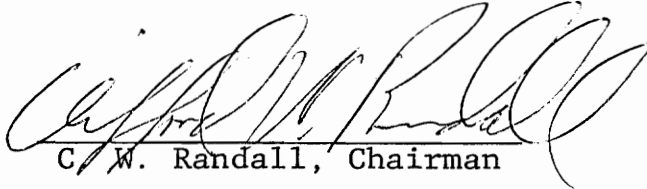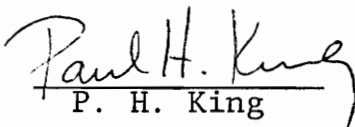COAGULATION STUDY OF A

BOUND WATER BULKED SLUDGE

by

J. Holland Scott

Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirement for the degree of
MASTER OF SCIENCE
in
Sanitary Engineering
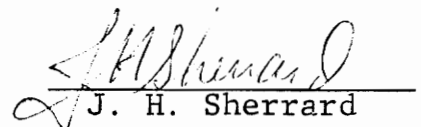
APPROVED:

C. W. Randall, Chairman

P. H. King

J. H. Sherrard

November, 1976

Blacksburg, Virginia

To my parents: Their support
    and sacrifice enabled me to
    complete my college education.
    To them I tender my heartfelt
    thanks.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude and appreciation to his committee chairman, Dr. Clifford W. Randall, and Dr. Joseph H. Sherrard and Dr. Paul H. King for their constant guidance and encouragement throughout the preparation of this text.

Also, the author wishes to acknowledge his fellow graduate students, most especially W. Michael Stallard, for their comradery and support.

A special thanks is extended to Mr. Glen Willard for his invaluable assistance in the laboratory.

To Ms. Ann Winesett he extends his deep appreciation for her consideration and thoughtfulness in typing the manuscript.

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I. INTRODUCTION

It is well known that the discharge of untreated wastewater into streams can produce deleterious effects and greatly reduce the value of the stream as a resource. Because of the potential effects, increasingly stringent laws and regulations have been passed in recent years to limit and control such discharge. In response, many different schemes have been proposed for the treatment of wastewaters, and research to find new and better methods of treatment continue, however, one of the most frequently employed methods of wastewater treatment, and generally the most successful, is still the activated sludge process.

In the activated sludge process a wastewater is introduced into an aerated tank filled with a high concentration of aerobic microorganisms. These microorganisms metabolize the organic material in the wastewater according to the following, oversimplified equation:

$$\text{Organic material} + O_2 \xrightarrow[\text{nutrients}]{\text{microorganisms}} \text{microbial mass} + CO_2 + H_2O$$
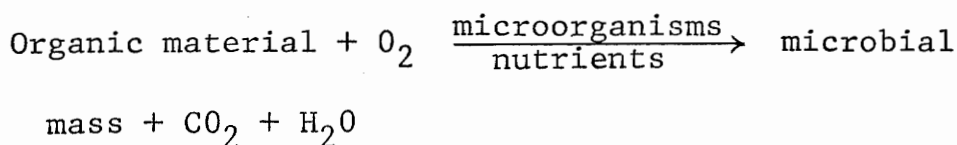
Upon completion of this biochemical process, the microorganisms must be physically separated from the supernatant in order to produce an effluent with as small an

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oxygen demand as possible. Since the soluble organic matter remaining after treatment is usually very small, the organic concentration in the effluent is primarily a function of the separation efficiency.

Separation of the microorganisms from the effluent in the secondary sedimentation tank is also of primary importance to the operation of the activated sludge process. Not only is efficient separation necessary to minimize the effluent oxygen demand, it is also necessary to insure that there will be a sufficient concentration of organisms in the return flow to maintain a mixed liquor biological solids concentration in the aeration basin for the efficient removal of organic matter. The most common cause of failure of the activated sludge process is poor solids separation in the secondary clarifier.

A sludge which will not settle efficiently in the secondary clarifier is generally termed a bulked sludge. It is most commonly caused by a change in the microbial population from the dominance of floc forming bacteria to filamentous forms, but may also result from rapid growth conditions and/or low dissolved oxygen levels without an attendant population change. An equally detrimental effect known as rising sludge may be caused by denitrification in the clarifier, resulting in sludge

being floated to the water surface by the released nitrogen gas bubbles.

In this investigation, the effects of coagulants which may assist the settling of activated sludge were studied. The intended focus was twofold. The improvement obtained by use of coagulants was studied with comparisons being made from the information being accumulated about each coagulant. Secondly, potential toxic effects of the respective coagulants upon the sludge microorganisms were investigated through monitoring of the oxygen utilized by organisms in performance of their metabolic processes.

II. LITERATURE REVIEW

In locating material which would provide a background for this study, it was found that literature pertaining directly to the topic at hand was in short supply, thus the topic of bulked sludge coagulation and subsequent determination of the effect of coagulation on dissolved oxygen uptake rate was broken down into several subtopics and a substantial amount of literature was available for these subtopics. These subtopics were: characteristics of a bulked sludge, biological flocculation, coagulation, flocculation, settling, and dissolved oxygen uptake. A combined understanding of these topics is central to the interpretation of this research.

Bulking Sludge Characteristics

Sludge bulking as a result of microbial growth can be attributed to two classes of microorganisms. According to Pipes (20) these are filamentous and non-filamentous. These are by no means the only causes of bulking sludge, as Pipes' article indicates; however, these are the types of bulking most likely to occur in a properly designed and operated treatment plant.

Filamentous bulking is caused by microorganisms which produce relatively long, microscopic tendrils or filaments that hinder the natural coagulation and

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flocculation processes taking place in normal activated
sludge. In the absence of these processes, settling occurs
at a very reduced rate.

The occurrence of filamentous microorganisms has been
attributed to a number of causes. Wastes deficient in
nitrogen or phosphorus give a competative advantage to
filamentous growth (1). Filamentous growth may thrive
in pH ranges well outside the span between seven and
eight normally associated with activated sludge. If
the dissolved oxygen concentration in an aeration basin
drops to a low level for a sustained period of time,
filamentous forms may multiply rapidly (16). Benefield,
et al. (2), observed that high dissolved oxygen concen-
trations in the range of eight to nine milligrams per
liter (mg/1) encouraged the proliferation of filamentous
growth.

It was once thought that filamentous bulking could
be attributed entirely to the existence of the bacterium,
Sphaerotilus. More recently the list of bacteria known
to cause filamentous bulking has been expanded to include
Bacillus, Sphaerotilus, Beggiatoa, Thiothrix, Nocardia,
and others. Certain fungi including Geotrichum have been
shown to cause filamentous bulking, especially under con-
ditions of reduced pH (20). The two microorganisms most
often associated with filamentous growth are the bacterium,

Sphaerotilus natans, and the fungus, Geotrichum candidum (2).

A number of treatment methods for the symptoms of sludge bulking have been proposed as well as techniques for eliminating the afore-mentioned causes. Chlorination has been found to control filamentous sludge bulking to some extent as have the addition of moderate quantities of iron sulfate, alum, lime, or anaerobic, digested sludge (22).

Non-filamentous sludge bulking is attributable to bacteria containing "bound" water. There are two types of water associated with hydrated bacteria, interstitial water and absorbed water. Interstitial water can be forced from the bacteria by the application of slight pressure. Absorbed water can only be removed mechanically by the application of enormous pressure. Relative amounts of these two kinds of water may vary considerably. The term bound water includes both types of water associated with bacteria. There is no clear distinction between water that is bound to an organism and that which is not. There is a gradual transition between bound and free water due to the fact that the affinity between the water-colloid system lessens as the distance from the bacteria increases (12).

A sludge containing a significant percentage of bound water (a bound water content of 400 percent of the

cell weight would not be extraordinary) will have an
accompanying decrease in its specific gravity, causing
a greatly reduced settling rate. Bulky sludge tends to
produce a very irregularly shaped floc which creates
frictional resistance to settling. A bacterium's sheath
of bound water can cause alterations in the water-colloid
relationship which would reduce the settling velocity.
Heukelekian and Weisburg (12) established that the sludge
volume index, a measure of sludge settlability and com-
paction, varied directly with the quantity of water bound
to the sludge.

It has been found that as the food to microorganism
ratio of an activated sludge system increases, the system
will exhibit more of a tendency to bulk. In the presence
of an abundant food supply, bacteria will surround them-
selves with a capsular layer composed chiefly of poly-
saccharides and proteins. The bacteria making up a
bulked sludge will frequently form a matrix of this
hydrated capsular material. This type of hydrated
material is most often associated with the bacterium
Zooglea and is termed a zoogleal matrix. Zooglea type
bacteria are typically present in a sludge that shows
no tendency toward bulking. With an increase in food to
microorganism ratio, however, sludge bulking may occur,
not because of a shift in microorganism population, but

by a change in the physical characteristics of the existing population (12).

Chlorination of return sludge has been found to be effective against bound water sludge bulking. Initially it was thought that chlorination worked by keeping in check excessive biological activity and selectively killing the bacteria. Heukelekian and Weisburg (12) have concluded that such is not the case. They postulate that chlorine induces the bacteria to release bound water by the denaturing of extracellular proteins.

Bioflocculation

Briefly stated, coagulation-flocculation is the destabilization of colloidal material followed by transportation and aggregation in order that this material might be separated from the supernatant by settling.

Biological agglutination or natural bioflocculation constitutes a convenient and effective means of separating microorganisms from effluent in the activated sludge process. At one time, activated sludge flocculation was attributed to the action of one bacterium, Zooglea ramigera. The theory asserted that a small proportion of this bacterium in the sludge produced a zoogleal matrix which enmeshed the remaining microorganisms. McKinney, et al. (15), disproved this theory by demonstrating that several types of bacteria can institute bioflocculation

in the absence of <u>Zooglea ramigera</u>. McKinney sites re-
searchers who have attributed bioflocculation specifically
to the presence of poly-beta-hydroxy-butyric acid or poly-
saccharides produced by the bacteria. More recently,
Friedman, <u>et al</u>. (9), have shown that bioflocculation
results from the interaction of naturally produced, high
molecular weight, long chain polyelectrolytes and the
bacterial cells. These polymeric electrolytes include
polysaccharides, proteins, and the nucleaic acids, DNA
and RNA. They link one cell to another through the
phenomenon of bridging.

Observations indicate that biological flocculation
does not reach maximum effectiveness until the sludge
microorganisms have entered the endogenous phase (19).

<u>Coagulation</u>

Surface charge is an important factor dictating the
stability of a colloid. A colloidal particle will most
often have a charge, and microorganisms in particular
acquire surface charge through the ionization of carboxyl
and amino groups. The charge imparted to microorganisms
is generally a negative one (16).

There are a number of currently accepted theories
used to explain coagulation. These include double layer
compression, adsorption and charge neutralization, en-
meshment in a precipitate, and adsorption and bridging.

A colloid dispersed in water does not have a net charge. The previously mentioned charge associated with a colloidal particle is counterbalanced by an equivalent excess of ions of opposite charge (counterions) accumulating near the particle surface. This accumulation of charge is termed an electrical double layer. The concentration of counterions is greatest near the particle surface and decreases with increasing distance from the particle. A diffuse layer of counterions is associated with the colloidal particle. As any two colloidal particles near each other, their diffuse layers interact and repel due to the presence of like electrostatic charges. Van der Waals forces and the kinetic energy of a colloidal particle are the naturally occurring forces which serve to overcome the repulsive forces of electrical double layer interaction, provided they are given the opportunity through double layer compression (25).

Double layer compression is achieved when high concentrations of electrolyte in solution generate high counterion concentrations. With a reduction in double layer size, colloidal particles can get closer to one another before repulsive forces begin to have effect. The attractive forces vary inversely as the distance between colloidal particles; therefore, the reduced diffuse layer size brings about colloidal destabilization. The effectiveness of a counterion varies

according to its charge, with the concentrations of counterion of +1, +2, and +3 charge necessary to achieve destabilization varying in an approximate ratio of $1:10^{-2}:10^{-3}$. The empirical relationship describing this phenomenon is termed the Shultze-Hardy rule (18).

High concentrations of a metal salt or a metal oxide used in coagulation can lead to the formation of a precipitate. Colloidal particles become enmeshed in the precipitate and are separated from the supernatant through this mechanism, termed sweep floc. The colloidal particles can serve as nuclei for the formation of such a precipitate, resulting in an inverse relationship between the optimum coagulant dose and the amount of colloidal material (25).

The bridging theory of coagulation proposes that a natural or synthetic polymer adsorbs to a colloidal particle through a number of mechanisms; electrostatic interaction, ion exchange, hydrogen bonding, the formation of coordinate bonds, van der Waals forces, and the interaction of coagulant and aqueous phase (18). Once a polymer has attached itself to an adsorption site, the remainder of the polymer molecule is free to adsorb at the surface to another colloidal particle, thus forming a polymeric bridge between the two. If an adsorption site on another particle is not readily available, the polymer may adsorb at another site on the original particle, restabilizing it.

Overdosing with polymer coagulant can lead to a saturation of available adsorption sites and eventual restabilization of the colloid. Agitation of a destabilized polymer can cause a break in polymer, surface bonds, allowing the polymer to wrap itself around a single particle and restabilize the colloid (18).

When polymers are used as coagulants, the coagulation-flocculation process can be broken down into two steps: the adsorption of the polymer from solution and the collision of particles to form multiparticle aggregates. Particle collision has been shown to be the rate determining step in polymer usage. It has been demonstrated that, frequently, only a narrow range of polymer dosages will be effective. Too low a dosage will be insufficient to bind colloidal particles together; whereas, too high a dosage will cause individual polymers to adsorb to a single particle so that no interparticle bridges are formed. In the case of overdosing, additional power input during the flocculation process has been found to aid in producing interparticle bridging (4).

Iron (III) and aluminum (III) salts are commonly used coagulants. When these salts are present in water in quantities such that the solubility limit of the metal hydroxide is exceeded (as is normally the case in coagulation), species ranging from simple hydroxo complexes to hydro-metal polymers are produced. The following

are examples of these reactions:

$$FE(H_2O)_6^{3+} + H_2O \longrightarrow Fe(H_2O)_5(OH)^{2+} + H_3O^+$$

$$Al(H_2O)_6^{3+} + H_2O \longrightarrow Al(H_2O)_5(OH)^{2+} + H_3O^+$$
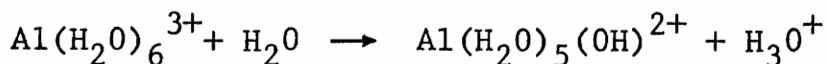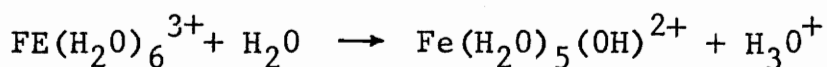
These are termed hydrolytic reactions and examination of the equations reveals that they will produce acidic conditions. The species and quantity of hydroxo-metal complexes produced depends upon the pH of the system (25). The hydroxo-metal complexes are readily adsorbed at particle surfaces, whereas simple aquo-metal ions are not. Once adsorbed, these unstable, inorganic polymers destabilize colloidal material. Restabilization can be induced if a colloid is overdosed (24).

The action of a metal salt can be broken down into three segments. These include the rate of formation of hydrolysis products, the rate of the destabilization step, i.e., coverage of the colloid particle surface by hydroxo-metal species, and the rate of particle transport. Hahn and Stumm (10) suggest that the destabilization step is slow due to a low rate of diffusion for the hydroxo metal complexes. Despite this, the particle transport step was found to be rate determining.

No single theory of coagulation has been found to be completely accurate in describing the coagulation process.

More recent investigators have come to the conclusion that no one phenomena is responsible for the coagulation of colloids. Instead it is thought that coagulation is the result of combinations of previously mentioned mechanisms and perhaps some other mechanisms which have not been examined. In any case there is currently no theory available to base a predictive model of the coagulation process upon (24).

The small scale jar test is effective in predicting effective coagulant dosages. It has been demonstrated in the past that the results of such tests can be scaled up to full plant operations with little difficulty (25).

It has long been known that rapid mix units, small holding tanks with a very high degree of agitation, greatly enhance the effectiveness of the coagulation-flocculation process. Vigorous agitation induces uniform production and adsorption of metal salt coagulant species and to a lesser extent aids in the distribution of synthetic polymers. Weber (25) gives three reasons why rapid mixing is essential: rates of formation of polymeric species are very fast, rates of adsorption of small polymeric species may be rapid, and the production of a uniform coagulant species requires a uniform pH and coagulant dosage throughout the system. Though the rapid mix

step is less critical when synthetic polymers are used as coagulants, it is still necessary to insure an even distribution of coagulant.

Flocculation

Flocculation can briefly be described as the transport and aggregation of colloidal particles which have previously been destabilized through coagulation. Three different mechanisms of flocculation are recognized.

Perikinetic flocculation is also termed "Brownian movement" or "Brownian diffusion" after the English botanist who discovered it. Interparticle contacts are generated by rapid, random bombardment of the colloidal particles by fluid molecules. The motion of the fluid molecules is induced by thermal energy within the fluid medium. Perikinetic flocculation plays a minor role in systems which are mechanically flocculated, and a much greater role in simple sedimentation systems (25).

Orthokinetic flocculation is attributable to agitation of the fluid medium by an external power source. Spatial changes in velocity are characterized by a parameter termed the mean velocity gradient, G, which reflects the power dissipated in the water.

$$G = \left(\frac{P}{V_\mu}\right)^{1/2}$$

where:

P = power input to the fluid.

V = flocculator volume.

μ = fluid viscosity.

Care must be taken to insure that G is high enough to promote interparticle contact but not so high that floc which had previously been formed will be torn apart.

The third flocculation mechanism occurs during settling. Particles with different settling velocities collide, resulting in aggregation of the particles to form a single, larger particle (25).

A flocculation tank is designed to promote inter-particle contact through orthokinetic flocculation. Flocculation tanks generally have large, mechanically operated paddles to induce a very gentle mixing and perhaps stationary paddles or stator blades to break up the mass rotation of the liquid. In water treatment practice, where more extensive study into the floccu-lation process has been conducted, it has been found that when Al(III) and Fe(III) are used as coagulants, effective mean velocity gradients are found to range between 10 and 100 inverse seconds. Since wastewater treatment deals with a much higher solids concentration, implying shorter interparticle distances, somewhat lower mean velocity gradients have been found to be effective (16).

Flocculation is dependent upon particles adhering to one another once they colloide; however, such is not always the case. The percentage of collisions which result in successful particle aggregation can range from one to almost fifty. Despite this, extremely long flocculation times are ineffective due to the relatively high particle concentration in wastewater treatment. Extended flocculation may even cause particle restabilization. What is indicated here is that both velocity gradient and time of flocculation must be experimentally determined to maximize particle removal. While it is possible to scale up coagulant selection data from a small scale jar test to plant scale, it is impossible to do so with flocculation rates and times (25).

Sedimentation

Sedimentation is the separation of water and particles that are heavier than water by gravitational settling. The objective in the secondary settling basin is twofold, production of a clarified effluent and a sufficiently concentrated sludge to insure maintenance of sufficient biological solids in the aeration basin for effective waste treatment. Four types of settling are generally recognized, each having a different design procedure associated with it.

Type-1 settling is observed in suspensions of low concentration. Particles are considered to be discrete and there is no significant interaction between neighboring particles. Type-1 settling may be known by other names such as discrete settling or free settling. Design in this case is based upon classical laws formulated by Stokes and Newton.

Type-2 settling occurs in relatively dilute suspension because particles will coalesce as they settle. As large particles are formed during sedimentation, the rate of settling increases. Design of a sedimentation tank for type-2 settling is done on an empirical basis using results from a sedimentation test column.

Type-3 settling may also be termed zone settling. It occurs in suspensions of intermediate concentration where interparticle forces hinder individual particle settling. Suspension particles tend to remain in fixed positions with regard to one another. A very distinct interface will develop between the settling sludge and the supernatant.

Type-4 settling involves the formation of a lattice like structure composed of flocculated particles at the bottom of the settling tank. The structure is eventually compressed by the weight of particles which continue to

accumulate atop the compression layer. This type of settling may also be termed compression settling (16).

In the settling of activated sludge, a compression region will usually form at the tank bottom. Within the upper reaches of the settling tank, discrete and flocculant settling may be taking place. The zone settling region will fall between these extremities and exhibit, to some extent, a gradation of solids concentrations. In effect, examples of all four types of settling are very likely to be found in settling a single sludge sample (16). Design of facilities involving this range of settling types is done on a graphical basis, using a settling curve which plots the height of the sludge-supernatant interface versus time.

Dissolved Oxygen Effects

Cell metabolism consists of the production and utilization of energy for the construction of new cell parts, the synthesis of chemical components such as enzymes and nucleic acids, cell maintenance, and cell multiplication. Extremely large amounts of energy are required for these functions and this energy is provided through the steps of biological pathways. Energy is produced by a series of chemical reactions in which adenosine triphosphate (ATP) is used to both release and store energy. Aerobic

respiration systems produce ATP through a series of biological oxidation reactions. Oxygen is essential to this system as an electron acceptor. When dissolved oxygen concentrations drop to a critical level in activated sludge mixed liquor, another electron acceptor must quickly be found (facultative organisms) or cell metabolism will come to a halt (6).

