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DESIGN CONSIDERATIONS FOR EXTENDED AERATION IN ALASKA

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FEDERAL WATER QUALITY ADMINISTRATION
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ALASKA WATER LABORATORY
College, Alaska

DESIGN CONSIDERATIONS FOR EXTENDED AERATION IN ALASKA*

by

Sidney E. Clark
Harold J. Coutts
Conrad Christianson

FEDERAL WATER QUALITY ADMINISTRATION
ALASKA WATER LABORATORY
College, Alaska

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A Working Paper presents results of investigations which are to some extent limited or incomplete. Therefore, conclusions or recommendations--expressed or implied--are tentative.

CONCLUSIONS

The feasibility of the extended aeration activated sludge process as a relatively economical and effective means of secondary waste treatment has been demonstrated in the laboratory and in the field. The process requires more consistent operation and maintenance than aerated lagoons and this is a disadvantage where costs are high and skilled operators are extremely scarce.

The Utilization of exposed aeration chambers for the extended aeration process is feasible. Earthen basins are also feasible for use where economic and construction conditions warrant. 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 failure of an activated sludge process.

Environmental protection in varying degrees should be provided for the remaining equipment, such as heated enclosures for pumps and flow measurement devices. Housing must be provided for secondary sedimentation basins and should include a minimum of an unheated structure with panels which can be removed for warm weather operation.

Effective solids separation is the key to successful operation of extended aeration facilities and is dependent on both the biological and physical aspects of the system. It has been demonstrated that a sludge can be developed which will perform very efficiently at temperatures <1°C. A turbid effluent will result at cold temperatures with an unacclimated sludge or loading rates that are too high. Under these conditions, a less stabilized sludge develops with a corresponding relative decrease in numbers of stalked ciliates and an increase of dispersed bacteria which appears to contribute to turbidity (22).

A bulking sludge may develop at cold operating temperatures. This type of sludge can lead to separation problems but will provide a very clear effluent at temperatures ranging down to less than 1°C.

Properly designed tube settlers will provide effective cold (0 to 4°C) temperature solid separation. This is true for sludges with SVI's ranging up to 250. A backwash cycle should be provided for reliable operation and is mandatory for operation with high MLSS concentration (4000 mg/l) and bulking sludges. Some effort should be directed toward developing upflow clarifier configurations for cold temperature application since the method has advantages (27). The tube settler does provide an upflow clarifier type action in high MLSS activated sludge solid separation applications. Providing consistent solids separation with tube settlers at warmer temperatures (greater than 4°C) appears to be the most demanding and yet insufficiently defined area of need in their application.

Cold climate sludge wasting and disposal for the extended aeration process must be given consideration for the following reasons:

(1) Excess solids production increases with decreasing temperature.

(2) Shorter detention times to prevent freezing will also increase solids production at a given MLSS level.

(3) Auto induced sludge wasting may be expected to be more severe, placing greater potential stress on the receiving water.

(4) Retarded assimilative capabilities of the receiving water at cold temperatures.

RECOMMENDATIONS

Facility Design

The following design recommendations are based on laboratory studies, experience with the Eielson Air Force Base pilot facility, and experience reported by others:

(1) Exposed aeration basins should be considered for reducing construction costs of waste treatment facilities. Raw sewage temperatures and heat loss effects must be considered to prevent freezing which can cause process failure by entrainment of solids from the system.

(2) Housing should be provided for pretreatment units such as bar racks, pumps and flow measuring equipment.

(3) Some minimum protection should be provided for aeration equipment such as strip heaters or minimum heat enclosures for compressors and unheated housing for oxidation ditch rotors.

(4) Housing should be provided for secondary sedimentation basins. Minimum housing would include a structure with panels which may be removed for warm weather operation.

(5) Where economic and construction considerations warrant, earthen basin designs should be considered for aeration chamber construction.

Otherwise, sidewalls that are vertical or near the angle of repose should be utilized to promote better mixing.

(6) Submerged settling units should be situated in the center of basins with low sidewall construction with aeration on at least two sides to promote adequate mixing. Several questions require answers before submerged settling units are practical.

(7) When basins with low sidewall slope construction are utilized without submerged settling units, the aeration devices should be clustered in the center of the basin for best mixing.

(8) Flexible membranes should not be used where the danger of heavy icing exists.

(9) Concrete block and concrete grout should be considered as economical liner materials where the design permits.

(10) Tube settlers with backwashing of tubes should be given consideration for both submerged settling units and sedimentation basin installations, however, more information is necessary before their reliability is predictable. Effective methods must be provided for removal of settled solids from the unit for recirculation. Lack of this capability will result in poor tube settler performance. Considerable thought must be given to maintenance, both routine and emergency, prior to and during the design phase for tubesettlers to be useful.

Process Design

The following preliminary recommendations for low temperature extended aeration systems are based on laboratory studies and experience reported by other investigators. Attempts will be made to verify these findings on a pilot plant scale.

(1) Organic loadings should be maintained below ∿ 0.20 #BOD/#MLVSS-Day. More studies are necessary at higher F/M values, especially up to 0.4 #BOD/#MLVSS.

(2) Provision should be made for sludge wasting of ∿ 0.5 #MLSS/#BOD removed, particularly at shorter detention times such as a 12 hour detention time system. Further studies are necessary to determine temperature and detention time influences.

(3) Tube settler overflow rates should be held below 0.5 gpm/ft^2 with high MLSS concentrations (∿ 4000 mg/l).

(4) Sludge wasting and disposal facilities or a polishing lagoon for effluent discharge should be provided where heavy discharges of suspended solids may place excessive stress on receiving waters.

Research and Development Needs

The following list of suggested research and development needs is not intended to be all inclusive but includes areas which have come to the attention of the authors through laboratory and pilot plant experience and a review of experience reported by other investigators:

(1) Sludge bulking conditions at lower temperatures (∿ 8°C and below) must be defined so the condition can be predicted in actual application.

(2) Further develop low temperature bio-kinetic parameters at detention times ranging from 4 to 36 hours and varying MLSS levels.

(3) Further develop low temperature tube settler design criteria and backwashing techniques at various MLSS levels.

(4) Investigate upflow clarifier designs for low temperature application.

(5) Investigate methods of sludge digestion and disposal under low temperature conditions; particularly the use of the freeze-thaw cycle as an aid to promoting better drainability.

(6) Develop reliable methods for positive recirculation of settled solids from submerged settling units.

(7) Further investigate criteria for predicting heat loss from exposed basins.

(8) Continue evaluation of cold temperature bio-kinetic design parameters on pilot plants and existing facilities.

(9) Develop design and operation criteria for low temperature horizontal flow clarifiers.

(10) Investigate power requirements and mixing characteristics of various earthen basin configurations.

(11) Further investigate the effects of heavy ice cover on solids entrainment in aeration basins, particularly where flow patterns are parallel to the surface as in the oxidation ditch.

INTRODUCTION

Alaska is the largest state of the United States, sparsely populated and with a variety of climates, including arctic, subarctic, marine subarctic and temperate. The population is small and widespread with 294,417 people (preliminary 1970 census figure) 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 in general, and excessively so in remote areas (1.5 to 5 times Seattle construction cost index). Skilled personnel for operation of treatment plants are scarce and, in most cases, nonexistent.

The effect of man's waste on Arctic and Subarctic ecosystems has received little attention in the past and is not well understood. Because of recent increased interest in the Arctic region, some information is now becoming available on man's possible influence. For example, during the winter, dissolved oxygen (DO) of ice-covered Alaska rivers may reach extremely low levels of 3 mg/l or less under natural conditions (10, 12, 28). Because of the retarded ability of Alaska streams to replenish DO under total or nearly total ice cover, it becomes essential that the natural balance not be upset by man. Under these conditions, high level secondary sewage treatment will be required to assure adequate stream protection.

One of the major advantages of biological processes for provision of secondary treatment is their ability to oxidize waste without large inputs of energy, thus reducing shipping costs, etc., associated with materials required for chemical treatment. All factors considered, extended aeration systems have considerable potential for reliable and economical secondary treatment at larger governmental installations and larger communities in Alaska (populations greater than 250).

Current extended aeration research is being conducted by several groups:

1. Corps of Engineers
    Cold Regions Research and Engineering Laboratory
    Alaska District
2. University of Alaska
    Institute of Water Resources
3. Federal Water Quality Administration, Alaska Water Laboratory
    Cold Climate Research Program

Waste treatment research at the Alaska Water Laboratory is concerned primarily with adapting methods developed in the contiguous United States to the extreme cold climates found in Alaska. The scope of the present work on activated sludge is, in general, limited to extended aeration, and includes investigations in the following areas:

1. Low temperature bio-kinetics
2. Low temperature solids removal

3. Degree of environmental protection required for equipment and processes.

4. Aeration requirements

5. Aeration chamber mixing

6. Waste sludge characteristics and disposal

The above investigations are being conducted on a laboratory and pilot plant scale. Monitoring of existing facilities is also taking place.

