THE EFFECT OF INITIAL SUBSTRATE CONCENTRATION ON THE SETTLING CHARACTERISTICS OF ACTIVATED SLUDGE

By

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CHAPTER I

INTRODUCTION

Water is essential for life; and as the earth's population increases by exponential numbers, the value of clean water also increases. Clean water is not only required for human consumption, but it is also required for industrial processes. In order to maintain a clean water supply, the treatment of municipal and industrial wastes is required prior to their being discharged into the streams.

One of the most common ways of treating a waste is by biological means. This presents a problem in that the microorganisms used to reduce the soluble organic matter of the waste are themselves organic matter. As such, they exert a Biochemical Oxygen Demand upon the stream. Therefore, the separation of these microorganisms from the treatment plant effluent is necessary before the effluent is discharged into the stream.

One of the most common methods used to separate this bio-mass is quiescent gravity settling. The importance of this process makes it imperative to understand the effects of different variables upon this physical operation. It is the purpose of this study, then, to examine the effect of initial substrate concentration upon the settling characteristics of activated sludge.

CHAPTER II

LITERATURE REVIEW

A. Sedimentation

Sedimentation is the physical operation by which solids are separated from a suspension by gravity. Sedimentation serves a dual purpose in a wastewater treatment plant. First it provides for the clarification of the treatment plant effluent prior to its discharge. The settling eliminates suspended matter from the waste treatment plant effluent, thereby clarifying it. This suspended matter includes microorganisms from the bio-reactor which have been carried away with the effluent from the bio-reactor. Eckenfelder and Melbinger (1) illustrate that the clarification capacity of a sedimentation tank is related to the settling velocity of the particles it contains. Secondly, it provides for the thickening of the treatment plant organic solids. The settling and compaction of the organic solids allow for the recycle of a certain portion of the solids to the bio-reactor, an operation needed to maintain the proper microorganism concentration in the bio-reactor. This thickening also permits the drawing off of some of the organic solids, or sludge, to be disposed of in some manner. Eckenfelder and Melbinger again demonstrate that the thickening capacity of a sedimentation tank is related to the depth of the sludge in the tank and the time the sludge is in the compression zone.

Much of the basic theory utilized today in the design and in the research of the sedimentation process for the treating of municipal wastes had its roots in the metallurgical field. Researchers seeking to determine the capacity of slime-settling tanks carried on research to determine the settling behavior of slime pulps consisting of water, finely divided sand, and colloidal material.

This was the case of H. S. Coe and G. H. Cleavenger (2). Their early research revealed the existence of four settling zones encountered in the sedimentation process. These zones can be called zone A, B, C, and D. When a thoroughly mixed suspension is placed in a cylinder or tank, it is first comprised of a homogeneous mass. Next, floc particles begin forming; and as the particles settle, they form four distinct zones.

The dense, coarser particles settle first to the bottom. Next, flocculated particles nearest the bottom settle, filling any empty spaces. By settling upon each other, they comprise a zone of increasing depth. This zone, where the floc particles rest upon each other, is called zone D. Within zone D, further separation of floc particles from liquid must occur due to the liquid pressed out of the spaces between the flocs. The zone above zone D is zone C. It is termed the transition zone. The suspension in zone C decreases in solids concentration from the bottom of the zone to the top. Also, the settling velocity decreases in this zone because of the increasing density and viscosity of the suspension surrounding the particles. At the bottom of the zone, the particles enter zone D; at the top of the zone, the concentration of solids is equal to the concentration of the original suspension prior to any occurrence of settling. Zone B lies just above zone C. Zone B consists of a constant concentration of particles throughout the zone and contains the same concentration of solids as the original suspension prior to settling. Eckenfelder and Melbinger (1) point out that the particles settle at a uniform rate through zone B. They also conclude that the magnitude of this velocity is a function of the initial solids concentration. The constant concentration of particles in zone B will remain constant until the particles approach zone C. Above zone B is zone A. It is the clear water or supernatent zone. Zone A is sometimes turbid, due to finely divided matter remaining in suspension.

When the particles in zones B and C descend without pressing on the layers beneath them, they are termed free settling flocs. There are places, however, in this free settling in which the floc particles contact each other due to their interlocking structure.

There is a point in the settling in which the particles at the top of zone D just rest upon each other without any compression occurring at the top of this zone. At this point zone C is just disappearing. This point is called the Critical Settling Point. At this time, any removal of liquid from zone D must now occur by compression.

Fitch (3), studying the settling behavior of a "swarm of particles", observed that the particles are apt to settle in any of four different ways. He placed each way of settling in a class of its own, namely, Classes I, II, zone settling, and compression. He further put Classes I and II in the area of clarification. Which way the particles settle is determined by the dilution of the suspension, by particle interaction, and by the relative tendency of the particles to cohere.

Fitch found that at higher dilutions particles settle either separately or flocculantly. At these high dilutions, there is no clear line of demarcation between settling suspension and supernatant. Class I includes those particles in the clarification regime which settle individually. As individual particles, they exhibit a somewhat constant rate of settling. They cannot maintain an exactly constant rate due to the fact that the solids concentration changes in the settling operation. As Fitch has pointed out, however, this deviation from constancy is neglected in practical classification theory.

Hazen (4), in studying the settling behavior of Class I particles, determined that the efficiency of a sedimentation tank in removing solids was a function of the overflow rate and not of the detention time.

Camp (5), conceived the idea of an "ideal" settling basin in which the direction of flow was horizontal and the velocity was the same for all parts of the settling zone. Fitch (6) realized that the idea of an ideal settling tank, in which each particle settles separately, with its own constant velocity, would be very useful in analyzing the settling behavior of an ideal basin. Camp also believed that the removal of Class I particles is governed by the overflow rate and that detention time of flow is not a factor in determining the removal of particles. In other words, Class I clarification is determined by area and not depth. Camp (7, 8) went further, however, and proposed the idea that the same would hold true for particles belonging in Class II. Fitch (9) and Eliassen (10) show that it is quite likely that solids removal from Class II would rely more heavily on detention time than on overflow rate.

Less research has been undertaken for Class II suspensions. This is primarily due to the fact that Class II suspensions are encountered less often in the metallurgical field than are Class I suspensions. Class II suspensions also involve high dilutions. The difference in Class II from Class I is that Class II suspensions settle in a flocculant manner rather than as individual particles. This flocculation is brought about by the collision of particles in such a way as to cause them to cohere. Another difference is that the particles in Class I settle at a constant rate, whereas, the particles in Class II do not. This is due to the fact that the floc particle increases in size as it settles, causing its settling rate to increase.

Zone settling occurs at lower dilutions than those encountered in Class I or Class II. In this class, the floc particles form one descending mass. It is believed that this is due to the closeness of the particles to each other. Thus, they cohere immediately into one mass. All particles in this mass settle at the same rate. There exists, in this class, a sharp line of demarcation between the settling solids and the supernatant. So the settling rate can be said to be a function of the solids concentration; the flux of water past the solids, or solids through water, is also a function of the solids concentration. Zone settling, as has been demonstrated by Comings (11), creates a limit as to the amount of solids which can pass through any concentration. For example, if the feed rate in a thickener produces less flux than that which could be carried through the most limiting concentration, no solids are backed up. On the other hand, if the feed rate is greater than that which can be delivered by the limiting concentration, the excess created backs up as a zone of this concentration. A back up zone of this kind will also occur if the area required to handle the solids flux delivered by the feed rate is not great enough. It can be seen, therefore, that area is the critical design factor for zone settling. Also if enough area is supplied so that there is no back up zone, then no zone settling layer will form. So, detention time is not a factor in zone settling.

Coe and Clevenger (2) developed a model and equation for the determination of the required thickener unit area. Their procedure involves making several batch tests at various initial concentrations and determining the free-settling behavior from the constant rate sections of the batch settling curves. Their model assumes that the most flux-limiting concentration will not occur in the compression range. The flux-handling capacity for zones of every concentration between that of the feed and that of compression is tested, using free settling data and Coe and Clevenger's equation. The overall solids-handling capacity of the thickener must equal the most limiting concentration found. Fitch (12) in his research has concluded that the Coe and Clevenger procedure, in certain cases, can yield results 50% lower than actual thickener performance.

Kynch (13) derived a graphical method for determining thickener unit area. Kynch started from the assumption that settling rate is a function only of solids concentration. Only when this condition is met is his procedure then valid. His method allows the required unit area to be read directly from a settling curve. However, when attempting to predict the performance of a continuous basin with the data from the batch settling test, there is often a wide margin of error found. The thickener often has a vastly larger capacity than was predicted. Fitch (3) concludes that this is probably due to some other variable or variables affecting the settling rate. Dick and Ewing (14) have noted that Kynch's method cannot be used to predict the settling behavior of activated sludge, because the settling rate of activated sludge is a function of sludge depth and the mixing of underlying layers as well as the solids concentration. They also point out that the required thickener unit area is not fixed by the observed settling velocity of the rate-limiting concentration of sludge. The required thickener unit area can be reduced by controlling the sludge depth and by varying the sludge to minimize the effect of interparticle forces.

Talmage and Fitch (15) took from Kynch's method the first falling-rate section of a single batch test and selected the limiting flux directly using a graphical method. As Fitch (12) later pointed out, however, this method produces conservative predictions.

The last class in Fitch's sedimentation classification is the compression regime. Compression occurs at lower dilutions. Coe and Clevenger (12) attributed the compression regime to the mechanical support of the layers of floc. Fitch (3) hypothesized that the compression regime was not entirely due to this mechanical support. He measured the pressure of the fluid at various depths in a compression zone. He found no difference which would result from mechanical support. He next deduced that the actual mechanical pressure on the structure of the solids would be rather insignificant. Eckenfelder and Melbinger (1) illustrate that the solids concentration in the compression zone is related to the depth of the sludge and the detention of the solids in the zone. Comings (11) demonstrated that for a given detention period a shallow compression zone depth will yield a higher underflow concentration than a deep depth. So as the depth of the sludge blanket is increased the sludge detention in the compression zone must also be increased for a specified underflow concentration.

Conventional design procedures for thickeners today rely a great deal upon determining the compression point. The average solids concentration at this point is used as the dividing line between free-settling and compression. As previously stated, Coe and Clevenger (2), in their procedure for determining thickener unit area, assume that the most flux-limiting concentration will not occur in the compression range. Since the Coe and Clevenger method is probably the most commonly one used today, the determination of the point is very important. Often the determination of the compression point is not difficult. Fitch (12) points out that in cases of doubt, a log-log plot of time versus pulp height may be helpful. Also, a Robert's (16) plot of the log of pulp height minus the height of the settled solids at infinite time versus time on a linear scale may be used.

B. Variables Affecting the Settling Characteristics of Activated Sludge

Activated sludge differs from many other sludges or slurries (i.e., metallurgical slurries) in that activated sludge is generally flocculant in nature. Two parameters used in characterizing the settleability of an activated sludge are zone settling velocity and sludge volume index. Zone settling velocity has previously been discussed. Sludge volume index is the volume of sludge settled in a specified time interval, divided by the sludge concentration. It is often used in evaluating the performance of a treatment plant. A low SVI (i.e., 50) denotes a good sludge; a high SVI (i.e., 250) denotes a poor sludge. SVI normally varies with the mixed liquor suspended solids content for the same sludge.

One of the most critical variables in affecting the settling characteristics of activated sludge is the initial solids concentration. As the solids concentration is increased, for the same sludge, the zone settling velocity decreases and the SVI increases. As Talmage and Fitch (15) point out, if the settling characteristics were independent of the initial solids concentration, then the same final solids concentration should be reached in all settling tests for a given sludge.

Eckenfelder and Melbinger (1) have determined that elongated aeration periods can significantly increase the settleability of activated sludge. Heukelekian and Weisberg (17) related SVI to the bound water content of the sludge. A sludge with a low SVI contained 100% bound water, whereas a sludge with a high SVI contained 380% bound water. Elongated aeration reduced the bound water content and the SVI.

Another variable affecting the settling characteristics of activated sludge is sludge depth. Dick and Ewing (14) conducted a study on three separate activated sludges at various concentrations. They observed the initial settling velocity at various initial sludge depths. They found in each test that an increase in the initial depth of the suspension was accompanied by an increase in the initial settling velocity.

Research by Mancini (18) and Dick and Ewing (14) were able to show that the mixing of underlying sludge layers could increase the zone settling rate. The increase, as Dick and Ewing concluded, was due to the increase in interparticle forces. They were not, however, able to establish any type of quantitative relationship between the intensity of the mixing and the settling velocity. Dick and Ewing felt that to attempt to quantitatively relate their findings to design practice was premature. More research of the settling characteristics of activated sludge is needed.

Vesilind (19) has pointed out that the diameter of the cylinder used in the settling test could cause error in observing and recording the settling rates of activated sludge. In his experiments he showed that cylinders with small diameters (i.e., two inches) exhibited an erratic settling behavior. He found that regions of large sludge clumps and void channels may form within the sludge bed. These may rise to the surface causing an increase in the settling velocity. Data obtained by Dick and Ewing (20) confirm that the diameter of a cylinder effects the settling behavior.