The critical dissolved oxygen level is generally defined as the level at which oxygen uptake begins to drop off rapidly. Critical dissolved oxygen concentrations can vary from one organism species to another or even between samples of the same species due to past organism history (11). Though the critical dissolved oxygen concentration for most species is on the order of 0.1 mg/l, much higher dissolved oxygen levels are necessary in activated sludge.

As activated sludge settles, cells aggregate to form flocs. Oxygen transfer to the cells within the floc proceeds at a very reduced rate due to the presence of surrounding cellular material (2). An American Public Health Association Committee on Sewage Disposal report in 1942 recommended, from experience, that a dissolved oxygen concentration of 2 mg/l is necessary in an activated sludge system to insure that dissolved oxygen is not a limiting factor in treatment.

Subsequent investigations have put the required con-
centration even higher in some cases, though 2 mg/l is
still an often used design standard (14). Mathematical
models describing the oxygen distribution within acti-
vated sludge flocs have been introduced by such re-
searchers as Wuhrmann (26) and Biryukov and Shofter
(5). Results obtained from these models vary widely.
Whereas Wuhrmann's model describes a floc that is
aerobic throughout with an ambient dissolved oxygen
concentration of 2 mg/l, the Biryukov and Shofter
model predicts a completely anaerobic core at the 2
mg/l dissolved oxygen concentration.

Some disagreement is evident in the literature as
to whether the period of zero dissolved oxygen which
activated sludge is subjected to during settling reduces
the biological activity of the organisms or not. Okum
and Lynn (17) found that treatment efficiency after a
period of settling tends to be better when the dissolved
oxygen concentration of the mixed liquor prior to settling
was increased. They also found that treatment efficiency
improved as periods of zero dissolved oxygen were reduced
in duration. These findings led Okun and Lynn to postu-
late that a high initial dissolved oxygen concentration
produced increases in oxygen resources within the floc
particles and even the cell cytoplasm. The presence of

this oxygen would reduce the period of zero dissolved oxygen and result in better treatment. The findings of Wuhrmann (26) disagreed with those of Okum and Lynn. He found that zero dissolved oxygen periods of up to four hours had essentially no effect on either endogenous or substrate utilizing respiration. His conclusion was that limited periods of zero dissolved oxygen had no effect upon the purification capacity of a sludge.

Biological oxygen consumption is a direct measure of stabilizing reactions. Together with substrate utilization, oxygen uptake is a tool often used or misused in design. According to Bhatla, et al. (3), oxygen utilization over and above that needed for cell maintenance is proportional to the quantity of organic material converted to cell material.

III. MATERIALS AND METHODS

The mixed liquor used in this investigation was
generated from samples taken from a package activated
sludge treatment plant operated by the State of Virginia
at a highway reststop near Radford, Virginia. In its
original form the sludge settled very well and the plant
had experienced no recent problems due to sludge bulking.

Pure cane sugar was used as a substrate to maintain
the bacterial population. The sludge was fed this sub-
strate for a period of one week while being maintained in
a five liter, cylindrical, plexiglass container and aerated
to a dissolved oxygen concentration of approximately
5 mg/l. Plastic screens were placed in the plexiglass
container at the end of one week and allowed to become
clogged with attached growth. The clogged screens were
washed down and the wash water containing the formerly
attached growth was retained as a bacterial seed from
which other bacterial populations could be grown. Micro-
scopic examination revealed that the majority of the
bacteria grown in this manner could be characterized as
gram negative, short rods.

A forty liter Pyrex glass container was filled to
a level of thirty liters with tap water and seeded
with approximately five grams of potassium phosphate as
a phosphorous source. The bacterial seed was transferred

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into this environment and fed cane sugar as a substrate in hopes of producing a bulked sludge due to nitrogen deficiency.

Mixed liquor volatile suspended solids (MLVSS) measurements were made daily. Samples of the mixed liquor were filtered through a Reeve Angel 934AH glass fiber filter, 5.5 centimeters in diameter placed in a Buchner funnel. The test was run in accordance with the methods outlined in Standard Methods for the Examination of Water and Wastewater (23).

Thirty grams of the cane sugar substrate were fed into the aerated tanks daily. This feeding was done twice a day with fifteen gram quantities being poured into the tanks at times approximately twelve hours apart.

Problems occurred when the bacteria were grown and maintained in this manner for longer than eight to ten days. Over the course of approximately twelve hours, there would occur a dramatic drop in pH from a normal operating value of seven to approximately three. The resulting mixed liquor could not be settled with any of the coagulants used in this investigation. To alleviate this problem, the Pyrex container was emptied and re-seeded. At the end of one week, a second, identical container was set up and seeded from the first. The first tank was emptied, prepared, and seeded from the

second at the end of the second week. Through the ensuing weeks the tanks continued to be reseeded, one from another, in this manner.

The sludge resulting from this procedure showed no tendency to settle and resembled Pipes's (20) description of dispersed growth. Initially, examination under a microscope revealed significant numbers of filaments. As the investigation progressed, the number of apparent filaments steadily decreased until there were almost no observable filaments at the end of the investigation. This did not improve settling at all, however, and almost no settling occurred even when filaments could not be observed.

Coagulation-Flocculation

The coagulants selected for use were ferric chloride, alum, and a synthetic polymer. Selection of the polymer required some preliminary testing. It was found, through settling tests, that anionic polymers were ineffective. Cationic polymers did appear to be effective, so a cationic polymer produced by Cyanamid, Magnifloc 575C, was selected for use. Stock solutions of ferric chloride and alum in concentrations of 10,000 mg/l and 20,000 mg/l were made up and allowed to sit for a week in order that they might stabilize in character. Stock solutions of cationic polymer at a concentration of 5000 mg/l were also made up.

Three MLVSS concentrations were selected for study; 1000 mg/1, 2000 mg/1, and 3000 mg/1. Preliminary study revealed that for all three coagulants, the dosages for most effective coagulation and settling would lie between 200 mg/1 and 700 mg/1 at the 1000 mg/1 and 2000 mg/1 MLVSS concentrations. The 3000 mg/1 MLVSS concentration required a somewhat higher range of coagulant dosages between 600 mg/1 and 1100 mg/1.

Each run consisted of six one liter samples containing different coagulant doses and the same MLVSS concentration. A control sample with the same MLVSS concentration and no coagulant was also run. Before the run a MLVSS test was performed. Using the results of this test, a dilution was determined which would yield, approximately, the desired MLVSS concentration for the run. In making up the dilutions for a run, the proper amount of coagulant stock solution was added to each sample. The combined coagulant-dilution water sample was decanted into a one liter volumetric flask. A Manostat, Varistaltic Pump was used to pump mixed liquor into the volumetric flask until the one liter mark was reached. The coagulant-mixed liquor sample was poured into a square (10 cm x 10 cm x 20 cm) battery jar and rapid mixed with a Waco Power Stirrer at approximately 100 revolutions per minute for thirty seconds using a 7.5 cm x 2.5 cm paddle. Each battery jar

was placed under a six place, Phipps and Bird laboratory
stirrer and its contents were flocculated for thirty
minutes at between fifteen and twenty revolutions per
minute, again using 7.5 cm x 2.5 cm paddles. At the
end of the thirty minutes the flocculated microorganisms
were pumped from the battery jar to a one liter graduated
cylinder. This was done using a Varistaltic pump with
three eights inch internal diameter Tygon tubing.
Pumping was done at a rate of approximately one liter
in five minutes and at this rate it was observed that the
microorganism flocs displayed no tendency to break up.
Once the flocculated microorganisms were transferred to
the graduated cylinder, the cylinder was stoppered and
gently inverted several times to insure that the flocs
were evenly distributed throughout the sample.

Settling

Graduated cylinders were used for all settling tests.
As soon as a sludge-supernatant interface appeared,
readings were taken to determine the volume occupied by
the settled sludge in milliliters. At intervals the
volume of the settled sludge was logged along with the
time that had elapsed since settling had begun. The
volume occupied by the settled sludge after one half hour
of settling was recorded in order to determine the sludge

volume index (SVI). The SVI was calculated from the
formula:

$$SVI = \frac{V}{MLSS} \times 1000$$

where:

V = volume occupied by the settled sludge at the
end of one half hour of settling (milliliters).

MLSS = mixed liquor suspended solids concentration
(mg/l).

SVI was selected as a parameter to model the settleability
of the coagulated sludge since it is defined as, "the
volume in milliliters occupied by one gram of activated
sludge mixed liquor solids, dry weight, after settling for
30 minutes in a 1000 milliliter graduated cylinder" (16).

In many cases the rate of settling was slow and
significant settling took place after the first half hour.
So that this might be reflected in the data collected, the
sludge was allowed to settle for one hour. At the end
of an hour the volume of the settled sludge was again
determined. This volume was used to calculate a sludge
volume index based on one hour's settling.

Supernatant

After completion of the settling test a sample of
the supernatant was withdrawn from the topmost two

hundred milliliters of the graduated cylinder. A
volatile suspended solids test was performed on samples
of the supernatant, following the volatile suspended
solids test procedures previously described.

The remainder of the supernatant sample was checked
to determine effluent pH. This pH reading, as well as
all other pH readings determined during this investi-
gation, was measured using a Corning Model 7 pH meter
which was calibrated regularly using a pH 7 buffer.

Dissolved Oxygen Uptake

The settled sludge in the graduated cylinder was
resuspended and used for the dissolved oxygen uptake
test. A glass rod was used to break up the settled
sludge and distribute it throughout the cylinder.
Additional agitation broke up the flocs to some extent.
Even though an effort was made to break apart the flocs,
they remained and their size varied greatly according
to the success achieved in the original flocculation
process.

Contents of the graduated cylinder were then aerated
vigorously to a dissolved oxygen concentration of between
5 mg/1 and 7 mg/1. Approximately 300 milliliters of
sample were transferred to a BOD bottle. As with all
dissolved oxygen measurements done previously, the dis-
solved oxygen uptake test was performed using a YSI

Model 54 Oxygen Meter equipped with a self-stirring probe. The meter was calibrated with each use and its probe membrane was changed after every second use. Before readings were begun, the meter was given time to settle down to what was considered to be an accurate reading. If the uptake rate appeared to be greater than .15 mg/l per minute of oxygen, then the dissolved oxygen concentration was read at one minute intervals for a period of eight minutes. In many cases the oxygen uptake rate appeared to be less than .15 mg/l per minute and difficulty in reading the oxygen meter dictated that the interval between readings be lengthened to two minutes for a total period of sixteen minutes.

The dissolved oxygen uptake test yielded values of dissolved oxygen at corresponding times. A plot was constructed showing concentration versus time and a line was drawn through any three or more points which formed a straight line, excluding points below 0.5 mg/l of dissolved oxygen. (Sample calculations are shown in Figure 1.) The slope of this line was calculated to determine the amount of oxygen utilized per unit of time. The resulting rate was divided by the MLVSS concentration of the sample to obtain the oxygen uptake rate on a per unit of MLVSS basis.

Time (min)	Dissolved Oxygen Concentration (mg/1)
0	6.350
1	6.000
2	5.675
3	5.300
4	4.975
5	4.625
6	4.275
7	3.900
8	3.575

$$\text{Oxygen Uptake} = \frac{dO_2/dt}{MLVSS} = \frac{.431}{2185} = 1.97 \times 10^{-4}$$

$$\frac{6.000 - 4.275}{6 - 2} = .431$$

Time (min)
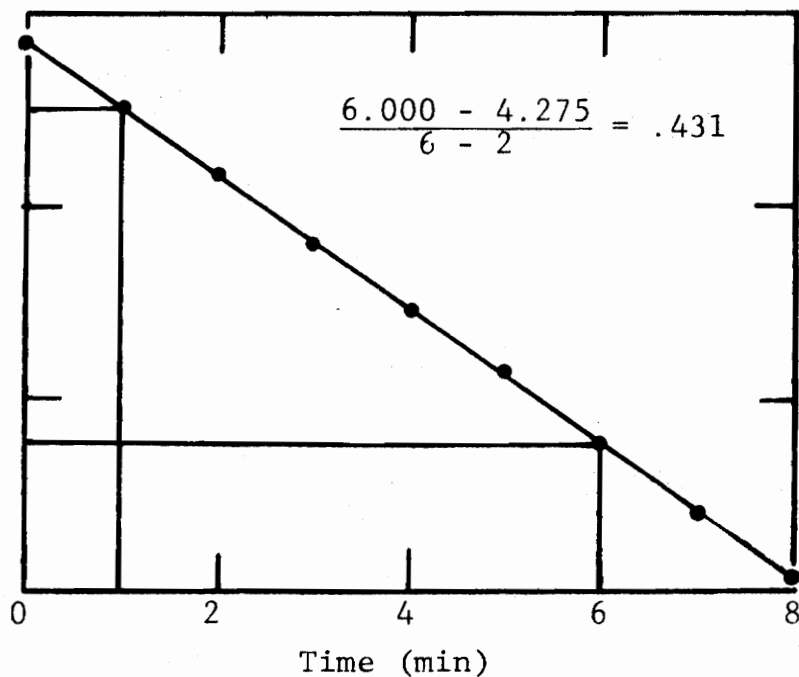
Figure 1. Sample calculations to determine oxygen uptake. In this case the coagulant used is cationic polymer at a dosage of 200 mg/1. The MLVSS concentration is 2185 mg/1.

Buffered Coagulant Doses

Tests were performed using buffered dosages of alum
and ferric chloride. These tests were run with 500 mg/l
coagulant doses operating on samples of approximately
1000 mg/l MLVSS concentration. Approximate volumes of
coagulant stock solutions were placed in a small beaker.
The beaker was swirled about a pH electrode as a sodium
carbonate-bicarbonate buffer was added to increase the pH.
The pH was brought up to the same level as that of the
mixed liquor. As the buffer was added to the metal salts,
they began to come out of solution and turn the samples
very turbid. Despite this the metal salts did not
settle. The coagulant sample was brought up to the
proper volume for dilution by the addition of distilled
water.

Mixed liquor samples containing ferric chloride,
alum, and no coagulant were rapid mixed, flocculated
and settled. The same oxygen uptake procedure outlined
previously was performed upon the samples. To determine
the effect of the buffer upon settling, the previously
described settling tests were run using buffered, 500
mg/l metal salt coagulant doses on a sludge of approxi-
mately 1000 mg/l MLVSS concentration.

IV. RESULTS

This research was designed to determine the effect of coagulants on a bulked sludge. The principle parameters used to measure effectiveness were settleability and supernatant volatile suspended solids, but the oxygen uptake rate of the settled sludge was also determined to ascertain whether the use of coagulants had a toxic effect on the microorganisms. The results are presented in both tabular and graphical form.

A number of different parameters were used during the study. For each coagulant dosage used, collected data included measurements of mixed liquor volatile suspended solids concentrations, timed values of the volumes occupied by the settling sludge, supernatant volatile suspended solids concentrations, timed values of dissolved oxygen concentrations in samples where the sludge was re-entrained and reoxygenated, and initial and supernatant pH readings. The basic data obtained, including calculated sludge volume index values, has been tabulated in Appendix Tables 1 through 11.

Settling Properties

Two parameters were used to indicate the settling properties of the coagulated sludge, sludge settling curves to illustrate the rate of settling and the sludge

volume index to demonstrate the effectiveness of the settling process.

Settling curves were generated by plotting the volume which the sludge had settled to, as indicated by the position of the sludge-supernatant interface in the graduated cylinder, versus time. The resulting curves are given in Figures 2 through 10.

The settling of a 960 mg/l MLVSS sludge after alum coagulation addition is shown in Figure 2. A lag period was evident as the sludge began to settle. Though the lag periods differed in duration with differing coagulant dosages, all samples had nearly completed zone settling after thirty minutes. Some significant settling did occur, however, between thirty minutes and one hour. It was also observed that the final settled volumes decreased somewhat with increasing coagulant dosage.

Ferric chloride coagulated samples displayed a much more rapid initial settling rate than alum at a 1000 mg/l MLVSS concentration as seen in Figure 3.

