PRACTICAL ASPECTS OF THE ACTIVATED SLUDGE

PROCESS WITH SEAWATER INCLUSION

by

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I. INTRODUCTION

The climate and topography of many United States controlled
Islands located in the South Pacific and Carribean present some unique
problems for wastewater treatment. Because of their climate and
topography the supply of potable water is extremely limited. In
many cases the supply of potable water is limited to production by
desalination methods. This limited supply of potable water encourages
conservation methods by island residents. The use of sea water in
toilet flushing systems is common place as a major conservation method.
In the past, many of these islands, because of their remoteness and
for other logistic reasons, discharged sewage with little or no treat-
ment into the ocean. Under the Water Quality Act of 1965 these
islands--e.g., American Samoa, Guam, Trust Territories of Pacific,
Wake, Phoenix group, and the Virgin Islands--have been in the process
of establishing water quality standards.

In much the same way, the supply of potable water has also
always been limited to all sea going vessels, both merchant and naval.
They too, as a method of conservation, use sea water in toilet
flushing systems. As a matter of ease and simple logistics, in the
past raw sewage was discharged into the worlds oceans and waterways.
Although individual states have jurisdiction over inland and adjacent
coastal waters, federal law prevails in most cases involving the
navigable waters in which these vessels primarily operate. The Water
Quality Improvement Act of 1970 prohibits the discharge of harmful

quantities of any materials into or upon the Navigable waters of the United States or their shores. It applies to on shore and off shore facilities, as well as to vessels. The 1970 legislation also gave the Environmental Protection Agency authority to set performance standards, which will be inforced by the Coast Guard for marine sanitation devices. Proposed standards were published in May, 1971, which required the equivalent of secondary treatment for vessel discharge.

Because of the Water Quality Act and its add-on legislation, the sewage discharge from these islands and vessels in the future will be controlled by treatment. The wastewater that will be treated will consist of a mixture of approximately 30 percent seawater and 70 percent fresh water. It is known that abrupt and major increases or decreases in salinity will cause decreased BOD_5 removal efficiencies, increased effluent turbidity, solids losses, and changes in the mixed liquor floc protozoan populations. The objectives of this study were to investigate the effects of gradual salinity increases on the activated sludge process. And it was designed to determine if such gradual increases could be accommodated by this type of treatment system. A bench-scale study was conducted because results obtained by such studies suggest trends, problems, and solutions likely to be significant in the operation of a full-scale activated sludge waste treatment plant or a package activated sludge waste treatment plant.

II. LITERATURE REVIEW

Investigations have been conducted in the past on the effects
of variable or high salinities on biological wastewater treatment
processes. Stowell (1) discussed pilot-plant and full scale trickling
filter performance at San Quentin Prison located in San Francisco Bay.
The wastewater-to-seawater ratio was about 1:1. When using a re-
circulation ratio of 1:1 to minimize chloride fluctuations it was
found that BOD_5 removals of up to 90 percent could be obtained.
Lawton and Eggert (2) using the highly saline whey produced in the
manufacture of cheese (averaging about 35,000 mg/l sodium chloride),
found that biological stabilization could be accomplished by the
trickling filter process. This stabilization was feasible provided
sharp changes in the sodium chloride concentration did not occur. If
BOD_5 loadings were not excessive, slime growths developed readily even
with high salt concentrations in the waste. It was noted that slimes
from highly saline wastes grew slower than those from weakly saline
wastes. The growths produced by the highly saline wastes resulted in
somewhat lower BOD_5 removals. Filter growths that were developed from
low salt content waste suffered a shock effect when high salt content
wastes were applied to them, and the converse was also true of the
growths developed in high salt environments. However, the growth that
developed when the highly saline wastes were applied could usually
become acclimated to the new substrate within 24 hours, whereas the
weakly saline developed growth, could need up to 5 days to acclimate.

Stewart et al. (3) found that a change from fresh water sewage to 30 percent seawater sewage had little effect on the effluent quality of the extended aeration process for shipboard application. They indicated that from available information a shipboard waste would consist of 30 percent seawater on a volume basis. It was further found that under a severe change from fresh water sewage to 100 percent seawater sewage in conjunction with high organic loadings, a temporary reduction in treatment efficiency was experienced. The time required to recover from this "shock load" was dependent on the duration and severity of the salinity and loading conditions.

Using bench-scale treatment units, Ludzack and Noran (4) studied the tolerance of the activated sludge process and the anaerobic digestion process to high salinities. For the activated sludge process, an incremental increase in influent sewage chlorides from 100 mg/1 to 20,000 mg/1 over a 2- to 3-week period caused a disruption of clarifier performance resulting in large solids losses from the unit. When the chloride concentration stabilized improvement occurred. A shock load in influent sewage chlorides from 100 mg/1 to 20,000 mg/1 induced greater settling disturbances. Solids losses were lower than when the change-over was gradual because of the magnitude of the upset period. Continuous operation of the aerobic treatment units with high chlorides resulted in poor sludge flocculation, high effluent solids and about a 10 percent loss in the 7-day BOD removal efficiency. BOD samples were incubated for 7 days at 20°C to avoid weekend complications. Nitrification was suppressed during high chloride operation,

averaging only 10 percent of that expected for the same operation at low chlorides. The authors reported that anaerobic digestors were much more sensitive to high chlorides than activated sludge units. Their results indicated that aerobic digestion would be more effective than anaerobic digestion for treatment plants operating on high or varying salinities.

Kincannon and Gaudy (5) found a decrease in substrate removal rate when sludges developed in fresh water were subjected to a slug dose of 30,000 mg/l NaCl. They further found that sludges developed in fresh water undergo severe impairment of substrate removal efficiency when subjected to NaCl slug doses of 45,000 mg/l. Sludge developed in fresh water is less drastically affected by a slug dose of salt than is sludge developed in high salt concentration by a rapid change to a fresh water environment. When sludges which are acclimated to a high concentration of salt are placed in a fresh water environment, the immediate response involves a release of cellular components indicative lysis of cells.

Hernandez, Kinney and Singerman (6) found that aboard ship, 20 gallons per capita per day can be expected. Little variation was noted from ship to ship. They also found that approximately 75 gallons per capita per day of sewage is produced at remote military sites. Because of the space and weight requirements, the extended aeration, activated sludge process, it is unattractive for naval ship-board use. They studied the use of a macerator-chlorinator. Ship-board evaluation of a macerator-chlorinator established the feasibility

of using a single unit for multiple fixtures. Their data indicated that a substantially coliform free effluent could be expected if available chlorine was maintained above 1300 mg/l per flush.

Burnett (7) found that alternating shocks of fresh water sewage and highly saline sewage severely disrupted the efficient operation of a 1.8 liter bench-scale activated sludge treatment plant. Noticable effects of the shock included decreased BOD_5 removal efficiencies, increased effluent turbidity, solids losses and changes in the mixed liquor floc protozoan and rotifer populations. It was concluded that the activated sludge process could operate efficiently on high salinity sewage provided alterations in the salinity are avoided. In addition, high salinities apparently are not strongly inhibitory to mixed liquor floc formation.

The operational failure of the activated sludge process has been correlated with the concentration of the chloride ion. Three ranges of chloride ion concentrations have been selected as most representative of operational problems in the activated sludge process:

(1) 0-5,000 mg/l Cl^-

(2) 5,000 - 10,000 mg/l Cl^-

(3) Greater than 10,000 mg/l Cl^-

On the lowest concentration, 0 to 5,000 mg/l Cl^-, the only significant effects on system performance results from high intensity shock loading. Within this range, the activated sludge process can acclimate to most any chloride concentration. The 5,000-10,000 mg/l Cl^- concentration is of most interest in this study. It is reasoned that

the sewage discharge from a system using seawater for toilet flushing
will contain slightly more than 5,000 mg/l Cl^- and less than 8,000
mg/l Cl^-. At the higher concentrations, lower treatment efficiencies
and longer times for recovery from shock loading can be expected. At
concentrations greater than 10,000 mg/l Cl^- the activated sludge
process requires such a high detention time and recirculation ratio,
that the unit virtually becomes a stabilization pond.

It was noted throughout the literature review that none of the
previous investigators conducted kinetic studies. In this study, the
food-to-microorganism ratio was constant. Oxygen uptake was used to
indicate steady state conditions and as a comparison between microbial
activity in the seawater unit and the fresh water units. Further
tests should be conducted on activated sludge units treating wastes
with high saline concentrations to substantiate the validity of
existing kinetics.

The food to microorganism ratio (F:M) is normally defined as the
rate of substrate applied per mass of microorganisms over a finite
time (8). This can be expressed as:

$$U = \frac{(DF/Dt)m}{Xm}$$

where

U = (F:M) ratio

$(DF/Dt)m$ = the mass of substrate applied per mass of
microorganisms over Dt, a finite period of time.

The activity of the microorganism is a function of the F:M ratio.

III. MATERIALS AND METHODS

A major part of this study involved the establishment and maintenance of two bench-scale activated sludge treatment plants, one operated with various percentages of sea water and the other operated with fresh water as a control. The units were constructed out of 9.5 mm thick acrylic plastic and the aeration chamber and the settling chamber were combined into a single tank (Figures 1-3). Sludge was returned to the aeration compartment by gravity from the wedge-shaped settling chamber. The depth of settled sludge, and thus the depth of product effluent, was controlled by raising or lowering the baffle. The units had a total liquid capacity of 10 liters each with approximately 3 liters in each settling chamber. The units were operated as conventional, diffused-aeration activated sludge systems, with sludge wasted manually to maintain the mixed liquor volitile suspended solids (MLVSS) at 2000 mg/l.

Activated sludge from a full-scale, package activated sludge plant located at a highway rest stop on Route I 81 east of Radford, Virginia, was used as the seed sludge source. After collection the sludge was settled and the supernatant decanted. The thickened sludge, about six liters, was then divided between the two bench-scale units and batch fed a synthetic substrate of the following constituents listed in Table I.

The pH of the substrate was 7.0. The units were fed five liters of the synthetic substrate every 12 hours for a period of five days.