Farnsworth and Dick (21) demonstrated that the degree of flocculation also affects the settling characteristics of activated sludge. As the parameter for quantitatively measuring the results, they measured the turbidity of the supernatant liquid during settling. Black and Chen (22) noted that the use of this parameter is sensitive to changes in flocculent dose. To simulate varying degrees of flocculation, Farnsworth and Dick used varying doses of a cationic polyelectrolyte. Their results yielded that the influence of polymers on the settling characteristics of the activated sludge was highly dependent upon the suspended solids concentration. With the sludge they used, taken from the Urbana-Champaign, Illinois Sanitary District main treatment plant, polymers improved settling velocity for concentrations less than about 5,250 mg/l but reduced settling velocity at higher concentrations. Thus, they concluded that flocculation significantly affected zone settling velocity at large initial sludge depths and had less effect on zone settling velocity at low depths.

The Mean Cell Residence Time (θ_c) also affects the settling characteristics of activated sludge. Bartle (23), in conducting research on the effect of θ_c and microorganism concentration on the thickening properties of activated sludge, came to several conclusions. He found that at a given initial sludge concentration, the SVI first increases to a maximum value with decreasing θ_c and then decreases with decreasing θ_c. Also the zone settling velocity decreases with decreasing θ_c. He found that the maximum concentration to which an activated sludge will settle decreases with decreasing θ_c. Research by Roper (24) confirms Bartle's findings. Roper found that reducing θ_c (i.e., from eight days to five days) would create a problem of liquid-solids separation due to the decrease in sludge settling velocity.

Bisogni and Lawrence (25) in their research expressed similar results to those of Bartle and Roper. From their findings, Bisogni and Lawrence concluded that the settling properties of activated sludge can be expressed as functions of θ_c of the sludge. They also determined that, based on the total bio-mass in the effluent, the best overall solids removal occurred at the values of θ_c in the range of four to nine days.

The organic loading also effects the settling characteristics of activated sludge. Ford and Eckenfelder (26) conducted research on three different types of waste, including domestic waste, by varying the amount of organic matter fed into the system. Their work yielded essentially the same results in each case. They found that as the organic loading was increased, the percent COD removal decreased. They also learned that as the organic loading increased, the SVI decreased to a point and then increased. Conversely, as the organic loading increased, the zone settling velocity first increased and then decreased rapidly. They contributed the poor settleability at the lower and higher organic loadings in each test to the presence of filamentous organisms.

CHAPTER III

MATERIALS AND METHODS

To study the effect of initial substrate concentration on the settling properties of activated sludge, a bench scale activated sludge unit was operated continuously under controlled conditions for approximately ten months.

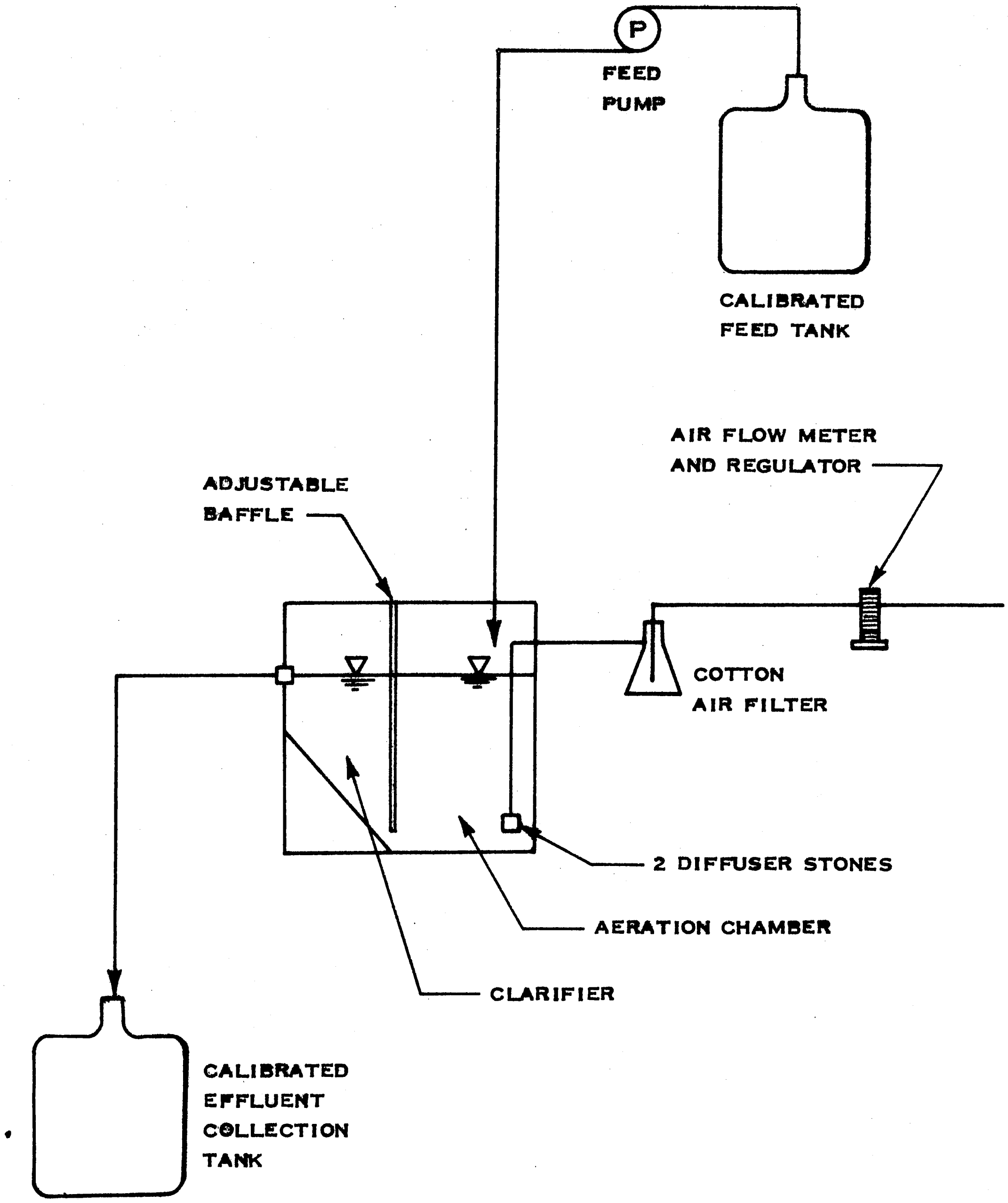
A. Laboratory Apparatus

A schematic diagram of the laboratory apparatus used is shown in Figure 1. The biological reactor was a rectangular tank constructed of one-fourth inch plexiglass. The tank was separated by an adjustable baffle into an aeration compartment and a clarifier. The volume of the aeration basin was 7.9 liters. The volume of the clarifier was 3.3 liters.

A feed rate of 7.9 liters/day was supplied to the reactor by the means of a Cole-Parmer variable speed tubing pump (model 7545-17). The feed rate was checked every other day by the use of a graduated cylinder and timer.

Air was supplied to the aeration basin through two porous diffusers. The diffusers served two purposes. They not only supplied air for the microorganisms, but they also controlled the internal recycle rate. Solids which entered the clarifier were drawn back into the aeration tank, providing a constant recycle system. The air flow was

Figure 1. Experimental Activated Sludge Unit



EXPERIMENTAL ACTIVATED SLUDGE UNIT
WITH INTERNAL SLUDGE RECYCLE

maintained between 6.5 and 7.5 cubic feet/hour. The air flow was monitored by the use of a Gelman air flow meter. A cotton filter was placed between the air outlet and the air flow meter to prevent oil from entering the air lines and the aeration tank.

The pH of the system was monitored weekly using a Beckman Expandomatic ss-2 pH meter. The pH of the aeration tank was maintained at approximately 7.0 by the use of a phosphate buffer.

The mixed liquor suspended solids were wasted daily from the aeration tank to maintain a Mean Cell Residence Time of 10 days. Since there was no measurable suspended solids in the effluent for each of the substrate concentrations tested, the amount of mixed liquor suspended solids wasted daily was 0.79 liters.

B. Feed Solution

The chemical composition of the feed solutions used is listed in Tables I, II, III, IV, and V. Concentrated stock solutions were made for carbon source, nitrogen source, salts, and buffer. The feed was obtained from these stock solutions.

C. Experimental and Analytical Procedures

The microorganism seed for this study was obtained from the effluent of the primary clarifier of the Stillwater, Oklahoma municipal treatment plant. The unit was operated on a batch basis until the microorganism concentration had built up to approximately 2000 mg/1. At that time the reactor was then operated as a continuous flow system.

The biological unit was operated with the initial substrate concentration chosen as the operational parameter. The concentrations of

TABLE I

COMPOSITION OF STOCK SOLUTION

Constituent	Stock Concentration (Per 2 L)
Dextrose	400 grams
Ammonium sulfate	200 grams
Potassium Phosphate buffer	
KH_2PO_4	77.5 grams
K_2HPO_4	249.0 grams
Salts	
$CaCl_2$	1.5 grams
$FeCl_3$	0.1 grams
$MgSO_4$	20.0 grams
$MnSO_4$	2.0 grams

TABLE II

COMPOSITION OF 200 mg/1 SUBSTRATE LEVEL FEED

Constituent	Volume of Stock Solution Per Liter of Feed (ml/1)	Feed Concentration (mg/1)
Dextrose	1.0	200
$(NH_4)_2SO_4$	1.0	100
Salts	2.0	
$CaCl_2$		1.5
$FeCl_3$		0.1
$MgSO_4$		20.0
$MnSO_4$		2.0
Potassium Phosphate Buffer	2.0	
KH_2PO_4		77.5
K_2HPO_4		249.0

TABLE III

COMPOSITION OF 400 mg/l SUBSTRATE LEVEL FEED

Constituent	Volume of Stock Solution Per Liter of Feed (ml/l)	Feed Concentration (mg/l)
Dextrose	2.0	400
$(NH_4)_2SO_4$	2.0	200
Salts	4.0	
$CaCl_2$		3.0
$FeCl_3$		0.2
$MgSO_4$		40.0
$MnSO_4$		4.0
Potassium Phosphate Buffer	4.0	
KH_2PO_4		155.0
K_2HPO_4		498.0

TABLE IV

COMPOSITION OF 600 mg/l SUBSTRATE LEVEL FEED

Constituent	Volume of Stock Solution Per Liter of Feed (ml/l)	Feed Concentration (mg/l)
Dextrose	3.0	600
$(NH_4)_2SO_4$	3.0	300
Salts	4.0	
$CaCl_2$		4.5
$FeCl_3$		0.3
$MgSO_4$		60.0
$MnSO_4$		6.0
Potassium Phosphate Buffer	4.0	
KH_2PO_4		232.5
K_2HPO_4		747.0

TABLE V

COMPOSITION OF 800 mg/1 SUBSTRATE LEVEL FEED

Constituent	Volume of Stock Solution Per Liter of Feed (ml/1)	Feed Concentration (mg/1)
Dextrose	4.0	800
$(NH_4)_2SO_4$	4.0	400
Salts	8.0	
$CaCl_2$		6.0
$FeCl_3$		0.4
$MgSO_4$		80.0
$MnSO_4$		8.0
Potassium Phosphate Buffer	8.0	
KH_2PO_4		310.0
K_2HPO_4		996.0

influent used were, in order of their use, 200 mg/1, 400 mg/1, 600 mg/1, 800 mg/1, and 400 mg/1. The 400 mg/1 concentration was repeated to insure that the results previously obtained were valid.

The feed was prepared every other day. The substrate concentration of the feed and the filtered clarifier effluent were checked two to three times weekly. The Chemical Oxygen Demand tests used to check these were carried out as set forth in Standard Methods (27).

The mixed liquor suspended solids and the suspended solids in the effluent were checked three to four times weekly as stated in Standard Methods (27). Membrane filters (Millipore Filter Corporation, Bedford, Mass.) with a pore size of 0.45 micrometers were used, however, rather than the glass filters stated. An analytical balance (Mettler Instrument Corporation Balance No. 1-910) was used to weigh the filters.

A determination, at each influent substrate concentration, was made for cell yield, specific utilization, zone settling velocity, and sludge volume index.

Once the system had reached steady state, as determined by the levels of the mixed liquor suspended solids, the effluent suspended solids, and the effluent substrate concentration, settling tests were run to examine the effects of the influent substrate concentration on the settling properties of the activated sludge. These were carried out by putting one liter of mixed liquor suspended solids into a one liter graduated cylinder. After thorough mixing, the solids were settled quiescently. Measurement of the descending solids, at the interface, was observed and recorded for one hour (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 30, 40, 50, and 60 minutes). For each influent substrate concentration, settling tests were made at various mixed liquor suspended solids concentrations. These different concentrations were achieved by either concentrating the solids, in which case the solids were allowed to settle and the supernatent was drawn off, or by diluting the solids, in which case supernatent is added to a desired lesser amount of solids to bring it to the one liter level.

The settling tests were made in two identical one liter, graduated cylinders with a diamter of 2 1/2 inches and a depth of 1.2 feet (to the 1000 milliliter level). These tests were carried out to observe the zone settling velocity and the sludge volume index. The sludge volume index was determined by the method set forth in Standard Methods (27).