The volumes which the sludge settled to tended to be lower for ferric chloride than alum. There was some evidence that ferric chloride dosages above 500 mg/l re-stabilized some of the solids at the 1000 mg/l MLVSS concentration. Settling was neither as rapid nor as complete at the 600 mg/l and 700 mg/l ferric chloride dosages
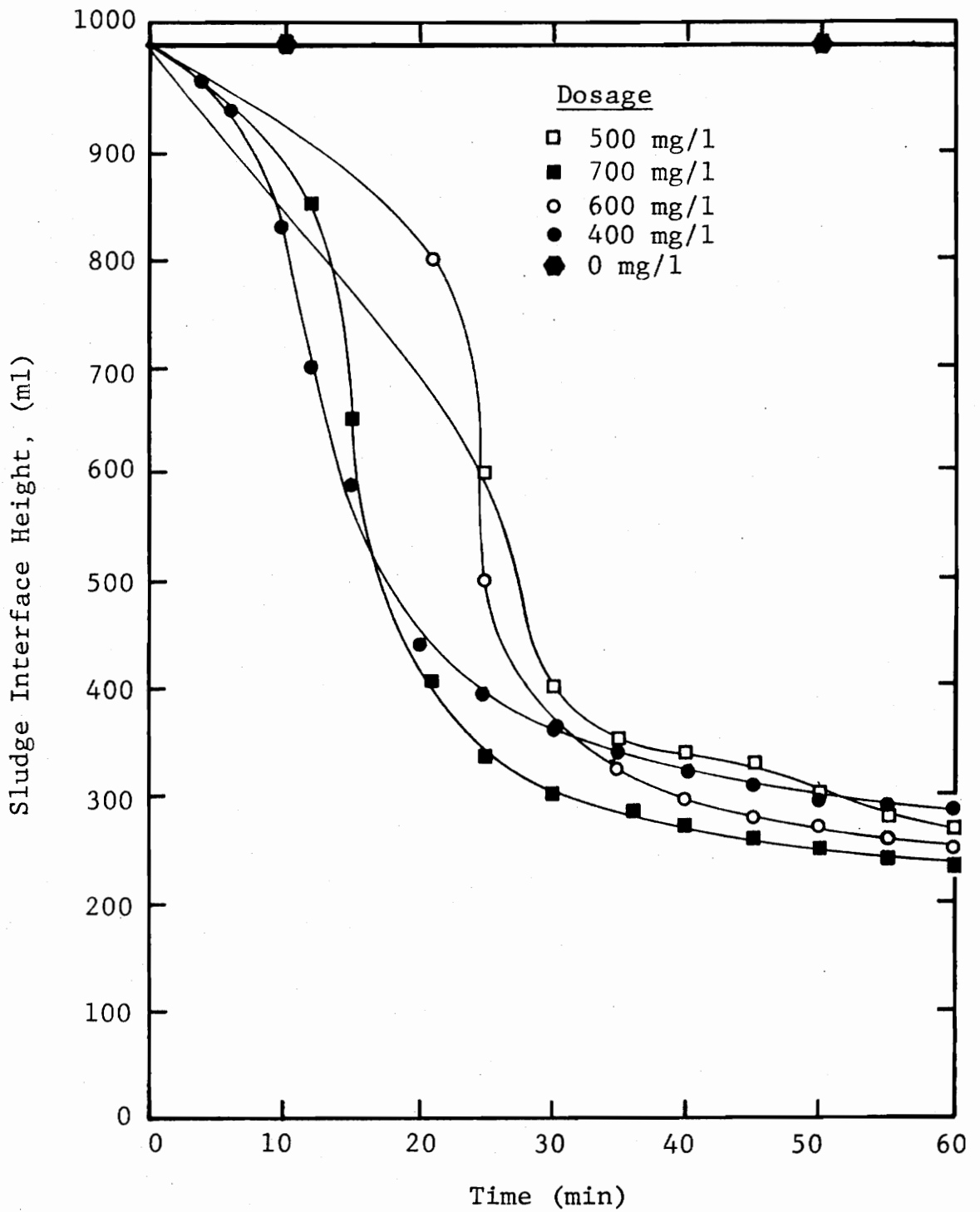
Figure 2.   Settling curves for alum dosages.   MLVSS = 960 mg/l.
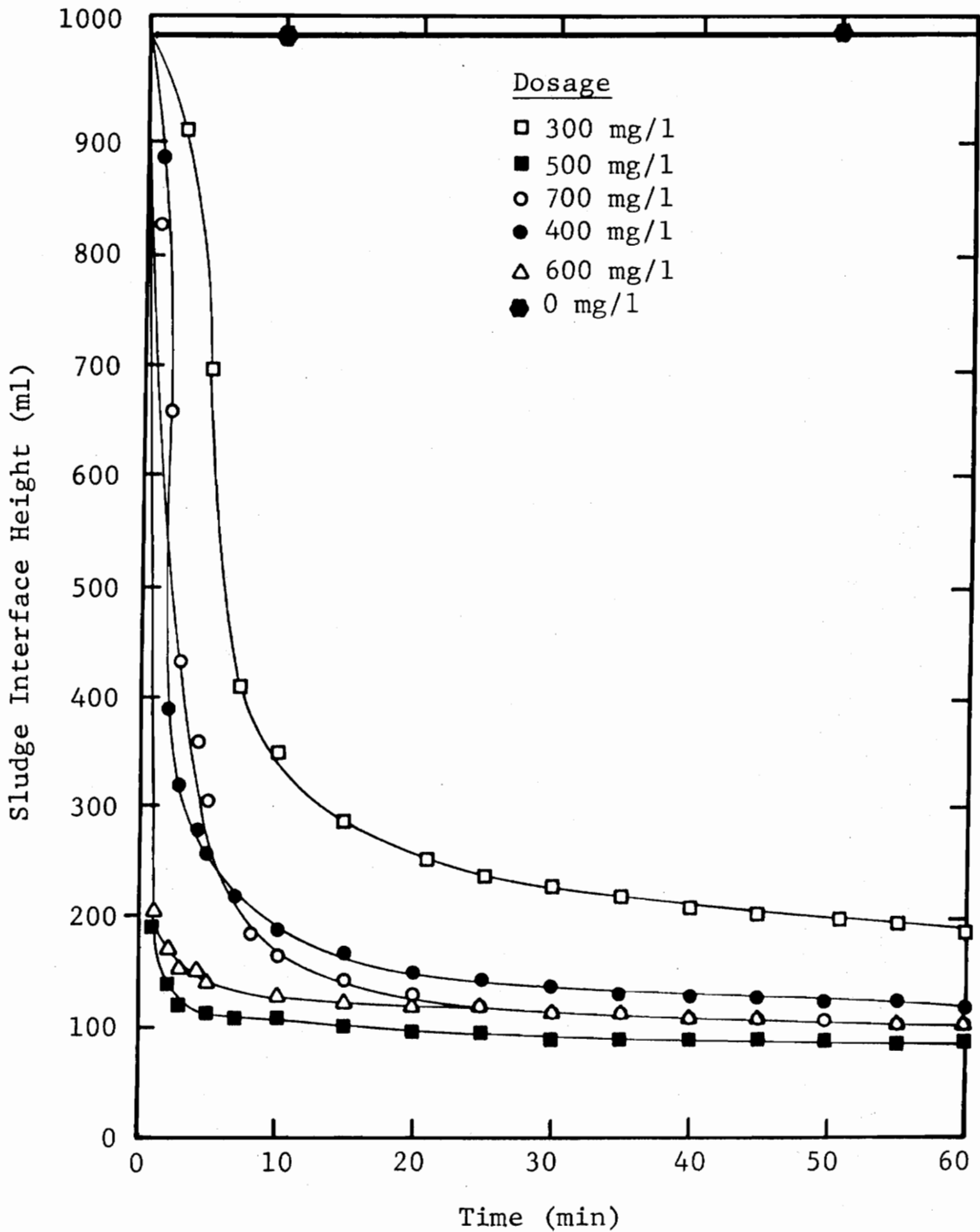
Figure 3.   Settling curves for ferric chloride dosages. MLVSS = 1000 mg/1.
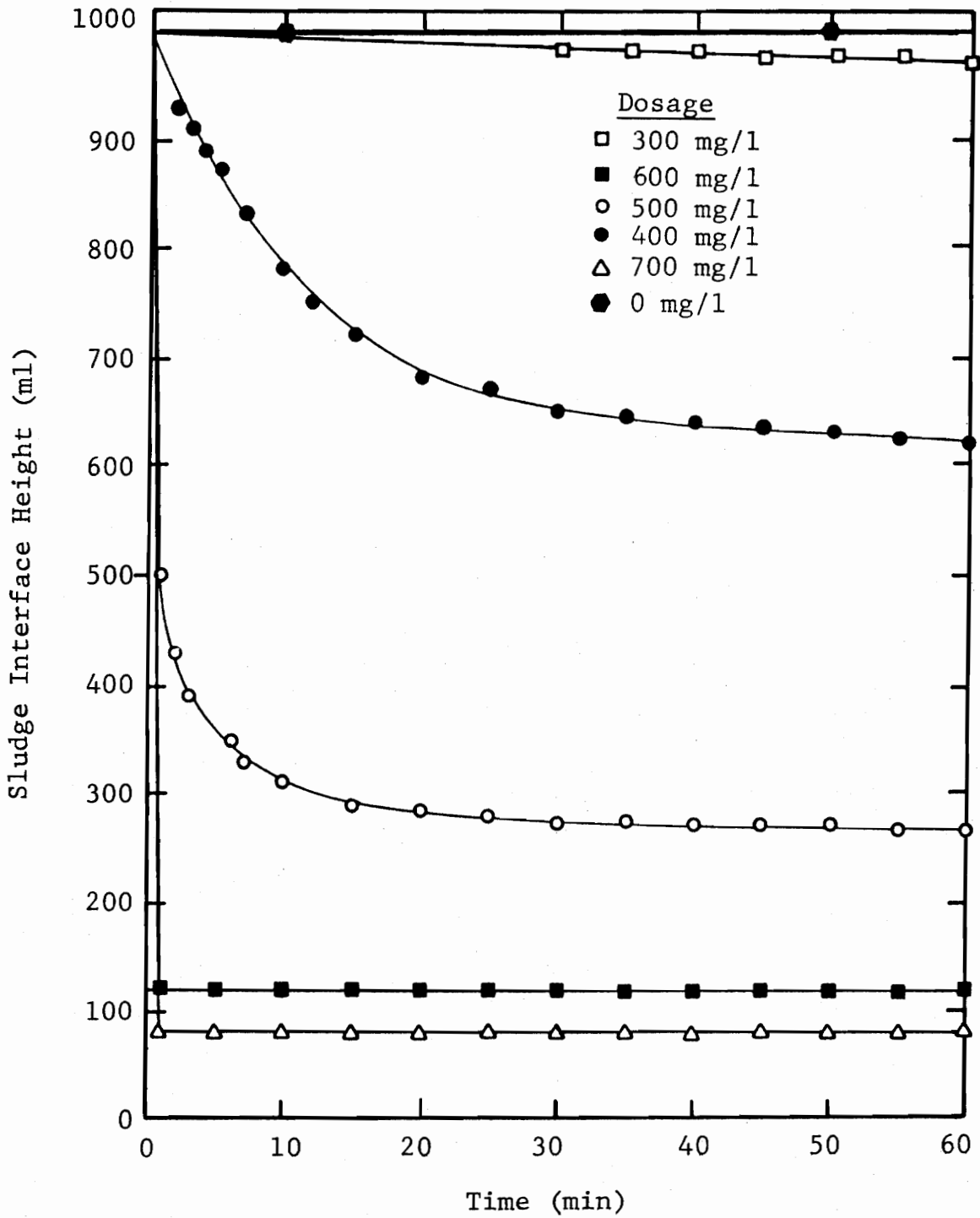
Figure 4.   Settling curves for cationic polymer dosages.
            MLVSS = 1125 mg/1.
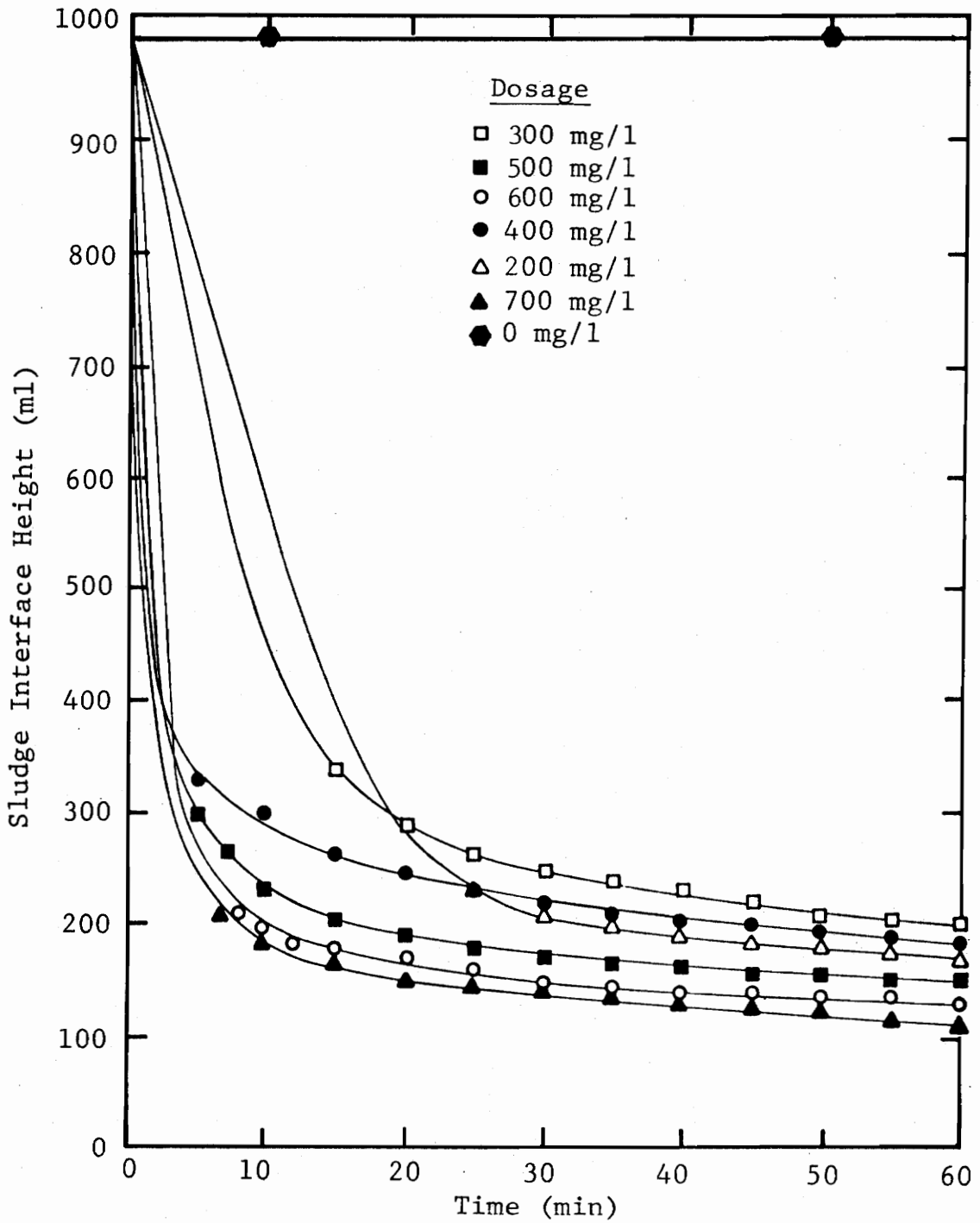
Figure 5.   Settling curves for alum. MLVSS = 1950 mg/1.
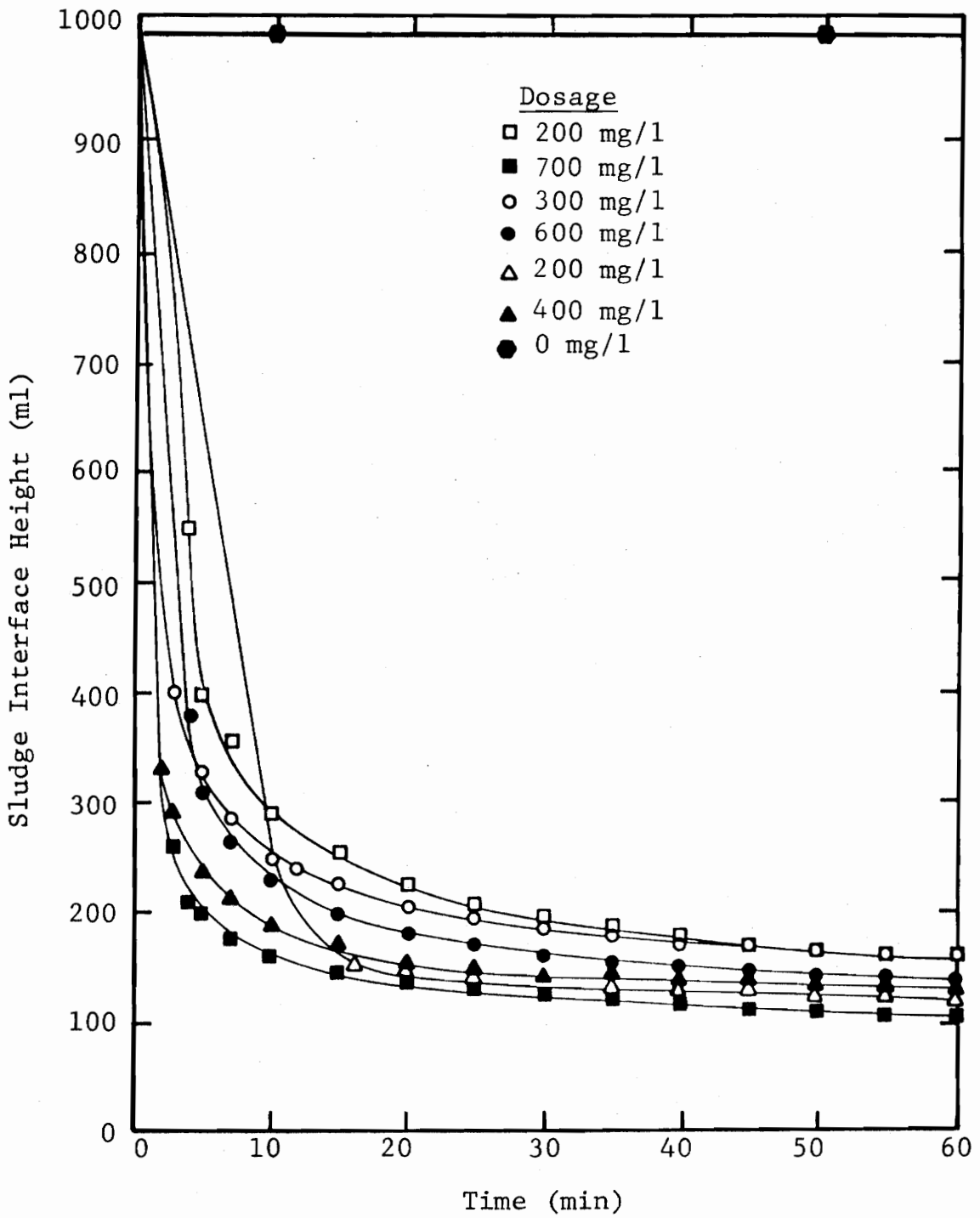
Figure 6. Settling curves for ferric chloride. MLVSS = 1965 mg/1.
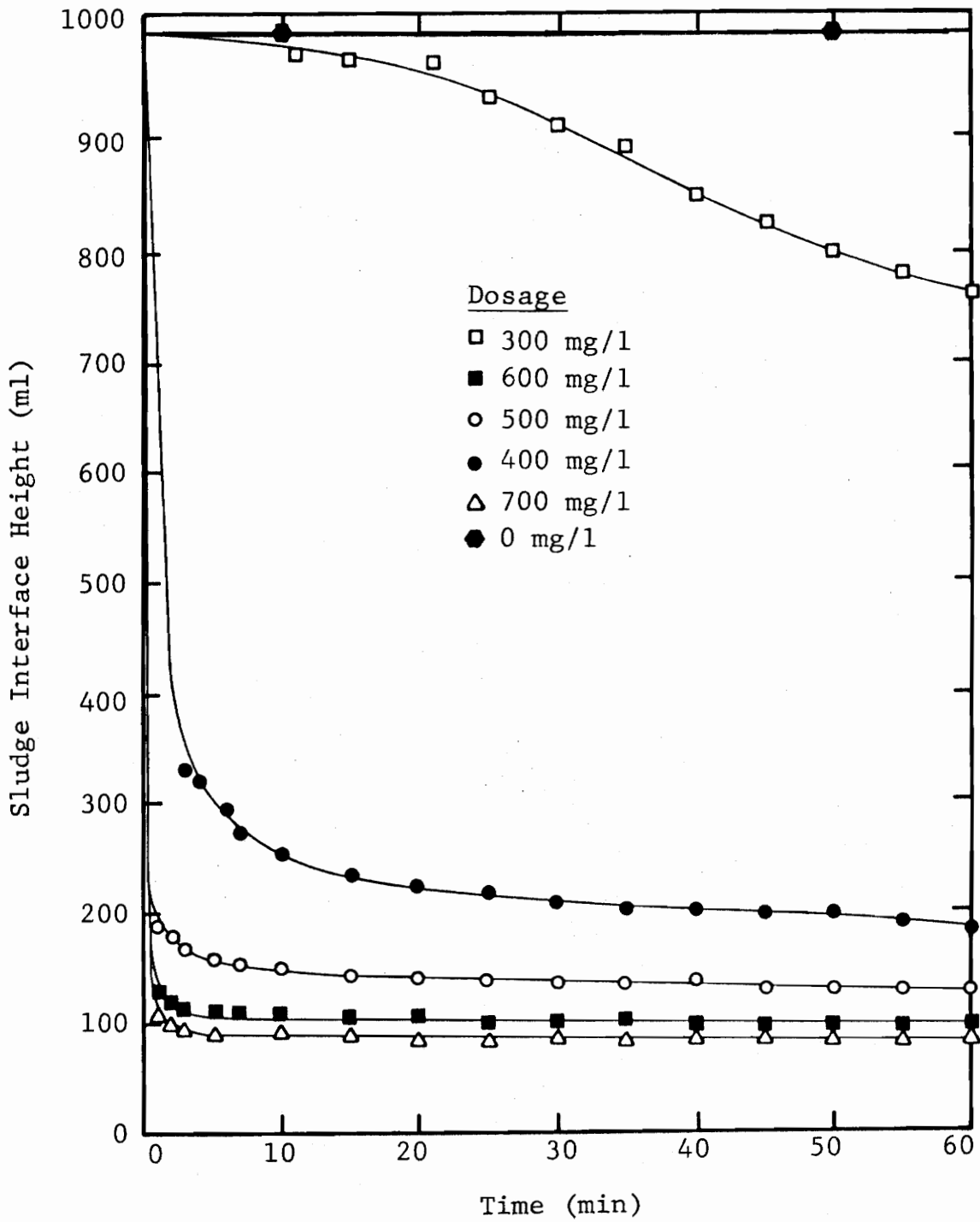
Figure 7.   Settling curves for cationic polymer MLVSS = 2185 mg/1.
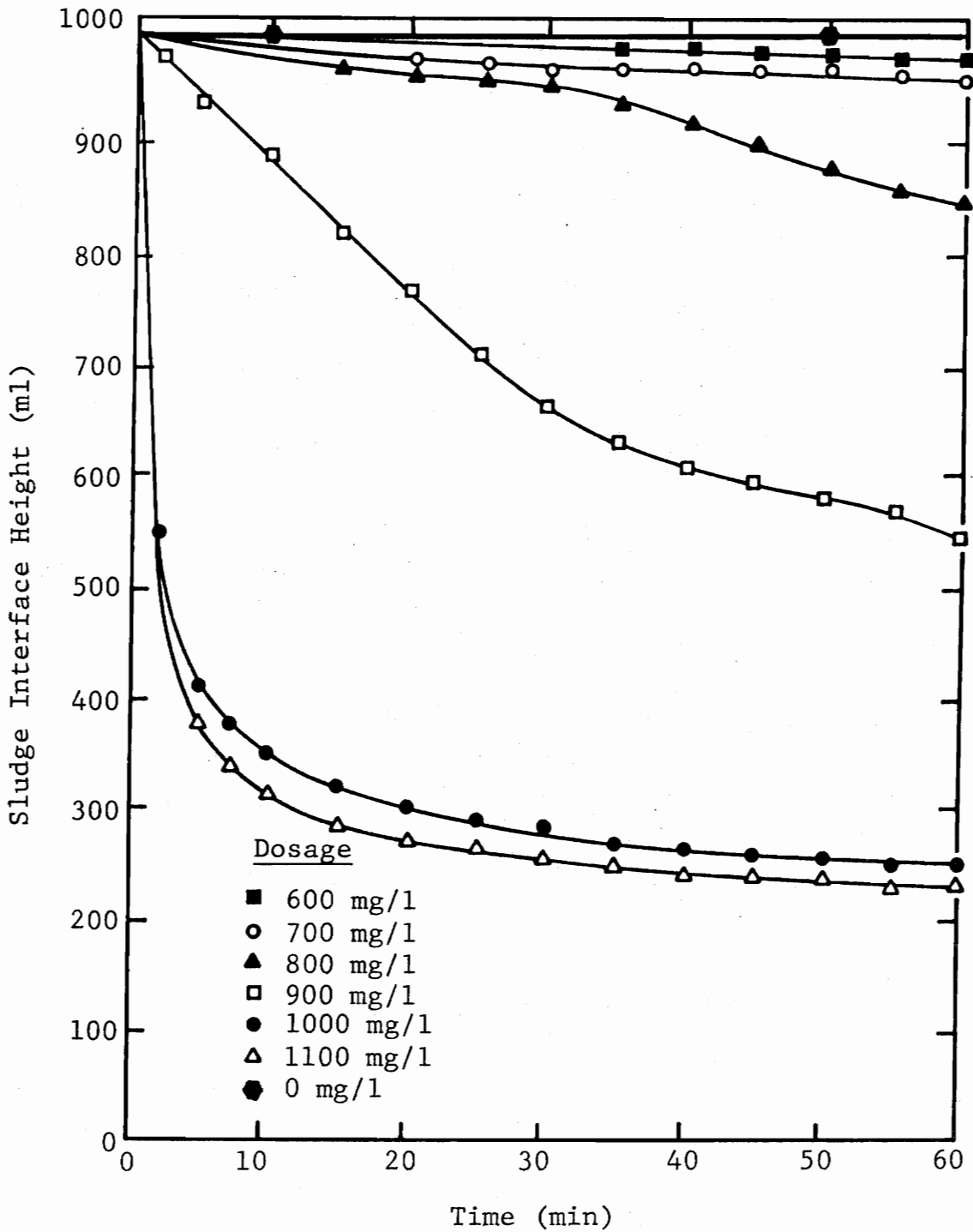
Figure 8. Settling curves for ferric chloride. MLVSS = 3050 mg/l.
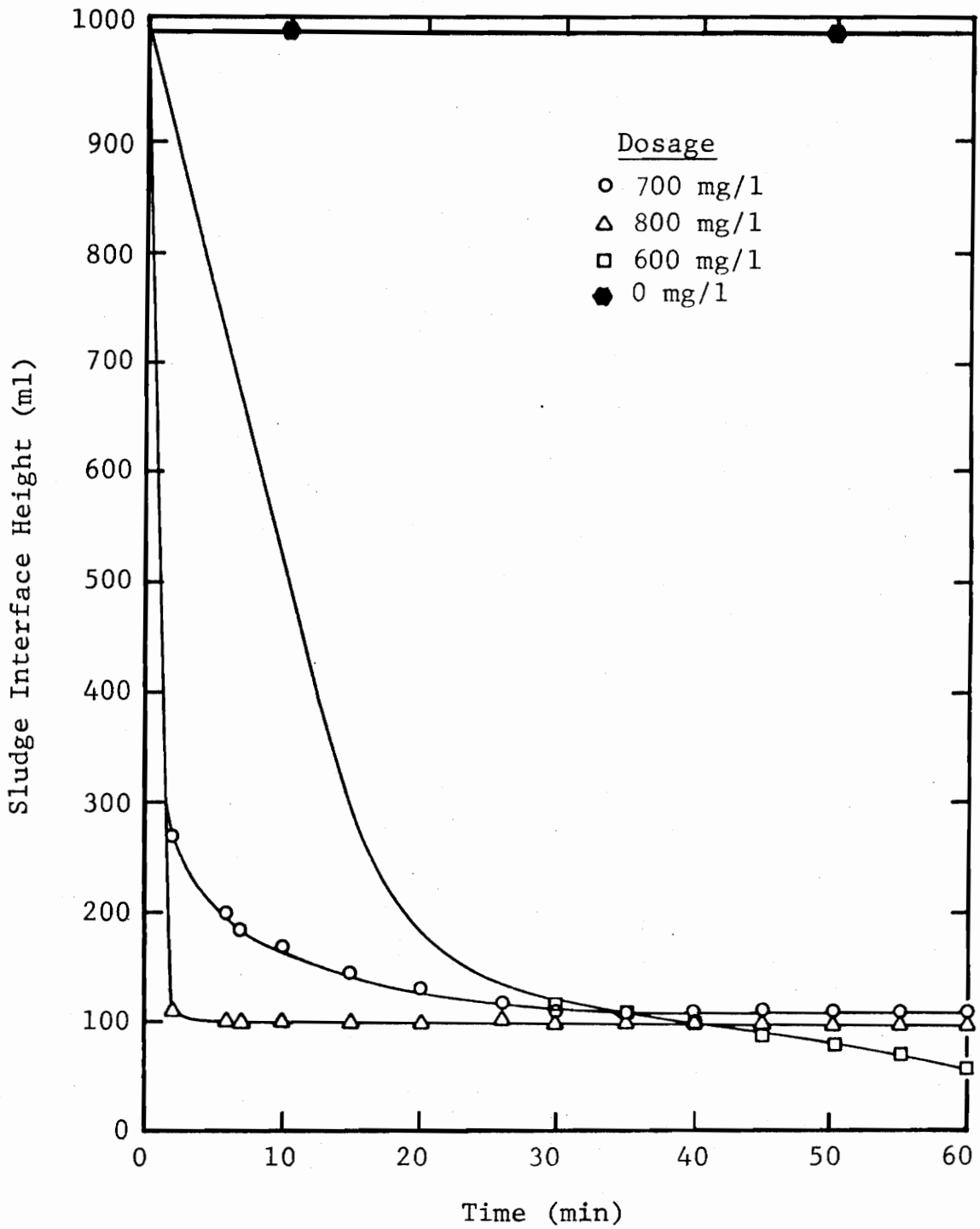
Figure 9.   Settling curves for cationic polymer.   MLVSS = 3050 mg/l.