Figure 1.   Bench Scale Activated Sludge Treatment Plant.
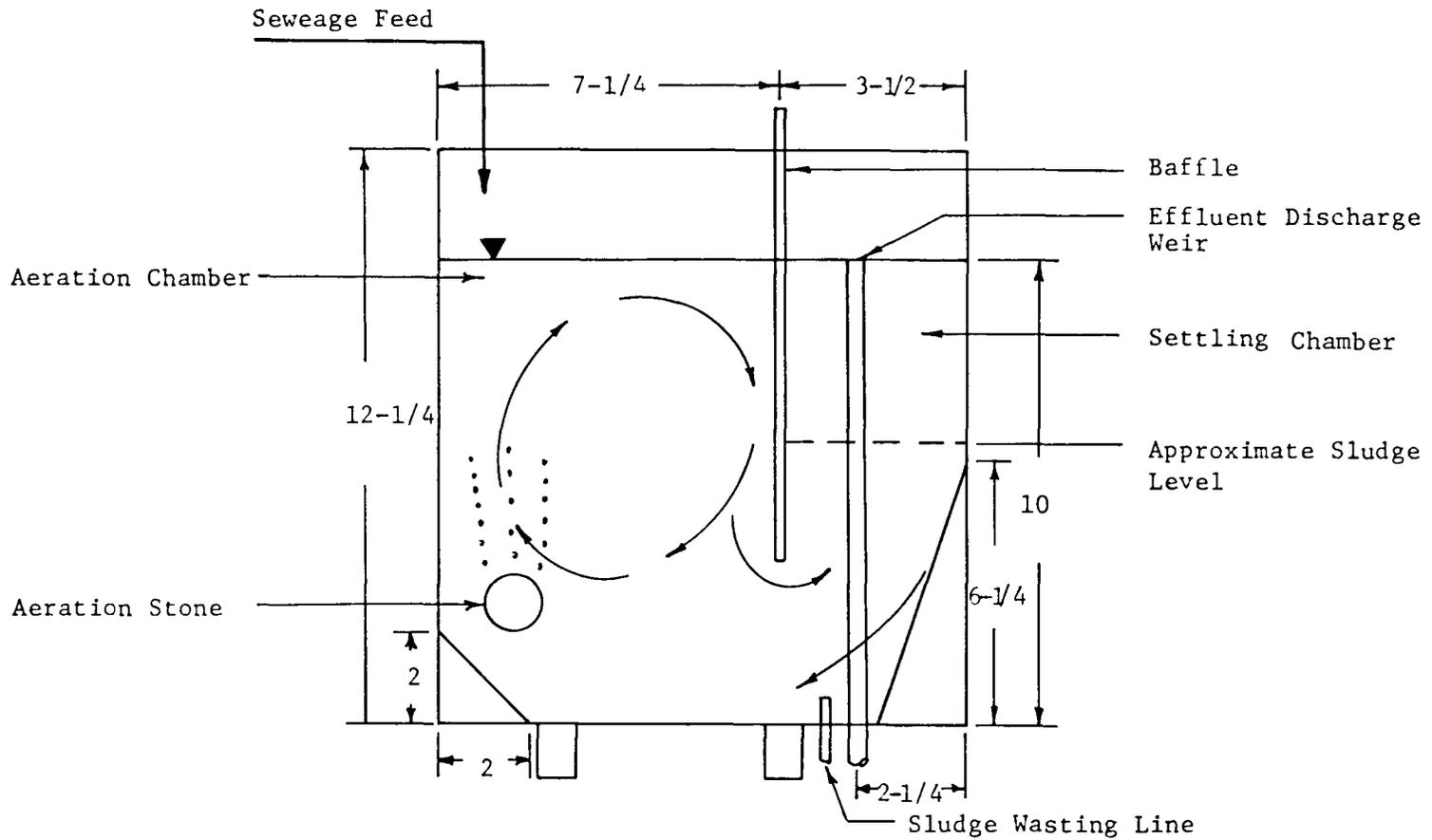
No Scale
All Dimensions in Inches
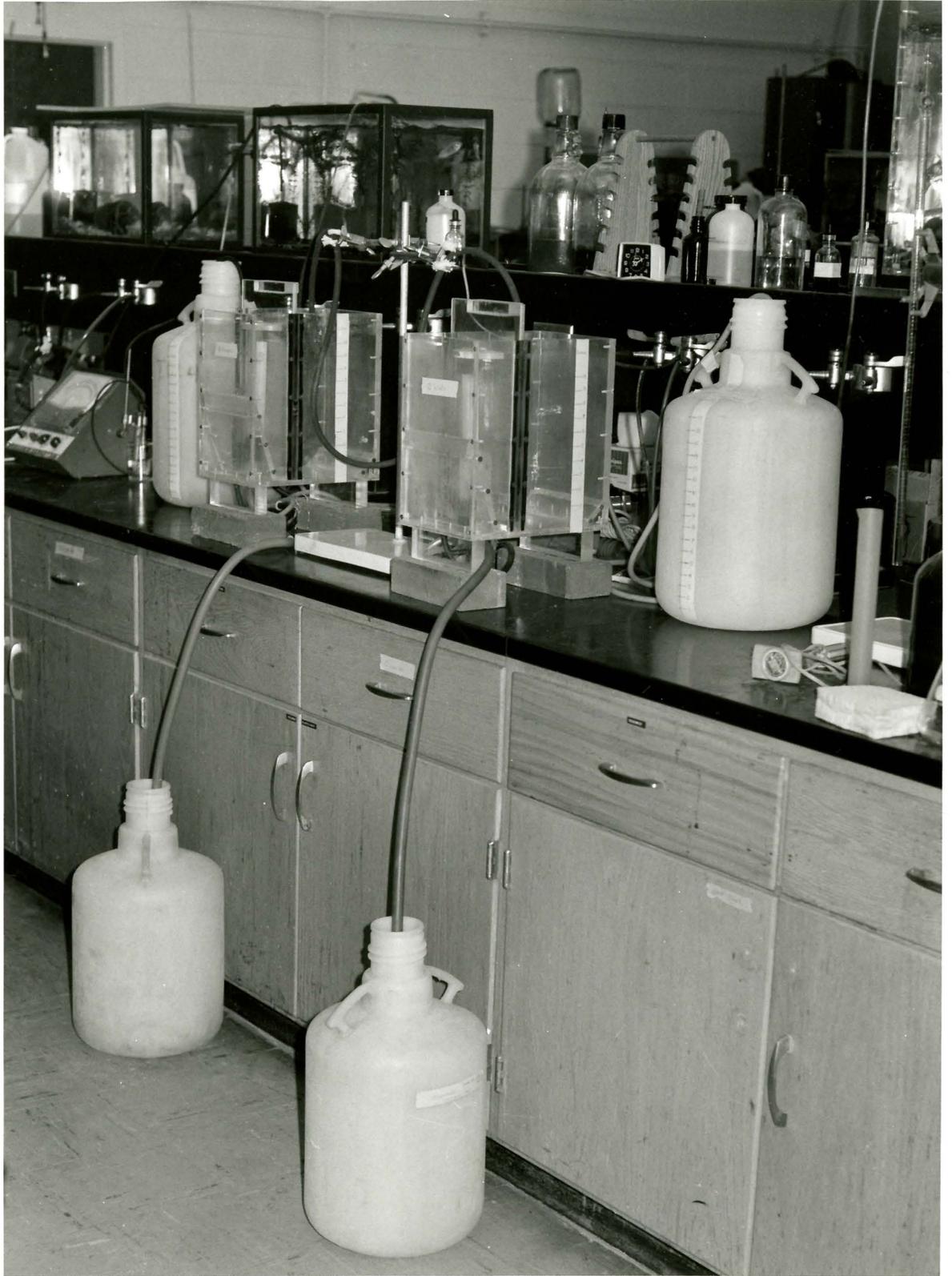
Figure 2. Setup of Bench Scale Activated Sludge Plant.

Figure 3. Bench Scale Activated Sludge Plant.

TABLE I

CONSTITUENTS OF SYNTHETIC SUBSTRATE

Compounds	Conc. mg/l
glucose	240
yeast extract	60
ammonium chloride	90
magnesium sulfate	25
ferrous sulfate	1
manganous sulfate	1
calcium chloride	1
potassium phosphate, monobasic	290
potassium phosphate	785

Organic Content	Conc. mg/l
BOD_5	230
COD	375

Before each feeding the sludge was allowed to settle and five liters
of supernatant was decanted to allow room for the new substrate. At
the end of five days the units were fed continuously using a Harvard
peristaltic pump, model 1201. Influent synthetic sewage was fed from
an 18-liter carboy at the rate of 12.5 ml/min giving a hydraulic
detention time of 13.3 hours in the units. The BOD_5 influent loading
was 4.14 grams BOD_5/day with a F:M ratio of 0.21 t^{-1} maintained in
each reactor. In this benchscale study the F:M ratio is held constant
by maintaining a constant BOD_5 of the influent and wasting MLVSS to
maintain a constant biomass. As an example the F:M ratio used in
this study is calculated as follows:

$$U = \frac{BOD_5/\text{day x Volume of substrate/day}}{\text{MLVSS x Volume of Reactor}}$$

$$U = \frac{230 \text{ mg/l x 18 l}}{2000 \text{ mg/l x 10 l}} = .21 \ t^{-1}$$

Oxygen uptake rate was used as a measure of steady-state conditions
and an indication of microbial activity. Oxygen uptake in the amount
of oxygen consumed per unit weight of mixed liquor Volitile suspended
solids. Oxygen uptake rate is determined by measuring the dissolved
oxygen concentration in a sample at 1/2 minute intervals. The
dissolved oxygen concentration is plotted against time. The slope
of this plot is the oxygen uptake rate (Rr). Rr is measured in $\frac{mg/l}{day}$.
The oxygen uptake of a system is:

$$O_2 \text{ uptake} = \frac{Rr}{MLVSS}$$

Therefore when the daily uptake rate remains constant the unit has reached steady state.

Air was supplied to each unit from the house air system through four aeration stones tied in series. Air flow was controlled using Bendix in-line flow gauges set at 4 LPM. Table II describes the operating conditions used in the investigation. Oxygen uptake and solids tests, both total suspended and valitile suspended, were made daily to establish when the units had become acclimated and stabilized to the synthetic substrate. Ten day acclimation periods with continuous feeding were used.

Sea water was then obtained from the Virginia Institute of Marine Sciences located in Glouster, Virginia. On 9 July, the 17th day of operation of the units, five percent sea water was added to the feed for unit Number 2 as it was to act as a parallel control. The five percent concentration of seawater was fed for four days, and on the fifth day the seawater concentration was increased to 15 percent. After three days, it was again increased this time to 25 percent and also was fed for three days. Then the concentration was increased to 40 percent and was maintained for six days. At the end of this six day period the feeding of substrate was stopped, the baffle was removed and the units were aerated for an additional four days. During the investigation period the following tests were conducted daily:

reactor pH

influent and effluent BOD_5

TABLE II

OPERATING CONDITIONS

10 Liter Reactor

Feed Rate	Influent BOD_5	Influent COD	BOD_5 Loading
12.5 ml/min	230 mg/l	375 mg/l	4.14 grams/day

Aeration Rate	F:M	MLVSS	θh
4LPM	.21 t^{-1}	2000 mg/l	13.3 hours

reactor number 1 influent and effluent Cl^-

reactor MLSS and MLVSS

effluent turbity

oxygen uptake

microscopic observations.

Settling data were taken during the last seven days of operation.