LITERATURE AND EXPERIENCE REVIEW

Low Temperature Biological Treatment Feasibility

Although the activated sludge process is affected by temperature, operation at temperatures approaching freezing is feasible. A number of investigators have reported a considerable amount of biological activity taking place at freezing temperatures and below (3, 15). Miller (23) has reviewed the information available on microorganisms indigenous to cold environments and found that research on psychrophilic organisms is still in the initial stage, but concluded that "truly psychrophilic microorganisms do exist and are distinguished by their ability to grow at very low temperatures and to do so at rates comparable to those of mesophiles at higher temperatures." The feasibility of effective biological treatment by full-scale extended aeration facilities at operating temperatures as low as 2°C has been demonstrated (2, 13, 30).

Temperature Effects

Pasveer (24) conducted laboratory scale temperature studies with activated sludge and reported that the process goes on almost as well at 3-5°C as it does at 20°C. Wuhrmann (34), found in his studies of the activated sludge process that "the BOD removal seems to be only slightly influenced by temperature, whereas nitrification is markedly higher in summer than in winter." Ludzack (21) conducted bench scale studies using a continuous apparatus with a detention time of 24 hours and a loading of 35# COD/1000 ft^3 and demonstrated COD removal efficiencies of <90% at 21-25°C, 90% at 10°C and 84% at 5°C. Hunter et al. (19) conducted batch operated laboratory scale studies on the effect of temperature and retention times on the activated sludge process. At temperatures between 4°C and 45°C, they found little change of BOD or suspended solids removal efficiencies. As the temperatures increased, they found less filamentous growth and increased protozoa and rotifer populations. Grube and Murphy (13) evaluated an oxidation ditch and found BOD removal efficiencies greater than 90% with liquid temperatures of 2°C, air temperatures ranging down to -40°C, and average detention times of 2.3 days. Influent temperatures averaged 16.6°C with a minimum of 7.5°C. Gustaffson and Westbury (14) evaluated the activated sludge process for application at Kiruna, Sweden, and obtained 75% BOD reduction with a 3 1/2 hour detention time system at 2.8-4.8°C and 2700-3500 mg/l MLSS.

Temperature Coefficient

The temperature coefficient, θ, is used in the relationship

$$k_1/k_2 = \theta\ (t_1 - t_2)$$

to define the effect of temperature on biological activity. The values k_1 and k_2 refer to velocity constants at temperatures t_1 and t_2

respectively. The value of θ indicates the extent of the temperature effect on the biological activity. Use of this equation, known as the Arrhenius relationship, to define the effect of temperature on wastewater and reaction rates, dates back to Streeter and Phelps (1925) and Theriault (1927), who reported θ values of 1.047 for domestic wastewater and river water (35). Pohl (25) concluded that θ was dependent on the mixed liquor concentrations: $\theta = 1.038$ at low MLSS and 1.000 at high MLSS. Benedict (4) conducted studies in the temperature range of 4-32°C and concluded θ ($\theta = 1.078$ @ 4°C) was independent of loading when the loading rate did not exceed 0.53 lbs BOD/day/lb/MLSS, but θ increased as loadings above 0.53 were imposed. Eckenfelder (8) suggested that θ, based on overall treatment efficiencies, was a function of the organic loading and reported θ values for activated sludge of 1.00 at low loadings and 1.02 at high loadings.

Solids Separation

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 high effluent BOD. Reed and Murphy (27) conducted an investigation on 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 (4) suggested that the effect of sludge settleability on gross COD removal was magnified at low temperatures and as the loading rate was increased.

Hansen (16) reported on a method of solids separation which successfully employed shallow depth sedimentation theory. The settling units consisted of small diameter tubes (1-inch) inclined at 5° and 2-4 feet in length. Detention times were very short and backwashing was necessary for removal of accumulated solids. Hansen (17) also reported on the use of steeply inclined tubes (60°) which permit solids deposited in the tubes to continuously slide down by gravity. A secondary clarifier of a trickling filter plant was converted to a biological reactor and the steeply inclined tubes utilized for solids separation which increased plant efficiency from 85 percent to more than 95 percent. The effluent suspended solids averaged 70 mg/l varying from a low of 7 mg/l to a high of 190 mg/l which was comparable to those produced by a conventional clarifier of an extended aeration plant of the same capacity (3000 gallons per day at 12-hour detention). Other reports are available which descirbe the use of tube settlers in water treatment and waste treatment solids separation (6, 29).

Pohl (26) investigated tube settlers in the laboratory and obtained the best results at room temperature but found the tubes passing excessive collodial solids occasionally.

Design Parameters

Little information is available on biological treatment process design for temperatures less than 5°C. Ludzack (21) and Hunter, *et al*. (19) observed that excess MLSS accumulation increased with decreasing temperature. The cell yield (c) increases with increasing temperature because it is believed a larger portion of BOD removed is utilized for energy at low temperatures than at high temperatures (32). Since the rate of endogenous respiration is depressed at low temperatures, the quantity of excess sludge produced is increased. Benedict (4) reports values for c and k (endogenous rate) at 4°C of 0.42 mg/mgCOD and 1.32 percent respectively.

Aeration

Eckenfelder and O'Connor (9) stated 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 indicated a temperature coefficient of 1.02 applied. The effects of temperature on stream reaeration has been studied under controlled experiments in the laboratory (1). A value for θ of 1.0241 for the temperature range of 5 to 30°C was found. Black (5) described a procedure for evaluation of aeration devices and stated that a θ value of 1.030 or higher should be used for cold water.

ALASKA WATER LABORATORY PILOT PLANT AND LABORATORY STUDIES

Laboratory Studies

During the past two years, three bench scale activated sludge reactors have been utilized for kinetics and solids separation studies. The three units are illustrated in Figures 1, 2, and 3. The systems have been operated as continuous flow through systems with the feed being primary effluent brought to the laboratory from the Eielson primary sewage treatment plant. Routine analysis included influent and effluent BOD and COD, mixed liquor and effluent suspended solids (SS) and volatile suspended solids (VSS). Nutrient analysis of the influent and effluent samples were made weekly and included ammonia, nitrite, nitrate, organic nitrogen, total phosphates and orthophosphates. A limited number of coliform counts were made on the influent and effluent. Microscopic examinations of the reactor contents were made on an irregular basis at times when apparent or suspected changes in the mixed liquor had taken place. 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 Standard Methods procedures (31). Coliform counts were made by the membrance filter method as described in Standard Methods and nutrient analyses were made in accordance with Federal Water Quality Administration Standards (11).

The cone reactors (Figure 1), when operated at 1.3°C and 6.5°C for long periods of time, showed some interesting characteristics which are summarized in Tables 1 and 2. Both biological sludges were relatively easy to establish.

The reactor runs started with the longest detention time first and the times decreased in chronological order. The 1.3°C reactor took a considerable amount of time to establish a stable system (more than 3 months). However, a good removal rate was obtained before the MLSS stabilized. There was apparently little difference in the biological activity at the two temperatures, but, operation of the reactor at 6.5°C was more erratic.

Both reactors generally showed "auto induced slude wasting" in the same manner as the College Utilities oxidation ditch described by Grube and Murphy (13). 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 within 2 to 3 weeks as opposed to the monthly occurrence 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 concentrations 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. 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, 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 as opposed to 3000 for the 1.3°C MLSS. Results of nutrient analysis are presented in Table 3. There was a significant 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. Ammonia was essentially not affected at 1.3°C. Total nitrogen removals were much higher at 6.5°C than at 1.3°C with little detention time effects.

Overall results of operation of the 8.9 gal and 12.45 gal reactors are presented in Tables 4 and 5. Temperature changes were accomplished by a gradual increase or decrease in the constant temperature room temperature. These reactors were operated at 12-hour hydraulic detention times with daily sludge wasting to maintain the MLSS at 4000 mg/l. The 8.9 gal reactor was later converted to a 24 hour operation. Sludge was wasted by drawing off the required amount of mixed liquor. A portion was used for a solids analysis to determine the exact amount of solids removed. The effluent BOD and COD figures of 9 to 21 mg/l and 46 to 96 mg/l indicate that a considerable amount of biological activity takes place at low operating temperatures.

Effluent BOD/COD ratios varied from 0.13 to 0.27 indicating that effluent organics were well oxidized. These were in comparison with the influent BOD/COD ratios of 0.55 to 0.66.