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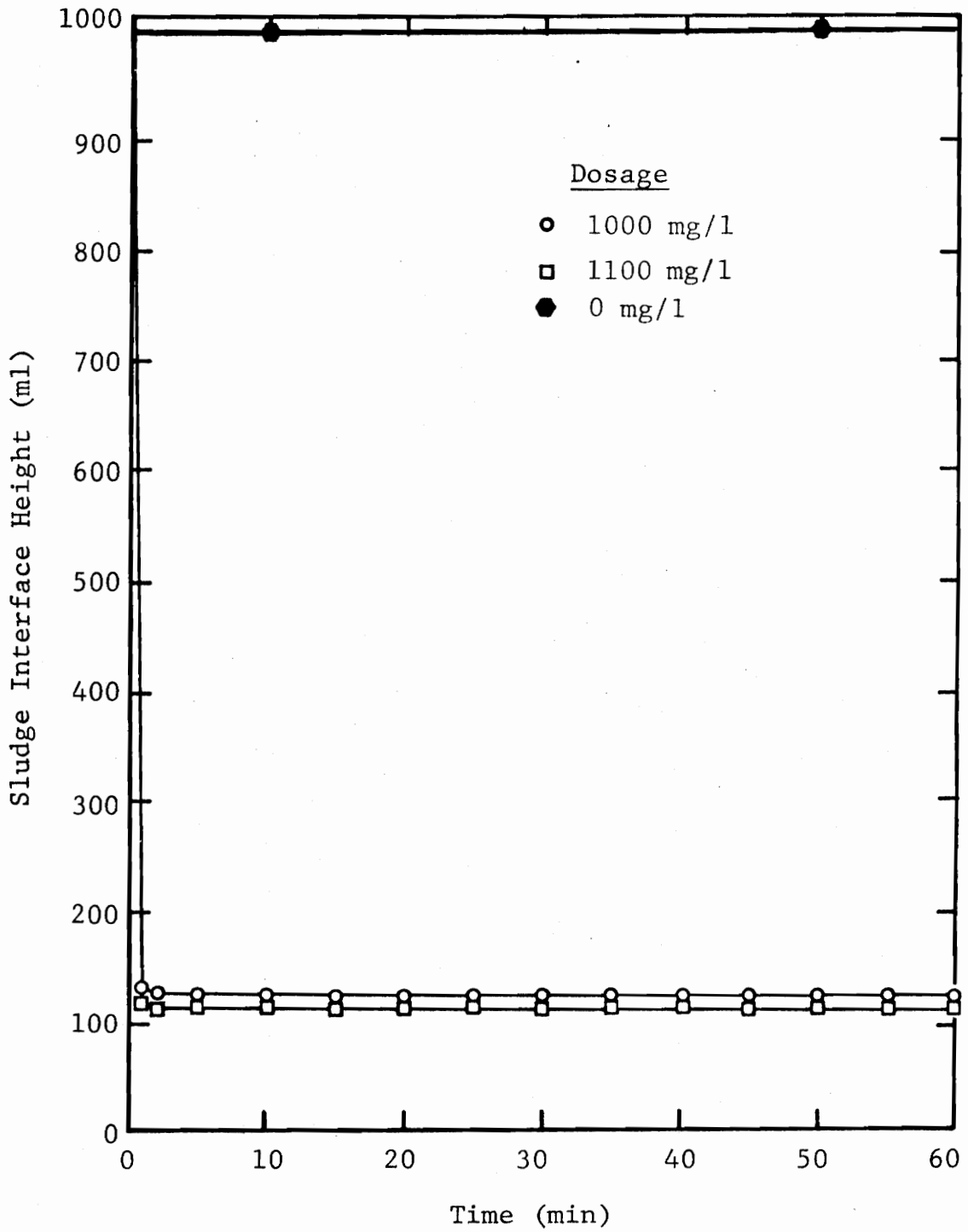
Figure 10.   Settling curves for cationic polymer.   MLVSS
= 3050 mg/l.

as at the 500 mg/l dose. Visual observations of the floc particle size revealed that it increased with coagulant dosage up to 500 mg/l and then began to decrease as higher dosages were used.

At 1125 mg/l MLVSS concentration, only the 200 mg/l polymer dosage failed to produce any settling at all. As can be seen in Figure 4, the difference in effectiveness of the coagulant as the dosage was increased was much more marked for the cationic polymer than for the metal salts. The settling curves showed that at the most effective polymer dosages, settling was extremely rapid. Once the rapid phase of settling was complete, significant additional settling occurred.

With a MLVSS concentration of 1950 mg/l, alum produced more rapid settling than at the 960 mg/l MLVSS concentration. Figure 6 demonstrates that ferric chloride continued to produce rapid settling rates at the higher MLVSS concentration. The cationic polymer dosed samples shown in Figure 7, continued to exhibit the most marked improvement in settling rates as dosages were increased. At the higher polymer dosages, settling was very rapid and practically complete before ten minutes of settling time had elapsed.

At a MLVSS concentration of approximately 3000 mg/l, no settling could be achieved using the coagulant

doses previously found to be effective (200 mg/l to 700
mg/l). The settling tests were rerun using a coagulant
dosage range of 600 mg/l to 1100 mg/l. Alum proved to be
ineffective in coagulating the 3000 mg/l MLVSS samples even
at the higher dosage range. Figure 8 demonstrates that
high ferric chloride dosages were effective in coagulating
the more concentrated mixed liquor. The cationic polymer
also produced effective settling at the high range of
coagulant dosages necessary for the 3000 mg/l MLVSS concen-
tration sample. An increase in polymer dosage increased
the settling rate to a small degree, but it had little
effect upon the volume to which the sludge eventually
settled.

The SVI is defined so as to imply that the lower the
SVI value, the better the settling properties of the
sludge. In the case of normal activated sludge, a SVI of
120 or below is considered to be a good settling sludge.
Sludge volume indexes between 120 and 200 constitute a
hazy area of classification between a good settling
sludge and a bulked sludge. A sludge having a SVI greater
than 200 is generally considered to be a bulked sludge.

Caution should be employed in interpreting the SVI
data presented in Appendix Tables 1 through 11. In some
samples a very definite interface developed between the
coagulated sludge and the supernatant, but the supernatant

still retained a large proportion of the biological
solids. The SVI test presupposes that very little sludge
remains in the supernatant after settling. When this is
not the case, the actual SVI numbers can be deceiving.

As the investigation progressed an interesting, and
perhaps, predictable, correlation began to appear. In
most cases the sludge volume index varied directly as
the observed size of the floc particles. For instance,
the 1000 mg/l MLVSS concentration sample being coagulated
with ferric chloride yielded floc sizes which increased
as the coagulant dosage was increased from 300 mg/l to
500 mg/l. Dosages of 600 mg/l and 700 mg/l produced
successively smaller floc sizes. This trend is reflected
by the sludge volume indexes at these coagulant concen-
trations.

Supernatant Volatile Suspended Solids

The concentration of the supernatant volatile sus-
pended solids gives some indication of the effectiveness
of a coagulant. As has been pointed out previously,
knowledge of the supernatant volatile suspended solids
concentration is necessary in order to properly evaluate
sludge volume index data.

From the standpoint of determining the overall
effectiveness of a sewage treatment plant, the super-
natant volatile suspended solids is perhaps the most

important parameter. The ultimate test of treatment plant efficiency is the determination of the oxygen demand of the effluent. Since any suspended organic material which flows over a settling basin weir will cause an effluent oxygen demand, minimization of the supernatant volatile suspended solids is important. Supernatant volatile suspended solids results are plotted versus coagulant dosage in Figures 11, 12, and 13.

pH

As was predicted in the discussion of the coagulation effects of metal salts, the mixed liquor sample pH dropped whenever a metal salt was added to it. Effluent pHs are depicted in Figures 14, 15, and 16, where pH is plotted versus coagulant dosage. In every instance a larger pH reduction was associated with the use of ferric chloride than with the use of alum (assuming equal coagulant doses). Also shown in these figures are the effects of various dosages of cationic polymer upon pH. The polymer produced no significant reduction in pH.

Dissolved Oxygen Uptake

Figures 17, 18 and 19 give the dissolved oxygen uptake rate as a function of coagulant dosage. As coagulant dosage increased, the dissolved oxygen uptake rate decreased in almost every case. The exception was
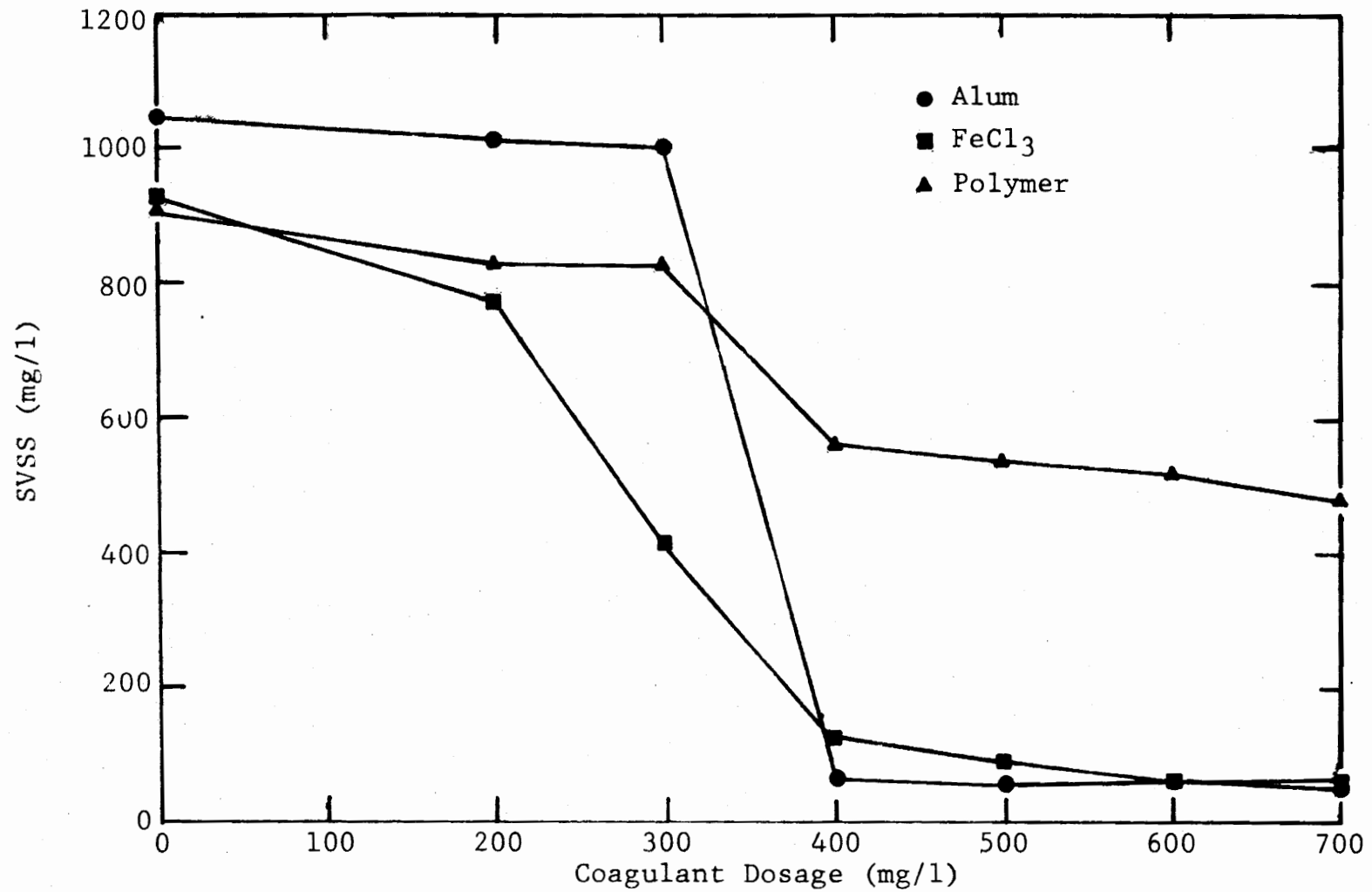
Figure 11. Variation of supernatant volatile suspended solids concentration (SVSS)
with coagulant dosage for MLVSS ≅ 1000 mg/l.
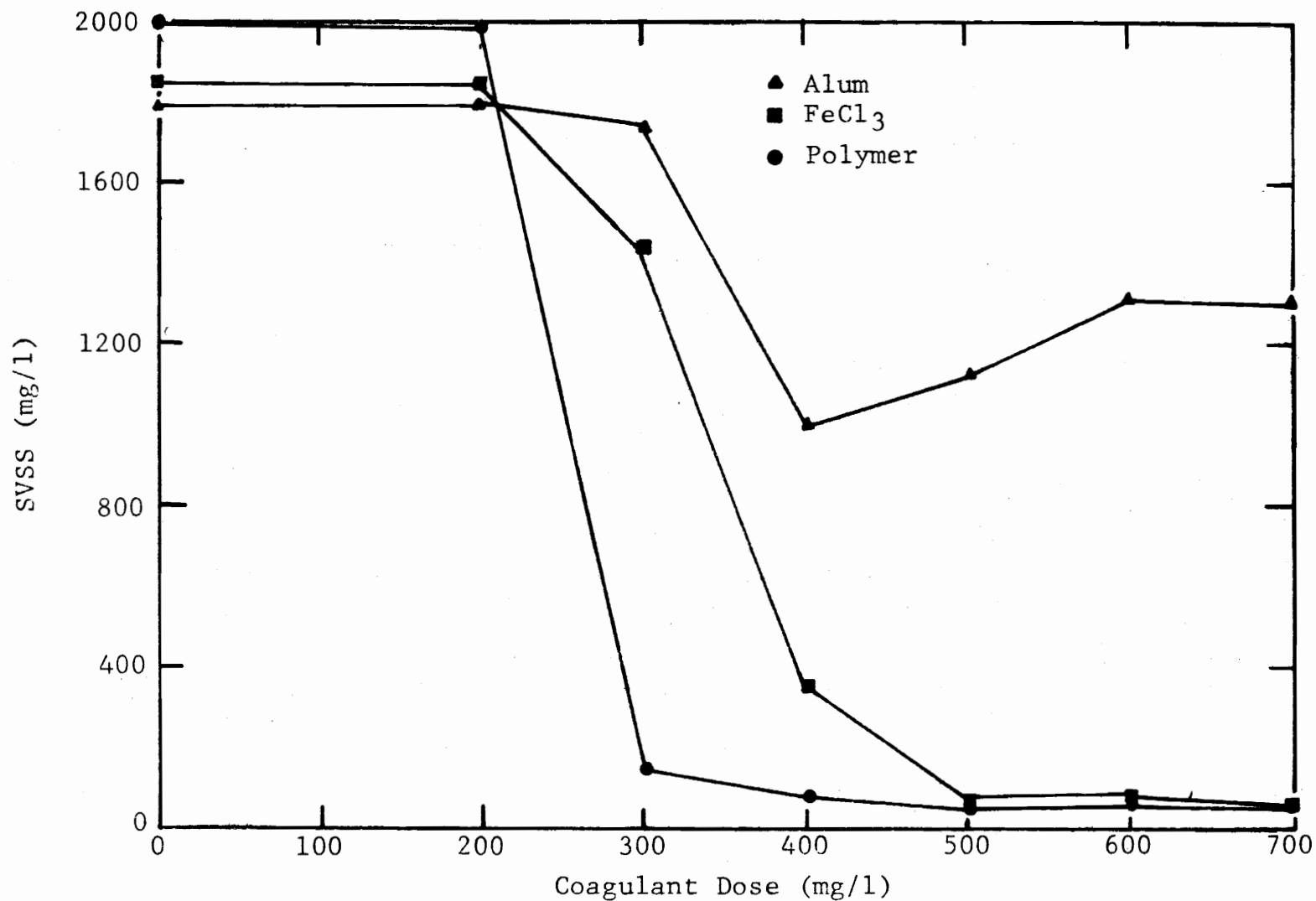
Figure 12. Variation of supernatant volatile suspended solids concentration (SVSS) with coagulant dosage for MLVSS ≅ 2000 mg/1.
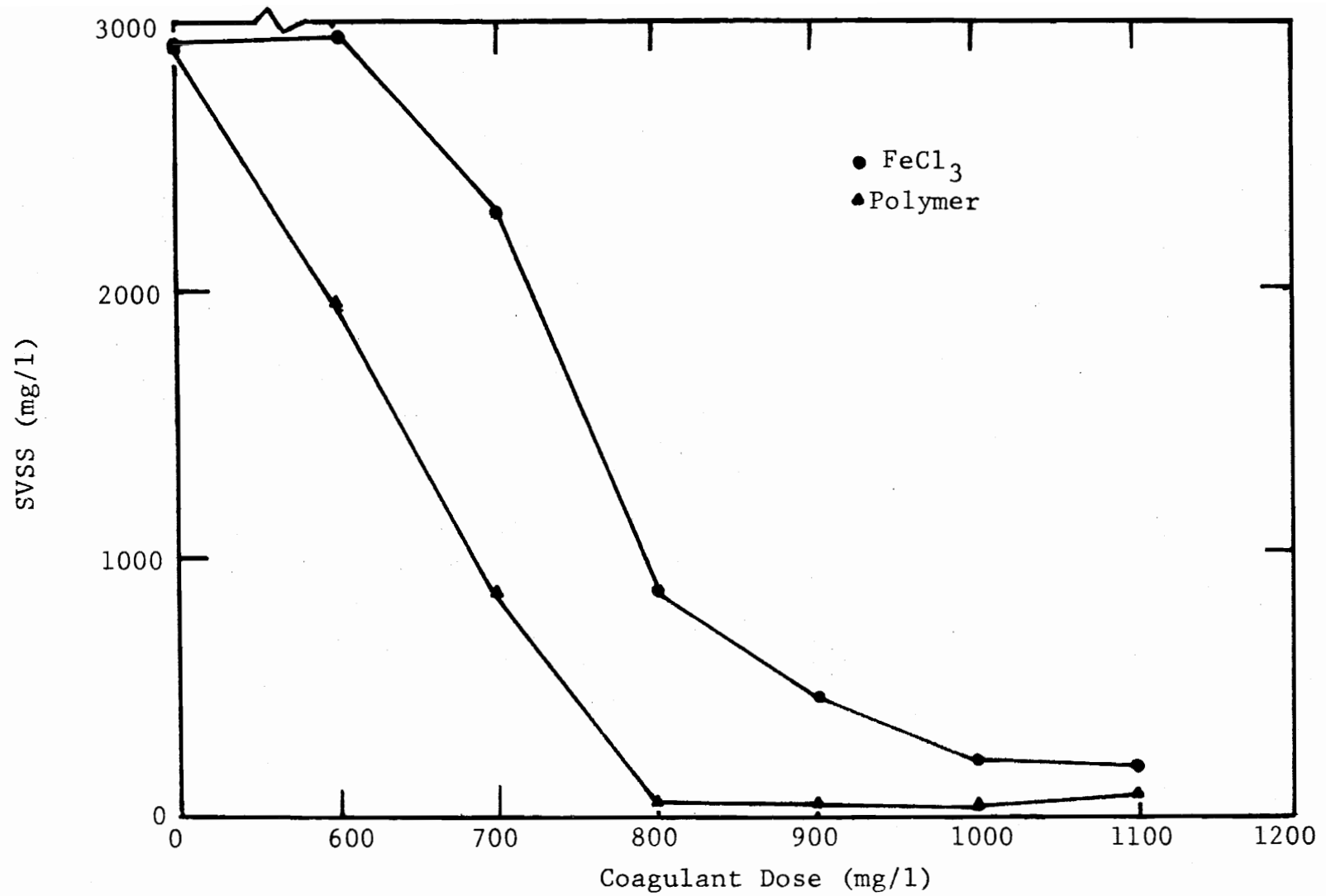
Figure 13. Variation of supernatant volatile suspended solids (SVSS) with coagulant dosage for MLVSS $\simeq$ 3000 mg/l.