Reactor pH was measured using an "Accument Model 120" pH meter.

Influent and effluent BOD_5 tests were conducted by measuring dissolved

oxygen (D.O.) using a Yellow Springs Instrument Company Model 54

electrometic meter with membrane probe. Procedures were followed as

described in Standard Methods (9) and the Report on Seawater Desali-

nation Analytical Procedures (10). Lawton and Eggert (2) reported

that in waters containing up to 14,000 mg/l NaCl which is equivalent

to 8200 mg/l Cl^-, dissolved oxygen measurements were accurate to about

98 percent. Therefore, no corrections were used when measuring D.O.

in water samples containing seawater. Chlorides were determined by

the silver nitrate titration method outlined in the Report on Sea-

water Desalination Analytical Procedures (9).

Mixed-liquor suspended solids and mixed liquor volitile suspended

solids were determined using the procedures outlined in Standard

Methods (8). Effluent turbity was measured using a Hellige Turbidi-

meter. Oxygen uptake was measured by filling a 300-ml sample bottle

with a well aerated sample from one of the activated sludge bench-

scale reactor. Dissolved oxygen was then measured every 30 seconds

for five minutes. Microscopic observations were made daily with an

Olympus phase contrast microscope with a PL 40 lens. During the last seven days of operation settling tests were conducted on each reactor using the procedure outlined in Standard Methods (9). In addition to the tests as outlined, the volume occupied by the sludge was recorded each minute for the first six minutes then every three minutes for a total time of 30 minutes.

In an effort to eliminate problems associated with filamentous growth, all air supply lines were filtered using activated charcoal and cotton to remove oils. The lines supplying synthetic sewage and the 18 liter carboys were chlorinated daily. Freshly distilled water was used in making up the synthetic sewage with trace elements added. Carbonate and bicarbonate buffers were added to maintain reactor pH between 7.0 and 8.0. The actual benefit of the precautions is unknown but filamentous organisms did not appear in either reactor during the course of the study. It was also noted that as the percent of seawater increased in the seawater reactor, it required much less buffer than did the control fresh water unit.

IV. RESULTS

The bench scale units were allowed to acclimate and stabilize

for 15 days. On the 16th day they were operating at BOD_5 removal

efficiencies of 98.6 percent for unit number 1, and 98.3 percent for

unit number 2. On the 16th day, 5 percent seawater was added to the

substrate for unit number 1. During the four days of operation at

5 percent seawater in unit number 1, the BOD_5 removal efficiencies

of both units remained above 98 percent (Table III). The BOD_5 of the

effluent averaged about 4 mg/l with an influent BOD_5 of 230 mg/l.

The synthetic sewage used in this study was chosen especially be-

cause it was easily metabolized and, therefore, would not introduce

a further variable parameter. Turbidity was exactly the same for both

units (Figure 4), and MLSS, MLVSS, and oxygen uptake remained

essentially the same as well (Figures 5, 6, and 7). On the fourth

day of operation the concentration of chlorides in the effluent

matched that of the influent (Figure 8). Microscopic observations of

the mixed liquor floc revealed no changes in the floc composition or

activity.

During the three days of operation with 15 percent seawater the

results were similar to those obtained at 5 percent seawater in that

no real changes in any test results were detected (Figures 4 through

9 and Table III). However, at the 25 percent level, the MLSS in the

seawater unit began to increase faster than those in the control unit

and in greater proportion than they had at the lower percentages

TABLE III

COMPENDIUM OF DATA

| Elapsed Time (days	% Sea Water	pH #1	pH #2	Turbity #1	Turbity #2	Effluent BOD_5 (mg/1) #1	#2	Removal % Efficiency #1	#2	mg/1 Cl⁻ Unit #1 Influent	Effluent
2	0					3.3	4.0	98.6	98.3	0	0
3	5			1.5	1.5	3.7	3.3	98.4	98.6	1000	452
4	5	8.0	8.4	1.3	1.3	2.3	2.4	99.0	98.9	1000	928
5	5	8.0	7.5	1.3	1.3	1.7	3.5	99.3	98.4	1000	1040
6	5	7.6	7.5	.95	.95	2.3	3.3	99.0	98.6	1000	1065
7	15	7.4	7.8	1.3	1.3	4.4	5.3	98.0	97.7	3200	1822
8	15	6.5	6.7	.95	.95	2.3	2.0	99.0	99.1	3200	3082
9	15	7.1	7.4	.95	.95	3.3	3.0	98.6	98.7	3200	3260
10	25	7.2	7.6	2.5	.5	3.8	2.0	98.3	99.1	5350	4101
11	25	7.2	7.6	.95	.95	2.0	5.0	99.1	97.8	5350	5140
12	25	7.0	7.7	1.5	.4	9.0	2.5	96.0	98.9	5350	5360
13	50	6.9	7.7	2.5	1.2	4.4	3.9	98.1	98.3	8200	6850
14	40	7.2	7.9	1.5	.95	3.0	3.0	98.7	98.7	8200	7700
15	40	7.1	8.0	1.5	.95	3.4	3.7	98.5	98.4	8200	7990
16	40	7.0	8.0	3.5	.5	6.0	4.0	97.4	98.3	8200	7820
17	40	7.0	7.8	3.5	1.2	4.6	4.0	98.0	98.3	8200	8199
18	40	7.0	7.0	3.5	1.2	5.3	5.3	97.7	97.7	8200	8170
19	N/A	7.0	6.8								
20	N/A	6.9	6.3								
21	N/A	6.8	6.4								
22	N/A	6.7	6.5								