The amounts of sludge wasted varied from 0.42 $\frac{\text{mg susp. solids}}{\text{mg BOD removed}}$ 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.

Poor settling sludges were developed during operation of these reactors with the Sludge Volume Index (SVI) consistently ranging above 200. The sludge produced appeared to be of a zoogeal type similar to that reported by Heukelekian and Wiesburg (18) 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 (21) also reported a poor settling sludge at low temperatures (5°C) with very poor drainability.

The significance of protozoa in an efficiently operating activated sludge process as reported by McKinney (22), was observed during operation of the reactors even at the coldest temperatures. The 12.45 gal reactor was started at temperatures <2°C with return sludge 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 (22), 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 stated that the presence of stalked ciliates indicates an activated sludge system with a low BOD effluent. Vorticella was present in both reactors after initial startup except for one period in the 12.45 gal reactor as described below.

After stable operation at temperatures <2°C and ~4°C the 12.45 gal reactor temperature was increased to 8°C over a period of 6 days. The effluent suspended solids increased from approximately 5 mg/l before the temperature increase to approximately 18 mg/l during the increase and reached a maximum of 46 mg/l after 3 days at 8°C. During this period, the effluent became turbid with few solids settling out in the effluent tank. The protozoa became very reduced in numbers and inactive. Again, the return to normal operation corresponded to an increase in the number of Vorticella and Paramecium present in the sludge. Coliform removal also corresponded directly to the numbers of protozoa present, dropping from 99.8 percent removal before the upset to less than 80 percent during the protozoa number reduction. Ten days after returning to stable operation at 8°C, the sludge was exhibiting the same characteristics as with the 8.9 gal reactor. That is, the SVI was ranging around 250 and the floc exhibited a fluffy snowflake appearance. Operation of the reactor was not impaired under these conditions because a backwash cycle was added to the settling apparatus. Protozoa increased in numbers when the systems stabilized at 12°C.

Sludge wasting and disposal in cold climates should be given attention. Based on data presented earlier, it would appear that provision should be made for wasting 0.5 lb solids per lb or BOD removed at colder operating temperatures (<5°C) and at organic loadings of 0.1 lb influent BOD per lb MLVSS-Day. Sludge digestion and disposal methods present a problem at colder temperatures due to added heat requirements and poor drainability. Ludzack (21) indicated that sludge development at cold temperatures may require digestion at higher temperatures before disposal. Thomas (33) indicated the freeze-thaw cycle may be taken advantage of in cold climates to increase drainability.

Tube settlers have been evaluated as a possible alternate means of providing solids separation and return. During operation, sludge rises in the tubes until it reaches a level at which it is in equilibrium with the effluent flow. Action in the tube consists of a rolling motion in which solids are being carried up along the top side of the tube in a mass with the effluent, as shown in Figure 4. The mass gradually settles toward the bottom side of the tube where it enters 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). In the temperature range of 0° through 4°C the SVI of the mixed liquor ranged around 230 and did not hinder the operation of the reactor. At 8°C and above, the SVI increased to values of 260 and greater 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 0.2 gpm/ft^2 resulted in lowering the DO in the effluent tubes to zero, which further complicated the problem. The studies indicate that some means for backflushing tube settler controlled upflow clarifiers must be provided if mixed liquor concentrations greater than 2000 mg/l are to be achieved with reliable operation.

The 12.45 gal reactor was operated for a period of time with a very low continuous overflow rate and then increased to an average rate of 0.5 gpm/ft^2 with an alternating on-off cycle. In other words, with the on 1/2 hour--off 1/2 hour cycle, the actual flow was 1 gpm/ft^2 for 1/2 hour. The SVI again ranged above 200 with very consistent solids removal. The effluent solids concentrations were very low for the whole range of studies. The longer on times for the on-off cycle (2-1/2 hours on as opposed to 1/2 hour) did indicate that longer cycles may result in higher effluent solids concentration. Summaries of the results obtained at various temperatures and overflow rates are presented in Tables 6 and 7, and Figures 5 and 6. Adding a backwash cycle provided a definite advantage in that it prevented a bulky sludge from becoming stagnant in the tubes.

Indications are that sludge bulking probably is a general problem in the activated sludge process at colder operating temperatures and special precautions in design will be necessary to assure effective solids control. This problem was reported by Ludzack (21). Bulking sludges have not been reported in cold temperature oxidation ditch studies (2,13); however, these ditches were operated at much longer detention times (1.6 to 2.3 days) which may be a factor. Downing (7) showed that settleability is improved by longer detention time (>10 hrs) and very short detention time (<5 hrs) when operating an activated sludge plant at warm temperatures. At any rate, indications are that backwashing in conjunction with lower overflow rates will overcome this problem.

Unless a polishing lagoon is employed, provision should be made for sludge wasting. These studies indicate a probably maximum wasting rate of around 0.5 #SS/#BOD removal.

Pilot Plant

In cooperation with the Alaskan Air Command, the Alaska Water 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 the facility was to increase the knowledge of biological waste treatment at cold temperatures and to develop design criteria.

Eielson Air Force Base is located 22 miles southeast of Fairbanks and has a similar subarctic climate. The mean annual temperature at Fairbanks is approximately 25°F with minimum and maximum recorded temperatures of -66°F and +99°F respectively (20). The area has approximately 150 degree days below 0°F.

Originally intended to serve as a facultative lagoon, the extended aeration unit consisted of an earthen basin lined with 20 mil polyvinyl chloride film (PVC) and tube settler modules as shown in Figures 7 and 8. The PVC film at the bottom of the basin was covered with 6 inches of sand and a concrete pad poured in the center for support of aerators. Aeration and mixing were provided by eight Hydroshear aerators, manufactured by the Chicago Pump Company. Air supply was by a 120 SCFM Sutorbilt blower, manufactured by the Fuller Company.

Solids separation was provided by two tube settler modules. The tube settlers were developed by Neptune Microfloc Company for use in water treatment. The manufacturer has recently initiated studies to adapt them for use in activated sludge separation (17). This type of settler was felt to provide optimum design for submerged operation which was desired to overcome icing problems. The basin was fed by a Marlow centrigal pump, manufactured by ITT Marlow Company. Pumping rate was approximately 180 gpm with the feed drawn from a manhole on the influent line just before entry to the EAFB primary treatment plant. Temperature of the sewage averages about 20°C with the sewer lines enclosed in a utilidor, which is heated during the winter months.

The extended aeration facility as described was built to provide the very simplest operation with a minimum of environmental protection for evaluation under cold climate conditions. Construction of the extended aeration facility was completed in December 1968 and the unit placed in operation later that month. The unit was operated at a 2-day detention time, which corresponded to an average overflow loading rate on the tube settler of 1.3 gpm/ft^2. A problem was encountered with breakage of pumps, due to entrained solids entering the pumping chamber. The feed line also filled with solid material and plugged. As a result, the basin was not fed for a week, during which time 3 feet of ice formed over the pond and frozen foam built up to 8 feet above the aerator.

Beginning in January 1969 and lasting approximately 6 weeks, a period of extremely cold weather occurred with ambient air temperatures dropping as low as -60°F. A detention time of 1 day was maintained during this period with no ice forming. The loading on the tube settlers was approximately 2.5 gpm/ft^2. The gear housing of a compressor was broken and teeth stripped from the gears while attempting to start it at a low temperature. Apparently, metal contraction had reduced clearances which caused internal rotating parts to make contact with and break the pump housing.

During February, the feed pumps were moved inside the Eielson primary treatment plant and feed taken from the grit chamber. For the remaining of the winter and the following spring, while operating at a detention time of 2 days, the MLVSS of the system generally did not rise above 500 mg/l.

Inadequate mixing was suspected as the cause of poor performance, and velocity measurements were made with an ice current meter obtained from the M. S. Geological Survey which measured the horizontal component only.

Velocities were generally lower than the 1.0 ft per second recommended for complete mixing, except within 2 feet of the surface. The aeration rate was 120 cfm, depth of the basin 11 feet and with approximately 4 horsepower input. Velocities were measured again at a later date with 300 cfm being delivered and 9 horsepower input with generally the same results except the surface velocities were higher. The velocities found were not considered low enough to cause the extremely poor basin performance.

The possibility of excessive turbulence being carried into the tubes was also considered because of the close proximity of the settler modules to the aerators (2-3 feet). To check the possibility, a new aerator was fashioned of a short length of 3-inch pipe attached to flexible hose and placed in the basin approximately 10 feet from the settler modules. The MLSS of the basin increased to 1000 mg/l during operation of this aerator which did indicate that basin turbulence or entrained air bubbles was effecting the settler operation.