50
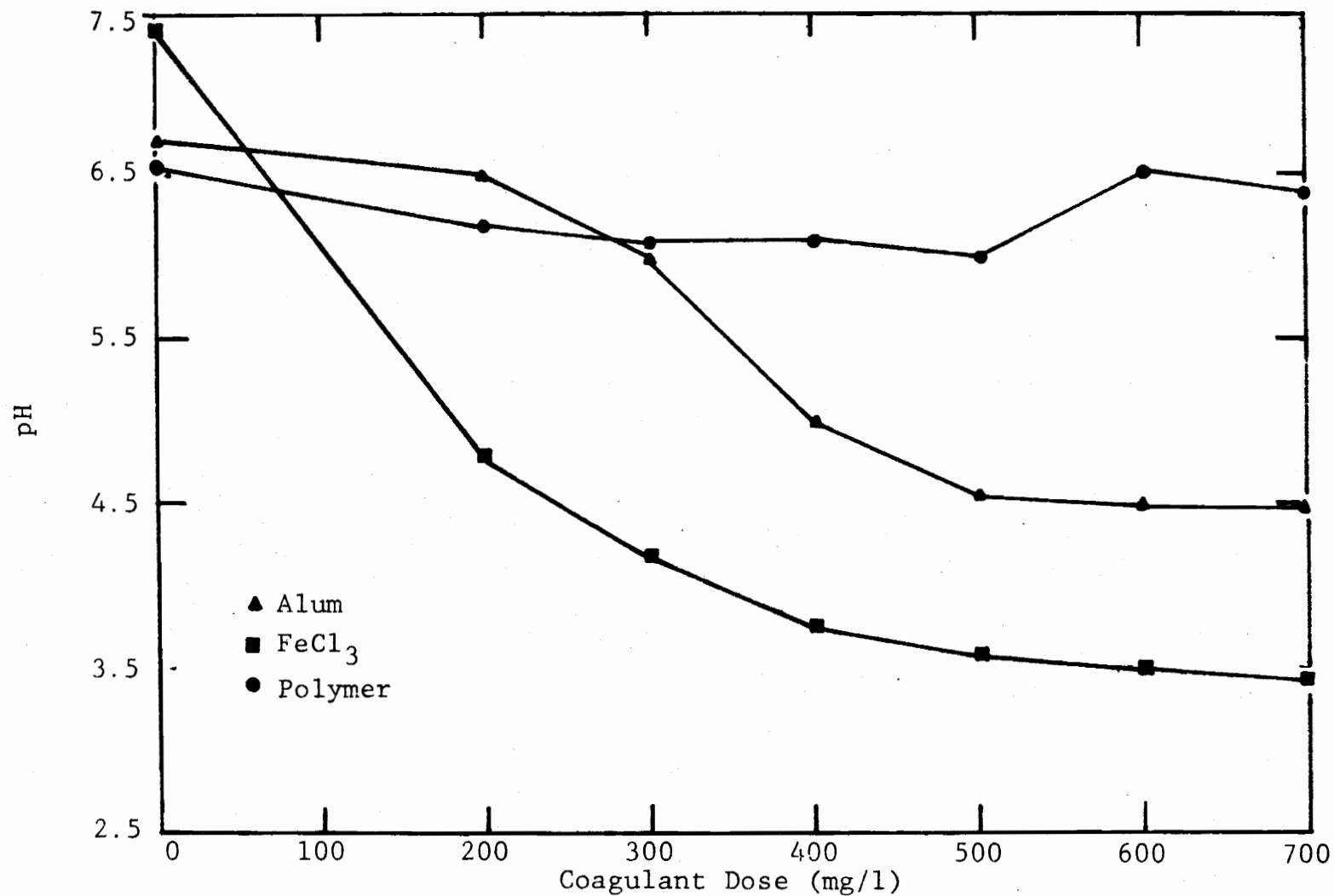
Figure 14.   Variation of supernatant pH with coagulant dosage for MLVSS ≈ 1000 mg/l.

51
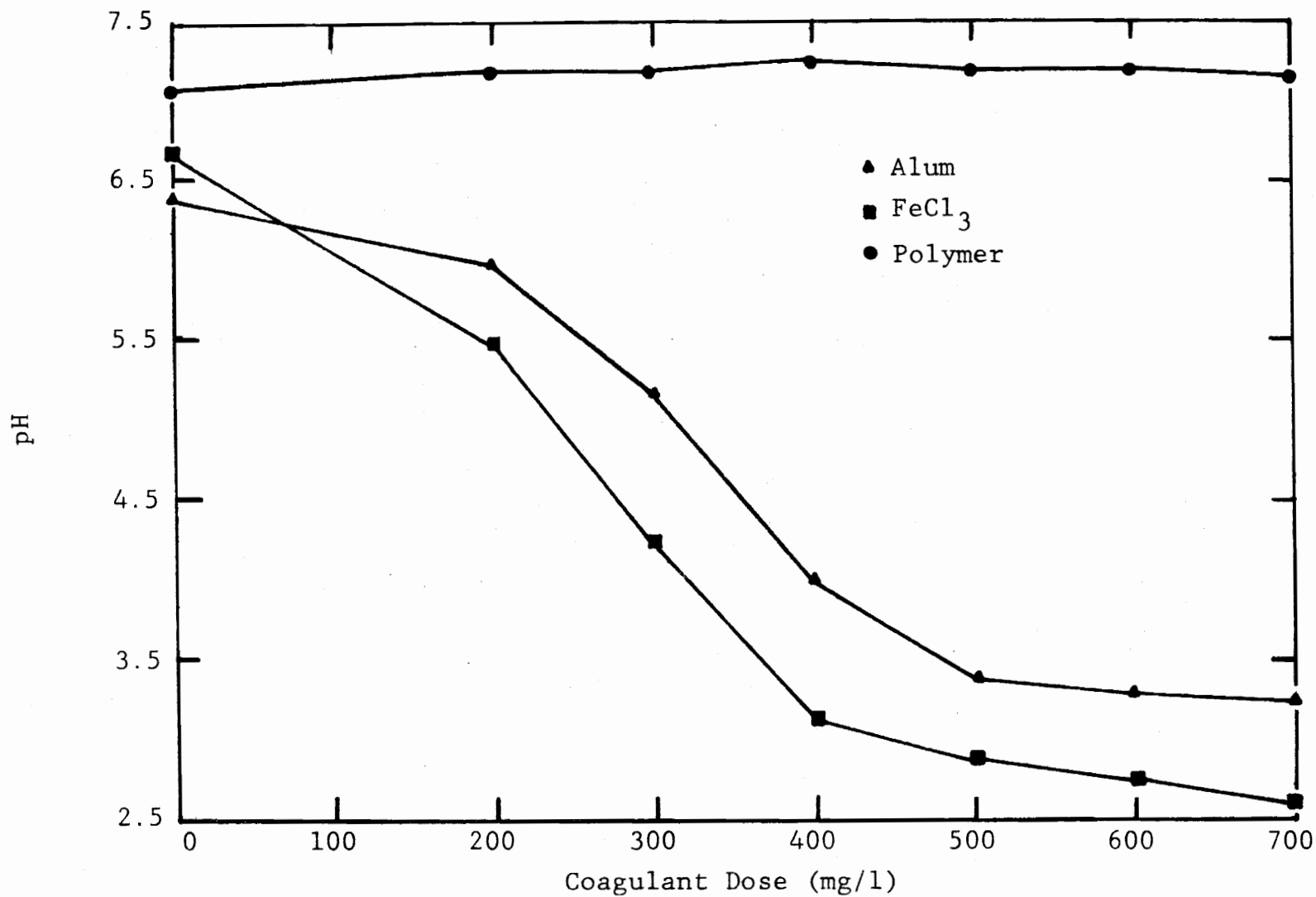
Figure 15.   Variation of supernatant pH with coagulant dose for MLVSS ≈ 2000 mg/l.
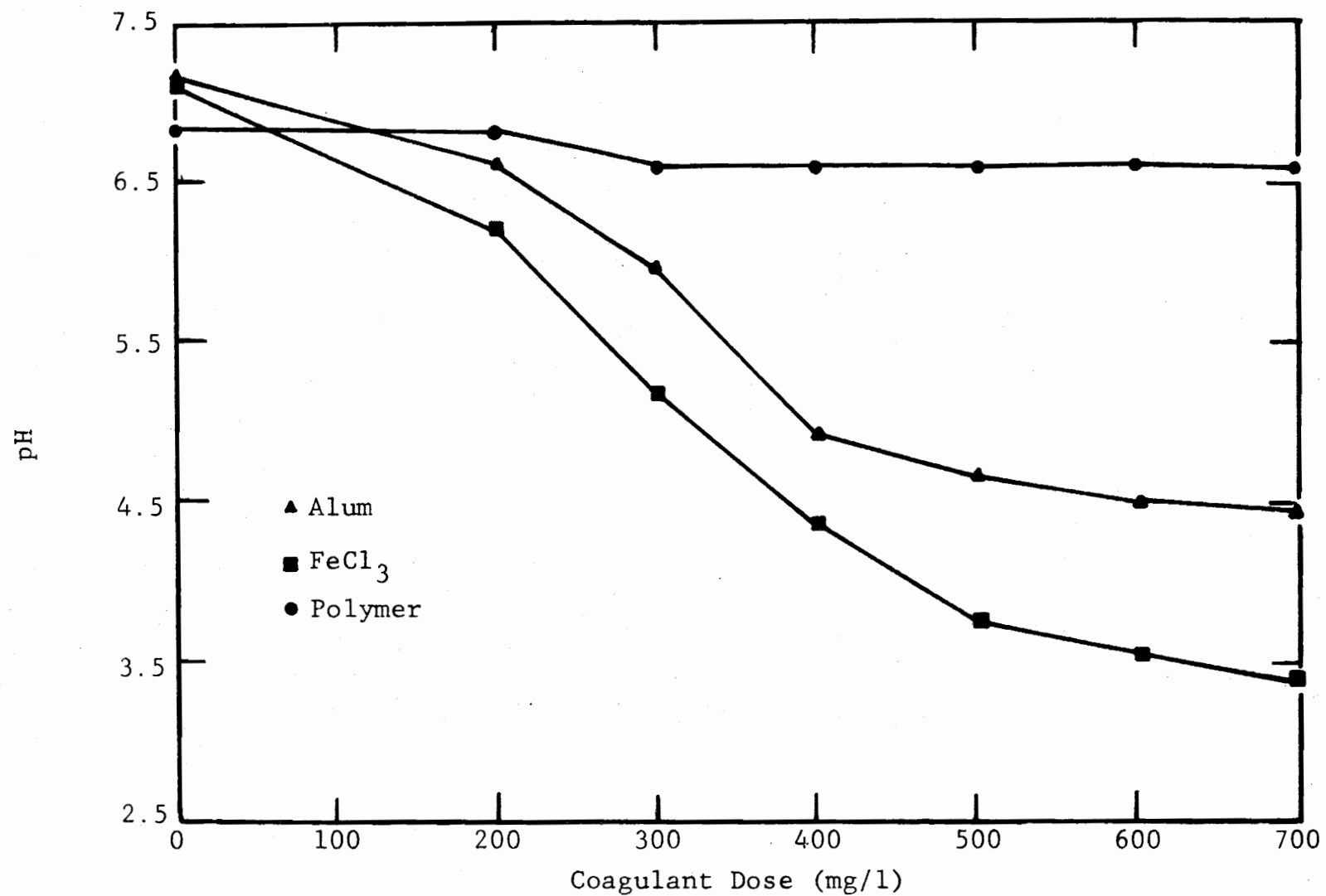
Figure 16.   Variation of supernatant pH with coagulant dosage for MLVSS ≃ 3000 mg/1.