* Unit #1 Sea Water
** Unit #2 Fresh Water
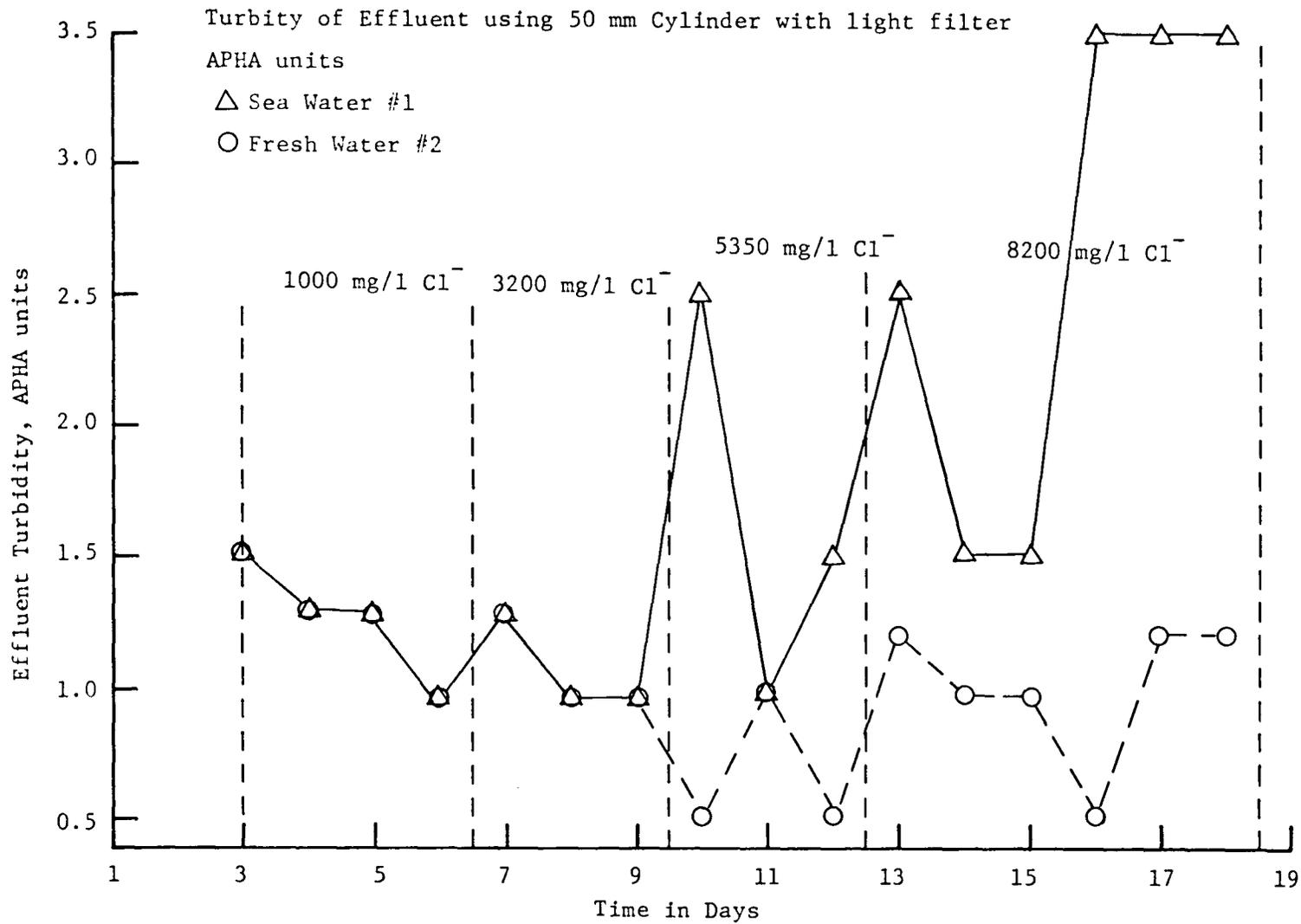
Figure 4. Daily Effluent Turbity.
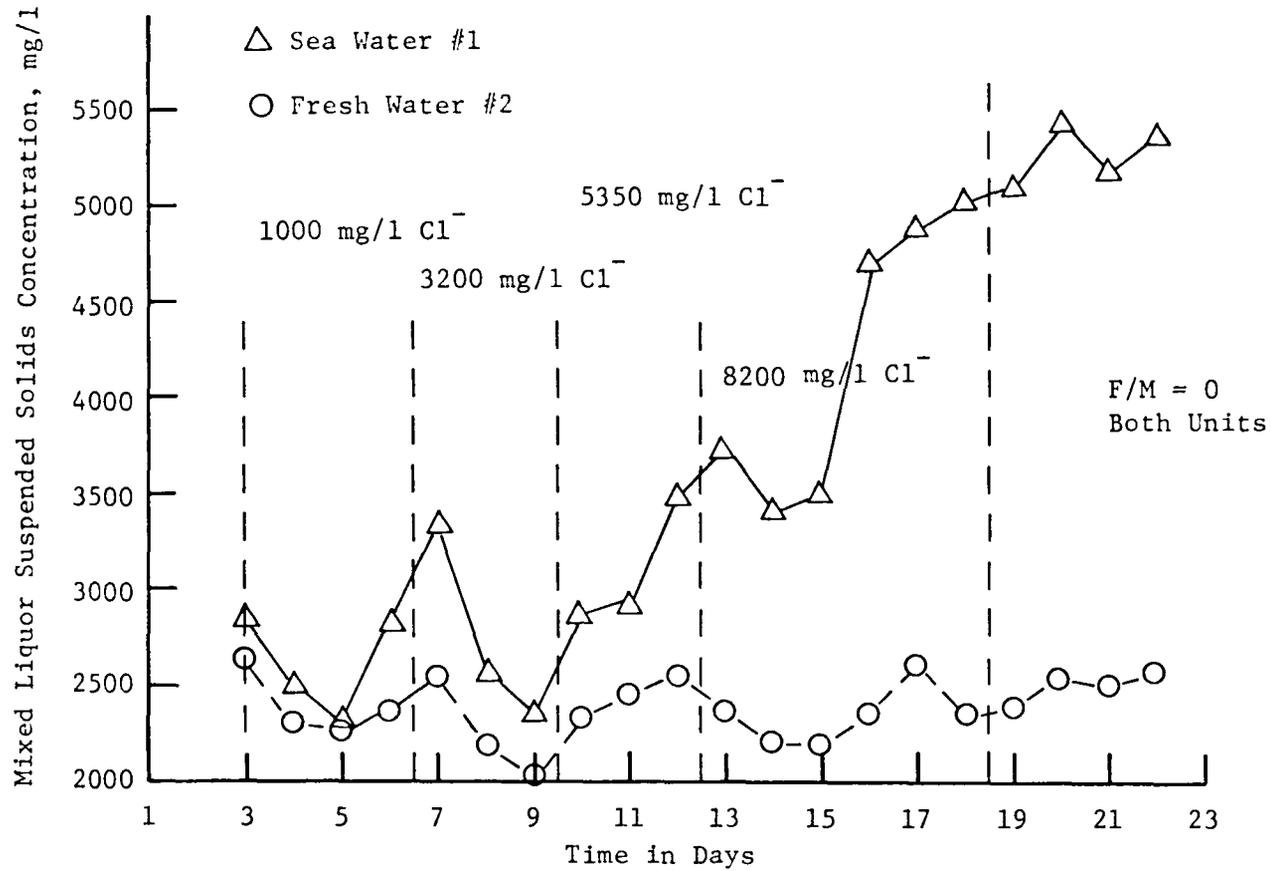
Figure 5. Reactor Mixed Liquor Suspended Solids.
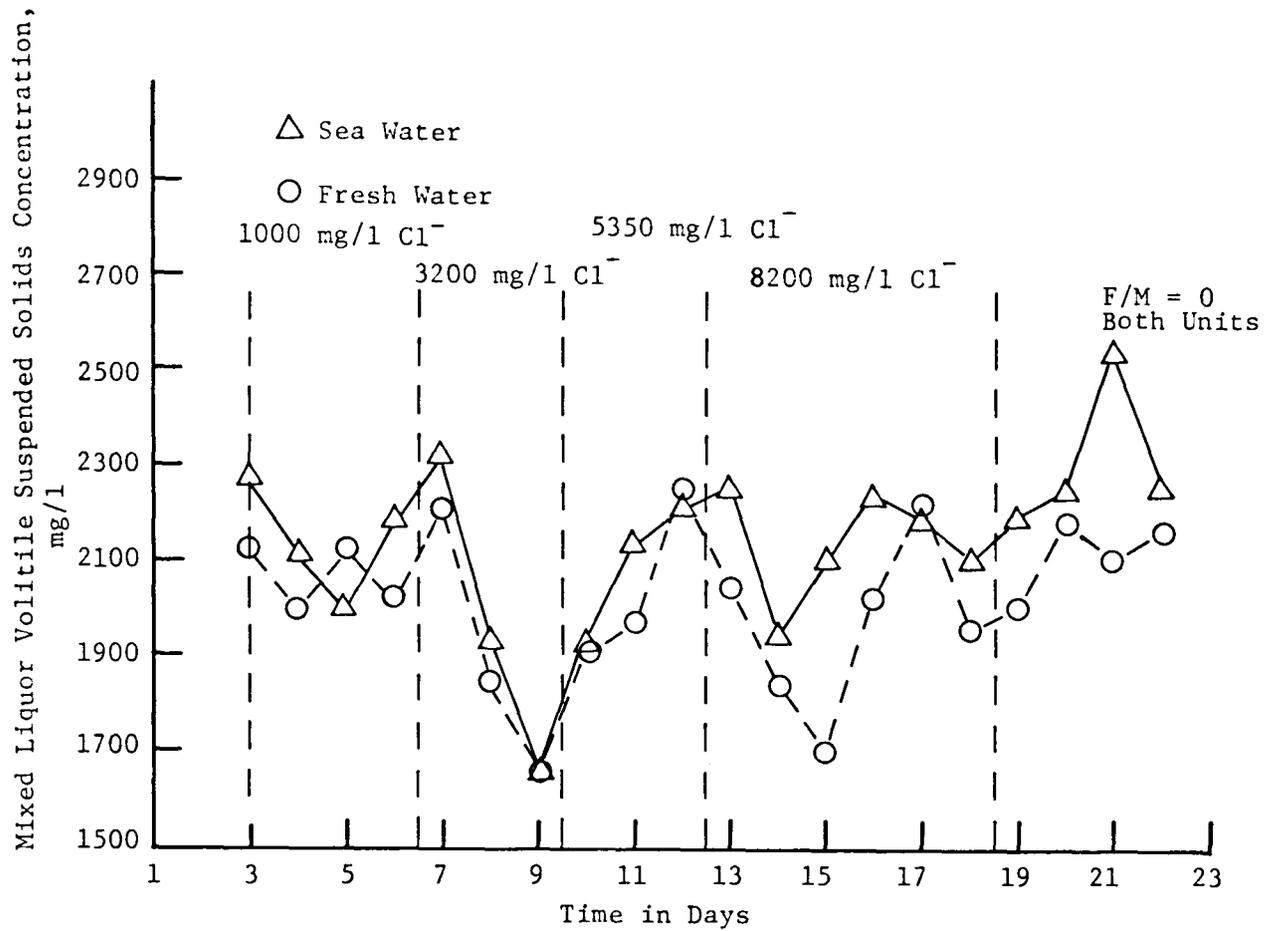
Figure 6. Reactor Mixed Liquor Volitile Suspended Solids.
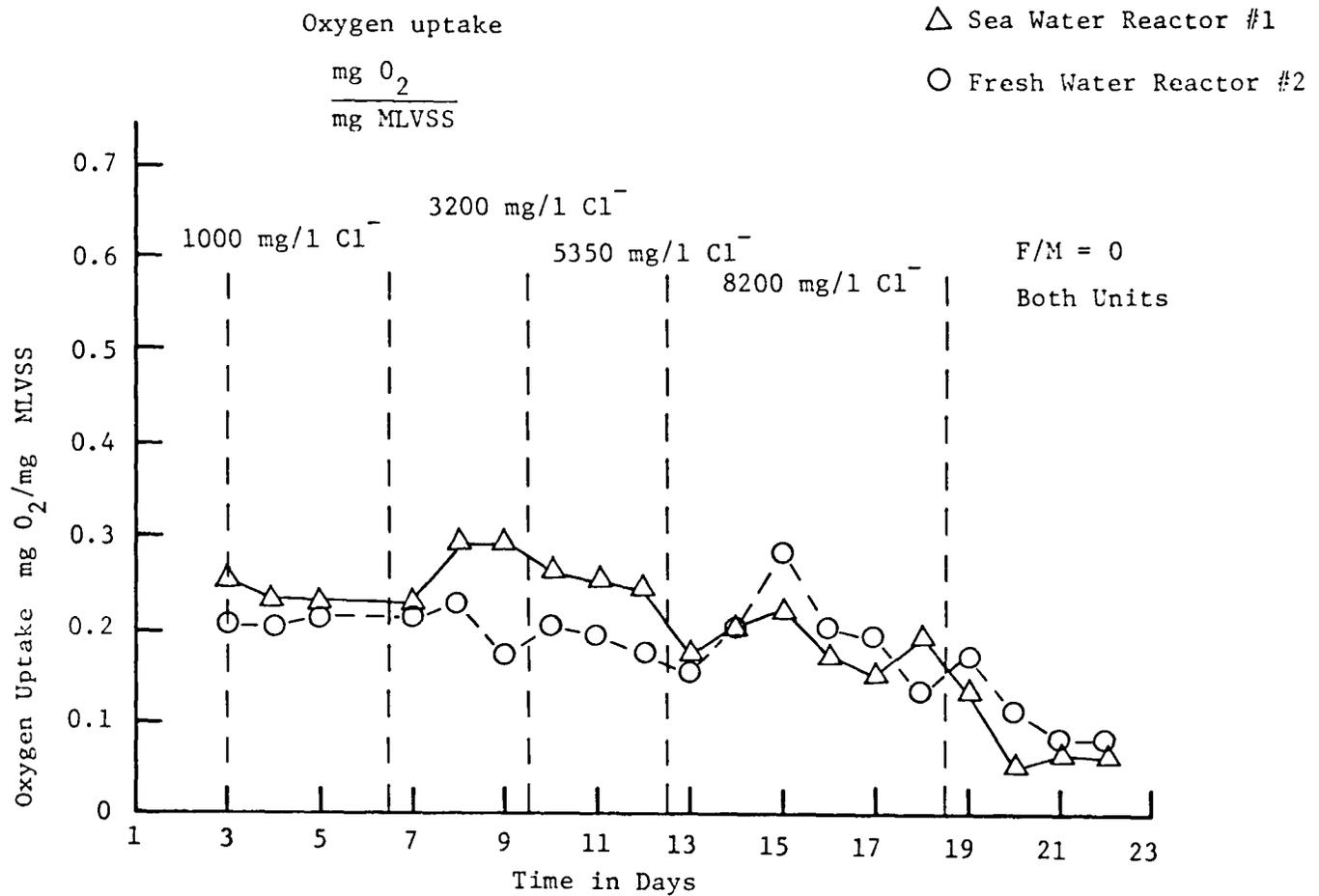
Figure 7.   Daily Oxygen Uptake
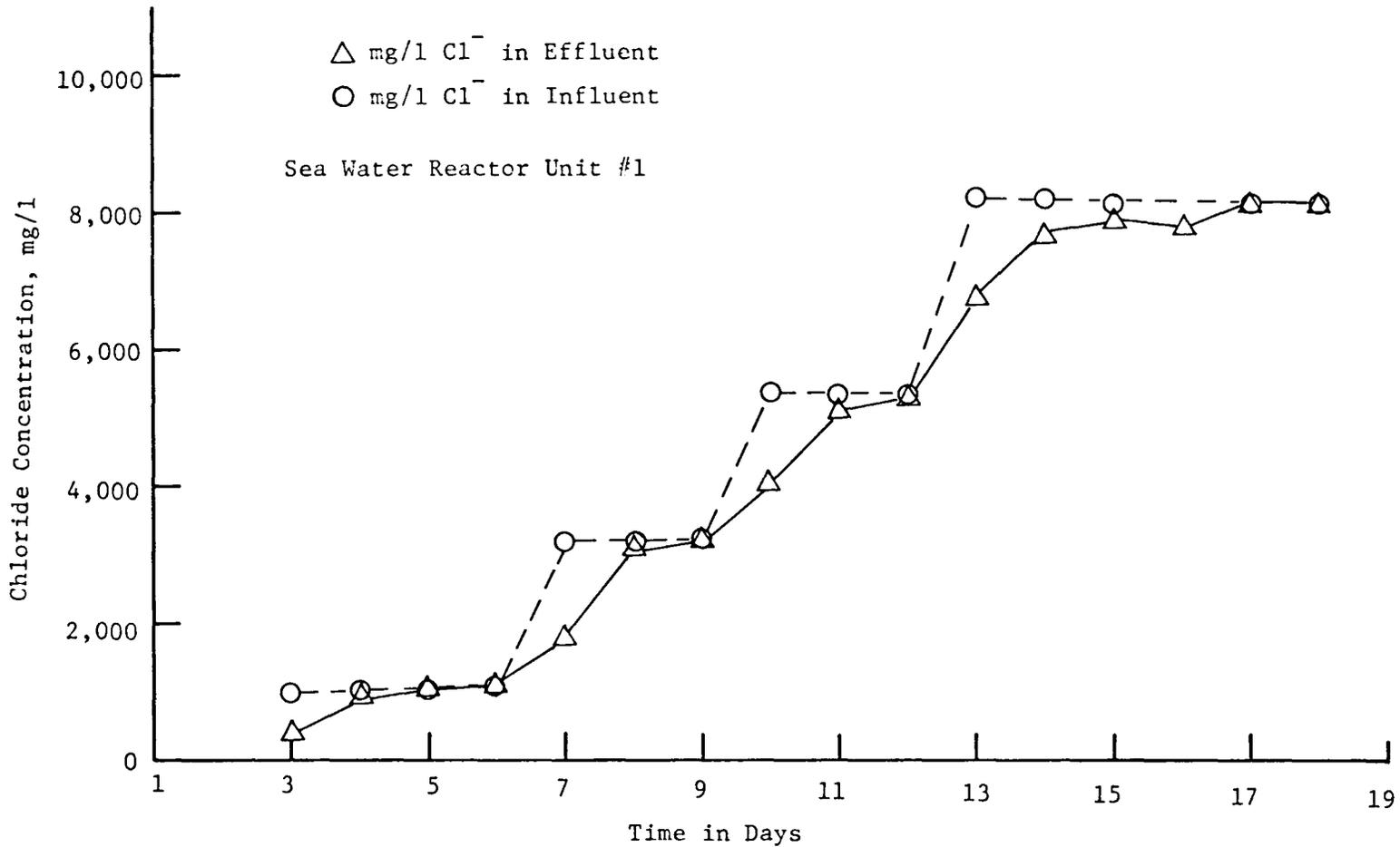
Figure 8.   Daily Influent and Effluent Cl$^-$.
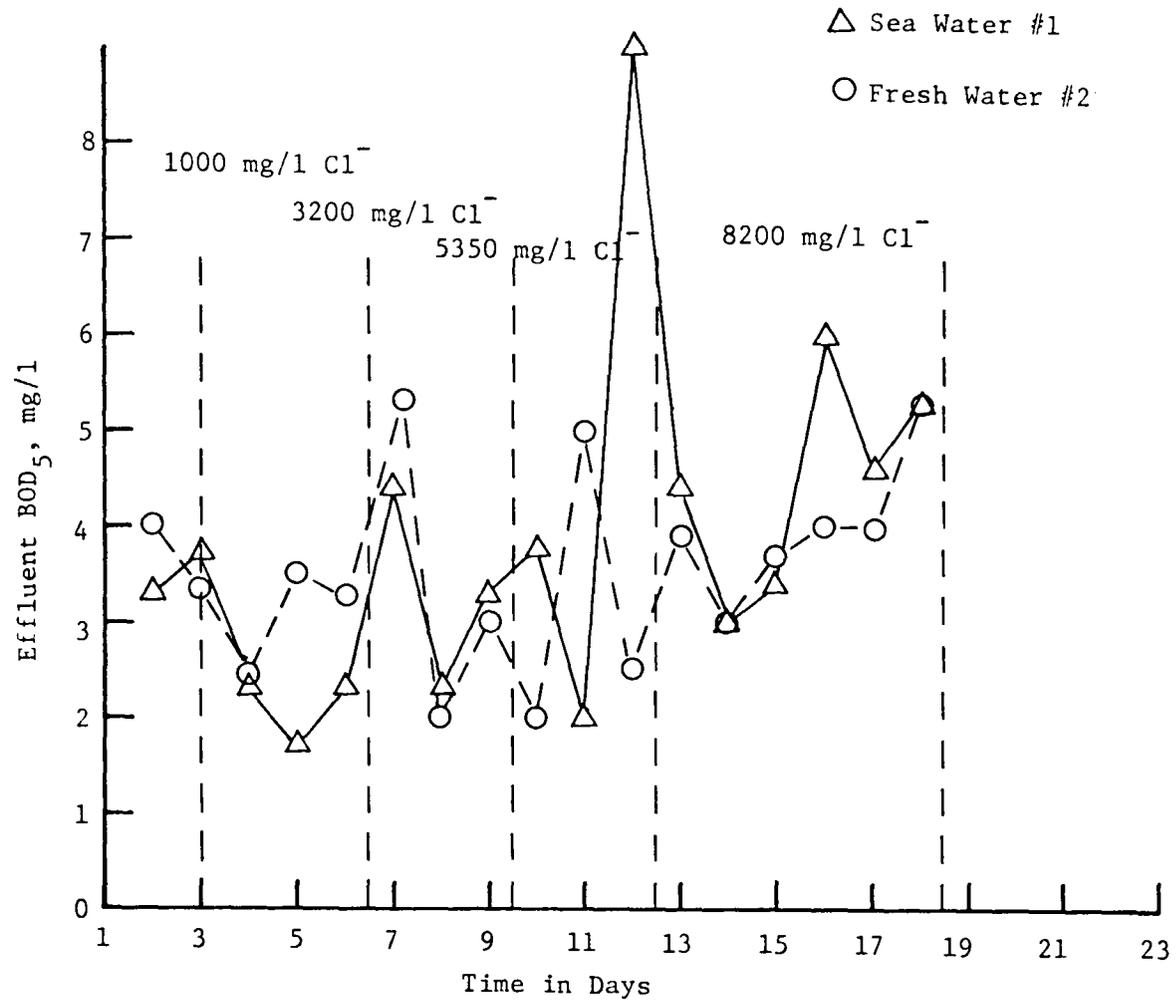
Figure 9. Daily Effluent BOD$_5$.