The basin was then taken out of operation to permit modifications in preparation for the next winter's operation. The modifications are illustrated in Figures 9 and 10. The system was placed in operation in December 1969. It was recogniized that at a detention time of 24 hours and with low winter operating temperatures, the hydraulic load on the tube settlers would be too great. An attempt was made to reduce the hydraulic load on the system while maintained a BOD load equivalent to a 24-hour detention time system by supplementing the feed with primary sludge from the Eielson tratment plant. Basin velocity proved to be restricted around and beneath the separator hoppers because of the low clearance and resistence offered by the settler support. As a result, a heavy sludge deposit blocked the separator hoppers, accumlated in the tubes and passed into the effluent.

During a cold period in January 1970, the surface of the basin began to freeze due to low heat energy being supplied. The sludge accumulated in the ice, reducing the suspended solids level in the pond from approximately 2500 mg/l to less than 200 mg/l. During this period, the mean ambient temperatures averaged -23°F, with a range of -8 to -35°F. Wind velocity ranged from 10 knots to calm and averaged 3 knots.

A block was cut from the ice and a sample taken of the unfrozen sludge beneath the ice. A cross section is shown in Figure 11. The ice had reached a thickness of 14 inches with a sludge layer of 17 inches beneath the sampling point. The sludge was not moving under the ice and apparently had attached itself, building up a thicker and thicker layer which eventually froze into the ice layer.

The long sloping side walls associated with earthen basins present two very important problems in activated sludge aeration chamber applications. The relatively high surface area to volume ratio will result in high heat energy losses from the system which may be very critical with low temperature influent. Greater heat losses will promote ice formation which will entrain MLSS from the system, destroying the effectiveness of the process.

The second problem is the difficulty in obtaining adequate basin velocities at lower depths without excessively high horsepower for mixing.

Even at high aeration rates, the minimum recommended velocities of 1.0 fps were generally not present in the pilot facility extended aeration basin at Eielson Air Force Base.

Another effect observed during operation in the second winter was that, with the aerators off center, a circular flow was induced in the basin in the horizontal plane around the aerators. The flow was similar to the Coriolis effect which may be observed when draining a bathtub, etc., and seemed to be promoted by the earthen basin shape of a large surface area to bottom area ratio. This effect will only become a problem in situations in which flow directions in the basin are important as in the Eielson AFB pilot facility, where the circular flow pattern did have an effect in hindering sludge removal from bneath the hoppers.

The cross sectional shape of a basin and the temperature to which it is exposed will, in general, determine the type of liner which should be provided. Material must be used which will prevent erosion and scouring by velocities in the basin. Side slopes of less than 1 vertical to 2 horizontal permit use of flexible liners, whereas, vertical sides will require bearing wall construction of impermeable concrete or wood crib design with an impermeable liner.

Experience with the PVC liner indicates it is not feasible for use in permanent installations for cold temperature applications. The liner becomes very susceptible to damage at low temperatures because of brittleness, and ice formation can cause extensive breaks in the lining. Aging and exposure to sunlight also increase its susceptibility to damage.

Impermeable liners such as low temperature butyl rubber membranes are feasible for use in earthen basins when the danger of major freezing does not exist. Care must be taken to insure that the liner is resistant to hydrocarbons which may be present in the sewage as softening or dissolution may result.

Concrete provides a reliable material for cold temperature application. However, construction is expensive in Alaska and particularly so in remote areas. Examples of the successful application of cheaper methods of concrete construction are the College Utilities oxidation ditch in Fairbanks, Alaska, and the oxidation ditch at Glenwood, Minnesota (2). Concrete block was used for the construction of vertical sides for the College Utilities ditch. Concrete silo staves were originally used for the sloping sidewall construction of the Glenwood ditch but were not sealed and soil behind the staves washed out. The problem was successfully alleviated by placing steel mesh and 4 inches of concrete grout over the staves to provide a smoother waterproof lining.

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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)	1,074	1,561	2,657	2,926
Volatile Susp. Solids (mg/l)	890	1,324	2,212	2,402
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 # BOD Feed / #MLVSS-Day	.19	.21	.17	.20
Product of MLVSS and Det. Time	14,700	19,500	28,000	21,600

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)	2,346	1,885	1,880	2,285
Volatile Susp. Solids (mg/l)	1,915	1,563	1,587	1,801
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 $\frac{\text{\# BOD Feed}}{\text{\#MLVSS-Day}}$	.08	.106	.18	.23
Product of MLVSS and Det. Time	31,600	23,000	23,300	20,600

TABLE 3

CONE REACTORS
RESULTS OF NUTRIENT ANALYSIS

13 Hour Detention Time

	1.3°C 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)	41.26	30.22	31.07	37.32	12.30	15.28
Total Nitrogen Removals (%)	--	27	25	--	67	59
O-PO_4 (Otho-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_3-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)	36.17	26.71	27.57	35.13	11.17	17.57
Total Nitrogen Removals (%)	--	26	24	--	68	50
O-PO_4 (Otho-Phosphate)	17	14	15	19	18	16

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

TABLE 4

SUMMARY OF RESULTS OF 8.9 GALLON REACTOR AND 12.45 GALLON REACTOR AT 12-HR DETENTION

Feed: Primary Plant Effluent

	REACTOR TEMPERATURE (AVG°C)			
	.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: lb Infl. BOD / lb MLVSS-Day	0.12	0.10	0.10	0.14
Sludge Wasted: mg/MLSS / 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
BOD/COD Ratio				
Influent	0.60	0.60	0.55	0.66
Effluent	0.24	0.23	0.25	0.16
Reactor	0.44	0.43	0.28	0.28

TABLE 5

SUMMARY OF RESULTS OF 8.9 GALLON REACTOR
AT 24-HR DETENTION

Feed: Primary Plant Effluent

	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: $\frac{\text{lb Infl. BOD}}{\text{lb MLVSS-Day}}$	0.07	0.07	0.07
Sludge Wasted: $\frac{\text{mg/MLVSS}}{\text{mg BOD Removed}}$	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
BOD/COD Ratio			
Influent	0.66	0.66	0.62
Effluent	0.27	0.19	0.13
Reactor	0.46	0.42	0.35

TABLE 6

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 (gpm/ft^2)	Susp. Solids (mg/l)	BOD (mg/l)	% BOD Removal	COD (mg/l)	% COD Removal
.35 (.3-.5)	95	244	292	3973	238	.4	10	12	95	69	76
.7 (.4-.9)	112	253	370	4237	238	.3	8	22	91	71	79
						.6	20	29	89	87	77
4.2 (2.8-6.4)	94	193	229	4147	---	.3	10	17	91	60	74
						.6	14	20	90	70	69
3.8 (3.5-4.1)	77	142	283	4067	229	.5	10	14	90	62	78
						.8	13	20	86	69	76

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

TABLE 7

12.45 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	SVI	Overflow[2] Rate (gpm/ft^2)	Tube Size	Susp. Solids (mg/l)	BOD (mg/l)	% BOD Removed	COD (mg/l)	% COD Removed
2.4 (1.4-3.5)	77	177	303	3957	---	.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	.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 (4.0-4.7)	93	223	321	4095	235	.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 (6.8-8.4)	87	194	313	4504	209	.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 parenthesis are minimum and maximum for that period
(2) Notes in parenthesis indicate the time cycle of effluent flow through the tubes