D. Methods of Data Analysis

The sludge age of the system was calculated by the use of the equation

$$\theta_c = \frac{VX}{Q_w X + (Q - Q_w) X_e} \tag{1}$$

The COD removed efficiency was determined by the use of the equation

$$E = \frac{(S_o - S) \times 100}{S_o} \tag{2}$$

The specific utilization was determined by the use of the equation

$$U = \frac{Q(S_o - S)}{VX} \tag{3}$$

The observed yield coefficient was determined by the use of the equation

$$Y_{obs} = \frac{Q_w X + (Q - Q_w)X_e}{Q(S_o - S)} \qquad (4)$$

where

θ_c = sludge age, days

V = volume of aeration tank, liters

X = aeration tank solids concentration, mg/l

Q_w = waste flow rate, liters/day

Q = influent flow rate, liters/day

X_e = effluent solids concentration, mg/l

E = COD removal efficiency, percent

S_o = influent COD concentration, mg/l

S = effluent COD concentration, mg/l

U = specific utilization, days^{-1}

Y_{obs} = observed yield coefficient, mg/mg

CHAPTER IV

RESULTS

A laboratory activated sludge unit was operated continuously under controlled steady state conditions. The initial substrate concentration was used as the operating parameter. The hydraulic detention time was maintained at 24 hours. The Mean Cell Residence Time was maintained at 10 days. The results of the study are presented below.

A. Operational Results

Figure 2 shows the Mixed Liquor Standard Solids concentration for the four substrate concentrations studied. The solids increased linearly with the increase in substrate concentration. This increase was to be expected.

Figure 3 shows the effluent suspended solids encountered at each substrate concentration. The data presented was collected during steady state conditions. During certain times between steady state periods, the effluent suspended solids fluctuated somewhat. When the microorganisms had become acclimated to the higher concentration, however, the effluent suspended solids returned to zero. Thus, excellent clarification occurred in all studies.

Figure 4 presents the effluent COD values obtained at each substrate concentration during steady state conditions.

Figure 2. Mixed Liquor Suspended Solids Versus Influent Substrate Concentration

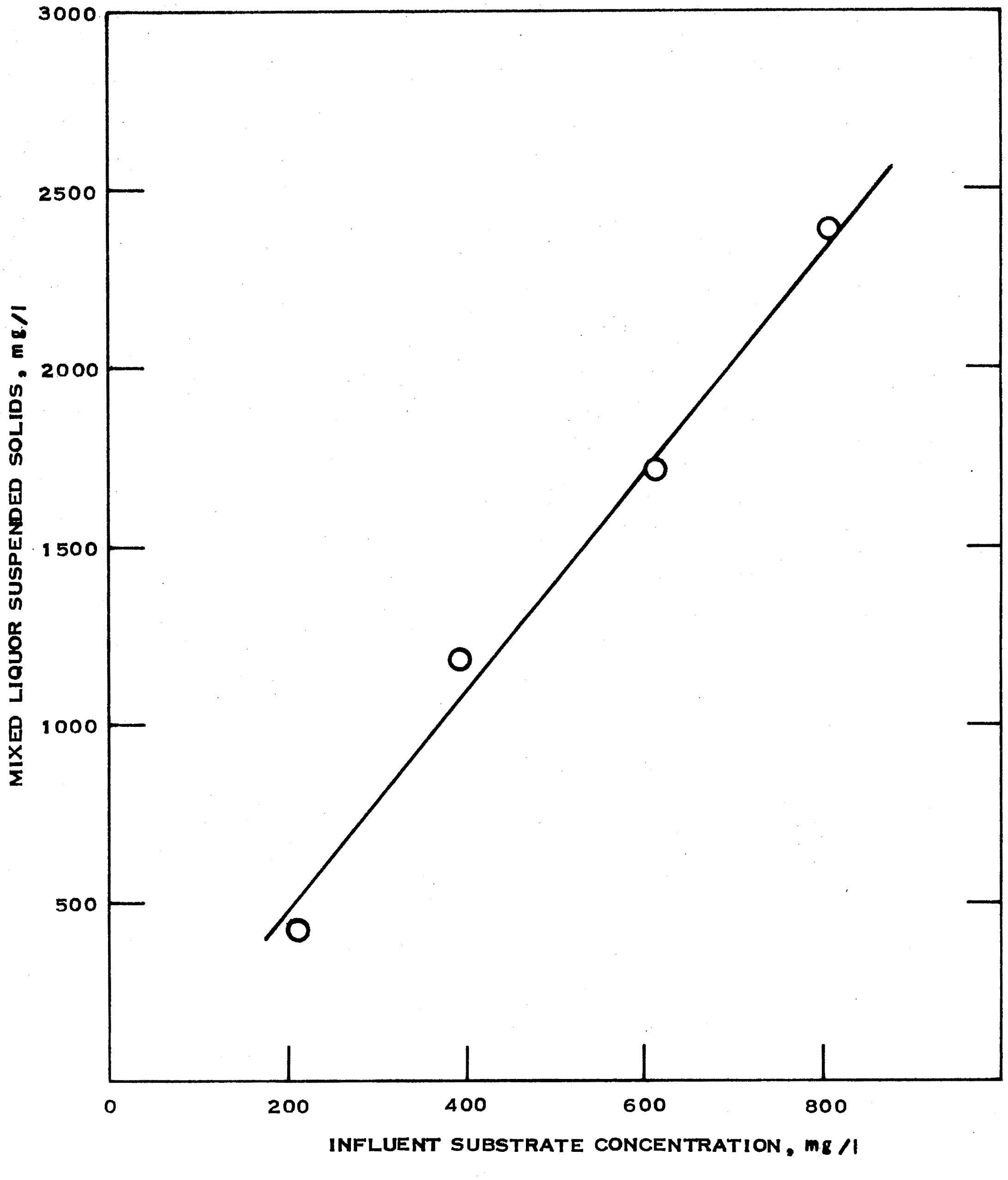

3000
2500
2000
1500
1000
500
0
200
400
600
800
MIXED LIQUOR SUSPENDED SOLIDS, mg/l
INFLUENT SUBSTRATE CONCENTRATION, mg/l

Figure 3. Effluent Suspended Solids Versus Influent Substrate Concentration

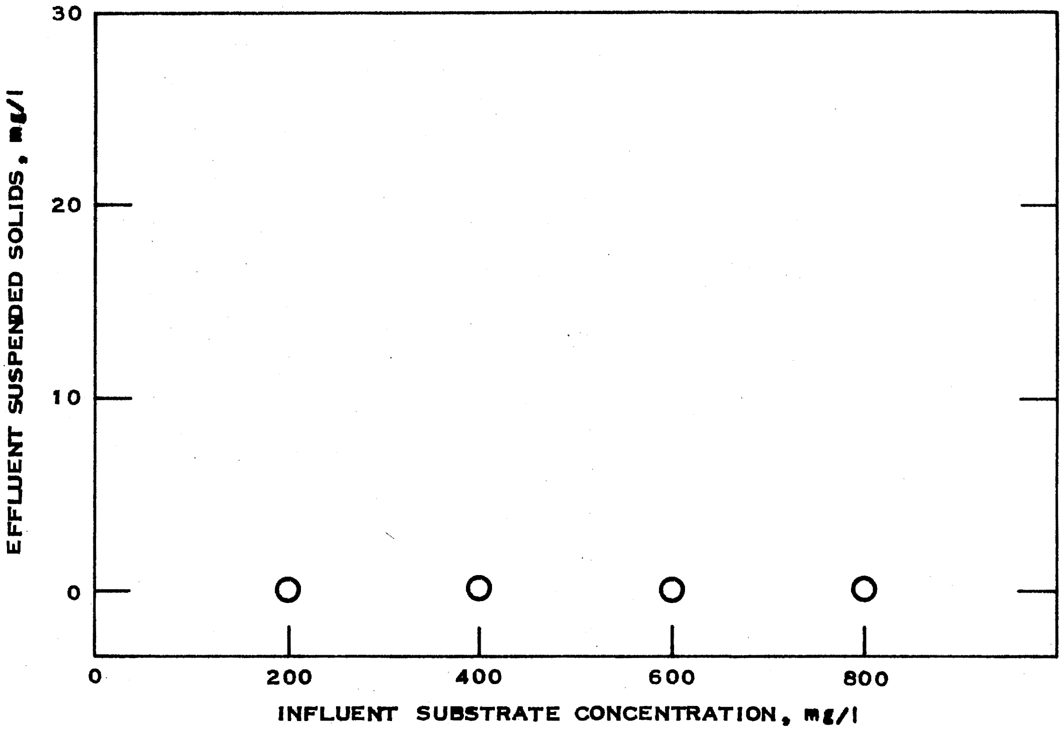

30
20
10
0
EFFLUENT SUSPENDED SOLIDS, mg/l
0
200
400
600
800
INFLUENT SUBSTRATE CONCENTRATION, mg/l

Figure 4. Effluent COD Versus Influent Substrate Concentration

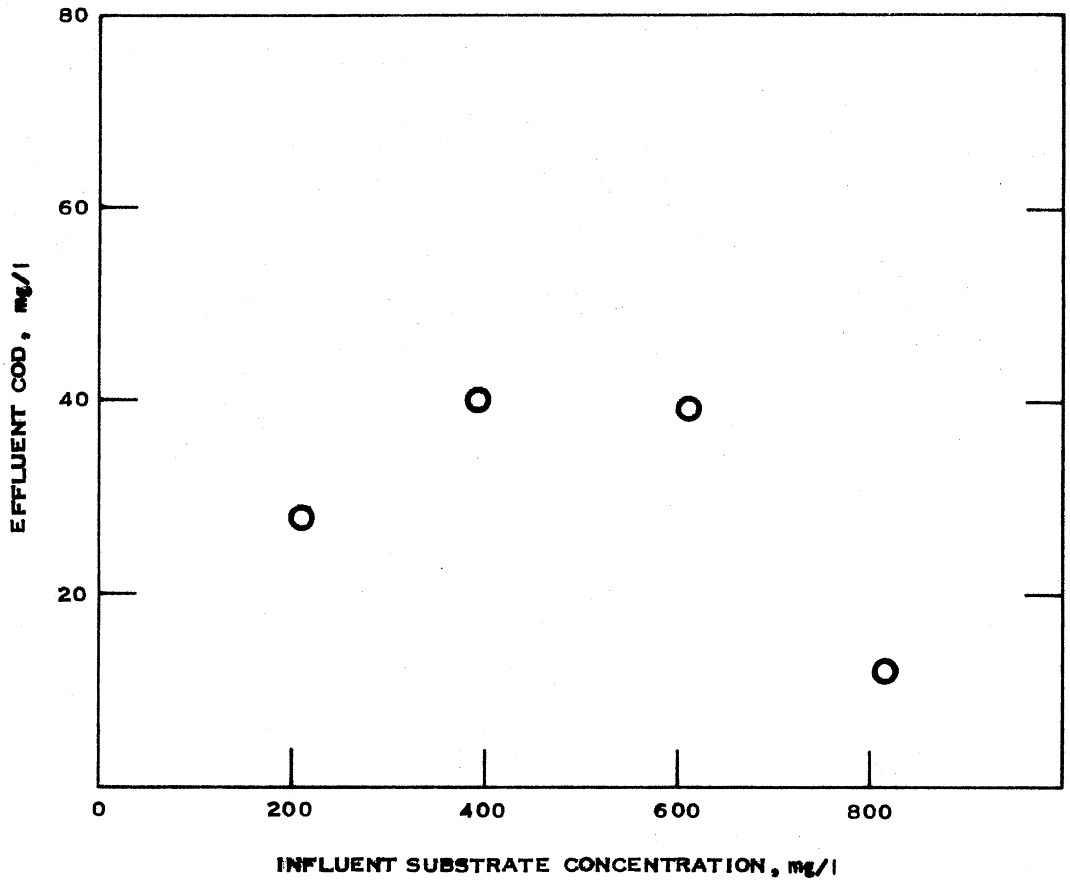

80
60
40
20
0
200
400
600
800
EFFLUENT COD, mg/l
INFLUENT SUBSTRATE CONCENTRATION, mg/l

Figure 5 presents the percent COD removed versus the substrate concentration. The percent removed increased linearly with an increase in the substrate concentration. The mean value for percent COD removed was about 92% for all influent concentrations.