(Figure 5). Daily wasting of MLVSS to maintain 2000 mg/l did not reduce the increasing difference in suspended solids (Figures 5 and 6). Effluent turbidity began to increase, but by no means could be considered a turbid effluent (Figure 4 and Table III). Oxygen uptake in the reactor and BOD_5 removal continued to parallel that of the control (Figures 7 and 9). Microscopic observation of the mixed liquor floc showed that the increase in salinity had caused a change in the mixed liquor floc composition. It appeared that there was a reduction in the rotifer and stalked and motile ciliate protozoa populations and an increase in what appeared to be a flagellate protozoan population.

During the second day of operation at the 25 percent concentration of sea water a color change began to take place in the reactor. The sludge color began to change from a dark brown to a buff gray. The buff gray then prevailed throughout the remainder of the test period.

When the sea water concentration was increased to 40 percent the MLSS continued to increase in the seawater reactor to a much greater proportion than did the MLVSS (Figures 5 and 6). The MLVSS growth in the sea water reactor paralleled that of the control reactor (Figure 6). During the second day of operation at 40 percent sea water some solids were lost over the effluent weir, however the unit had recovered by the third day.

As with the lower percentages of sea water, the BOD_5 removal and the oxygen uptake rate did not change drastically (Figures 7 and 9). The BOD_5 removal efficiency was quite comparable in both reactors

(Figure 9 and Table III). Effluent turbidity continued to increase in the sea water reactor and leveled off at 3.5 APHA units (Figure 4 and Table III). Foaming in reactor number 1 became quite apparent. Microscopic observations during the first two days showed a diminishing of the rotifer and ciliate protazoa populations. This initial reduction was overcome gradually. It is noted that during the population reduction, the BOD_5 removal efficiency did not suffer. It is therefore assumed that more tolerant forms or species indigenous to sea water would take over and proliferate under the new set of environmental conditions.

At the 40 percent sea water concentration the bench scale unit became extremely difficult to operate. The rapid increase in MLSS caused settling to take place in the aeration chamber. Sludge recycle from the settling chamber back to aeration chamber required constant adjustment of the baffle. In addition, the stone aeration device required daily cleaning because it would become clogged with solids.