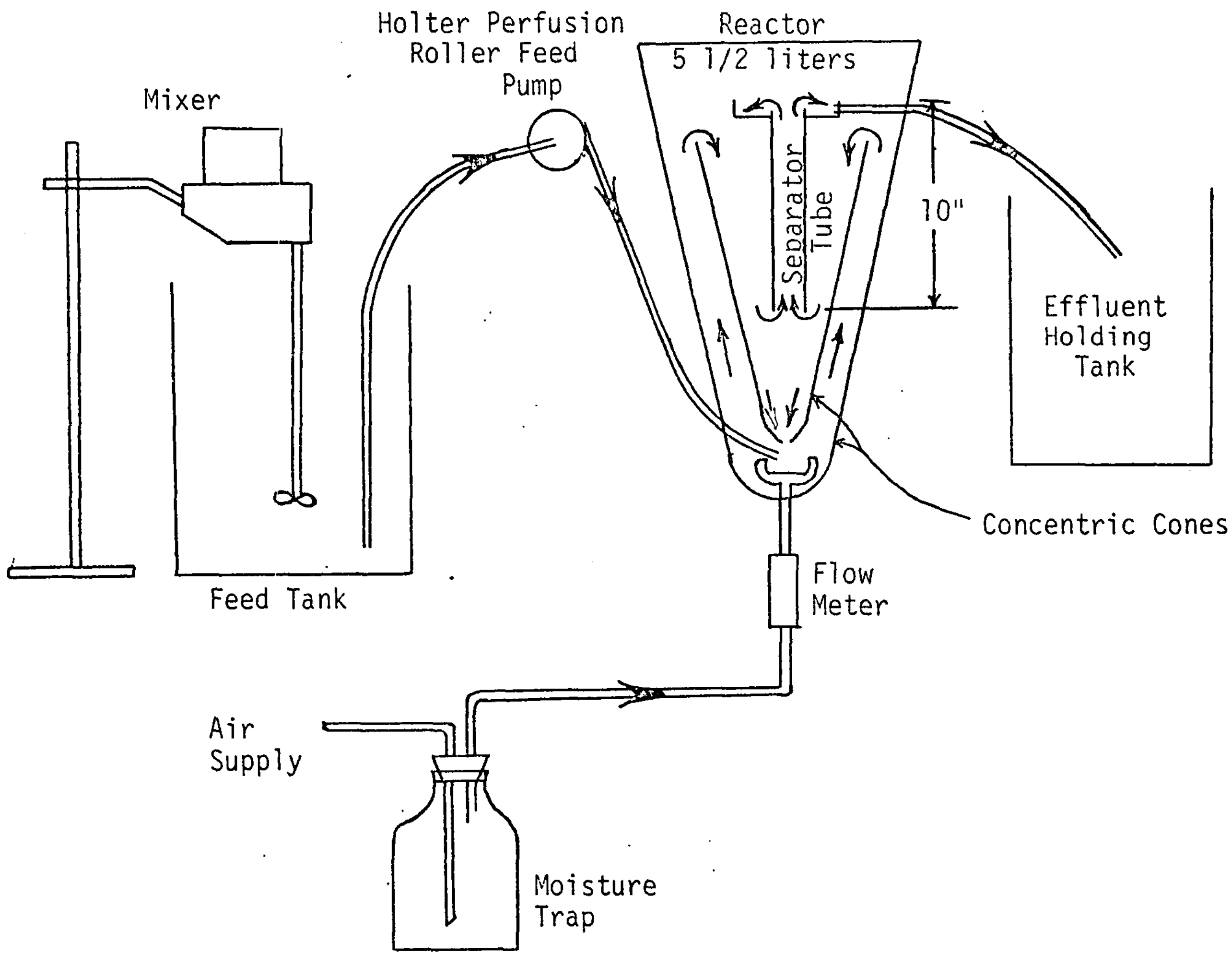

FIGURE 1

CONE REACTORS*
SCHEMATIC OF APPARATUS

*As manufactured by Pope Scientific

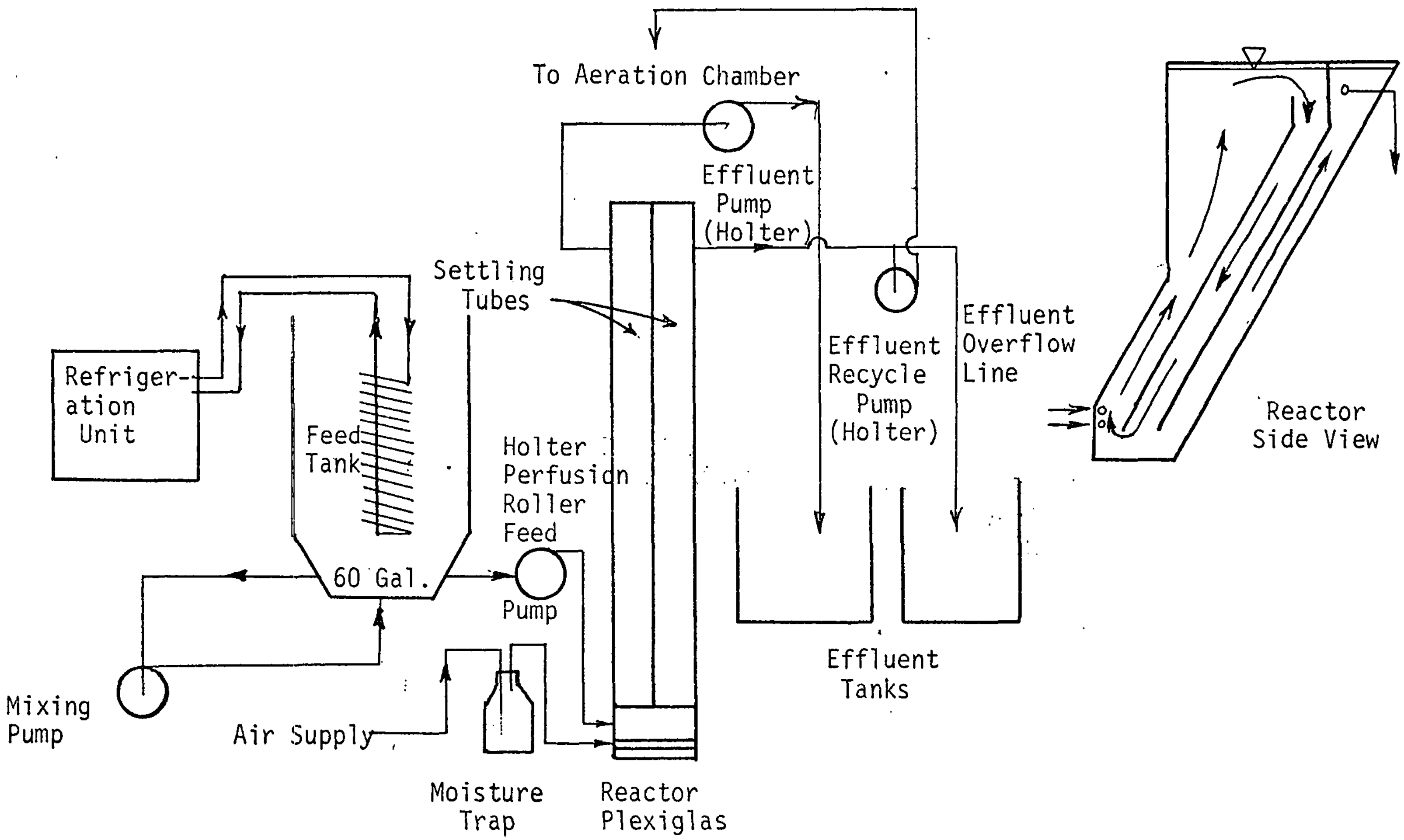

FIGURE 2

AWL REACTOR
8.9 GALLON
SCHEMATIC OF APPARATUS

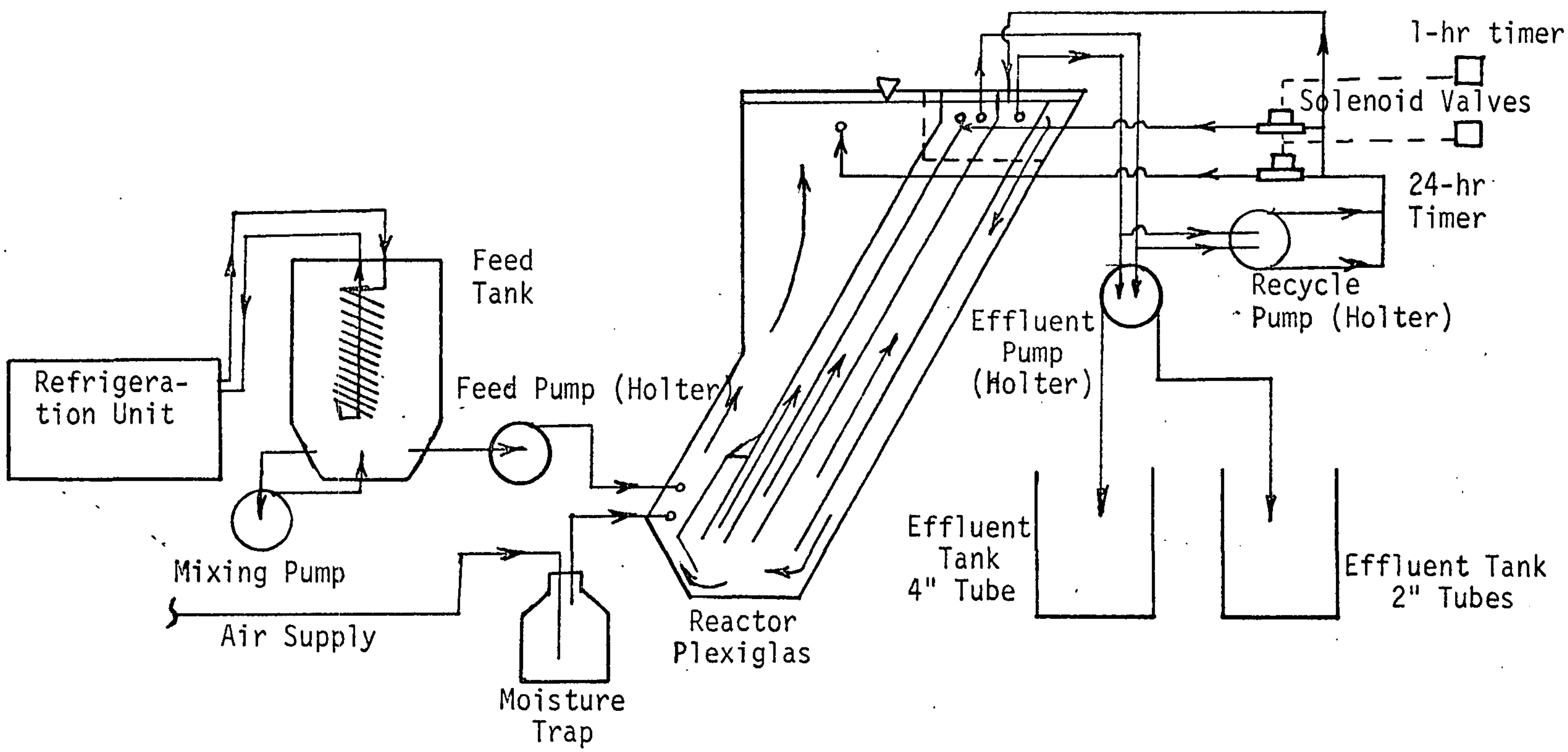

FIGURE 3

AWL REACTOR
