listed in Table 15. The highest effluent coliform levels are generally associated with the highest effluent suspended solid levels and lowest percent BOD removal. These data indicate coliform removal is not directly related to temperature but is dependent upon effluent solids levels. Percent total coliforms remaining can be somewhat misleading because 98 percent total coliform removal (2 percent remaining) may represent 10^3, 10^4, or more total coliform counts per 100 ml. The coliform removals experienced at the EAFB pilot plant are similar to removals found in warmer temperature extended aeration units.

No bacteriological data has been published for the College oxidation ditch.

TABLE 13

EIELSON AFB EXTENDED AERATION--NITROGEN CYCLE
Concentrations mg/liter as N

Date	Feed			Horizontal Effluent				Upflow Effluent				Horizontal Mixed Liquor		Upflow Mixed Liquor	
	NO_2+ NO_3	NH_3-N	TKN-N	NO_2	NO_3	NH_3-N	TKN-N	NO_2	NO_3	NH_3-N	TKN-N	T°C	Age Days	T°C	Age Days
10/13/71	0.14	14	23	1.3	0.22	13	15	0.32	0.02	53	27	15	50	15	20
11/17/71	0.05	22	32	0.14	19	1.8	4.5	1.2	1.4	17	22	10	22	12	44
12/08/71	0.31	24	26	0.05	17	1	2	0.04	0.01	20	22	8	80	8	13
01/12/72	0.14	24	25	0.09	5.3	14	13	0.04	0.05	11	10	4	32	4	3
02/09/72	0.02	25	27	0.03	0.17	21	22	0.03	0.24	22	21	3	17	3	21
02/23/72	0.02	24	26	0.01	0.01	23	24	0.01	0.01	23	27	5	24	5	7
03/01/72	0.02	26	27	0.01	0.01	23	26	0.03	0.04	26	26	2	83	2	27
03/08/72	0.03	21	29	0.07	0.02	19	22	0.01	0.13	20	23	0	167	0	25
03/15/72	0.02	23	26	0.09	0.05	20	23	0.01	0.07	22	25	1	130	2	32
03/22/72	0.03	21	26	0.06	0.01	18	24	0.01	0.01	21	25	1	132	1	35
03/29/72	0.02	21	27	0.10	0.05	25	28	0.01	0.01	23	24	3	---	3	---
04/05/72	0.02	24	27	0.14	0.09	22	25	0.01	0.01	24	23	5	308	4	90
04/12/72	0.03	24	27	0.02	0.10	21	25	0.01	0.03	21	24	--	63	--	32
04/19/72	0.02	28	33	0.01	0.09	20	21	0.01	0.04	18	19	5	491	5	192
04/26/72	0.02	15	22	0.03	0.11	18	23	0.02	0.01	30	31	3	778	4	5

TABLE 14

EIELSON AFB EXTENDED AERATION-PHOSPHORUS DATA

Concentrations mg/liter as P

Date	Feed		Horizontal Effluent		Upflow Effluent	
	T-P	O-P	T-P	O-P	T-P	O-P
12/08/71	12	14	11	13	13	15
01/12/72	10	10	10	10	3	3
02/09/72	12	12	11	10	9	10
02/23/72	13	14	12	13	13	13
03/01/72	13	13	13	13	13	14
03/08/72	14	13	13	13	13	13
03/15/72	11	11	10	10	10	8
03/22/72	13	13	13	12	13	13
04/05/72	12	13	13	12	12	13
04/12/72	14	14	11	15	15	14
04/19/72	10	10	8.7	9.1	8.9	9.1
Average Percent Removal			7	5	8	9

TABLE 15

EAFB PILOT UNITS
TOTAL COLIFORMS REMAINING BEFORE CHLORINATION

Period	Side	Average Mixed Liquor Temp. °C	Average % BOD Removal	Average Eff. SS mg/l	Average % Total Coliforms Remaining
I	Horizontal	12	81	36	1.7
I	Up	12	82	99	10
II	Horizontal	4	10	134	14
II	Up	4	-30	122	26
III	Horizontal	4	84	17	1.8
III	Up	4	76	50	2.6

SECTION IX

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SECTION X

GLOSSARY

BOD - Biochemical Oxygen Demand, 5 day - 20°C

cmm - cubic meters per minute

COD - Chemical Oxygen Demand, dichromate oxidation

DO - Dissolved Oxygen

EAFB - Eielson Air Force Base

gpm/ft^2 - gallons per minute per square foot

K cal - kilogram calories

lb - pound mass

Lit liter(s)

m^2 - sq m - square meter(s)

m^3 - cu m - cubic meter(s)

mg - milligram mass

MG - million gallon(s)

MGD - million gallons per day

MLSS - mixed liquor suspended solids

MLVSS - mixed liquor volatile suspended solids

O-P - orthophosphate

SCF - standard cubic feet

SCFM - standard cubic feet per minute

SS - suspended solids

SVI - sludge volume index

T-P total phosphate

TS - total solids

TVS - total volatile solids

VSS - volatile suspended solids

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16. ABSTRACT

In an effort to develop design criteria for biological treatment of low temperature domestic sewages, the Arctic Environmental Research Laboratory has designed and operated two parallel low temperature extended aeration units near Fairbanks, Alaska. The two units had exposed aeration basins utilizing submerged aerators and were differentiated by type of clarifier. One unit had conventional horizontal flow clarifier while the other had a modified upflow clarifier with tube settlers. The liquid temperature varied from 0°C to 19°C. In addition, 0.5 MGD subarctic, oxidation ditch and low temperature bench scale units were studied.

Organic loading was the parameter most seriously affected by low temperatures. It was found that BOD removals above 80% at liquid temperatures below 7°C could generally be maintained at loadings of 0.08 Kg BOD/Kg MLSS/Day or less. As in warmer climates, intentional sludge wastage was found to be required. Low temperature solids accumulation rates indicated that standard wastage criteria of 0.5 Kg SS/Kg BOD is usually adequate.

Other parameters investigated and reported were: (1) aeration for oxygen transfer and mixing; (2) comparative clarifier performance; (3) nutrient and total coliform removals.

17. KEY WORDS AND DOCUMENT ANALYSIS

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