While the sea water bench-scale plant became more and more difficult to operate at the higher levels of salinity, its settleability improved daily (Figures 10 through 16). During the entire test program the effluent chlorides would match the influent chlorides within a few days (Figure 8) of influent sea water concentration increases.
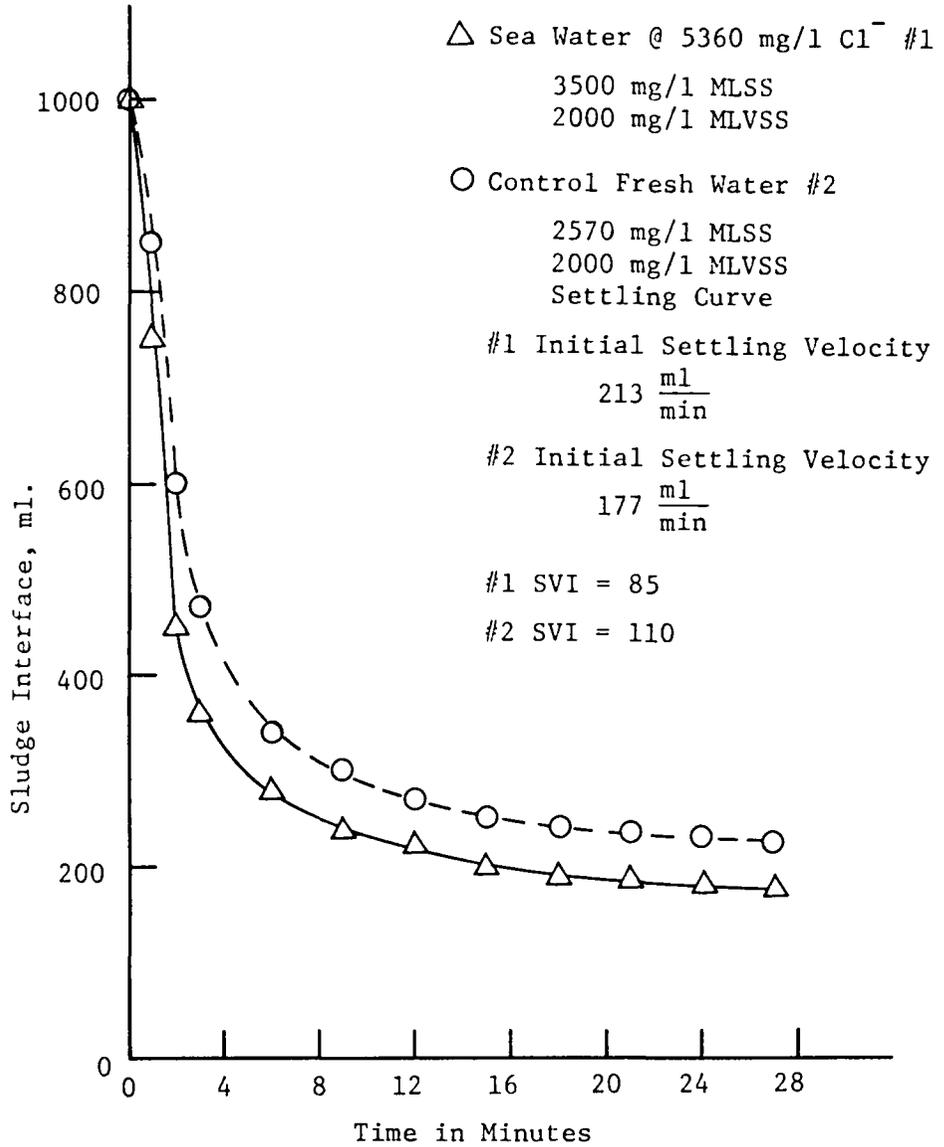
Figure 10. Settling Curve Number 1.
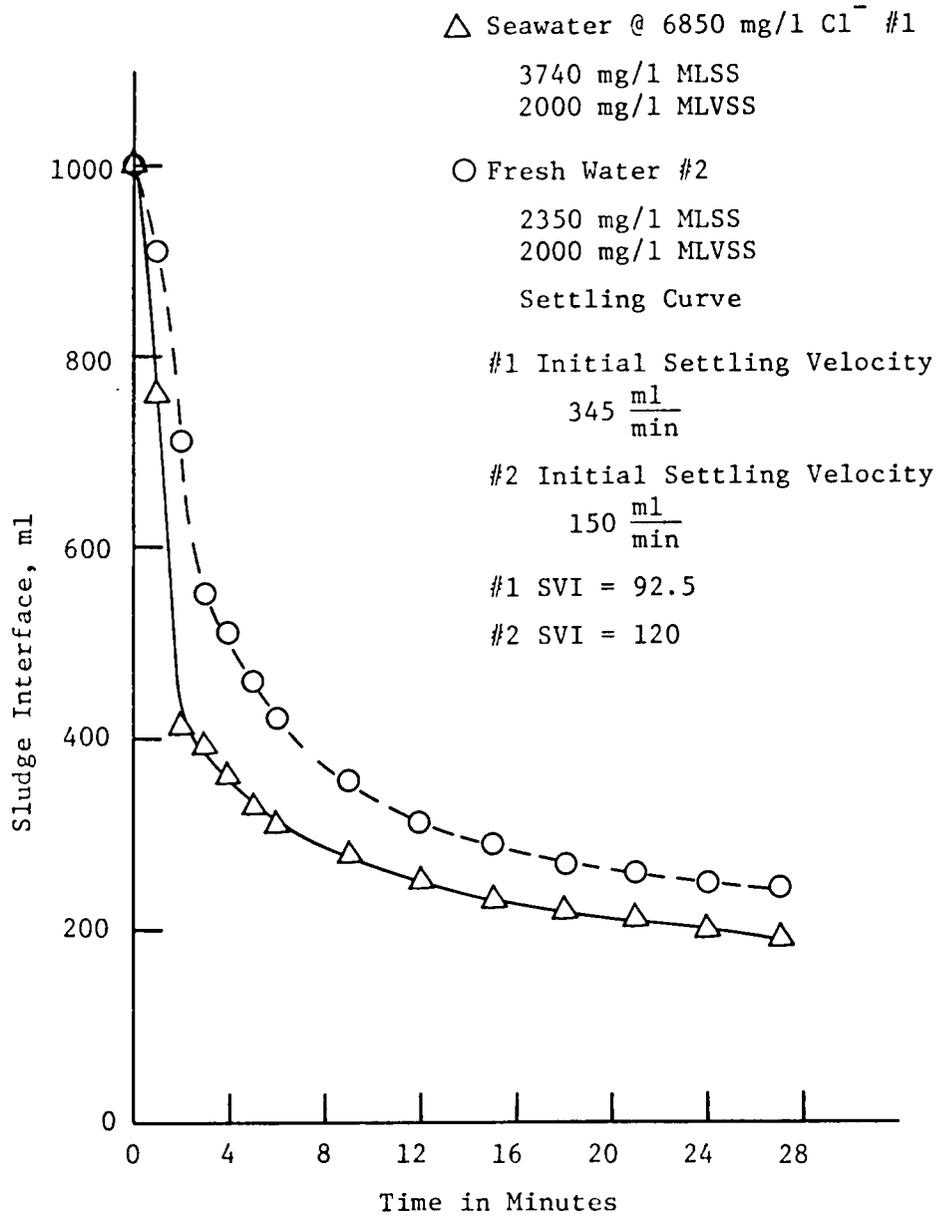
Figure 11. Settling Curve Number 2.
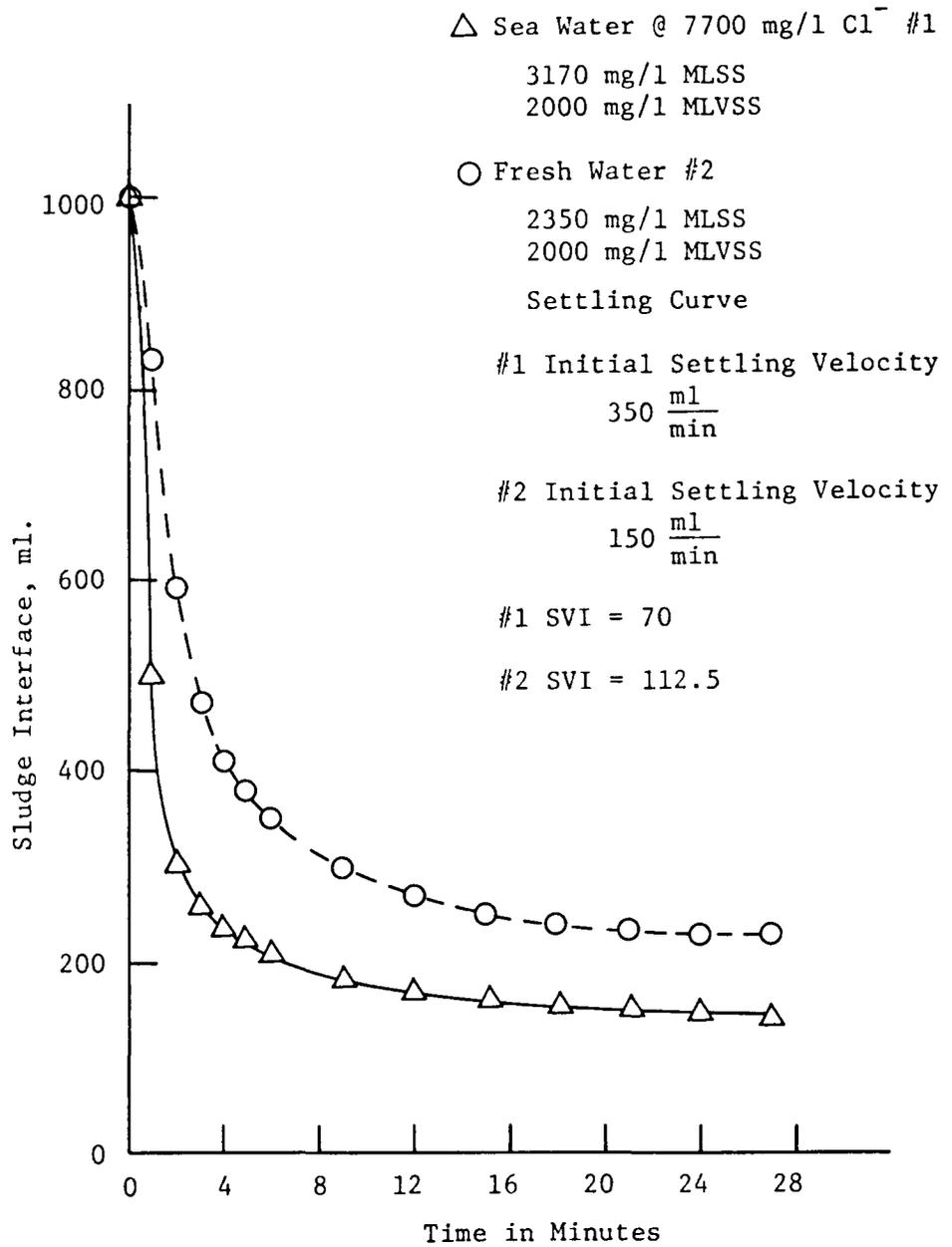
Figure 12. Settling Curve Number 3.
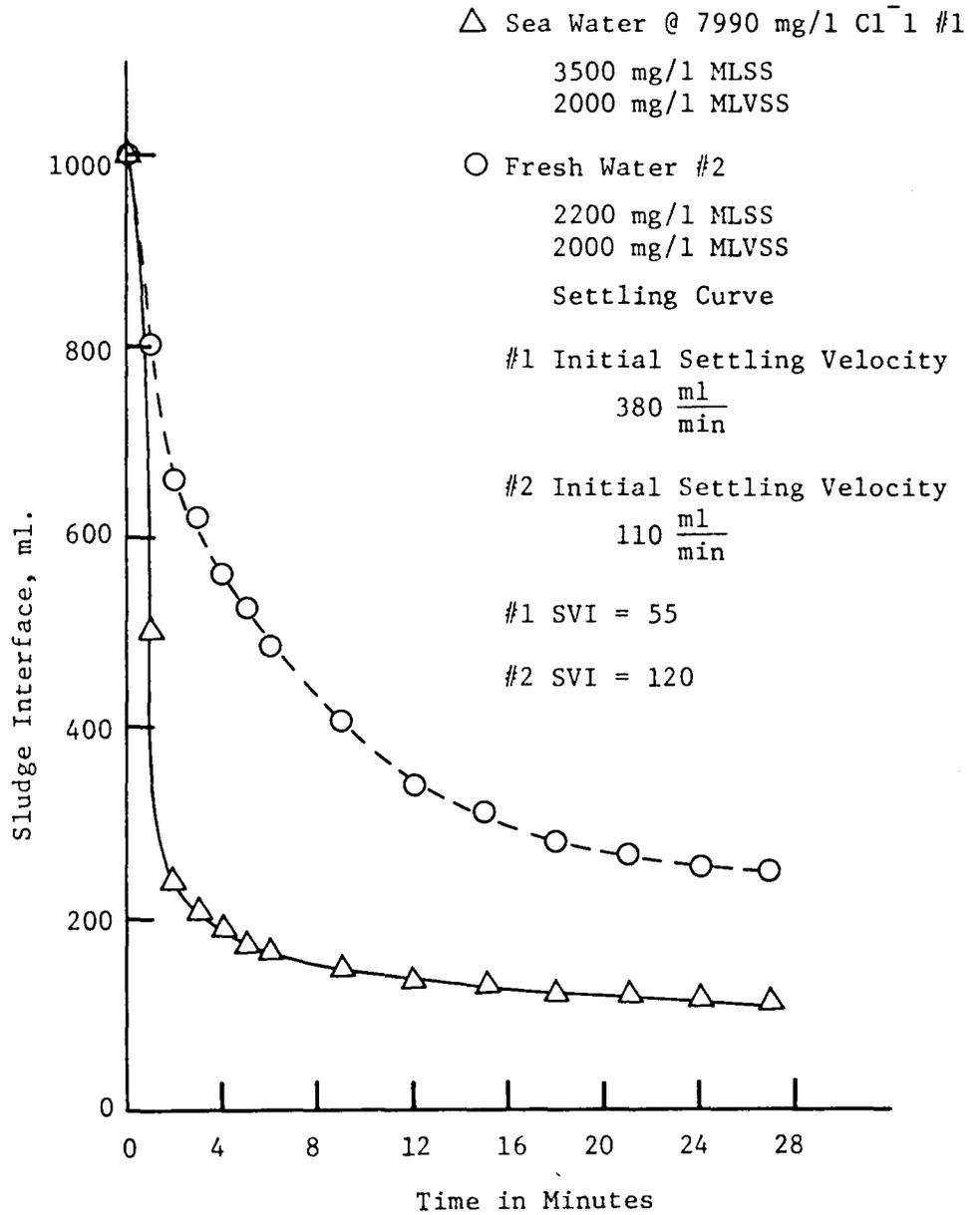
Figure 13. Settling Curve Number 4.