12.45 GALLON
SCHEMATIC OF APPARATUS

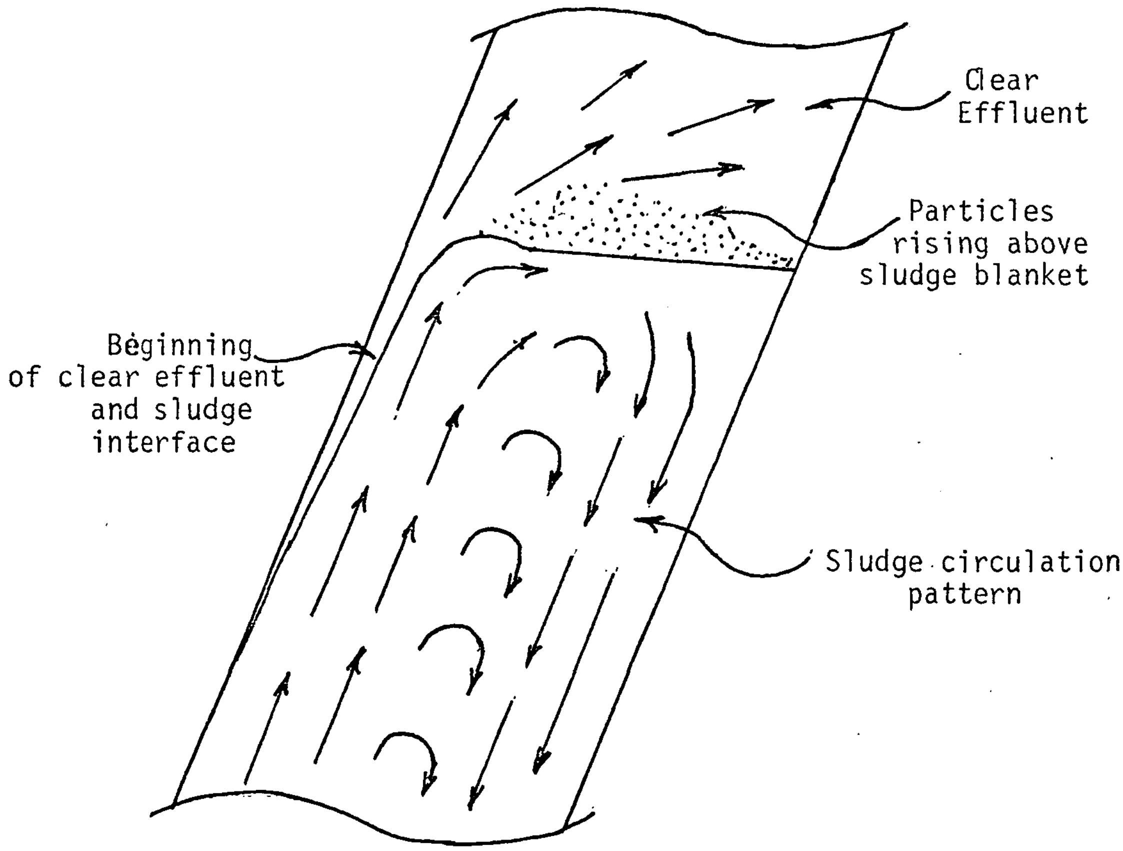

FIGURE 4

SLUDGE ACTION IN UPFLOW CLARIFIER SETTLING TUBES

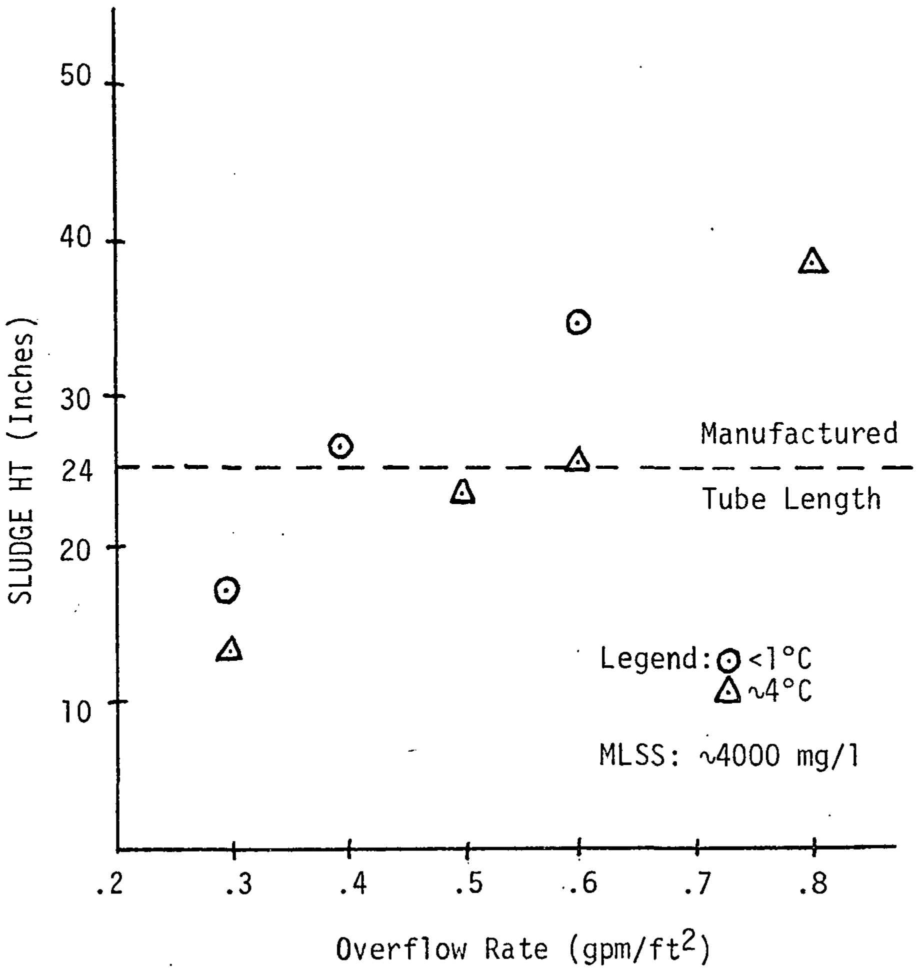

FIGURE 5

8.9 GALLON REACTOR
SLUDGE HEIGHTS IN EFFLUENT TUBES
vs
EFFLUENT OVERFLOW RATES WITH CONTINUOUS FLOW THROUGH TUBES