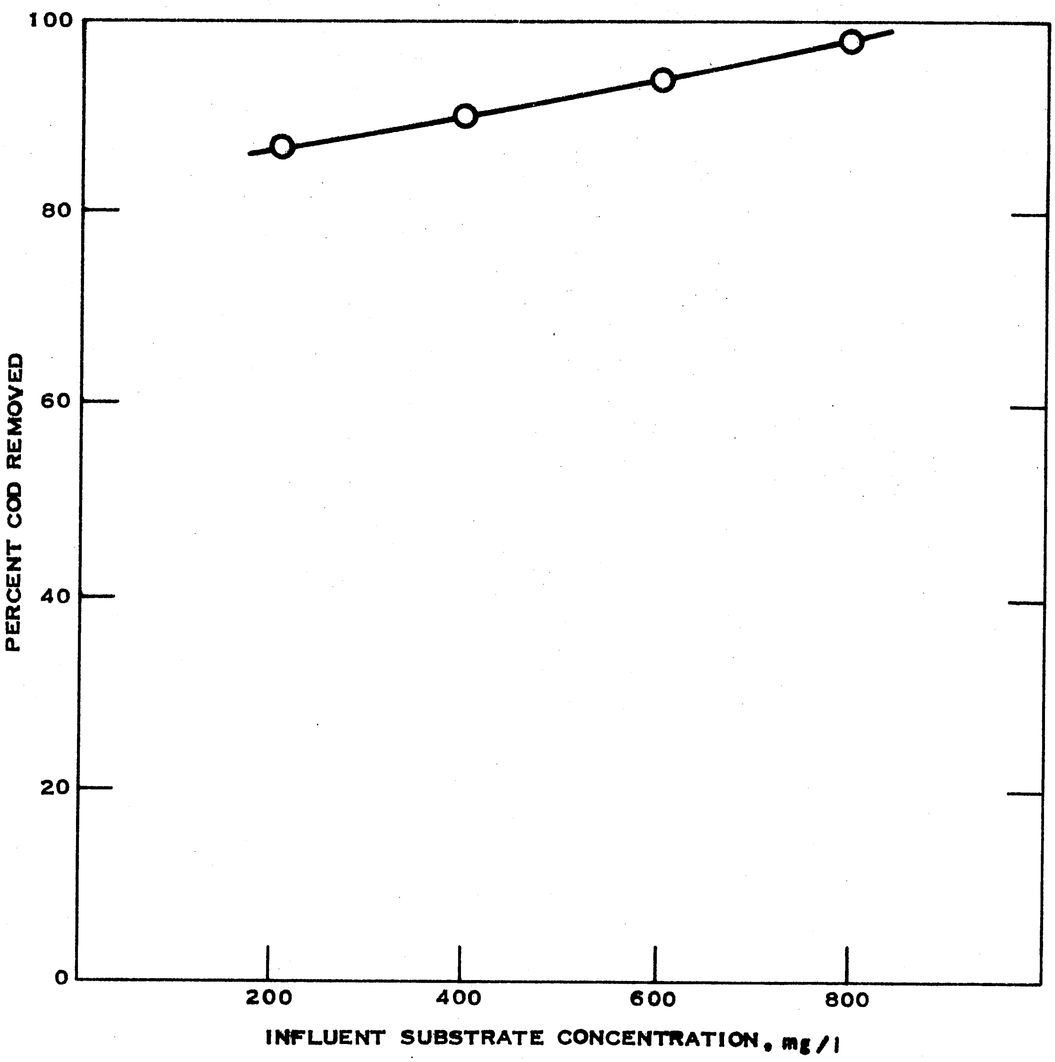
Figure 6 shows the observed yield for the substrate concentrations studied. As can be seen, the observed yield increased with an increase in substrate concentration to the 600 mg/l substrate concentration. The value found for the 800 mg/l concentration was observed to be approximately the same as that found for the 600 mg/l concentration.

Figure 7 relates substrate concentration to specific utilization. Specific utilization is shown to decrease with an increase in substrate concentration.

B. Settling Data

Figures 8 through 11 present zone settling velocities as a function of sludge concentration for each of the substrate concentrations. The results demonstrate that the zone settling velocity of a sludge decreases with an increase in sludge concentration. Figure 12 provides a capsuled view of Figures 8 through 11. It illustrates more clearly the decrease in zone settling velocity for a given sludge concentration with increasing substrate concentration. But more significantly, it shows very clearly that zone settling velocity definitely varies with influent concentration. As can be seen, for a given sludge concentration, the influent substrate concentration of 600 mg/l had higher zone settling velocities at all sludge concentrations above 800 mg/l. The influent substrate concentration of 400 mg/l had the lowest zone settling velocities at all sludge concentrations. Figure 13 shows the

Figure 5. Percent COD Removed Versus Influent Substrate Concentration



100
80
60
40
20
0
PERCENT COD REMOVED
200
400
600
800
INFLUENT SUBSTRATE CONCENTRATION, mg/l

Figure 6. Observed Yield Coefficient Versus Influent Substrate Concentration

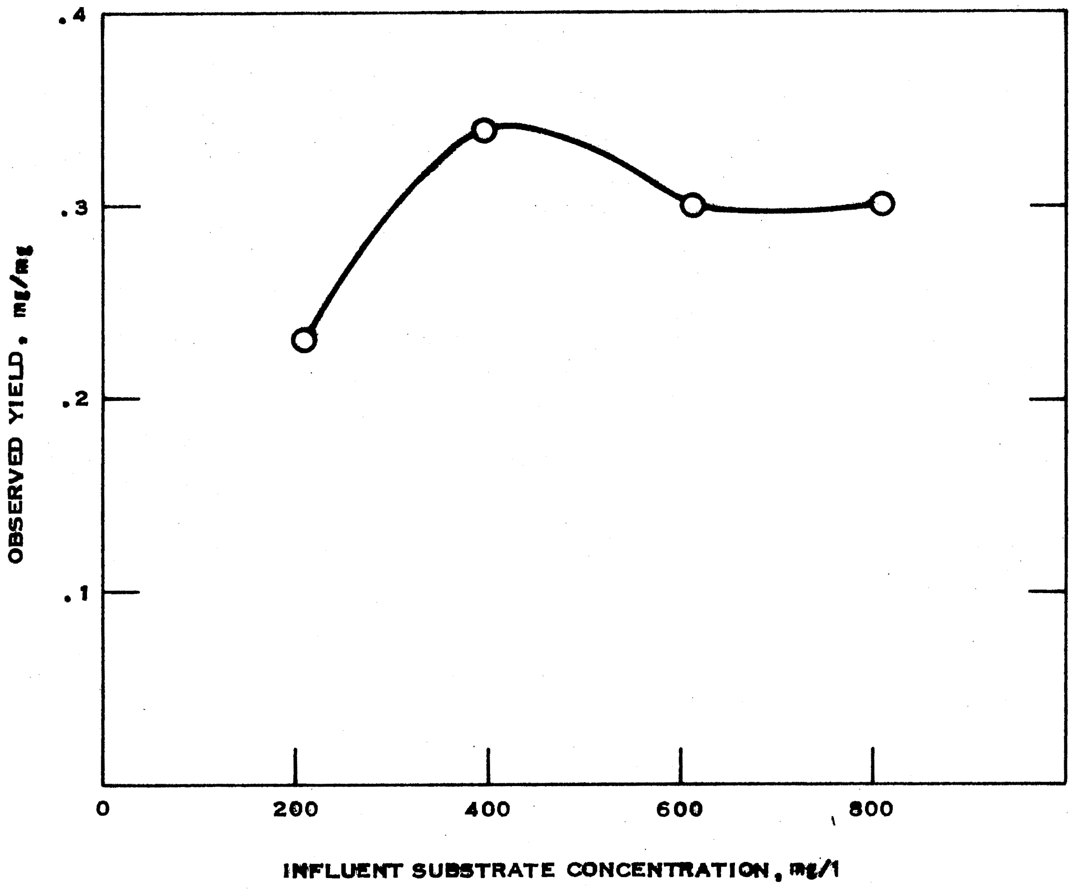

.4
.3
.2
.1
OBSERVED YIELD, mg/mg
0
200
400
600
800
INFLUENT SUBSTRATE CONCENTRATION, mg/1

Figure 7. Specific Utilization Versus Influent Substrate Concentration

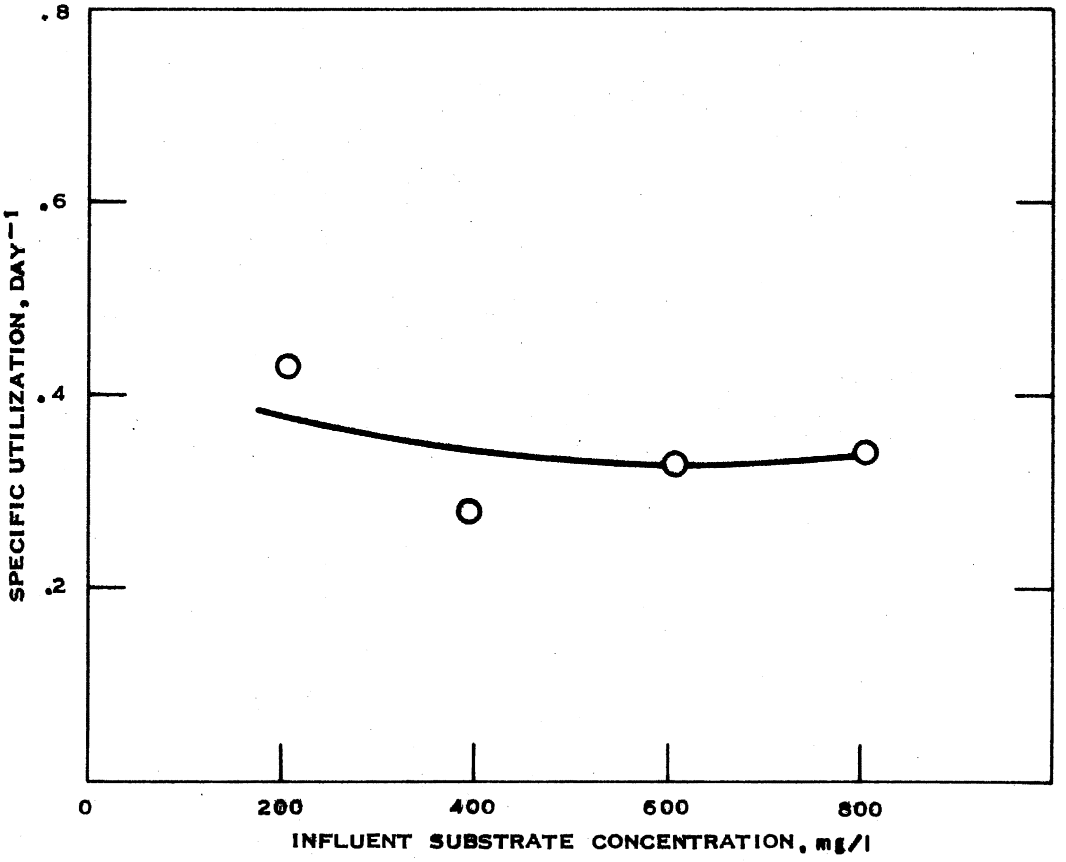

.8
.6
.4
.2
SPECIFIC UTILIZATION, DAY⁻¹
0
200
400
600
800
INFLUENT SUBSTRATE CONCENTRATION, mg/l

Figure 8. Zone Settling Velocity Versus Sludge Concentration at Influent Substrate Concentration of 200 mg/1