△ Sea Water @ 7820 mg/l Cl⁻ No. 1

   4720 mg/l MLSS
   2000 mg/l MLVSS

○ Fresh Water No. 2

   2345 mg/l MLSS
   2000 mg/l MLVSS

   Settling Curve

#1 Initial Settling Velocity
   $400 \frac{ml}{min}$

#2 Initial Settling Velocity
   $120 \frac{ml}{min}$

#1 SVI = 50

#2 SVI = 125
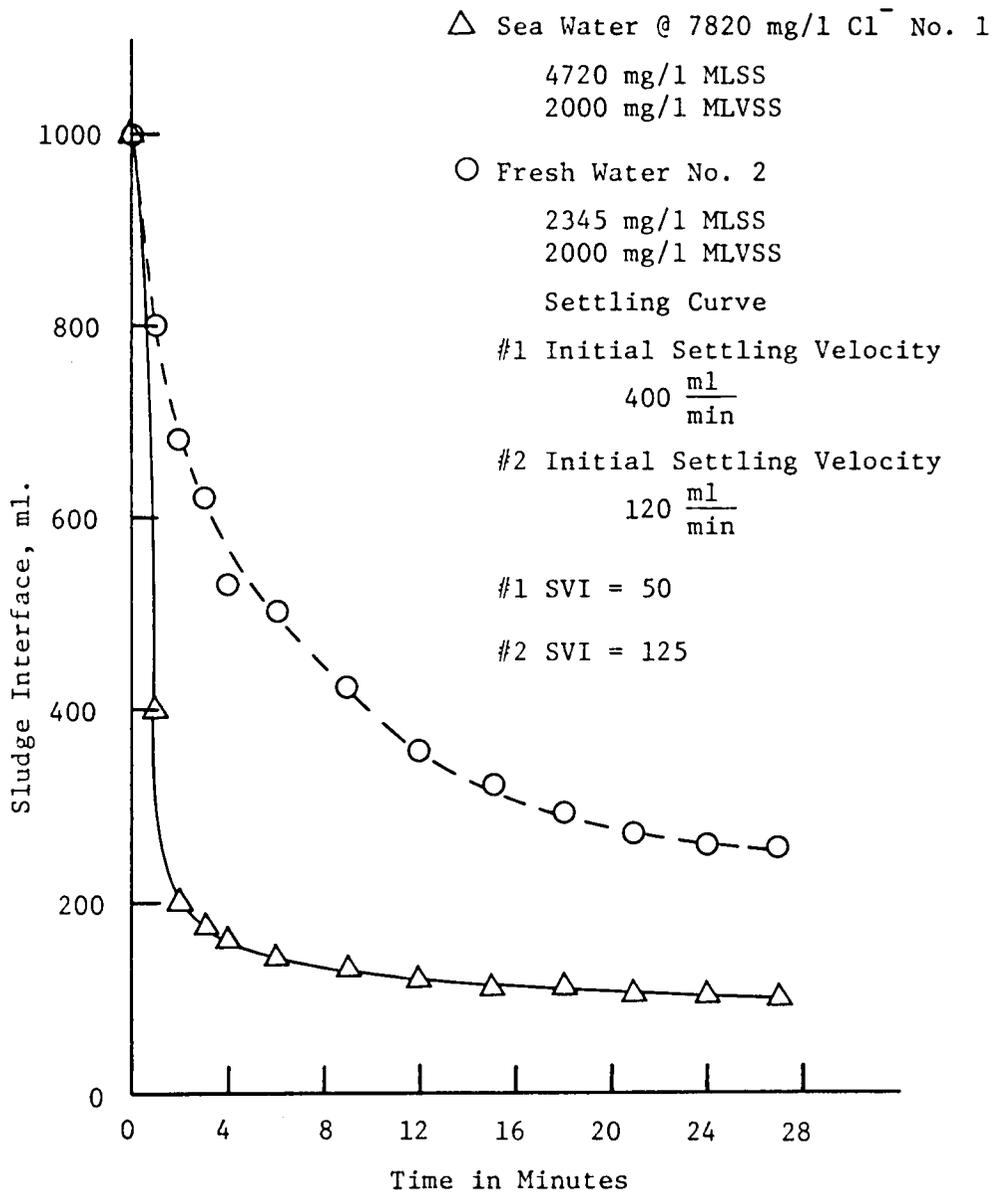
Figure 14.   Settling Curve Number 5.

△ Sea Water @ 8199 mg/l Cl⁻ #1
    4900 mg/l MLSS
    2000 mg/l MLVSS

O Fresh Water #2
    2585 mg/l MLSS
    2000 mg/l MLVSS

Settling Curve

#1 Initial Settling Velocity
    $420 \frac{ml}{min}$

#2 Initial Settling Velocity
    $100 \frac{ml}{min}$

#1 SVI = 40

#2 SVI = 125
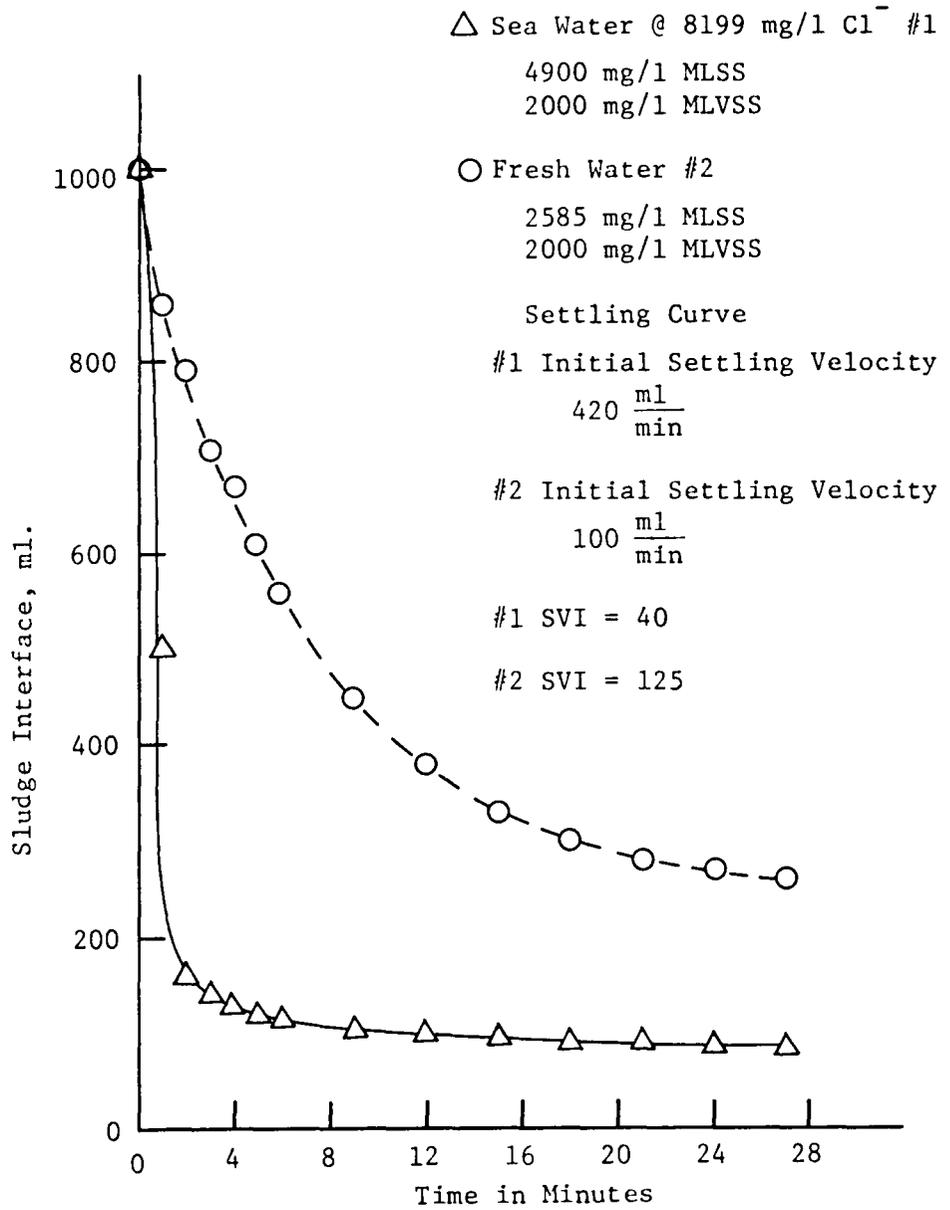
Figure 15. Settling Curve Number 6.