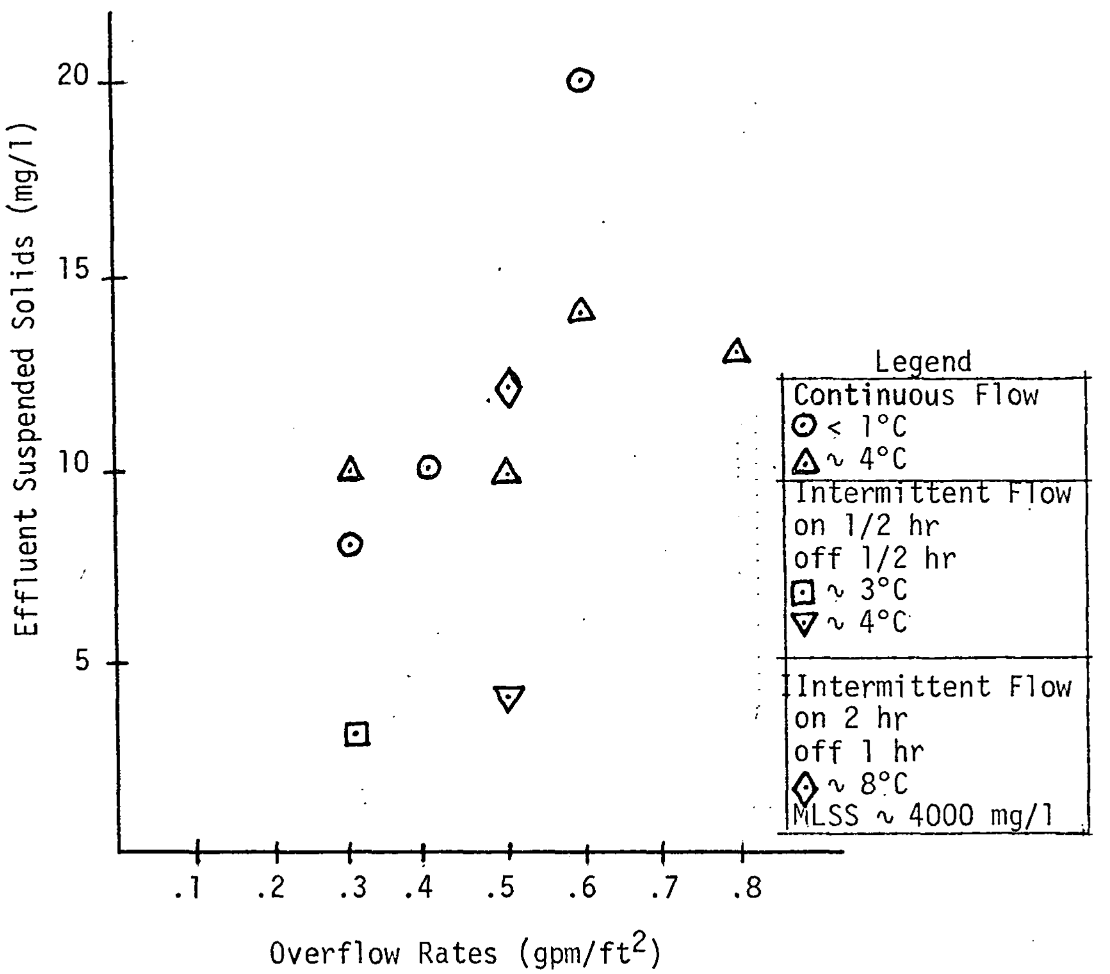

FIGURE 6

8.9 GALLON AND 12.45 GALLON REACTORS
EFFLUENT SUSPENDED SOLIDS vs
OVERFLOW RATES AT VARIOUS TEMPERATURES

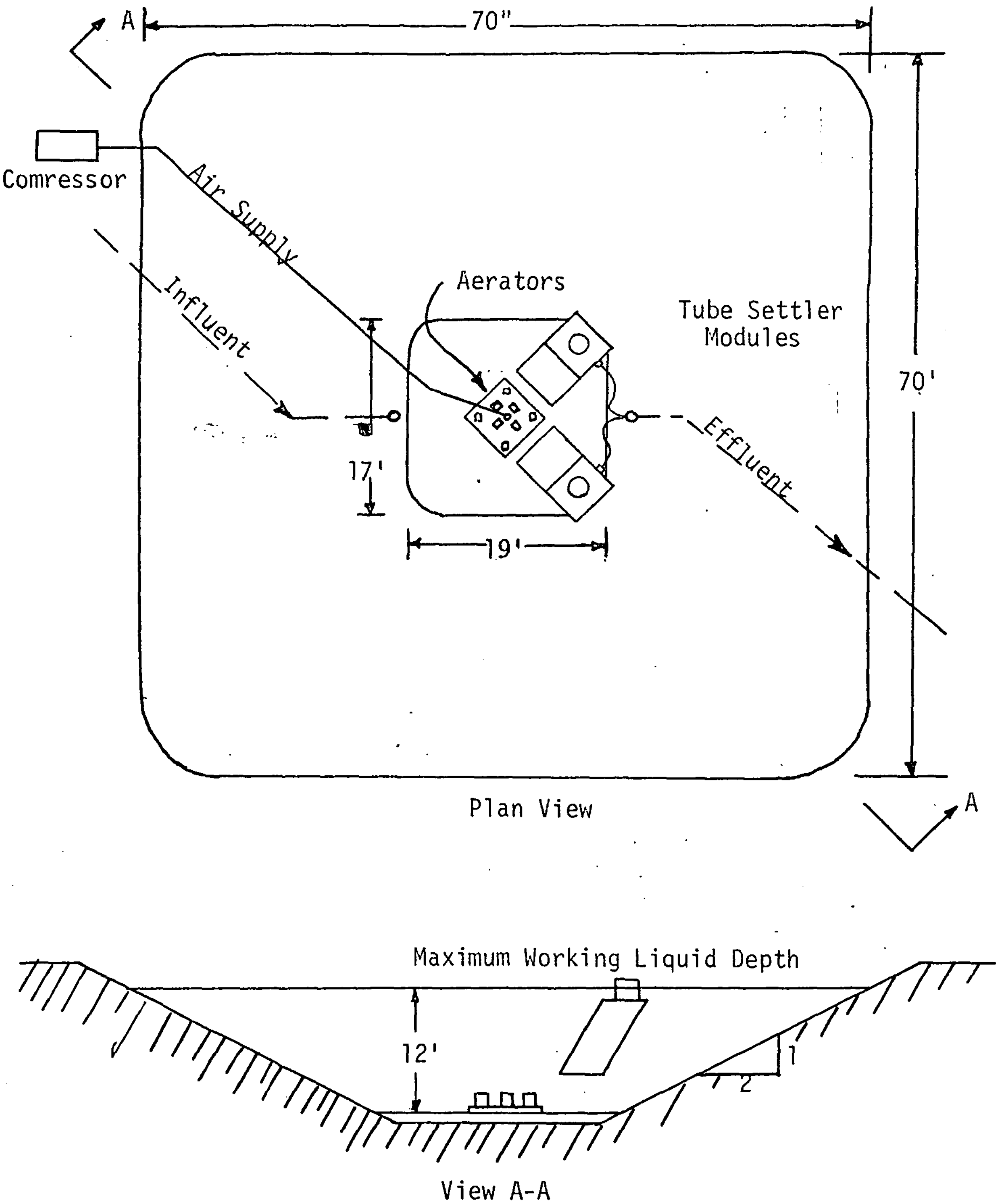

FIGURE 7

EXTENDED AERATION PILOT FACILITY
EIELSON A.F.B.