AT INFLUENT SUBSTRATE CONCENTRATION OF 200 mg/l

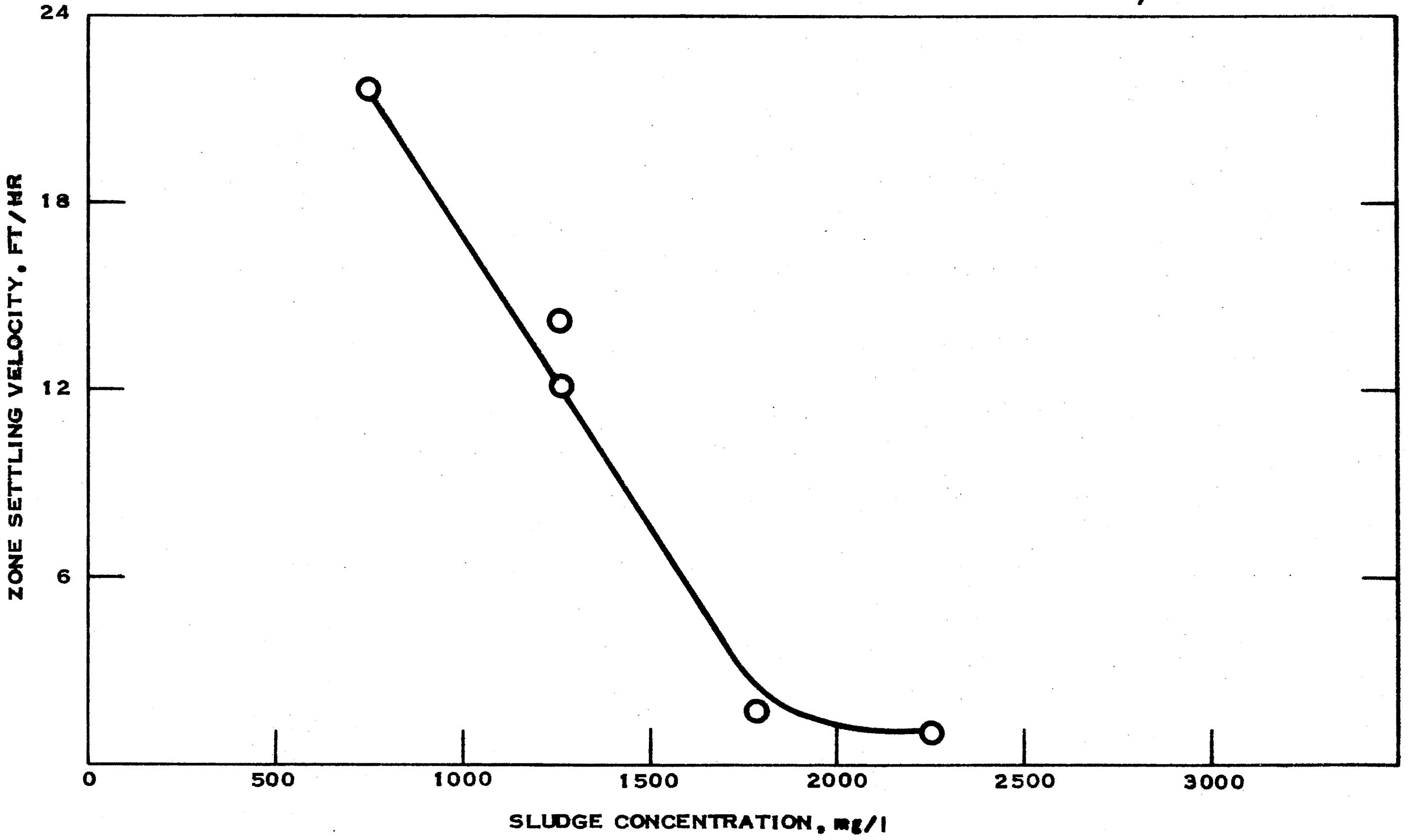
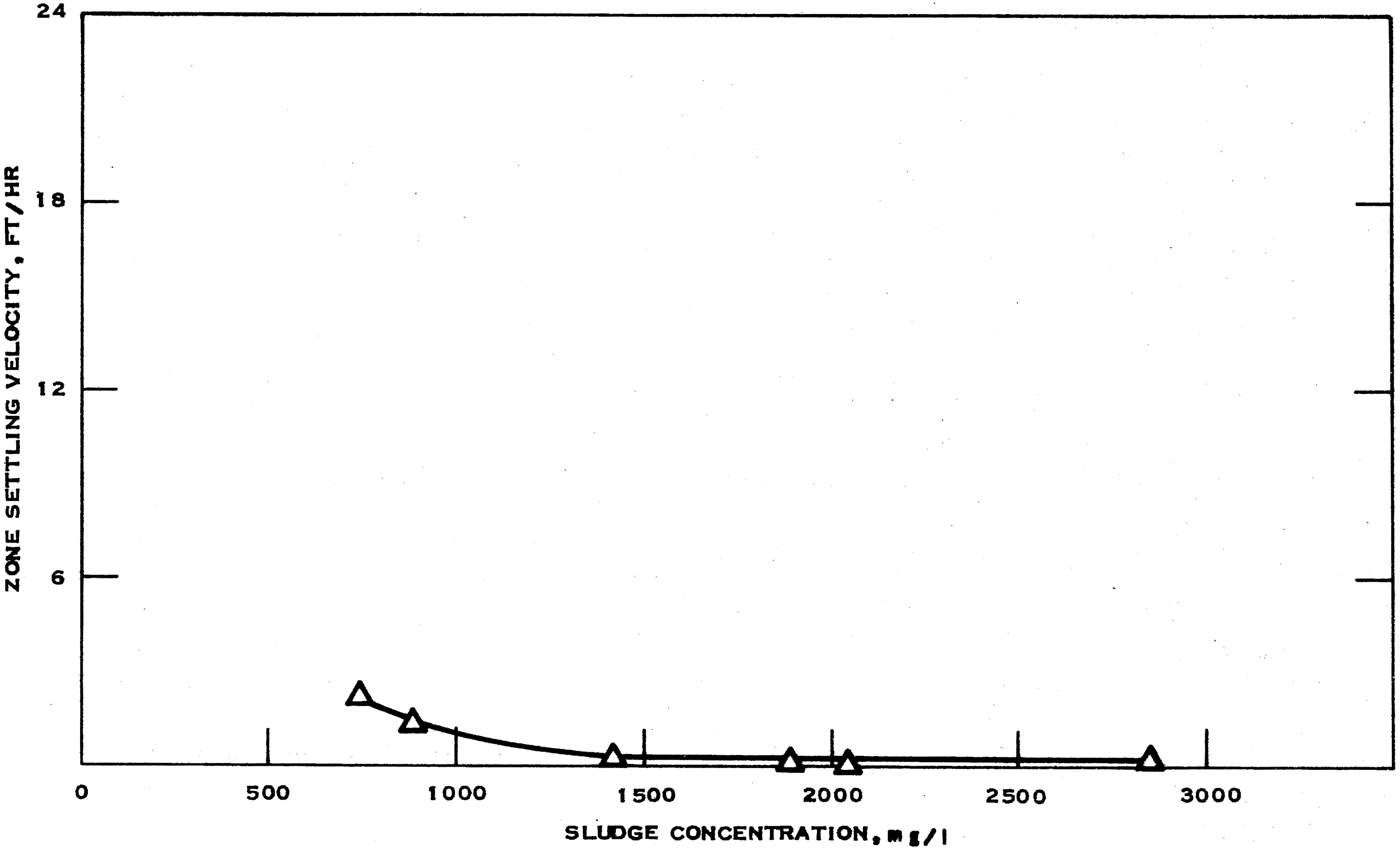


Figure 9. Zone Settling Velocity Versus Sludge Concentration at Influent Substrate Concentration of 400 mg/l



AT INFLUENT SUBSTRATE CONCENTRATION OF 400 mg/l

Figure 10. Zone Settling Velocity Versus Sludge Concentration at Influent Substrate Concentration of 600 mg/l

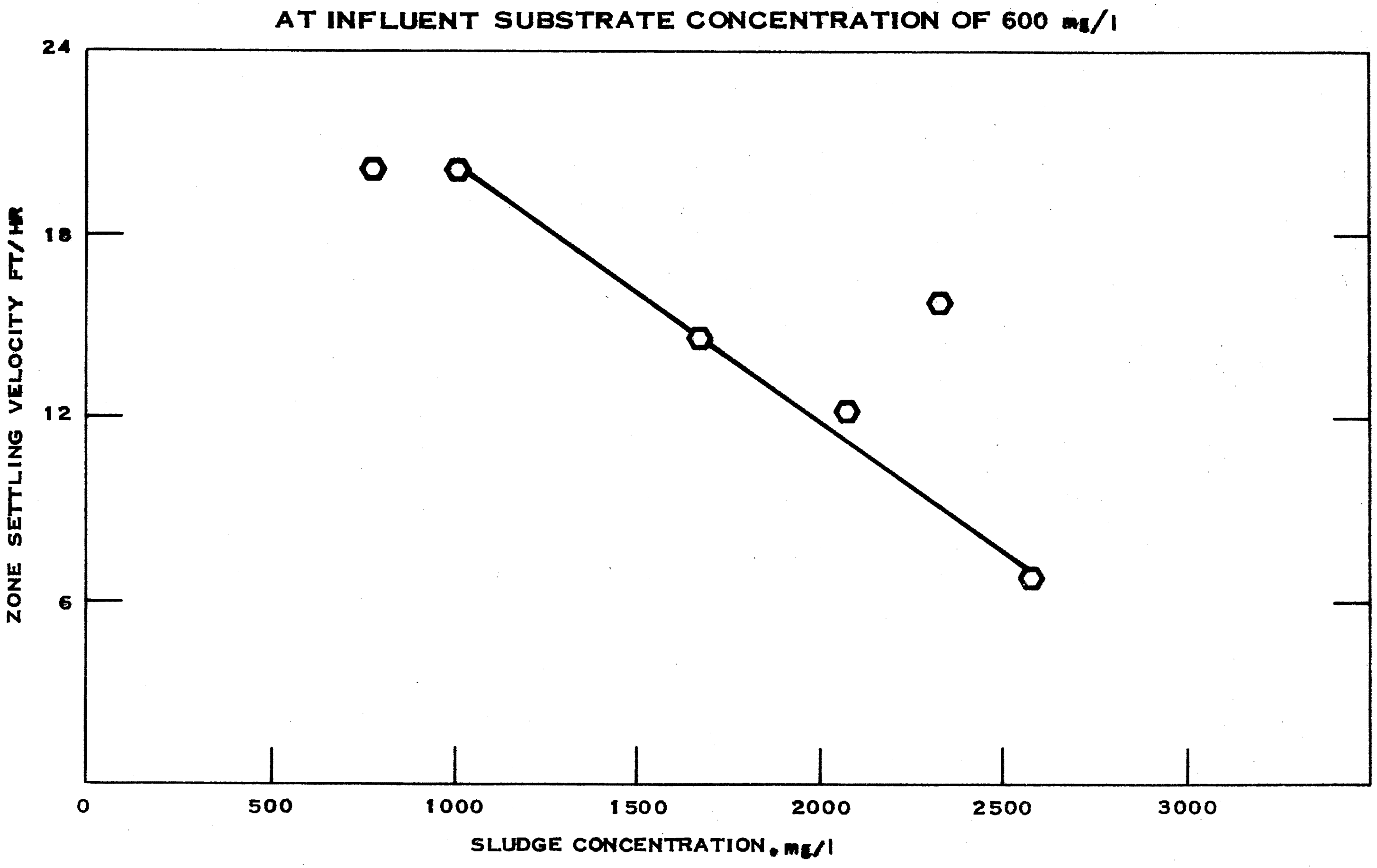

AT INFLUENT SUBSTRATE CONCENTRATION OF 600 mg/l
24
18
12
6
ZONE SETTLING VELOCITY FT/HR
0
500
1000
1500
2000
2500
3000
SLUDGE CONCENTRATION, mg/l

Figure 11. Zone Settling Velocity Versus Sludge Concentration at Influent Substrate Concentration of 800 mg/l

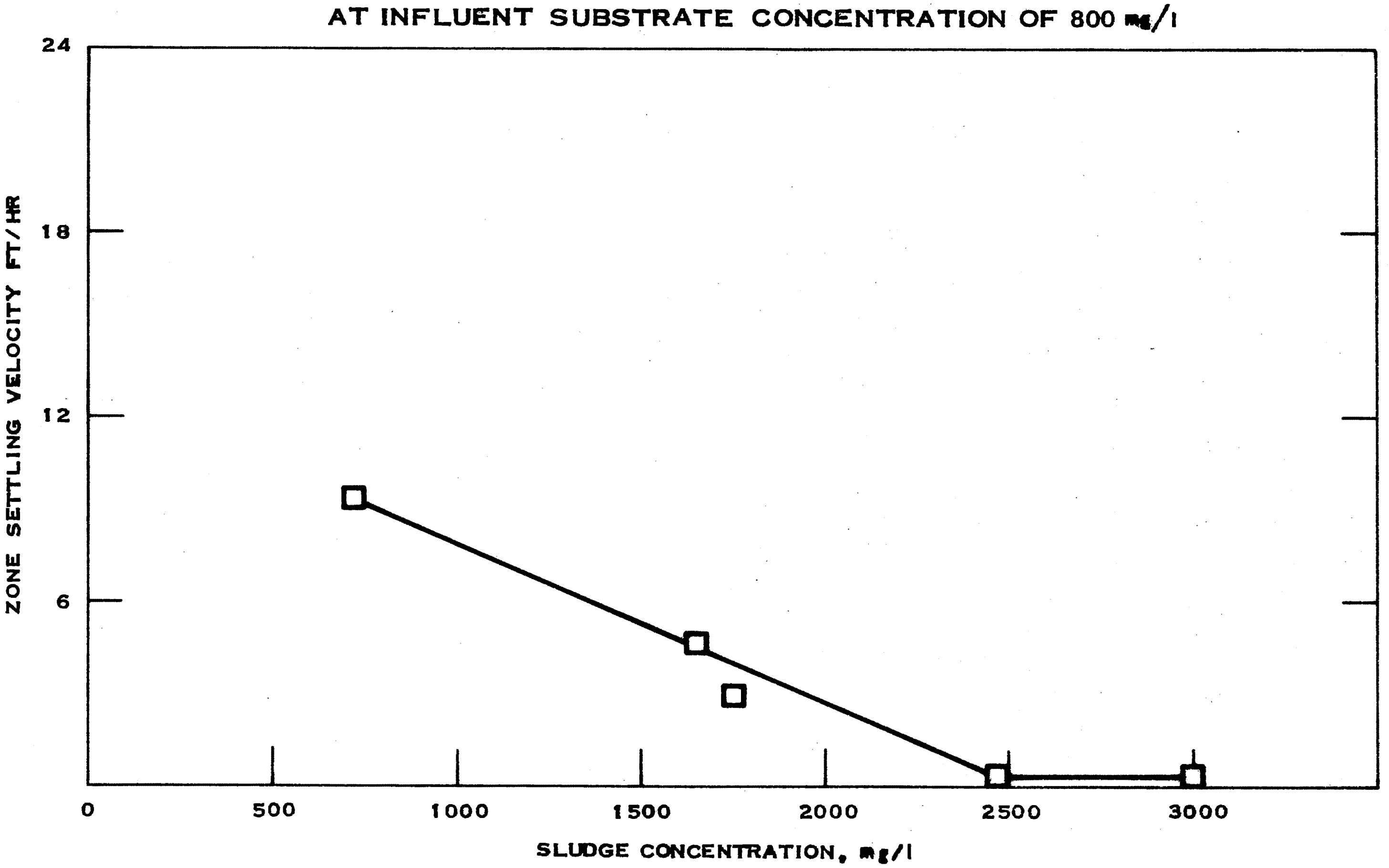

AT INFLUENT SUBSTRATE CONCENTRATION OF 800 mg/l
ZONE SETTLING VELOCITY FT/HR
24
18
12
6
0
500
1000
1500
2000
2500
3000
SLUDGE CONCENTRATION, mg/l

Figure 12. Zone Settling Velocity Versus Sludge Concentration at All Influent Substrate Concentrations