△ Sea Water @ 8170 mg/l Cl⁻ #1

5035 mg/l MLSS
2000 mg/l MLVSS

O Fresh Water #2

2585 mg/l MLSS
2000 mg/l MLVSS

Settling Curve

#1 Initial Settling Velocity
$420 \frac{ml}{min}$

#2 Initial Settling Velocity
$185 \frac{ml}{min}$

#1 SVI = 40

#2 SVI = 117.5
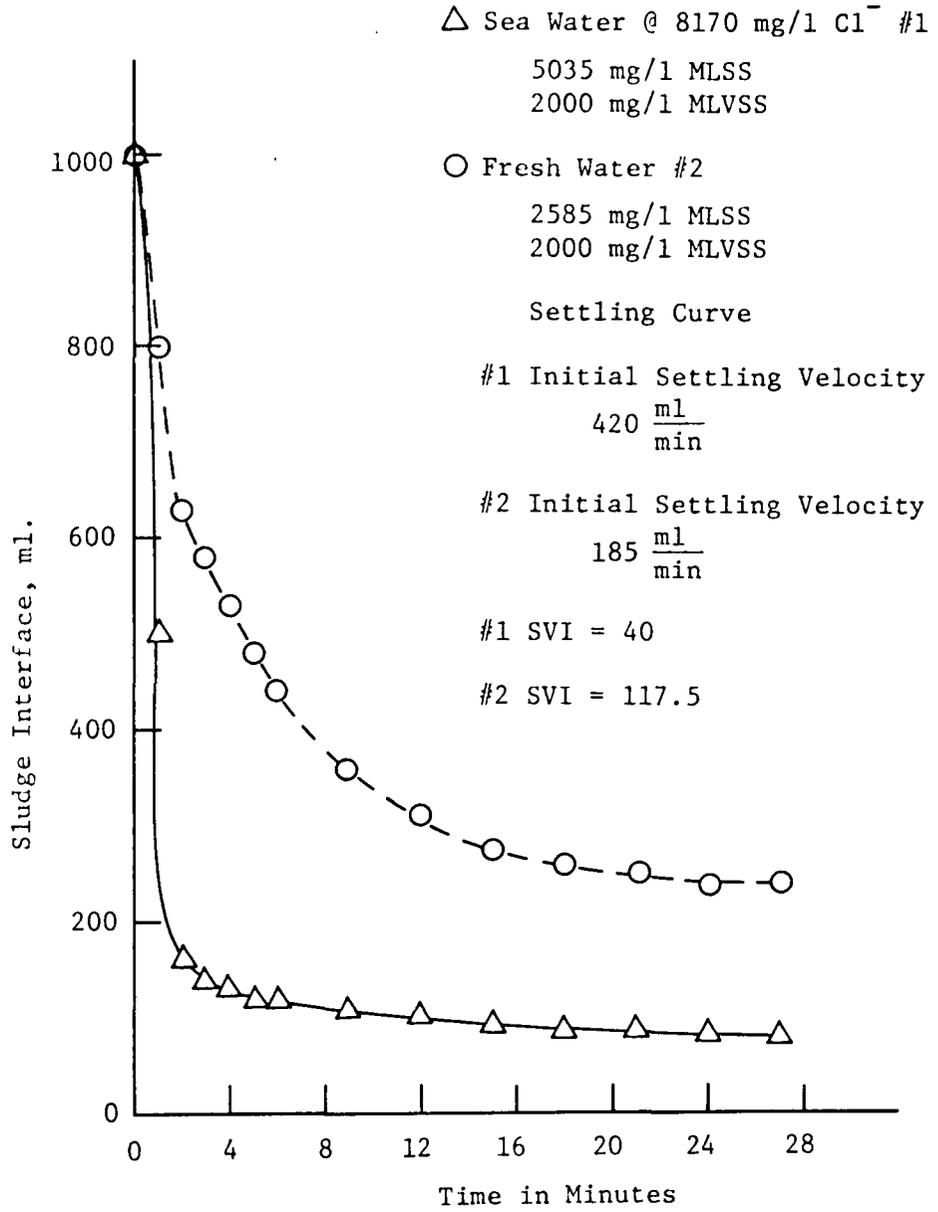
Figure 16. Settling Curve Number 7.

V. DISCUSSION OF RESULTS

The results of this study showed that the activated sludge pro-
cess can tolerate up to 25 percent seawater included with the effluent.
Above 25 percent the process becomes difficult to operate. The
operational problems of the process increased with increasing con-
centration of the chloride ion (Figures 4 through 9). This confirms
the findings and predictions of Lawton and Eggert (2), Stewart et al.
(3), Ludzack and Noran (4), Kincannon and Gandy (5) and Burnett (7).
These investigators concluded that a shock load of chloride con-
centrations somewhat less than seawater level would have little
effect on the operation of a biological sewage treatment plant. They
also predicted that when salts were slowly added to a treatment plant
microorganisms would easily adjust and there would not be any loss in
BOD_5 removal efficiency. The results of this study confirm their
predictions.

It was noted that as the seawater content was increased above
5000 mg/l Cl^- the rotifer and ciliate populations were reduced. This
reduction may be attributed to osmotic pressure differences between
fresh water and seawater. These reductions were quickly overcome,
however, and there was no real loss of BOD_5 removal efficiency
(Table III). The results of this study indicate that BOD_5 removal
efficiency (Table II and Figure 4) would not be the limiting factor
for biological sewage treatment in a seawater environment. Instead,
they indicate that the buildup of mixed liquor suspended solids would

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become the limiting factor (Figure 6). Stewart et al. (3) discussed

a similar increase in mixed liquor suspended solids while operating

a laboratory model extended aeration process. However, they

attributed this increase to greater BOD influent loading. In this

study the BOD_5 of the influent for each reactor was held constant

and therefore could not be held accountable for an increase in MLSS

in the seawater reactor. No increase was noted in the fresh water

reactor.

Substrate with 25 percent seawater would contain 5350 mg/l Cl^-

and approximately 10,000 mg/l total dissolved solids while substrate

with 40 percent seawater would contain 8200 mg/l Cl^- and approximately

14,000 mg/l total dissolved solids. It is therefore reasoned that

the increase in the inorganic weight of the MLSS was caused by either

dissolved solids coming out of solution and being sorbed onto the

surface of the existing solids or by incorporation of dissolved in-

organic solids within the microbial cells to maintain proper osmotic

pressure. It is most probable that the need to maintain osmotic

pressure was chiefly responsible for the increase in fixed suspended

solids.

Daily solids tests showed that the volatile portion of the solids

remained fairly constant in each reactor (Figures 5 and 6). The per-

cent volatile solids data indicate that as sorption occurred the

existing biological solids increased in weight rather than increasing

in cellular numbers. The rapid settling of the resulting sludge

(Figures 10 through 16) shows that the solids increased in specific

gravity which further indicates the noncellular nature of the increase. If the biological cells had increased in number, it would have become more difficult for the particles to settle because floc particle interference would have increased with the increase in concentration. Instead the settling tests showed that as the MLSS increased in weight (mg/1) the sludge settled faster.

As the dissolved solids were removed from solution the color of the floc particles in the reactor also changed. The color change, the increase in suspended solids, the development of settling and recirculation problems and the encrusting of the aeration stone all took place during the operation at 40 percent seawater inclusion. The buff color and the encrusting of the aeration device was also noted by Stewart et al. (3), although their investigation did not discover at what level of seawater concentration the encrustation problem became acute. In this study it was found to be acute at 25 percent seawater concentration or 5000 mg/1 Cl^-. However, it was noted that while the bench scale unit became extremely difficult to operate the BOD_5 removal and the oxygen uptake rate did not vary from the control reactor. The rotifer and ciliate population appeared as healthy and active in the 40 percent seawater as in the fresh water reactor.

The results of this study were limited in that only one loading rate was used, which was low and consisted of an easily metabolized synthetic substrate. The results are further limited by the short time of study. It was not clearly established when the solids

accumulation would reach equilibrium. From a practical standpoint, because of physical limitations, it did not appear that continuous operation on seawater would be successful in the activated sludge process without some modifications. The differences between the freshwater system and the seawater system were insignificant from a biological performance standpoint.

VI. CONCLUSIONS

The results of this investigation show that the presence of as much as 40 percent seawater in the wastewater causes no significant differences in the biological treatment kinetics of activated sludge. After a brief lag period the microbial population was able to adapt to the saline environment and, therefore, with acclimation the BOD_5 removal efficiencies remained high at all percentages of salinity used. It seems apparent that a full scale activated sludge plant receiving a highly saline wastewater would have no difficulty developing a good biological floc.

The primary limiting factor in the treatment of saline waste-waters with activated sludge would appear to be the accumulation of inorganic material in and on the biological floc. Whether this would eventually reach an equilibrium value was not determined in this investigation but the greater subsequent specific gravity of the floc resulted in operational problems because of rapid settling. The aeration of sewage composed of 25 percent seawater and greater also resulted in encrustation and eventual plugging of the aeration equipment. Therefore, full scale operation would most likely require frequent maintenance of aeration equipment if diffused air equipment is used. Surface aerators should provide more satisfactory operation.

There were no significant differences in influent and effluent salinities after a brief equilibrium period of two or more days. Because the effluent salinities did eventually reach the same values

as the influent salinities at all seawater concentration, it seems likely that encrustation of the sludge floc by inorganic solids would reach an equilibrium value corresponding to the influent salinity. It may further be inferred that because the influent and effluent salinities were equal the last two days of the run, the final percent volatile solids (46 percent) measured when waste was being treated was probably the minimum value for treatment of 40 percent seawater.

Because it is difficult to "scale-up" the results of laboratory tests to predict with certainty how the build up of inorganic suspended solids will affect the operation of an actual plant, it appears that a new avenue of exploration has been opened. The treatment of wastes when the ratio of volatile suspended solids to total suspended solids is low should be thoroughly investigated. Further studies also should be conducted to compare the tolerances of various activated sludge modifications to determine which one is best suited for situations where high salinity wastewaters would have to be treated.

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PRACTICAL ASPECTS OF THE ACTIVATED SLUDGE
PROCESS WITH SEAWATER INCLUSION

by

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(ABSTRACT)

The capability of the activated sludge process to operate with
sea water included in the influent substrate. Sea water was added
at various percentages from 5-40. The study concluded that from a
biological standpoint the activated sludge process could operate
successfully. However, rapid settling problems because of a build
up of total solids became the limiting factor.