53
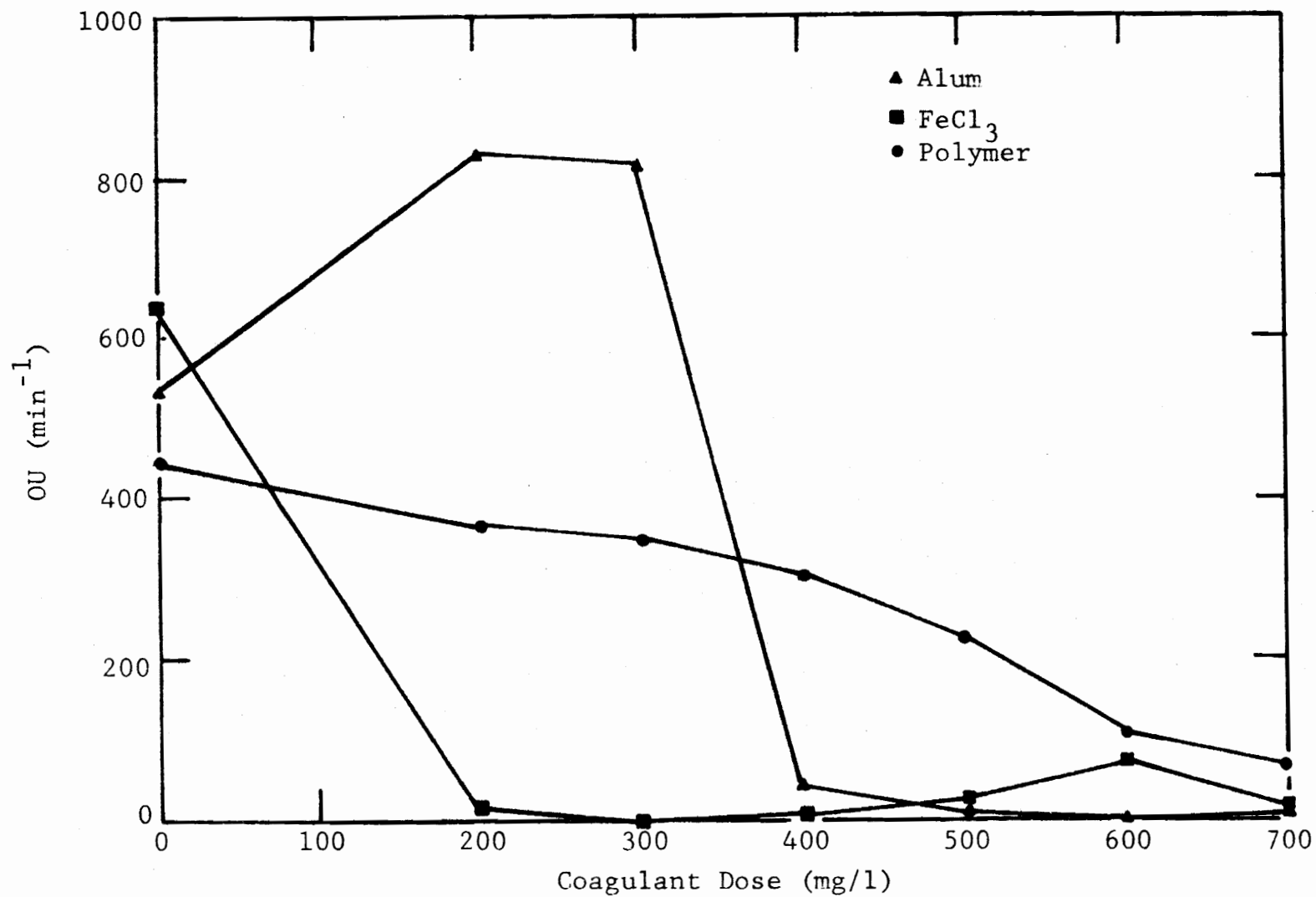
Figure 17.   Variation of oxygen uptake (OU), $\dfrac{dO_2/dt}{\text{MLVSS}}$, with coagulant dosage for MLVSS $\simeq$ 1000 mg/1.
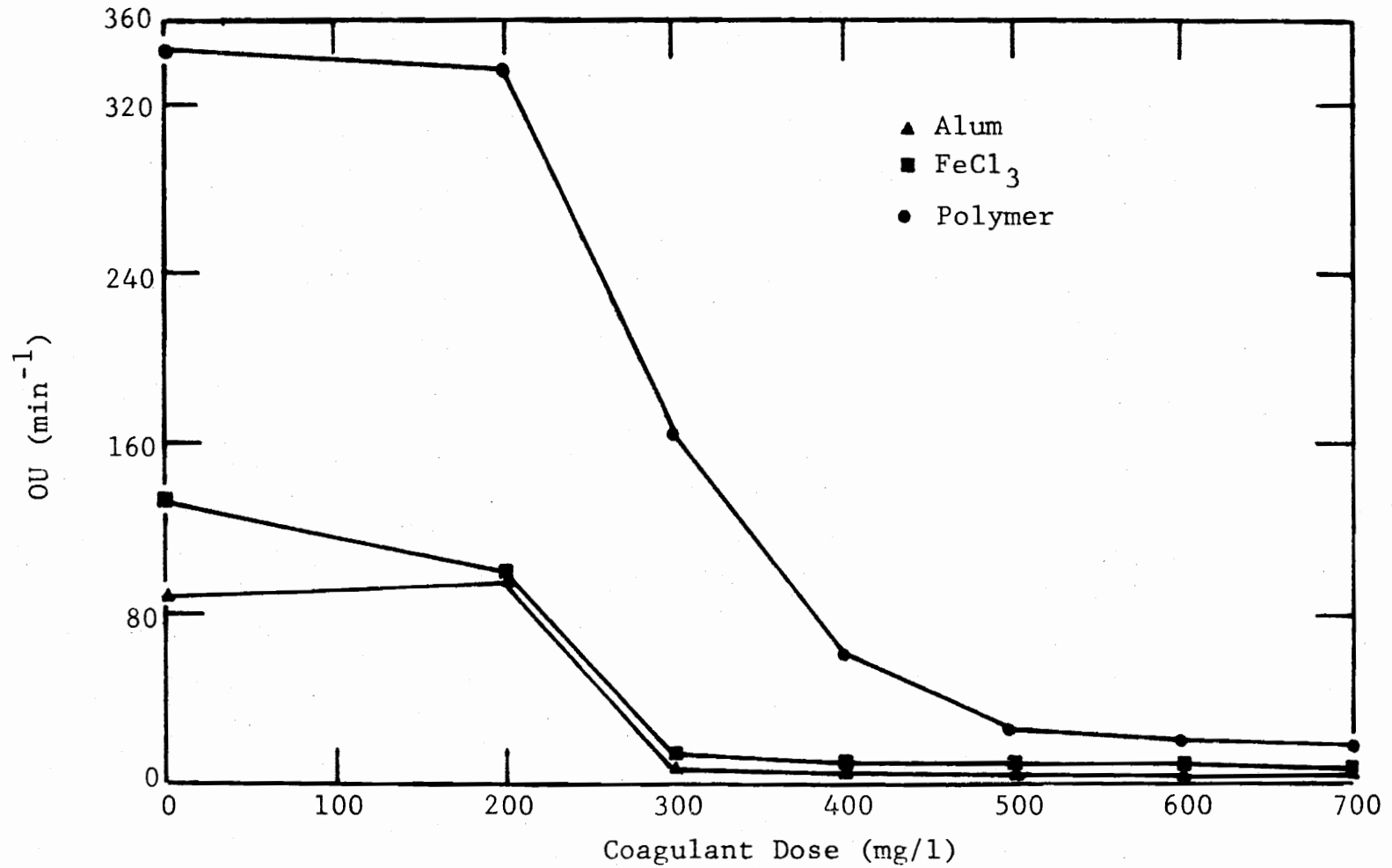
Figure 18. Variation of oxygen uptake (OU), $\dfrac{dO_2/dt}{\overline{MLVSS}}$, with coagulant dosage for MLVSS $\simeq$ 2000 mg/l.
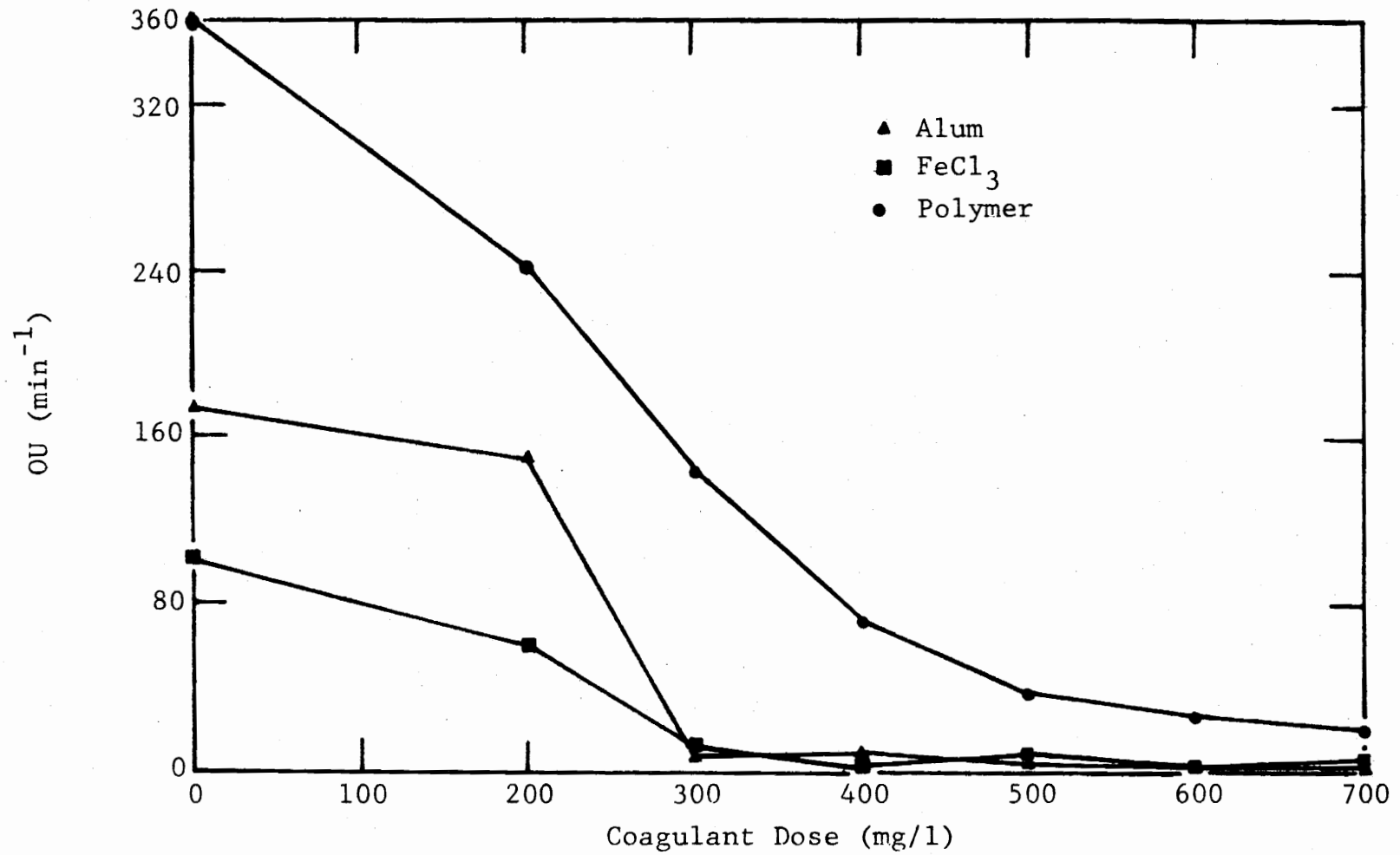
Figure 19. Variation of oxygen uptake (OU), $\dfrac{dO_2/dt}{\text{MLVSS}}$, with coagulant dosage for MLVSS $\cong$ 3000 mg/l.

the use of alum to coagulate 960 mg/l and 1950 mg/l MLVSS concentrations. At alum dosages of 200 mg/l and 300 mg/l there appeared to be some stimulation of oxygen uptake. The uptake rate increase was greater in the 960 mg/l MLVSS sample than in the 1950 mg/l MLVSS sample while no increase was observed in the 3155 mg/l MLVSS sample. When the dissolved oxygen uptake rates were very low, they began to vary randomly instead of keeping to the trend of uptake reduction accompanying increased coagulant dosages. This was considered to be related to the accuracy of the measurement procedure rather than of true significance.

Initial oxygen uptake rates associated with the coagulated mixed liquor samples tended to vary a great deal. Possible explanations for this were that the bacteria had not gone endogenous in the time allotted for them to do so, a population shift in the bacteria occurred, or some toxin was secreted by the bacteria in the batch tank and when the samples were diluted to produce the desired MLVSS concentration, the toxin was diluted to a more acceptable level. This problem was dealt with by expressing the oxygen uptake in each coagulated sample as a percentage of the oxygen uptake in the uncoagulated sample. See Figures 20, 21, and 22.
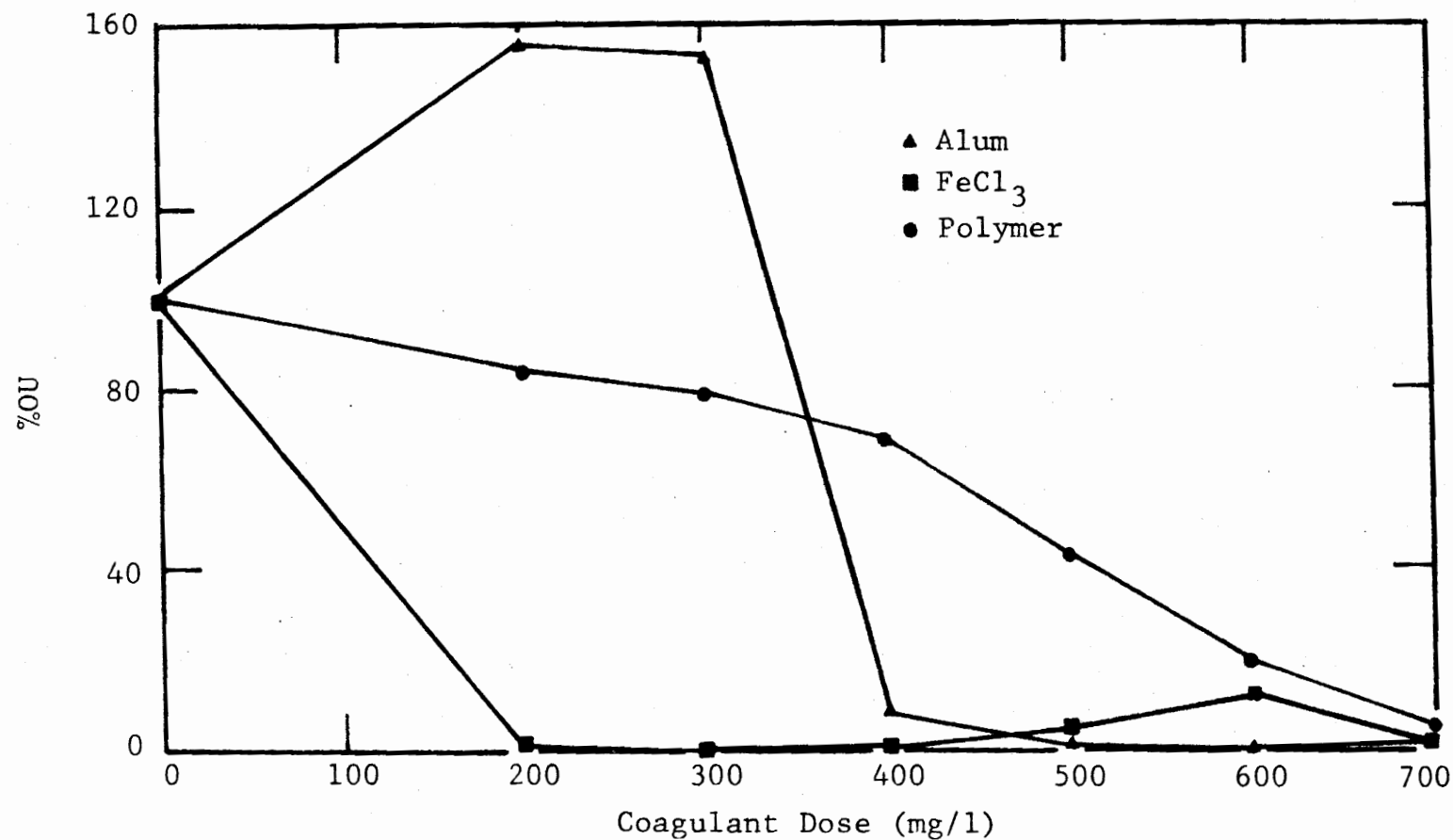
Figure 20. Variation of percentage of initial oxygen uptake (% OU) with coagulant dosage for MLVSS ≐ 1000 mg/l.
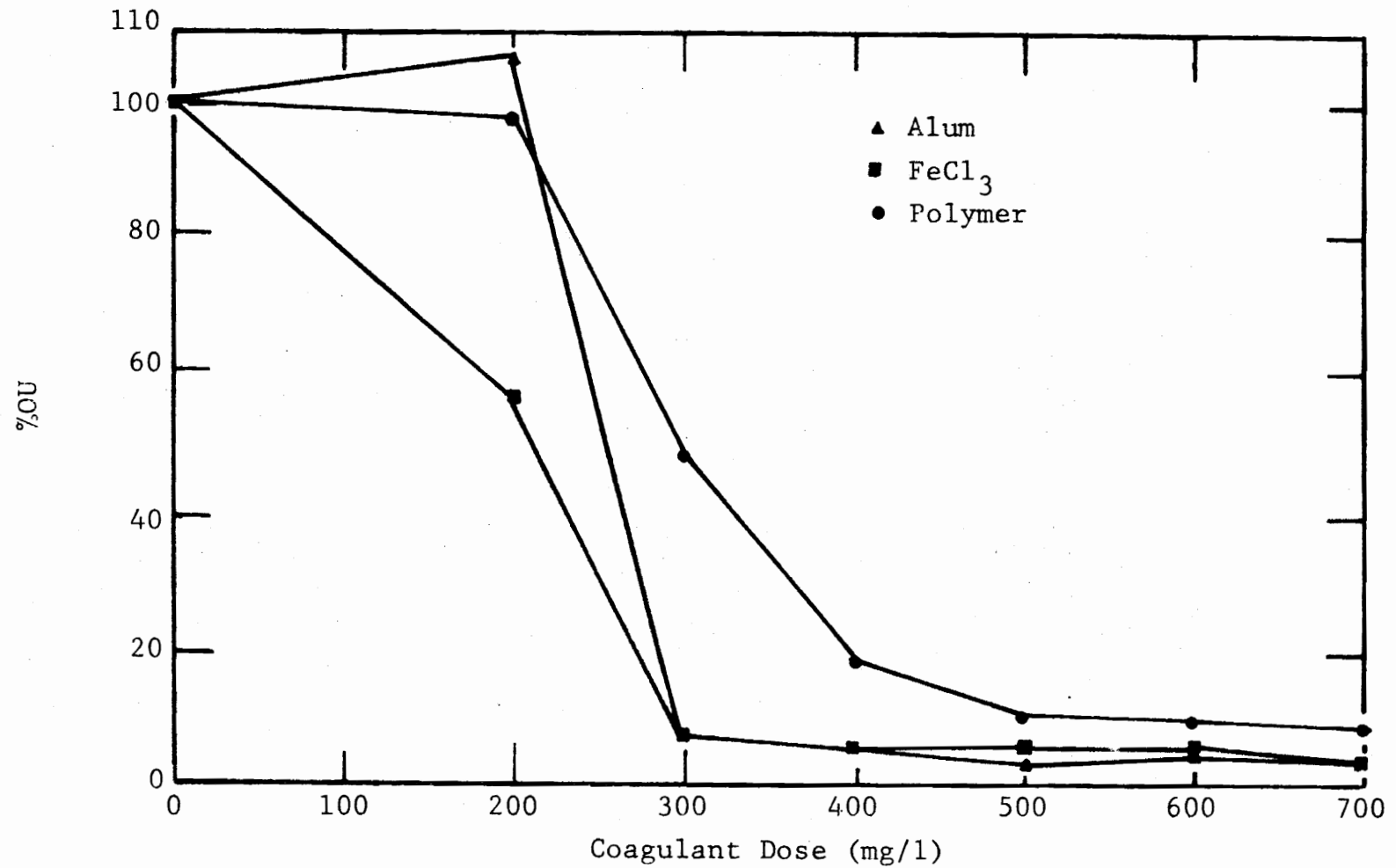
Figure 21.   Variation of percentage of initial oxygen uptake (%OU) with coagulant dosage for MLVSS ≈ 2000 mg/1.

59
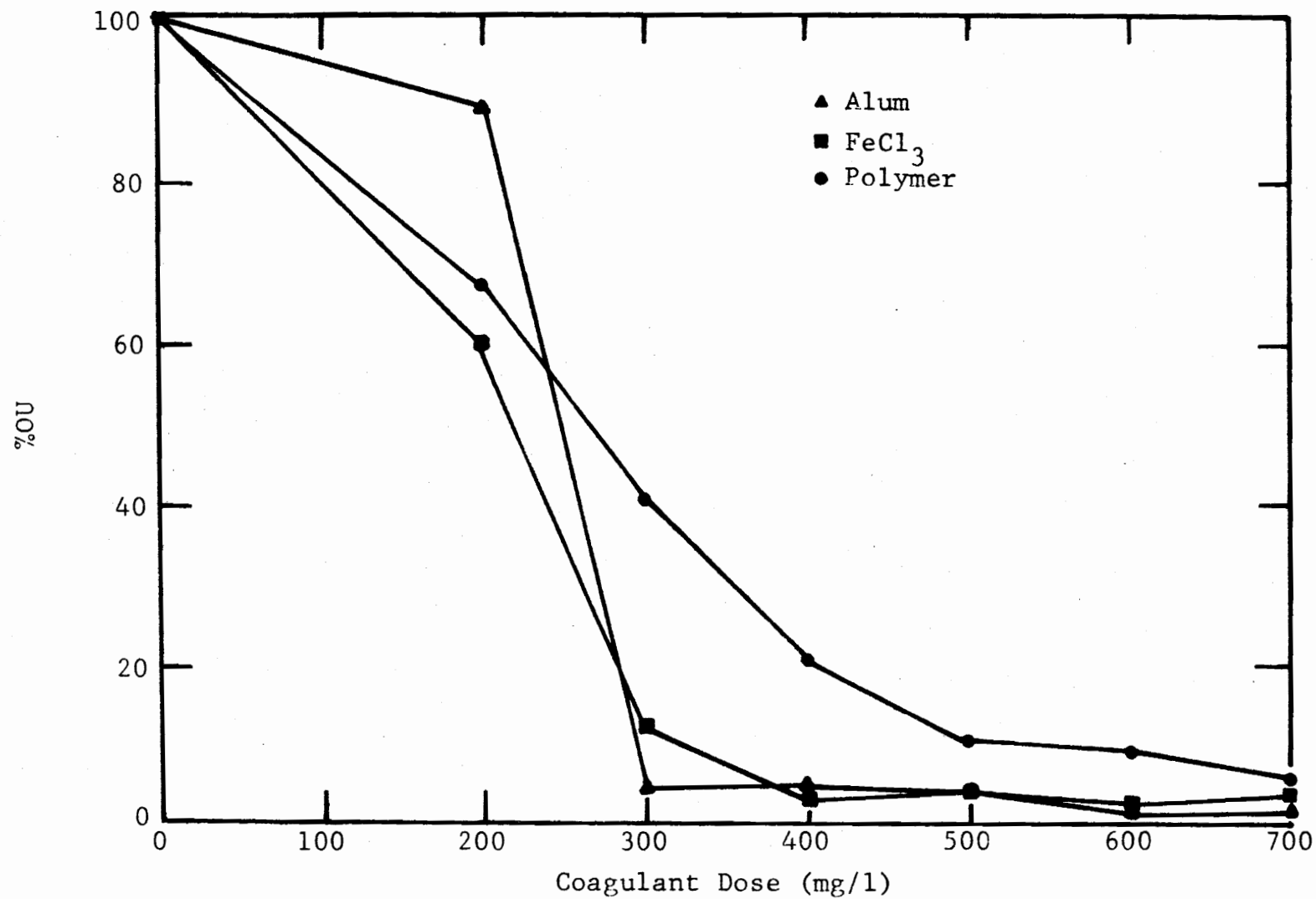
Figure 22. Variation of percentage of initial oxygen uptake (%OU) with coagulant dosage for MLVSS ≃ 3000 mg/1.

Buffered Coagulant Samples

To accurately determine the effects of the metal salt coagulants on the microorganisms, it was necessary to eliminate the normal pH drop that occurs. To do so, tests were run with buffered coagulant samples. Settling curve results are shown in Figure 23, while other results of these tests have been tabulated in Table 1.