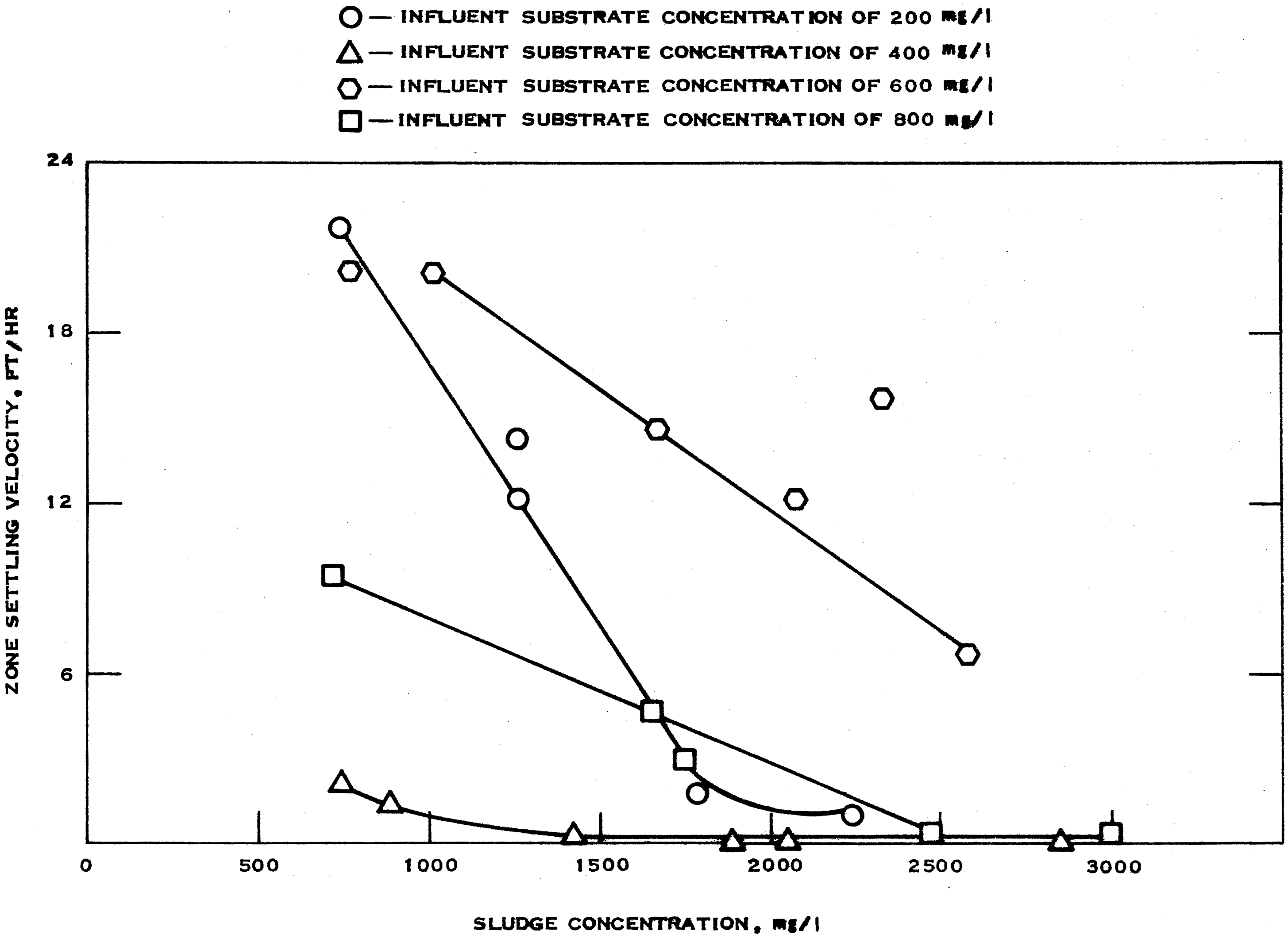
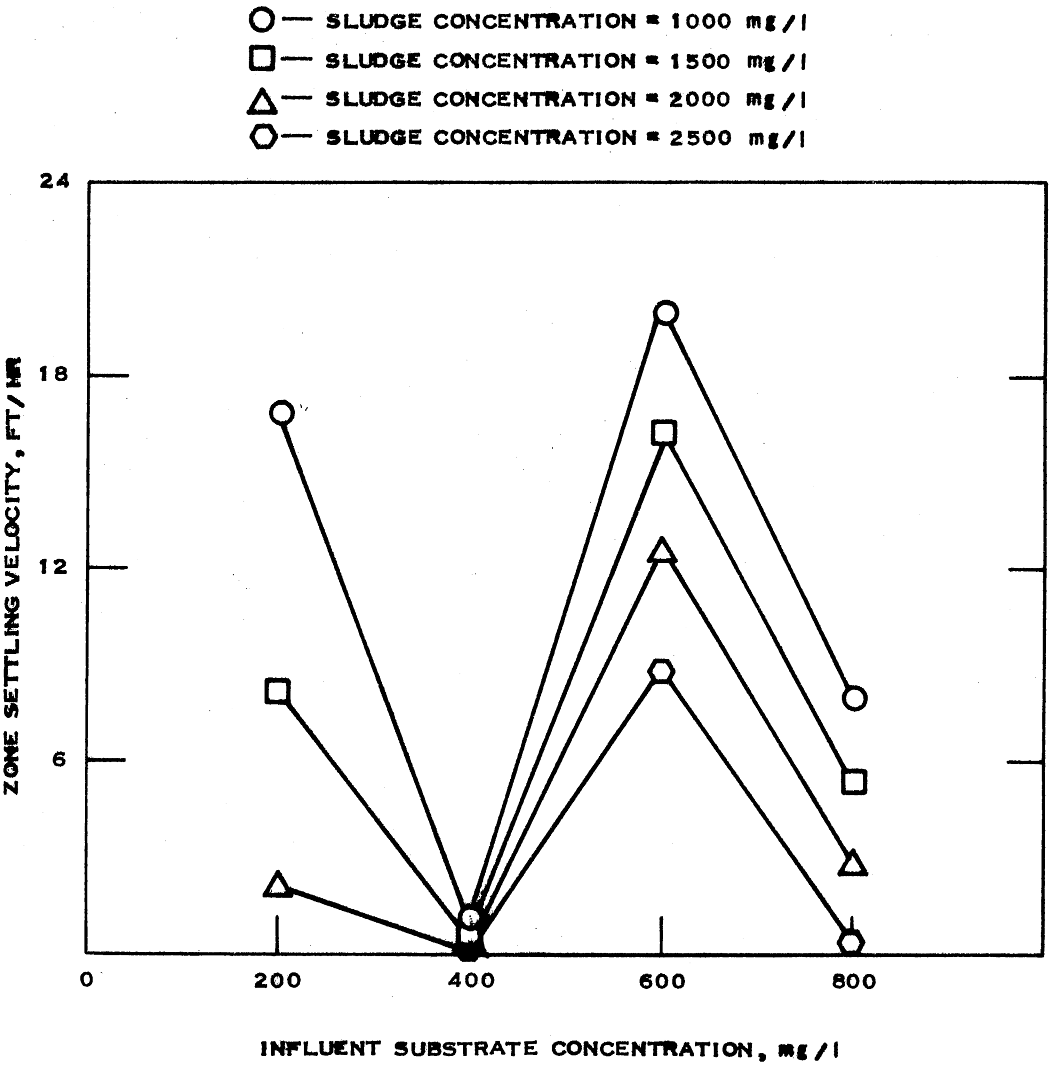

○ — INFLUENT SUBSTRATE CONCENTRATION OF 200 mg/l
△ — INFLUENT SUBSTRATE CONCENTRATION OF 400 mg/l
⬡ — INFLUENT SUBSTRATE CONCENTRATION OF 600 mg/l
□ — INFLUENT SUBSTRATE CONCENTRATION OF 800 mg/l
24
18
12
6
ZONE SETTLING VELOCITY, FT/HR
0
500
1000
1500
2000
2500
3000
SLUDGE CONCENTRATION, mg/l

Figure 13. Zone Settling Velocity Versus Influent Substrate Concentration at Various Sludge Concentrations


○— SLUDGE CONCENTRATION = 1000 mg/l
□— SLUDGE CONCENTRATION = 1500 mg/l
△— SLUDGE CONCENTRATION = 2000 mg/l
⬡— SLUDGE CONCENTRATION = 2500 mg/l
24
18
12
6
0
200
400
600
800
ZONE SETTLING VELOCITY, FT/HR
INFLUENT SUBSTRATE CONCENTRATION, mg/l

zone settling velocity as a function of substrate concentration and sludge concentration. It clearly shows again that zone settling velocity varies with influent substrate concentration. This figure also shows that zone settling velocity does not steadily increase or decrease with increases in influent substrate concentration. Also, it shows that, at a given influent substrate concentration, zone settling velocity decreases with increases in sludge concentration.

Figures 14 through 17 express the SVI as a function of sludge concentration. At a substrate concentration of 200 mg/l, the SVI varied slightly between 200 and 300 for sludge concentrations between 500 and 2500 mg/l. For a substrate concentration of 400 mg/l, the SVI decreased from 650 to 350 with increasing sludge concentration from 700 to 2800 mg/l. For an influent substrate concentration of 600 mg/l, the SVI remained approximately constant at about 100 with increasing sludge concentration. For an influent substrate concentration of 800 mg/l, the SVI varied between 200 and 350 for sludge concentrations between 700 and 3000 mg/l. Figure 18 presents the SVI data in a more clear manner. It shows that the SVI definitely varies with the influent substrate concentration. It also shows that, at all sludge concentrations, the influent substrate concentration of 400 mg/l had the highest SVI. The influent substrate concentration of 600 mg/l had the lowest SVI at all sludge concentrations. The influent substrate concentrations of 200 mg/l and 800 mg/l had approximately the same SVI at all sludge concentrations. Figure 19 shows the SVI as a function of sludge concentration and influent substrate concentration. It also shows that the SVI varies with the influent substrate concentration. It also shows that

Figure 14. Sludge Volume Index Versus Sludge Concentration at Influent Substrate Concentration of 200 mg/1

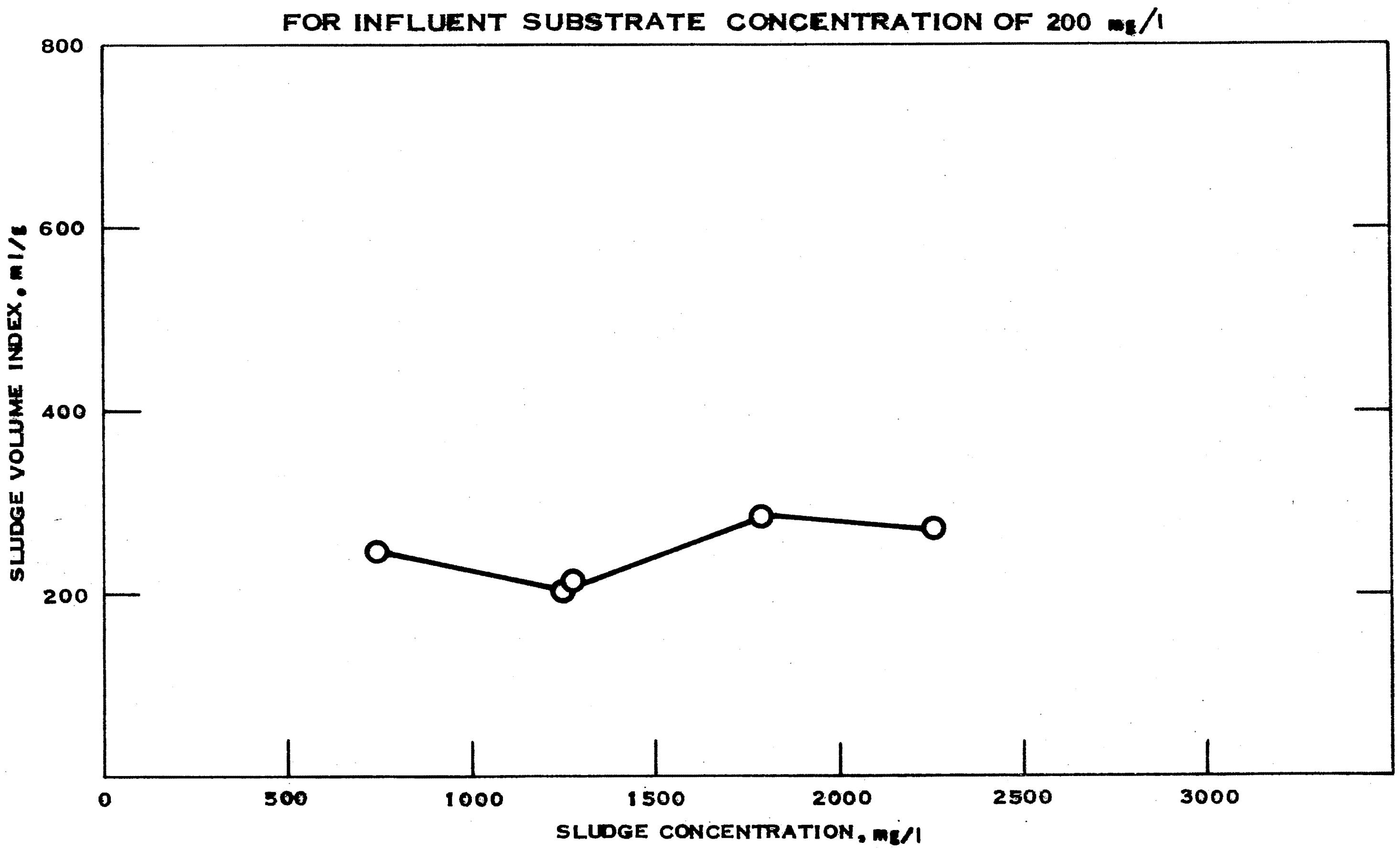

FOR INFLUENT SUBSTRATE CONCENTRATION OF 200 mg/l
SLUDGE VOLUME INDEX, ml/g
800
600
400
200
0
500
1000
1500
2000
2500
3000
SLUDGE CONCENTRATION, mg/l