1968 Configuration

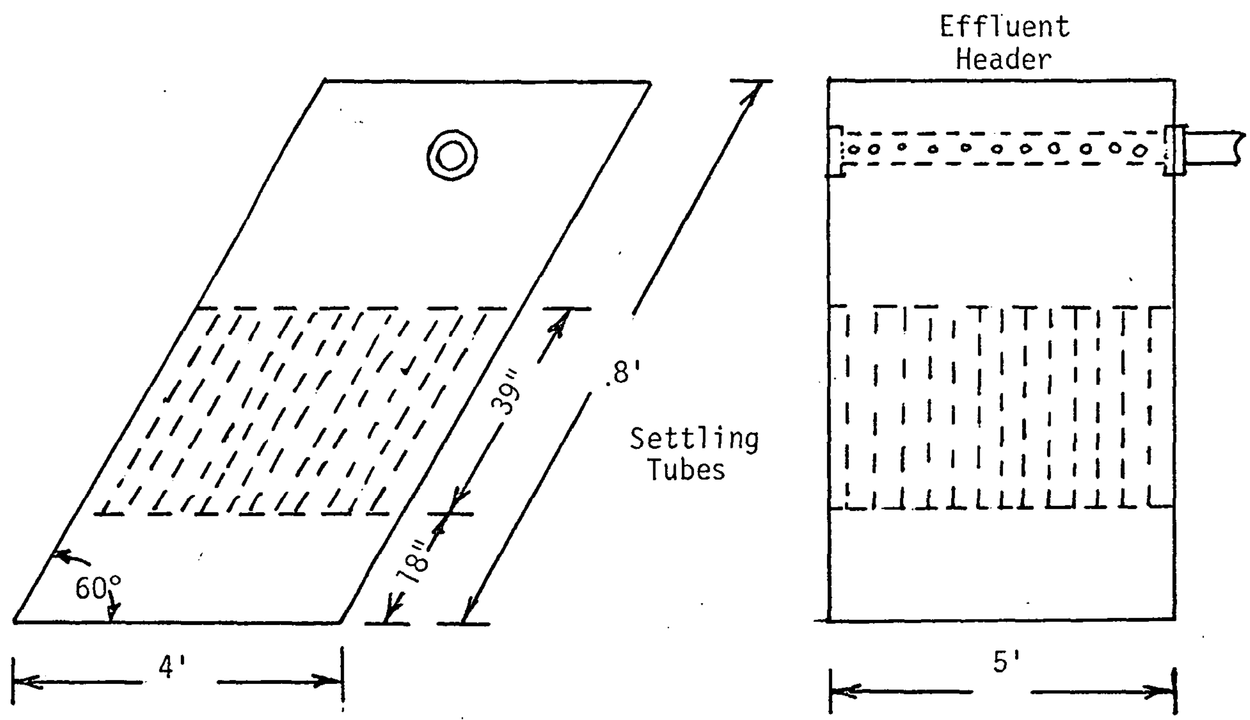

FIGURE 8

TUBE SETTLER MODULE

1968 Configuration

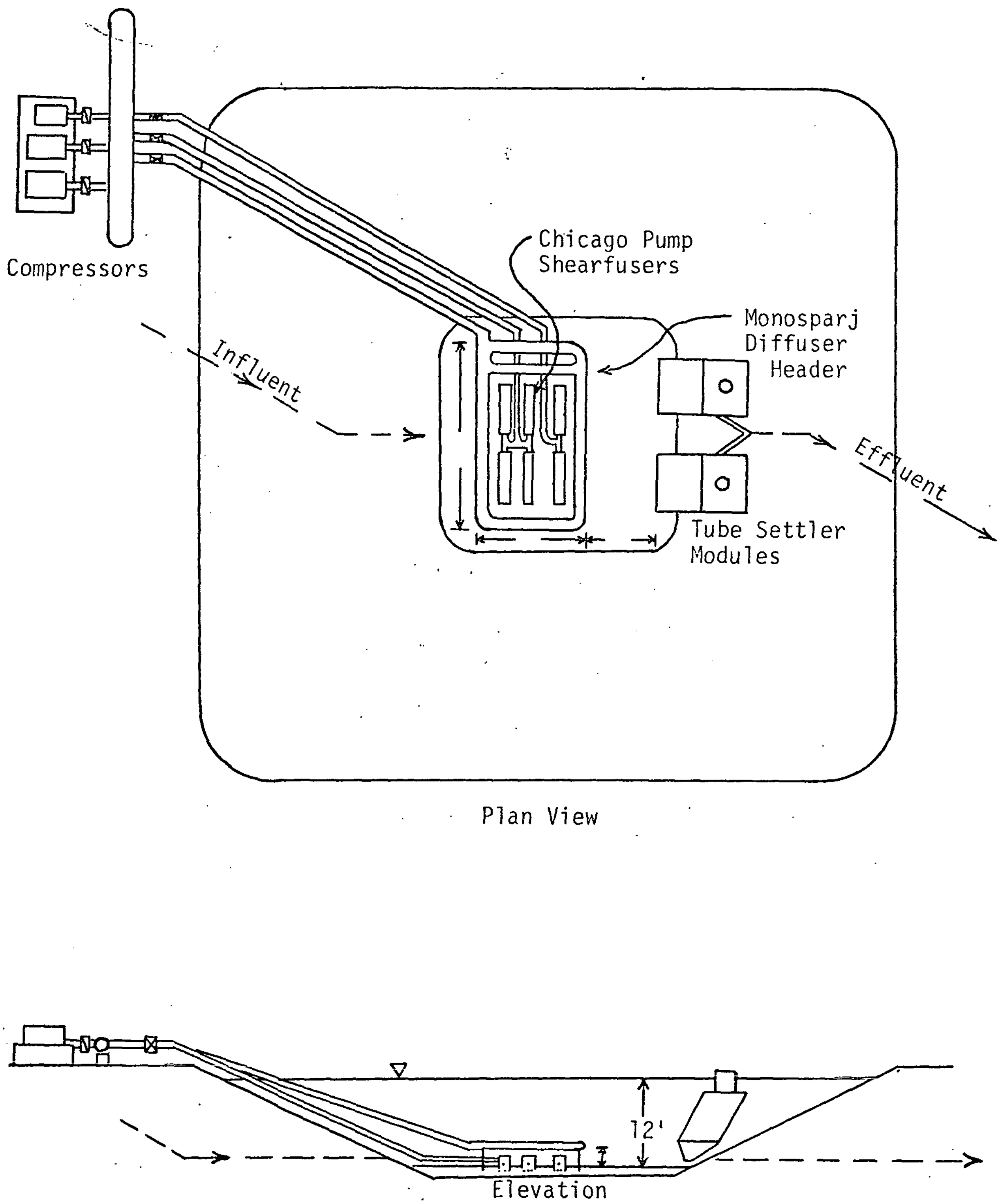

FIGURE 9

EXTENDED AERATION PILOT FACILITY AFTER MODIFICATION
EIELSON A.F.B.

1969 Configuration

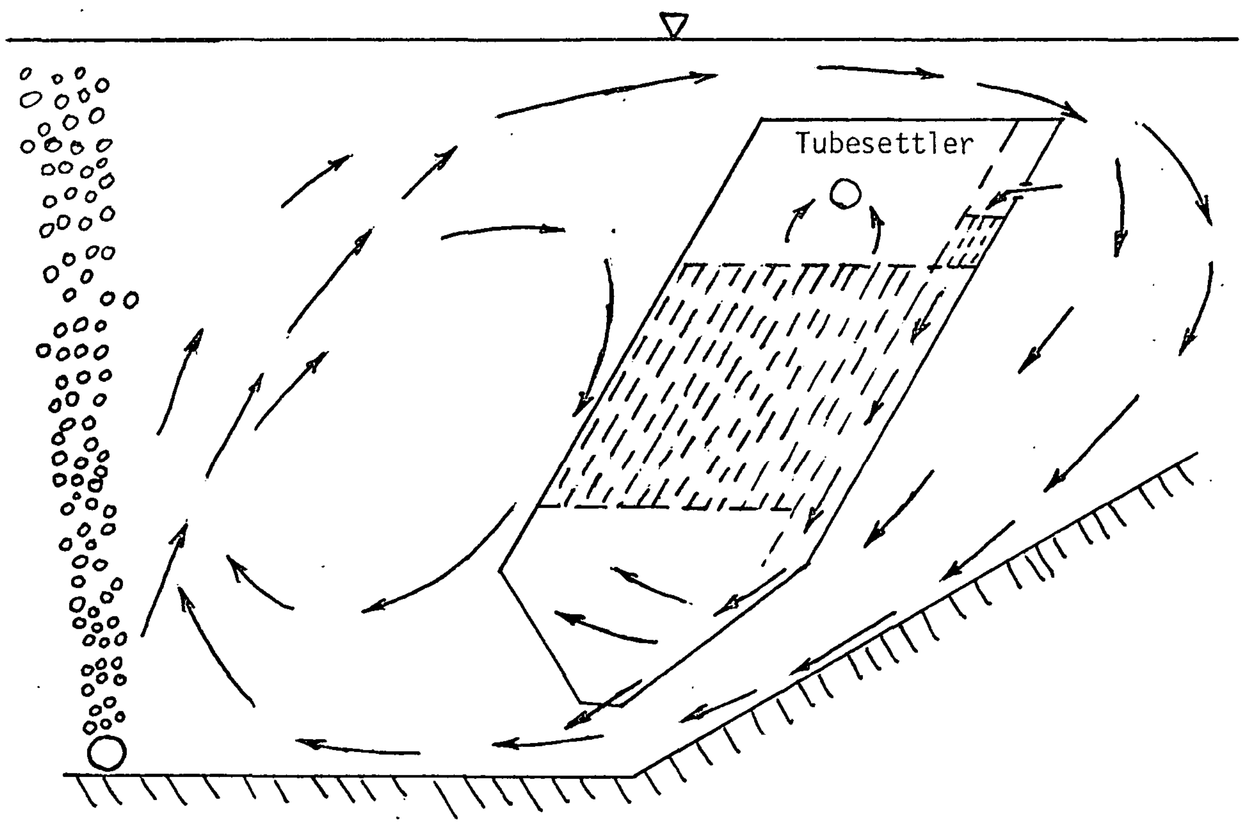

FIGURE 10

TUBE SETTLER MODULE DESIGN
..WITH FLOW BENEATH THE HOPPER

1969 Configuration