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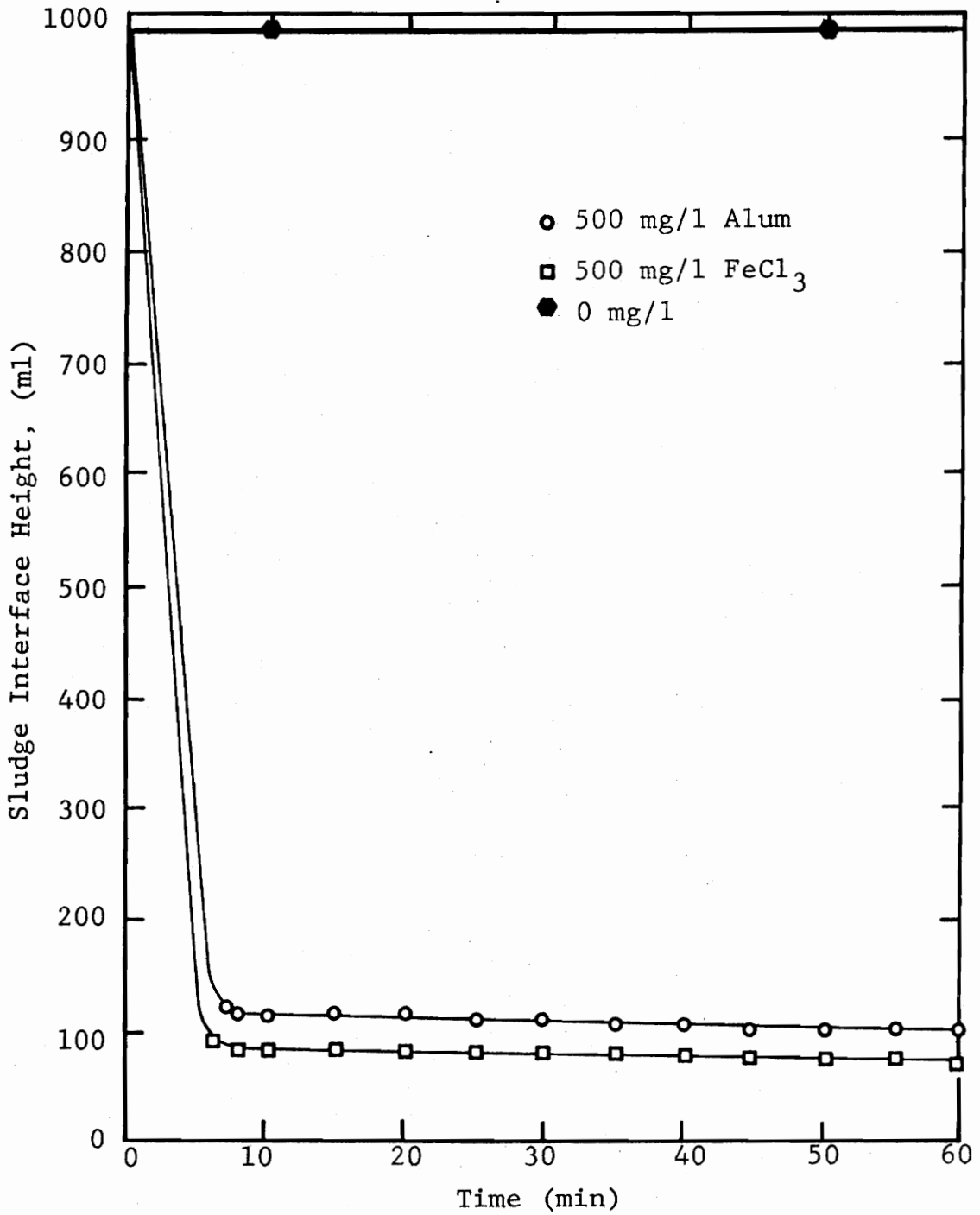
Figure 23. Settling curves for buffered coagulant dosages
with a MLVSS concentration of 865 mg/1.

Table 1. Data from buffered coagulant studies.

Run 1   MLVSS = 1350 mg/1

Coagulant/dosage (mg/1):	none/0	alum/500	FeCl$_3$/500
Oxygen uptake X 10^6:	398	436	428
% of control oxygen uptake:	100	110%	108

Run 2   MLVSS = 865 mg/1

Coagulant/dosage (mg/1:	none/0	alum/500	FeCl$_3$/500
Oxygen uptake X 10^6:	325	336	310
% of control oxygen uptake:	100	103	95

Settling data for buffered coagulant run. mg/1 MLVSS concentration.

Coagulant/dosage mg/1	Supernatant Volatile Suspended Solids (mg/1)	SVI	Hour SVI
Alum/500 mg/1	407	124	112
FECl$_3$/500 mg/1	642	90	79

V.   DISCUSSION OF RESULTS

This chapter is designed to reveal and expand upon
points which may be interpreted from data presented
previously.   In the performance of this objective it
is perhaps best to divide the subject matter at hand into
broad catagories of settling characteristics and factors
affecting dissolved oxygen uptake.

Throughout the time that this research was being
conducted the bacterial population was changing.   The
reduction of filaments in the mixed liquor is just one
example of this.   Because of this shifting population and
the unique manner in which it was produced, the individual
numbers presented in the data are not nearly as important
as the trends that can be observed when these numbers are
composited.

Settling Characteristics

This investigation was performed under what has been
described by Pipes (20) as dispersed growth conditions.
No improvement in unaided settling was observed despite
the fact that the quantity of filaments was observed to be
steadily decreasing.   This indicates that bulking was of
the non-filamentous variety and probably attributable to
a high proportion of bound water as described by
Heukelekian and Weisburg (12).   Even after an hour's

settling time the mixed liquor showed no inclination whatsoever to settle.

Pipes (20) maintains that any treatment scheme in which the biological solids will not settle from the supernatant cannot be an activated sludge system. However, if a coagulant can be used to settle a bulking sludge under even the worst bulked conditions, represented here, then the return flow can be sufficient to maintain an activated sludge system.

Alum appeared to be somewhat effective in coagulating mixed liquor samples with relatively low volatile suspended solids concentrations. At a MLVSS concentration of 3155 mg/l, it had no effect whatsoever even though dosages up to 1100 mg/l were used. If one were to examine both the settling curves and sludge volume index figures for the alum coagulation of mixed liquors with volatile suspended solids concentrations of 960 mg/l and 1950 mg/l, it would appear that the coagulant's effectiveness increases with MLVSS concentration. Such is not the case. Supernatant volatile suspended solids figures reveal that when the 1950 mg/l sludge was settled with alum, more than half of the volatile suspended solids remained in the supernatant. Though alum produced a slightly better supernatant when coagulating a 960 mg/l MLVSS sludge, settling was poor and the sludge volume

index was at an unacceptably high level for the range of coagulant dosages used. If alum were to be used to coagulate a mixed liquor of this type, the MLVSS concentration would have to be low (below 1000 mg/l).

Ferric chloride gave much better results in the settling tests. It proved to be effective at all three MLVSS concentrations (1000 mg/l, 1965 mg/l, and 3050 mg/l) though the 3050 mg/l MLVSS concentration tests required a ferric chloride range between 600 mg/l and 1100 mg/l. In every case, the ferric chloride dosage at the upper end of the dosage range used produced a supernatant with a volatile suspended solids concentration less than 100 mg/l. Effective concentrations of ferric chloride produced a rapidly settling sludge and a sludge volume index well within acceptable limits.

When ferric chloride was used to coagulate a mixed liquor with a volatile suspended solids concentration of 1000 mg/l, it was evident that overdosing with ferric chloride is possible. The observed floc size increased as expected when coagulant dosages were increased from 200 mg/l to 500 mg/l. As higher ferric chloride concentrations of 600 mg/l and 700 mg/l were used, the floc size became smaller. This phenomena can also be seen in the sludge volume index data. Though overdosing may have been detrimental to both floc size and sludge volume

index, it had no effect on the reduction of supernatant volatile suspended solids, however. They continued to decrease as the coagulant dosage was increased. The overdosing phenomenon was not really evident when ferric chloride was used to coagulate a 1965 mg/l MLVSS concentration sludge. This would indicate that the primary factor in creating an overdosed situation is the ratio of coagulant to biological solids.

A relationship was observed between the coagulant dosage per unit of MLVSS and supernatant quality, expressed in terms of the supernatant volatile suspended solids concentration. It can be seen in Figures 24, 25, and 26. As the ratio of coagulant to MLVSS increased, supernatant quality improved. This relationship was not well defined for alum use but a ratio of coagulant dose to MLVSS of 0.4 for ferric chloride and 0.3 for cationic polymer produced supernatants with volatile suspended solids concentrations of 100 mg/l or less. Further addition of coagulant brought about very limited reduction in supernatant volatile suspended solids.

In every situation tested, the performance of the cationic polymer improved with increasing polymer dosage. At optimum dosages, the polymer was the most effective of the three coagulants used in terms of settling rate, sludge volume index, and supernatant volatile suspended solids.
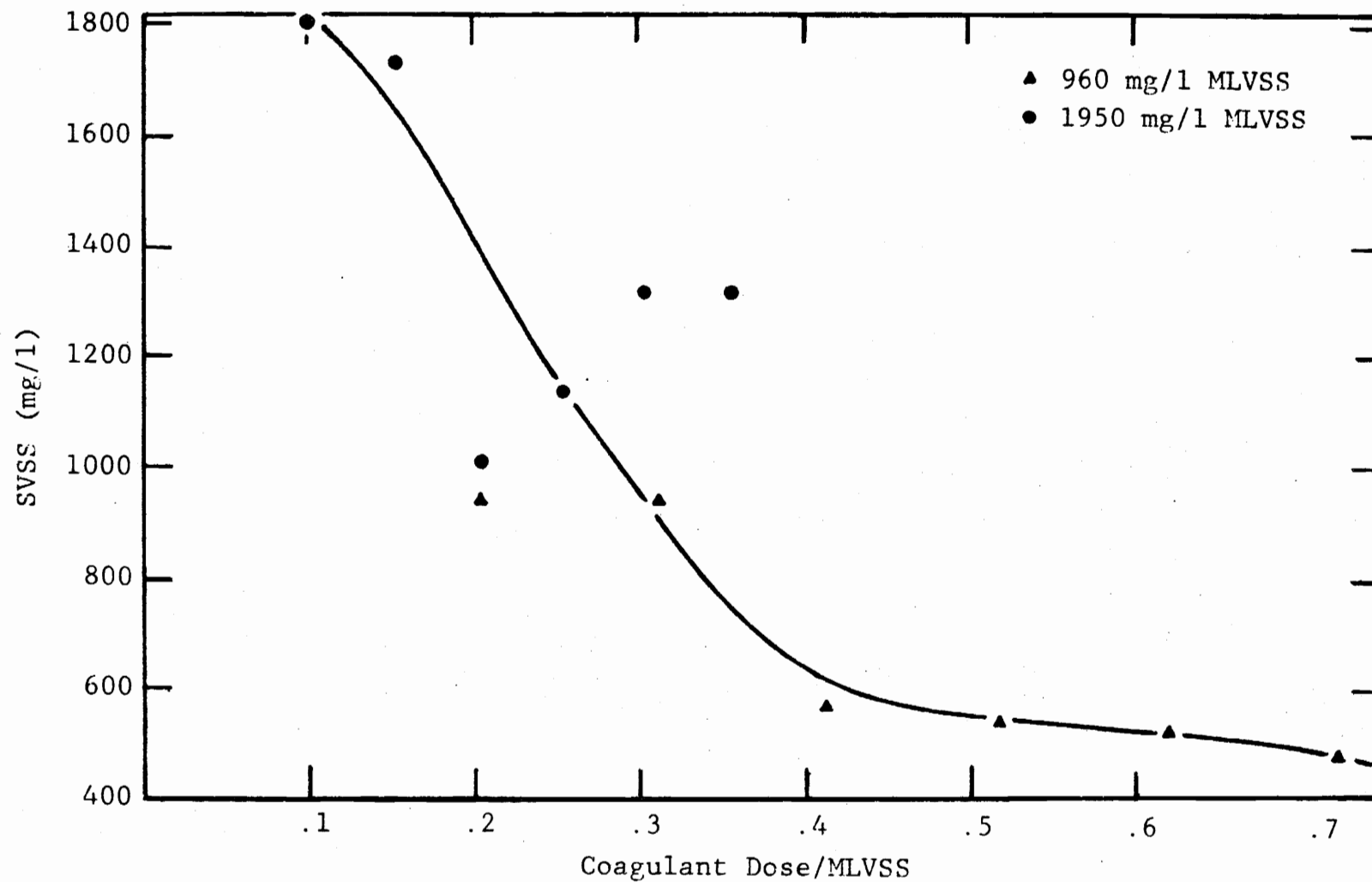
Figure 24.   Correlation of supernatant volatile suspended solids (SVSS) with alum dosage per unit MLVSS.
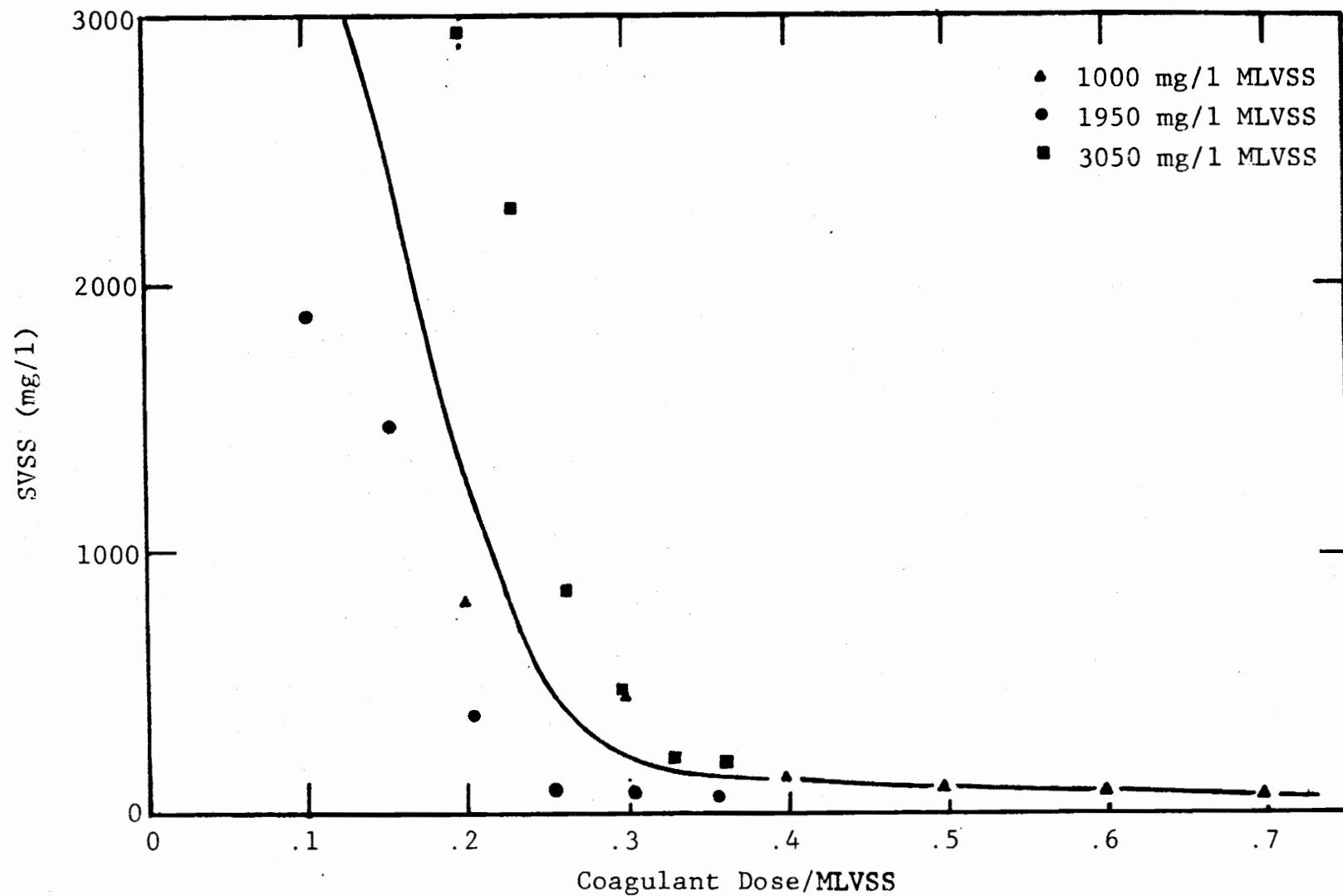
Figure 25. Correlation of supernatant volatile suspended solids (SVSS) with ferric
chloride dosage per unit MLVSS.
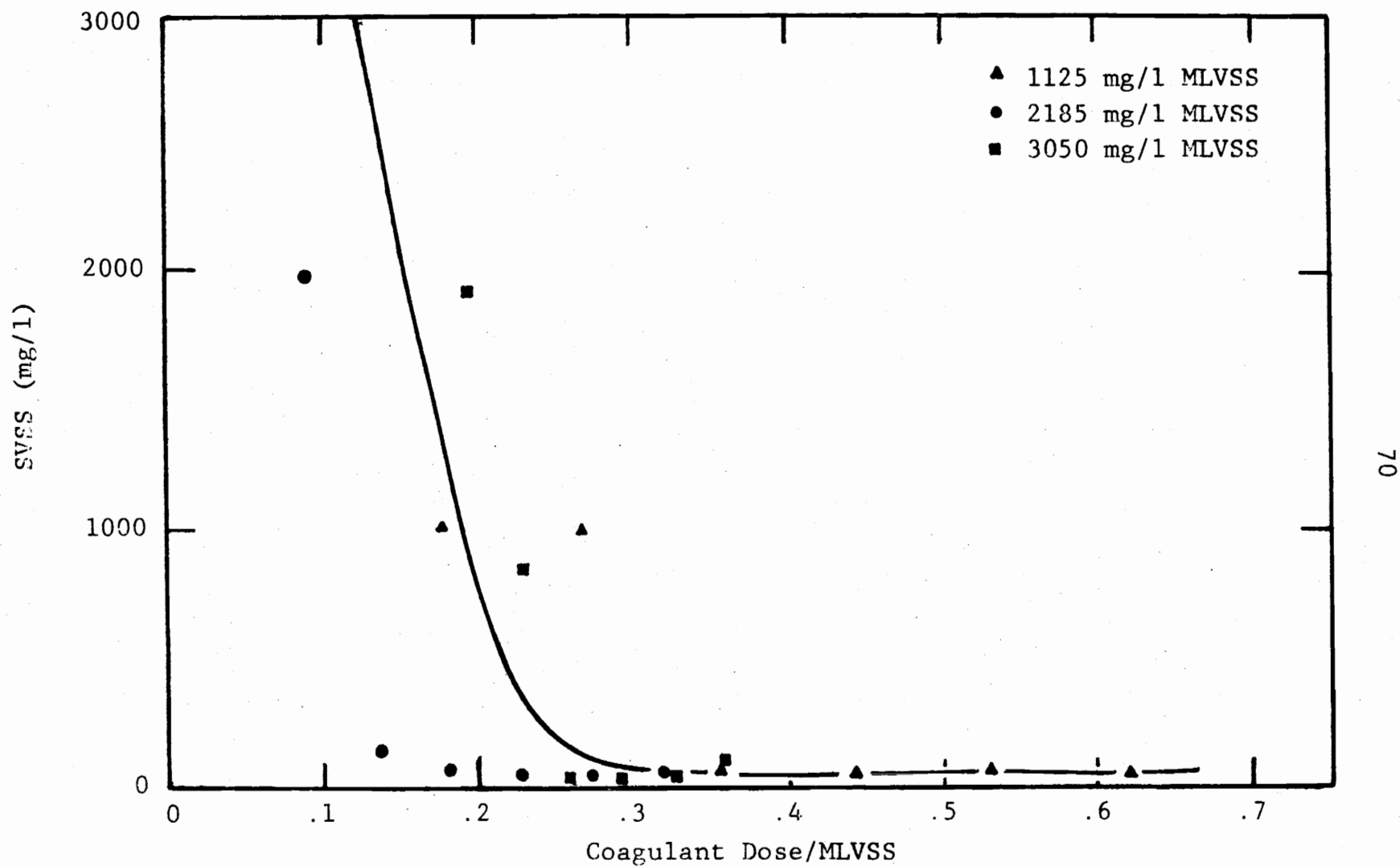
Figure 26.   Correlation of supernatant volatile suspended solids (SVSS) with polymer dosage per unit MLVSS.

Upon completion of the settling tests, the well coagulated samples required a great deal of agitation to break up the flocs. Even after the flocs were broken apart, if quiescent conditions prevailed they would reform and settling would be begin again at very nearly the original settling rate.

Polymer coagulated samples presented their own problems. Extremely large flocs could be formed with the polymer and these exhibited a tendency to adhere to any surface with which they came in contact. When polymer dosages of 600 mg/l and 700 mg/l were used to coagulate a sample with a MLVSS concentration of 1125 mg/l, an amorphous ball of coagulated sludge was formed. This presented handling problems for polymer coagulated sludges.