Figure 15. Sludge Volume Index Versus Sludge Concentration at Influent Substrate Concentration of 400 mg/l

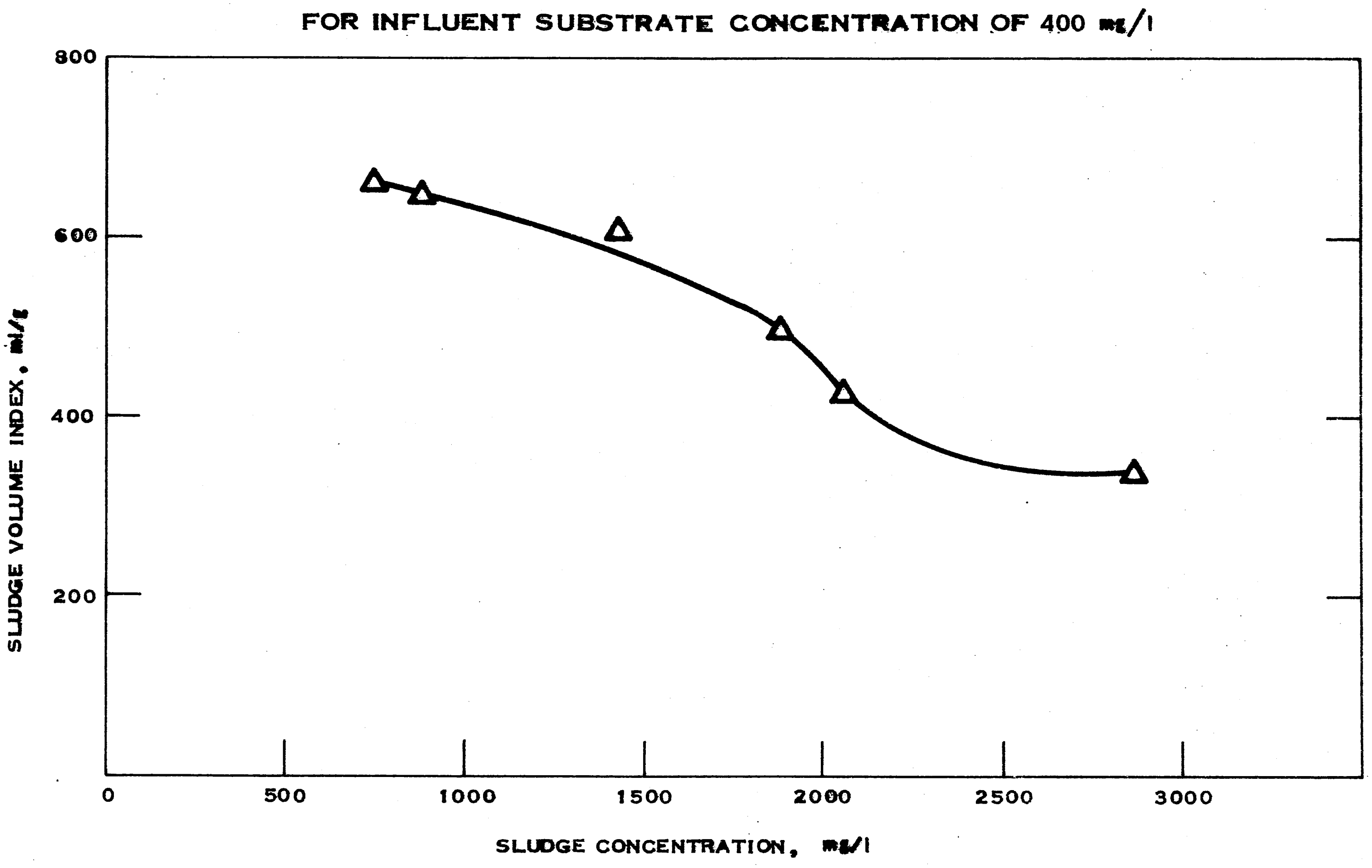

FOR INFLUENT SUBSTRATE CONCENTRATION OF 400 mg/l
800
600
400
200
SLUDGE VOLUME INDEX, ml/g
0
500
1000
1500
2000
2500
3000
SLUDGE CONCENTRATION, mg/l

Figure 16. Sludge Volume Index Versus Sludge Concentration at Influent Substrate Concentration of 600 mg/l

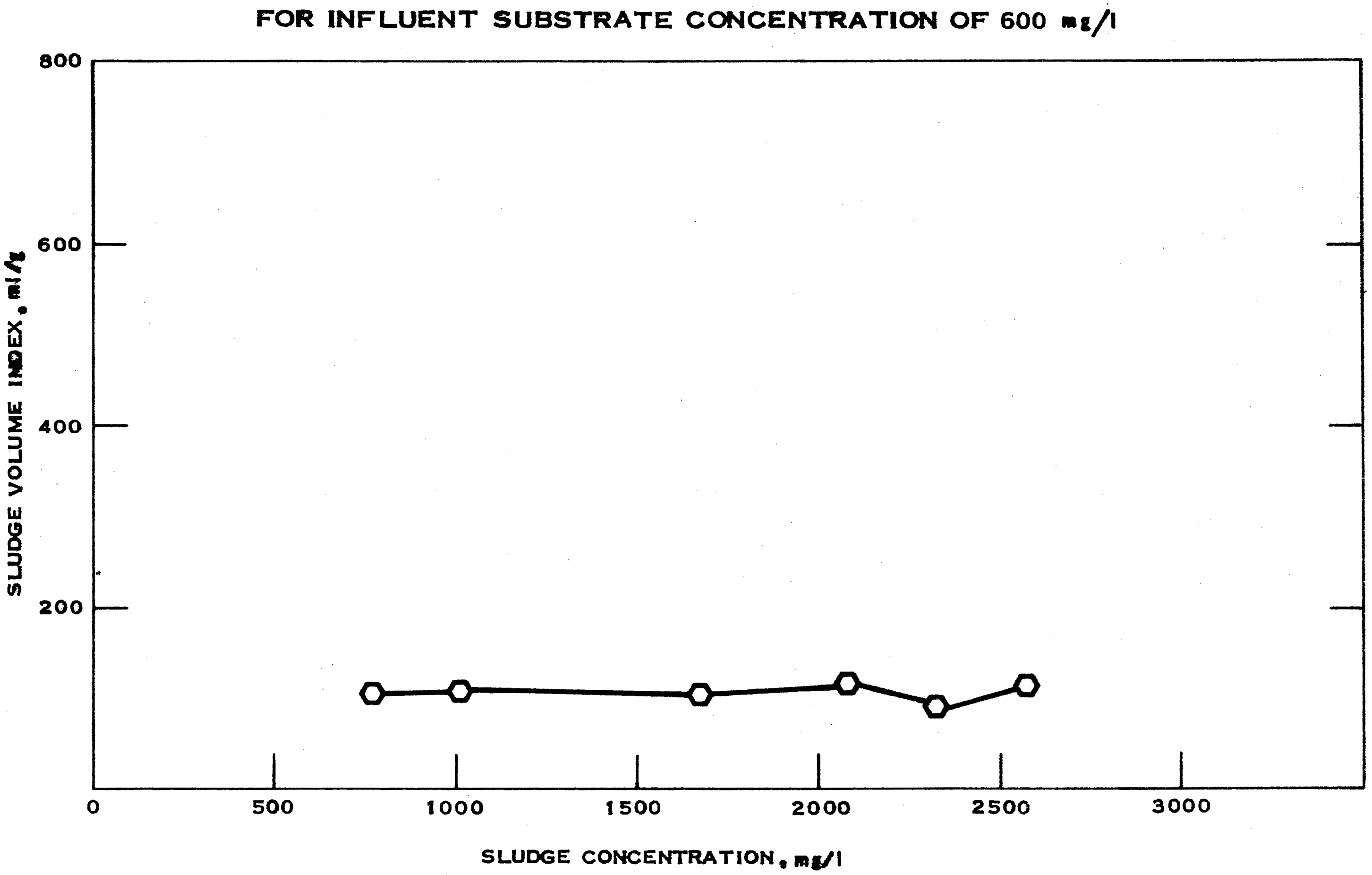

FOR INFLUENT SUBSTRATE CONCENTRATION OF 600 mg/l
SLUDGE VOLUME INDEX, ml/g
800
600
400
200
0
500
1000
1500
2000
2500
3000
SLUDGE CONCENTRATION, mg/l

Figure 17. Sludge Volume Index Versus Sludge Concentration at Influent Substrate Concentration of 800 mg/l

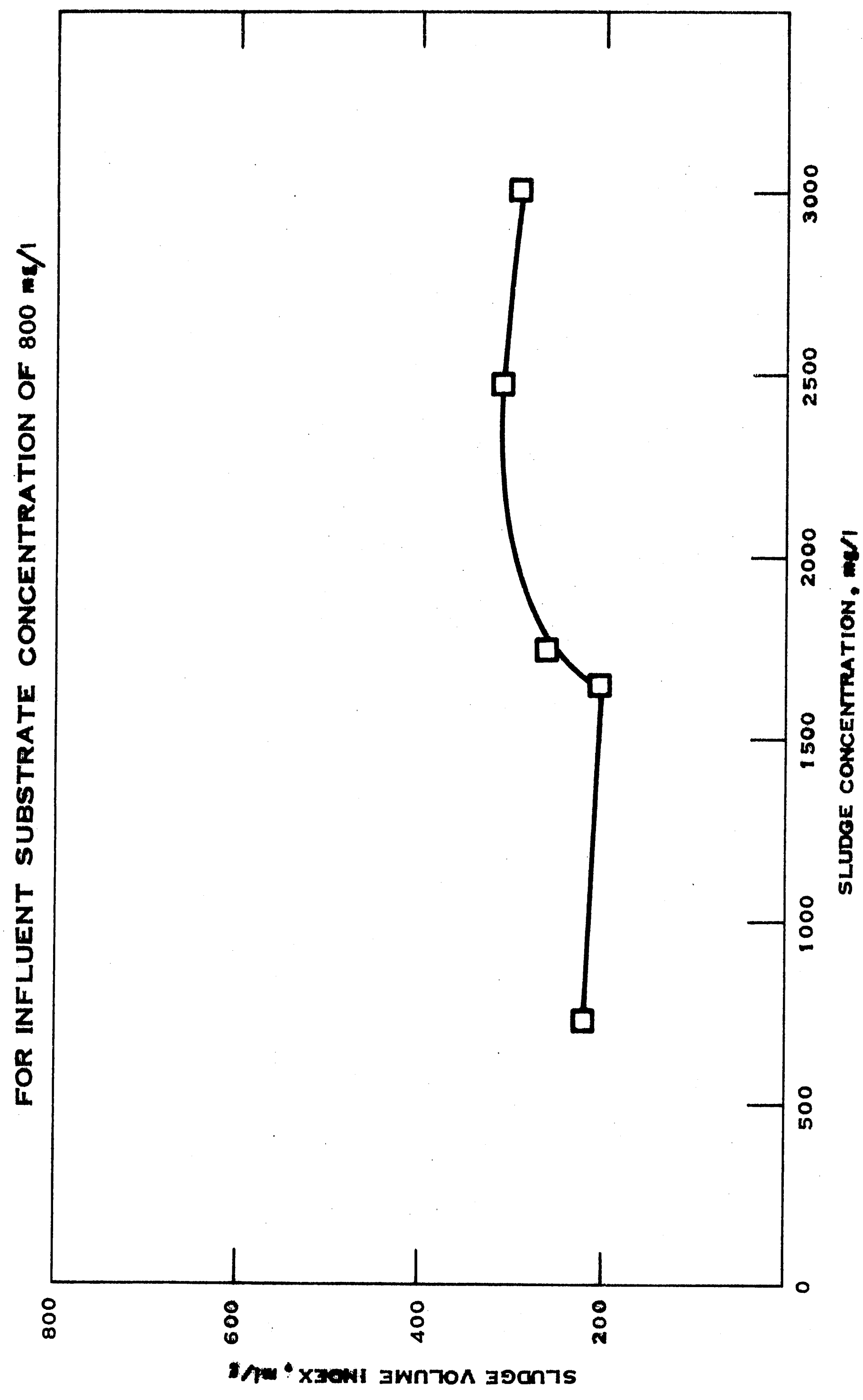

FOR INFLUENT SUBSTRATE CONCENTRATION OF 800 mg/l
SLUDGE VOLUME INDEX, ml/g
800
600
400
200
SLUDGE CONCENTRATION, mg/l
0
500
1000
1500
2000
2500
3000

Figure 18. Sludge Volume Index Versus Sludge Concentration at all Influent Substrate Concentrations

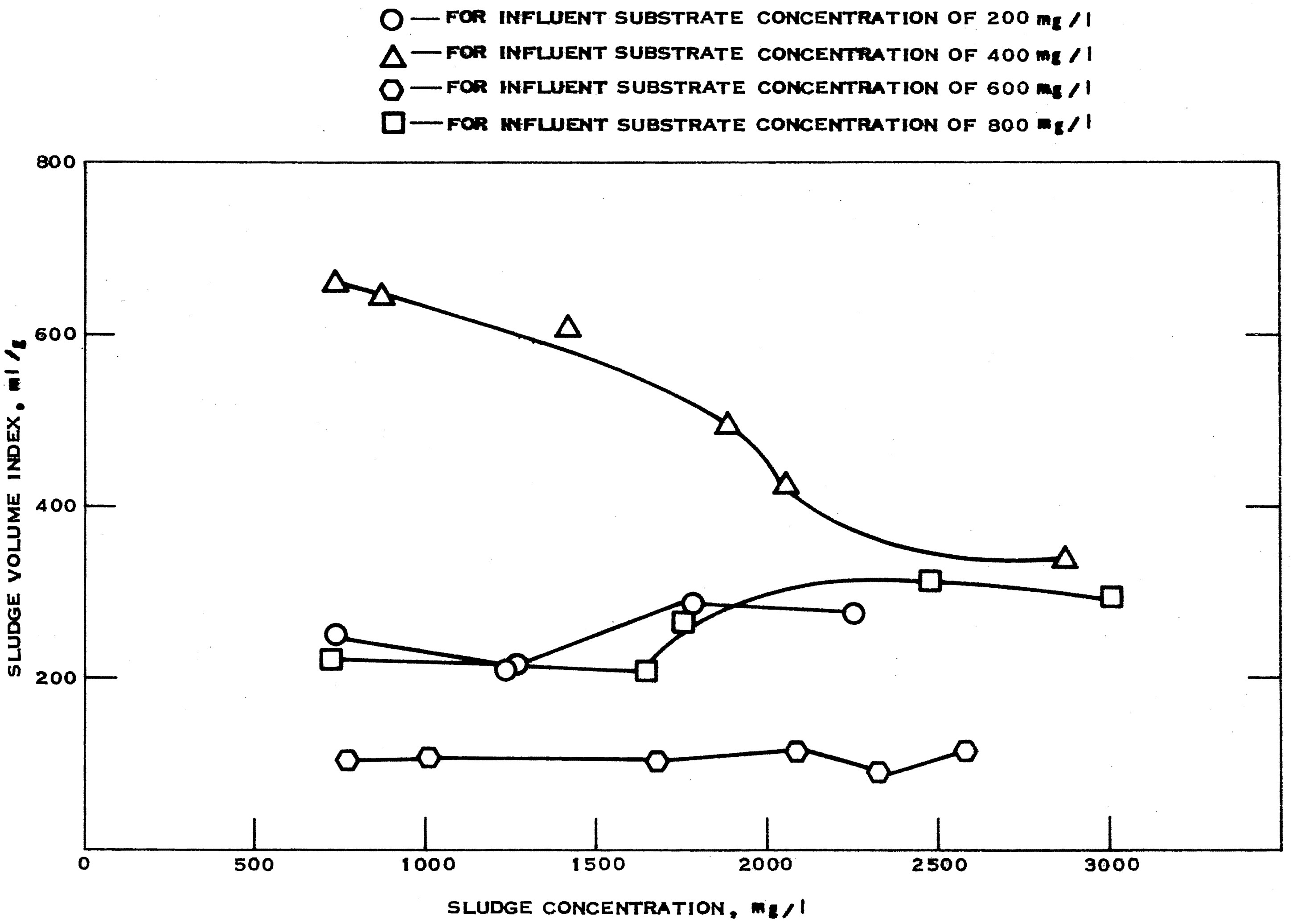
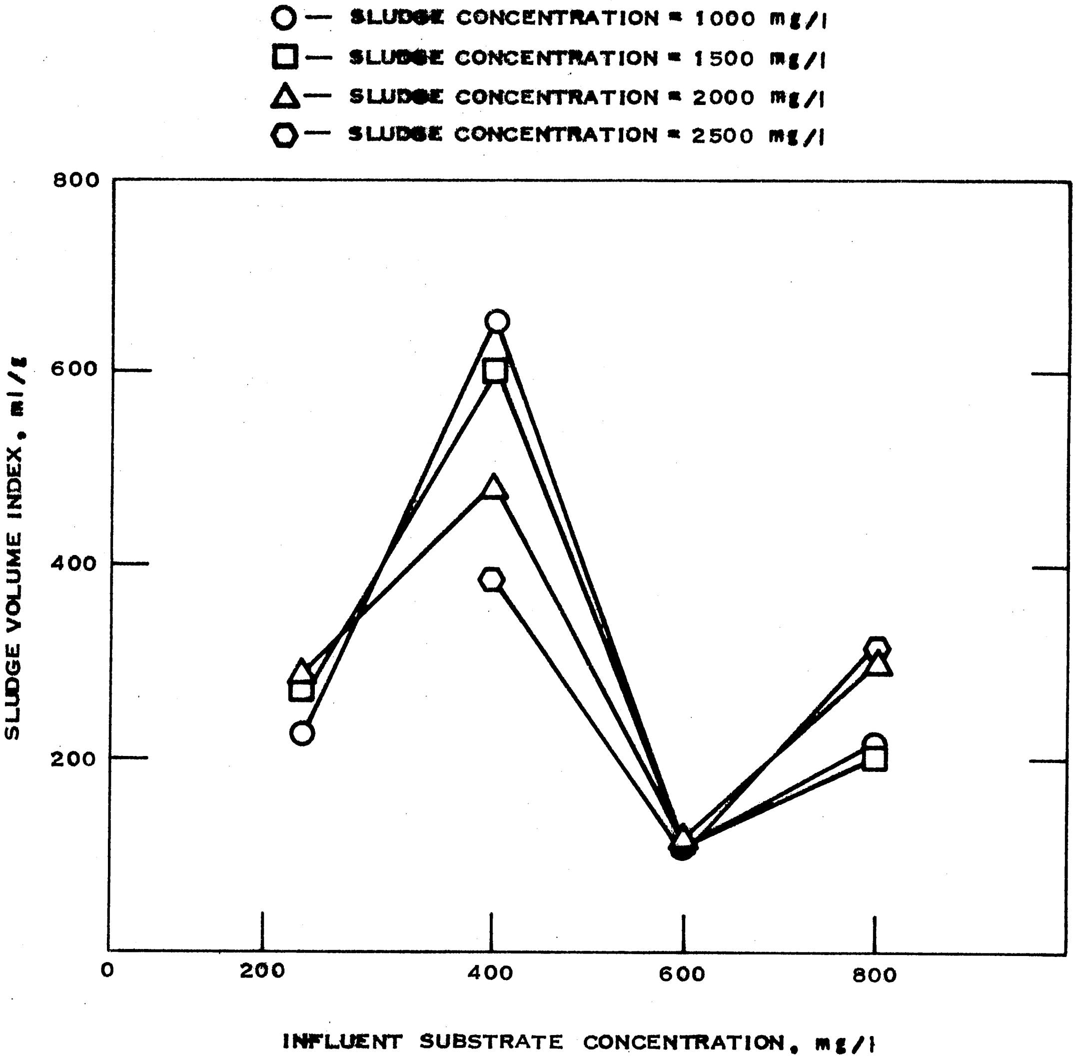

○ — FOR INFLUENT SUBSTRATE CONCENTRATION OF 200 mg / l
△ — FOR INFLUENT SUBSTRATE CONCENTRATION OF 400 mg / l
⬡ — FOR INFLUENT SUBSTRATE CONCENTRATION OF 600 mg / l
□ — FOR INFLUENT SUBSTRATE CONCENTRATION OF 800 mg / l
800
600
400
200
SLUDGE VOLUME INDEX, ml / g
0
500
1000
1500
2000
2500
3000
SLUDGE CONCENTRATION, mg / l

Figure 19. Sludge Volume Index Versus Influent Substrate Concentration at Various Sludge Concentrations


○ — SLUDGE CONCENTRATION = 1000 mg/l
□ — SLUDGE CONCENTRATION = 1500 mg/l
△ — SLUDGE CONCENTRATION = 2000 mg/l
⬡ — SLUDGE CONCENTRATION = 2500 mg/l
SLUDGE VOLUME INDEX, ml/g
800
600
400
200
0
200
400
600
800
INFLUENT SUBSTRATE CONCENTRATION, mg/l

the SVI does not steadily increase or decrease with increasing influent substrate concentration.

CHAPTER V

DISCUSSION

The scope of this study was to examine the effect of initial substrate concentration on the settling characteristics of activated sludge. It has been said that all too often treatment plant operators do not understand anything but the mechanics of operating the plant. They don't know how to improve the efficiency of the plant by controlling the different variables affecting the performance of the process.

As regulations and guidelines become more stringent, as treatment plant processes become more sophisticated, and as the waste entering the treatment plant becomes more variable in source and greater in volume, the more qualified the treatment plant operator is going to have to become to be able to produce the effluent that will be required. This is especially going to hold true for operators in metropolitan areas. They are going to have to know in-depth how to control the variables affecting the plant. One of these variables could possibly be the influent substrate concentration. At this time, nothing is done to control it. It would not be feasible at this time to do so. Since the performance of a treatment plant is related to the settleability of the activated sludge through its clarifying and thickening functions and the settleability of the activated sludge has been shown to be related to the initial substrate concentration, then the performance of the treatment plant is also related to the initial substrate concentration.

Although the purpose of this study was to observe the effect of initial substrate concentration on the compaction or thickening properties of activated sludge, an interesting result has been observed at each of the influent substrate concentrations used. For each influent substrate concentration used, very good clarification occurred (Figure 3). When tests were taken at steady state conditions, there were no measurable suspended solids in the effluent. Although some filamentous organisms were observed during the experimentation, they apparently did not effect the settling behavior so much as to cause the suspended solids to overflow into the effluent.

Also, a high efficiency was observed, in terms of substrate removed. The efficiency increased linearly from about 87% at an influent substrate concentration of 200 mg/l to 98% at an influent substrate concentration of 800 mg/l (Figure 4). These high efficiencies, however, correlate with the COD in the effluent (Figure 5).

As was pointed out earlier, zone settling velocity decreased with increasing sludge concentration. This correlates with the results achieved by others (1, 2, 15, 19, 21, 24, 25).

The purpose of this study was to observe whether the influent substrate concentration had any effect upon the settling characteristics of activated sludge. Figures 12 and 13 show very clearly that the influent substrate concentration definitely has an effect upon the settling characteristics of activated sludge. There appears to be no discernible pattern as the influent substrate concentration is varied.

When the influent substrate concentration is varied (i.e., continually increased), the zone settling velocity does not vary in any steady or constant manner. To insure the validity of the results observed, the influent substrate concentration of 400 mg/l was repeated several months after the first influent substrate concentration was used. The results varied little. Again, at the influent substrate concentration of 400 mg/l, the zone settling velocities observed were very low, varying little from the previous results at that concentration. And, the SVI was the highest, varying little, again, from the previous results at that concentration.

Another check of the results was made using the results observed by Bartle (23). By taking the zone settling velocities observed by Bartle at various sludge concentrations and at an influent substrate concentration of 500 mg/l and a θ_c of about 10 days, the zone settling velocities were interpolated into Figure 13. The results correlated closely for all sludge concentrations. This further shows that zone settling velocity varies with influent substrate concentration.

This brings out an interesting point. There are researchers in the field (i.e., Vesiland, Bisogni and Lawrence) who have derived equations for relating zone settling velocity to initial solids concentration. Bisogni and Lawrence have incorporated θ_c into their equation. Their equations do not take into account, however, that zone settling velocities vary with initial substrate concentration. To be able to relate zone settling velocity to initial solids concentration, the zone settling velocity is going to have to be shown as a function of the initial substrate concentration, and showing its variance with the initial substrate concentration.

In observing the results from the SVI tests (Figures 14 through 19), no discernible patterns were again noted. They, however, showed that the influent substrate concentration of 400 mg/l had the highest SVI, and that the influent substrate concentration of 600 mg/l had the lowest SVI. The SVI values for the influent substrate concentrations of 200 mg/l and 800 mg/l were approximately the same. Another significant point observed was that the SVI for the influent substrate concentrations of 200 mg/l, 600 mg/l, and 800 mg/l varied little between sludge concentrations of about 750 mg/l to about 2600 mg/l. The SVI for the influent substrate concentration of 400 mg/l, however, decreased between sludge concentrations of about 650 mg/l to 2800 mg/l.

There are no obvious answers to why the variances in the zone settling velocities and the sludge volume indices occurred. One possible solution lies in the content of the activated sludge. At some influent substrate concentrations, certain species of microorganisms might have dominated; whereas, they were unable to dominate, for some reason, at other concentrations. Perhaps some of the species dominating in the activated sludge which had lower zone settling velocities were filamentous organisms. They might not have been able to compete for the food at other concentrations. Thus, the activated sludge had a higher zone settling velocity.

CHAPTER VI

CONCLUSIONS

Based upon the results of this study examining the effect of initial substrate concentration on the settling characteristics of activated sludge, the following conclusions can be made:

1. Zone settling velocity varies with initial substrate concentration.

2. SVI varies with initial substrate concentration.

3. At a given influent substrate concentration, the zone settling velocity decreases with increasing sludge concentration.

CHAPTER VIII

SUGGESTIONS FOR FUTURE STUDY

1. Study the effect of initial substrate concentration on the percent of filamentous organisms contained in continuous flow activated sludge unit.

2. Study the effect of initial substrate concentration on the performance of a biological tower.

3. Study the effect of subjecting the activated sludge to various periods of anaerobiosis on the settling characteristics of activated sludge.

4. Study the effect of initial substrate concentration on the settling characteristics of activated sludge when θ_c is maintained at a low value.

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