As was indicated in Chapter II, the species of hydroxo-metal coagulant complex formed by a metal salt is pH dependent. When the pH of a sample to be coagulated is reduced, larger quantities of the most effective hydroxo-metal polymers are produced (25). In this investigation, buffering a metal salt coagulant had an apparent dele-terious effect upon the degree to which coagulation took place. The sludge volume indexes produced with buffered coagulants were low; however, the supernatant volatile suspended solids concentrations remained high. Buffered alum performed at a level almost comparable to the

unbuffered alum at approximately the same MLVSS concentration. Hydroxo-metal polymers most effective in coagulation are produced at a lower pH when ferric chloride is used as a coagulant as compared to alum. The reduction in effectiveness when ferric chloride was buffered is more marked than the reduction for buffered alum. Coagulation with a 500 mg/l dosage of buffered ferric chloride reduced supernatant volatile suspended solids by only 34% whereas a comparable unbuffered dosage reduced volatile suspended solids in the supernatant by 92%. Visual observations confirmed this reduction in effectiveness of the buffered coagulant samples. The importance of the pH drop associated with the use of metal salts as coagulants is highlighted when one realizes that the ferric chloride, which created a larger pH reduction than alum, was more severely limited in effectiveness when the pH reduction was eliminated.

Factors Affecting Oxygen Uptake

Some question has been raised in the past concerning the usefulness of the dissolved oxygen uptake test in sanitary engineering. When dissolved oxygen uptake is used as a basis for design, different methods of analysis may yield different results. This is immaterial when one considers the use to which oxygen uptake is put in this

investigation. Here the only requirement is that the dissolved oxygen uptake be proportional to the rate at which microorganisms carry on their metabolic processes. Only one parameter is allowed to change in the handling of various mixed liquor samples and that is the coagulant dose. It follows then that dissolved oxygen uptake can be used on a strictly comparative basis.

The data indicates that increasing dosages of coagulant produce a very definite reduction in the dissolved oxygen uptake rate. The coagulants can be divided into two categories in order to explore explanations of the oxygen uptake reduction. The metal salts, ferric chloride and alum, combine to form one category while the other includes the cationic polymer.

It was noted that increasing dosages of metal salts brought about better coagulation and increased floc size. Benefield, et al. (2) describe a floc with an aerobic outer region and a reducing oxygen gradient which extends to the floc core. In some cases, the theory predicts that the floc core will be totally anaerobic. This incorporation of bacteria which were once very much aerobic into an anaerobic floc core could account for a reduction in oxygen demand. This was not found to be the primary mode of dissolved oxygen utilization reduction, despite the fact that some very large and persistent flocs were

formed. There were instances where a reduction of oxygen uptake occurred despite the fact that there was no observable floc formation.

A reduction in pH as well as dissolved oxygen uptake accompanied increasing dosages of metal salts. Clearly, pH reduction played the major role in killing the microorganisms or at least slowing their metabolic processes enough to bring their oxygen uptake almost to a halt. Mixed liquor samples which were coagulated with buffered metal salts proved that the oxygen uptake decrease could be attributed to pH reduction. There was no significant drop in dissolved oxygen uptake rate in the buffered samples. In fact, the uptake rate tended to be greater in the buffered, coagulated samples than in the unbuffered, uncoagulated control samples. Perhaps the metal ions, when not accompanied by a pH drop, stimulated respiration or the buffer, coagulant mixture changed the pH to a range more suited to the microorganism metabolism than the original pH in the control sample.

Figures 27 and 28 demonstrate the relationship between the pH reduction brought about by the addition of metal salt coagulants and reduction of the oxygen uptake rate. pH reductions down to 5.2 brought about reductions in oxygen uptake to 12% or less of the oxygen uptake value in the uncoagulated sample. In general, oxygen uptake
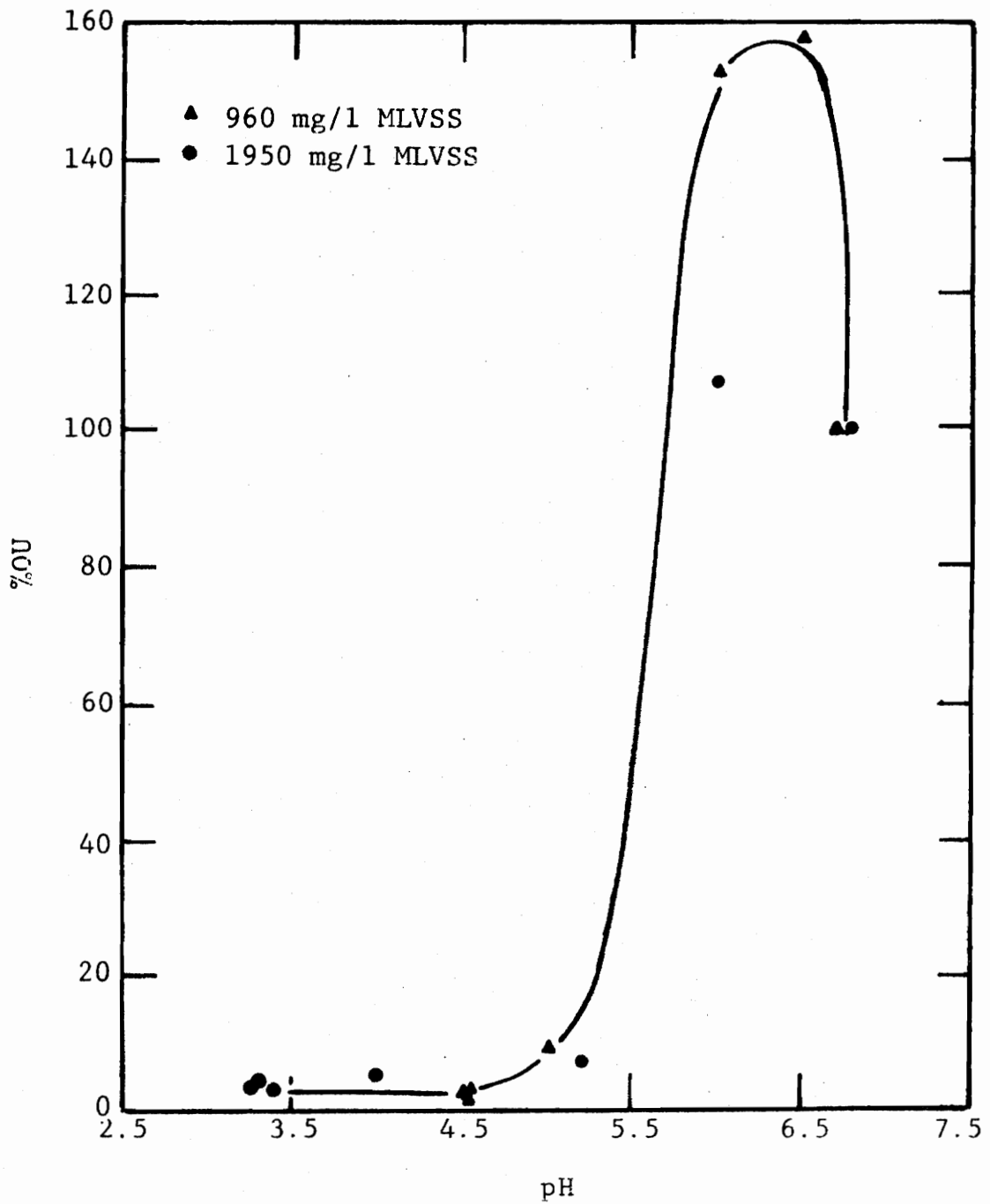
Figure 27. Correlation of percent of initial oxygen
uptake (%OU) with pH for alum coagulant.
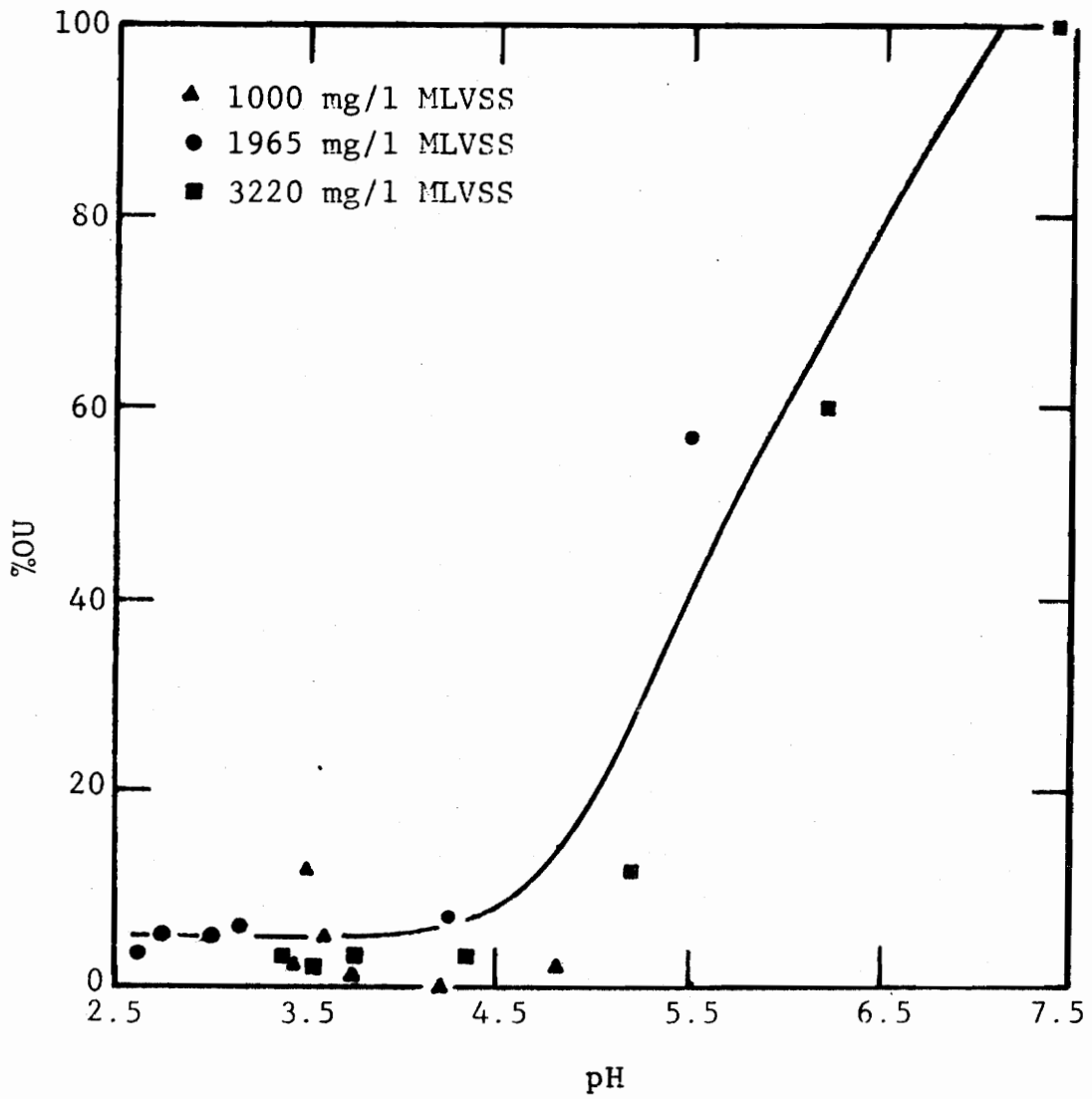
Figure 28.   Correlation of percent of initial oxygen
uptake (%OU) with pH for ferric chloride
coagulation.

continued to drop as pH droped. Figure 29 shows that for ferric chloride use, the percentage reduction of oxygen uptake may be associated with the dosage of coagulant used per unit of MLVSS.

The results showed that cationic polymer doses would reduce the dissolved oxygen rate to a great extent. Whereas the metal salts produced an abrupt decrease in uptake rate as the coagulant dosage was increased, the decrease associated with increased dosages of cationic polymer was more gradual. Clearly, pH could not have been a factor in this instance because there was no significant pH change associated with the use of polymer as a coagulant. These results would appear to support the previously mentioned theory concerning a partially anaerobic floc.

In one segment of this investigation dosages ranging from 200 mg/1 to 500 mg/1 of cationic polymer were applied to a mixed liquor having a volatile suspended solids concentration of approximately 3000 mg/1. These polymer dosages did not produce any apparent coagulation or settling because there was no visible floc formation. Still, the dissolved oxygen uptake rate for the sample containing 200 mg/1 of polymer was 67% of the value for the uncoagulated control while the 500 mg/1 polymer sample reduced oxygen uptake to 10% of the initial level.
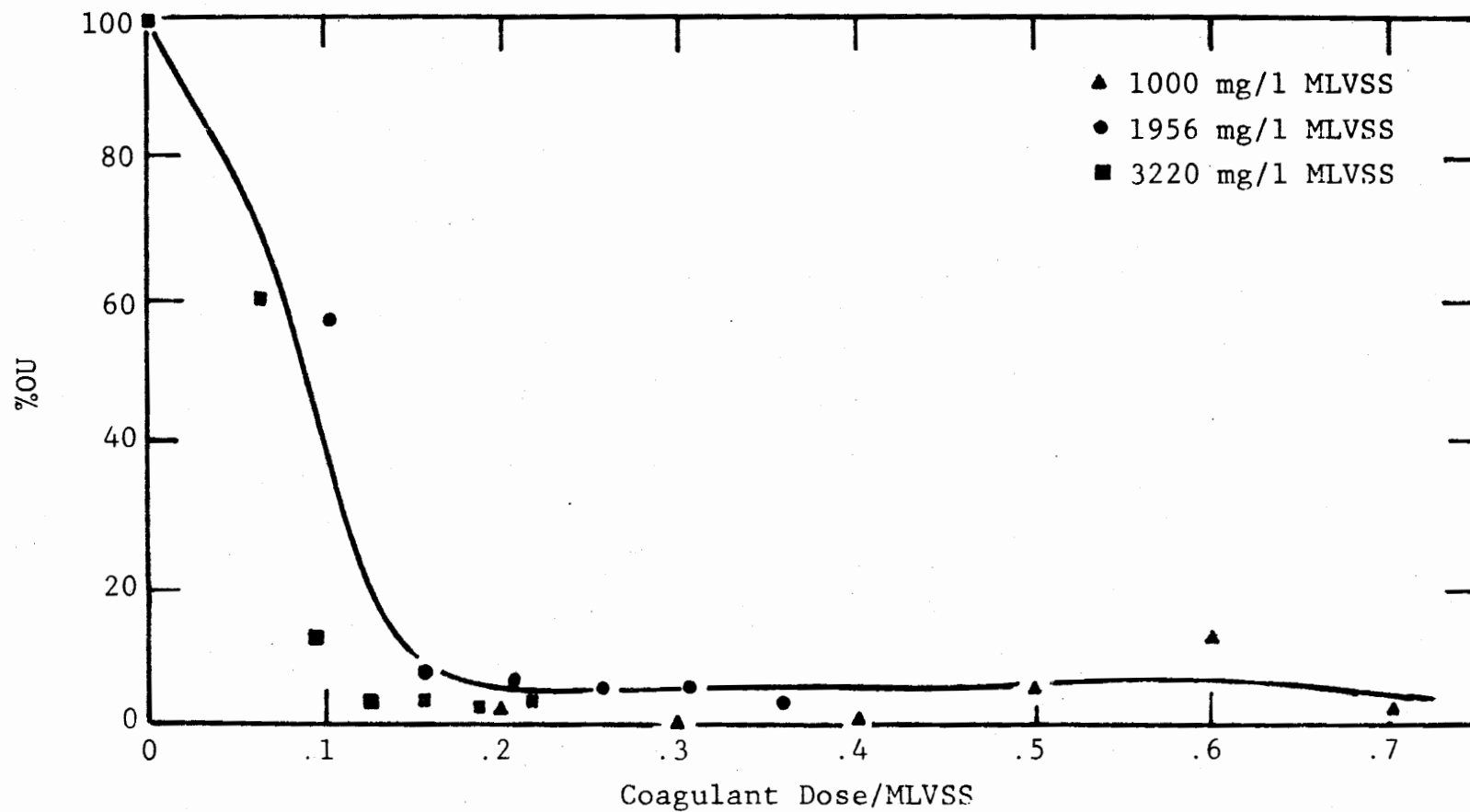
Figure 29.   Correlation of percent of initial oxygen uptake (%OU) with ferric
             Chloride dosage per unit MLVSS.

It would appear that, since there was no visible floc formation in either sample, the theory of a floc containing an anaerobic core could not account for these rate reductions.

As outlined in Chapter II, the coagulation mechanism for polymers is thought to be a long chain polyelectrolyte attaching itself to an adsorption site at the surface of the colloidal particle being coagulated. The data indicates that the adsorption of the polymer at the surface of the microorganisms being coagulated interferes with the microorganisms' ability to assimilate oxygen, causing a reduction in the oxygen uptake rate.

Use of Coagulant in Treatment

For one reason or another, a treatment scheme using the type of organisms involved in this investigation and a coagulant to produce a good quality effluent and an efficiently settling sludge would not work. Alum use never yielded an effluent low in volatile suspended solids or an efficiently settling sludge. Ferric chloride was able to meet both effluent and settling criteria but left microorganisms which showed little evidence of continuing metabolic processes. The ferric chloride could be buffered to reduce its deleterious effects upon the microorganisms, but this also reduced its effectiveness as a coagulant.

Coagulation with cationic polymer produced excellent settling and supernatant, but the polymer coagulated microorganisms were difficult to handle because of their tendency to adhere to almost any surface. Polymer dosages reduced microorganism metabolism to a great extent.

VI. CONCLUSIONS

Based on the data presented concerning the use of various dosages of three coagulants in coagulation of a bound water bulked sludge, and the subsequent effect of the coagulants upon dissolved oxygen uptake rate, the following conclusions have been drawn:

1. Alum was not very effective for coagulating a sludge which had bulked due to a high concentration of bound water because of the high level of suspended solids that remained in the supernatant.

2. Ferric chloride was very effective in coagulating the bound water sludge and producing a clarified effluent.

3. Synthetic polymer can coagulate a bound water sludge with satisfactory results.

4. The coagulant dosages required for effective treatment were very high for all three coagulants. Optimum doses were .5 mg of alum per mg MLVSS, .4 mg of ferric chloride per mg of MLVSS, and .3 mg of cationic polymer per mg of MLVSS.

5. A polymer coagulated microbial floc is very difficult to handle because of the adhesive properties of the floc.

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6. Buffering to a pH between 7.0 and 7.5 reduces the effectiveness of metal salt coagulants for bulked activated sludge separation. This is consistent with water treatment coagulation effects.

7. Overdosing is a possibility when ferric chloride is used as a coagulant, but in general, coagulation improves with an increase in coagulant dose.

8. The metal salt coagulants reduced the pH of the system and a significant reduction in the oxygen uptake rates of the microbial system occurred as a result of pH toxicity.

9. Buffering of metal salt coagulants eliminated any reduction of oxygen uptake when these coagulants were added to the microbial system.

10. The cationic polymer interferred with micro-organism metabolism as shown by a large reduction in oxygen uptake rate. It was not caused by a pH change.

11. All of the coagulants tested have significant shortcomings when used for coagulation of the bulked activated sludge used in this investigation.

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APPENDIX

Key to Tables 1 through 11:

Dose - coagulant dosage, mg/l.

MLVSS - mixed liquor volatile suspended solids, mg/l.

Dose/MLVSS - coagulant dosage divided by mixed liquor volatile suspended solids.

SVSS - supernatant volatile suspended solids concentration, mg/l.

SVI - sludge volume index.

Hour SVI - one hour sludge volume index.

pH - supernatant pH.

OU - dissolved oxygen uptake rate, $\frac{dO_2/dt}{MLVSS}$, min^{-1}.

% OU - percentage of oxygen uptake in the uncoagulated sample.

MLSS - mixed liquor suspended solids concentration, mg/l.

Table 1 - Data from coagulant runs. Coagulant, MLVSS, MLSS, and initial pH information preceed each data set.

Dose	$\dfrac{Dose}{MLVSS}$	SVSS	SVI	Hour SVI	pH	$OU \times 10^6$	%OU
Alum run. MLVSS = 960 mg/1. MLSS = 980 mg/1. Initial pH = 7.00.							
0	0	908	-	-	6.70	531	100
200	0.208	928	-	-	6.50	828	156
300	0.313	930	-	-	6.00	815	153
400	0.417	560	367	291	5.00	46	9
500	0.521	535	408	276	4.55	13	2
600	0.625	518	367	255	4.50	5	1
700	0.729	475	306	240	4.50	10	2
Ferric chloride run. MLVSS = 1000 mg/1. MLSS = 1020 mg/1. Initial pH = 7.60.							
0	0	930	-	-	7.40	634	100
200	0.200	773	-	-	4.80	12	2
300	0.300	412	240	201	4.20	0	0
400	0.400	125	137	118	3.75	7	1
500	0.500	84	98	98	3.60	30	5
600	0.600	63	127	118	3.50	76	12
700	0.700	63	137	123	3.45	17	2
Cationic polymer run. MLVSS =1125 mg/1. MLSS = 1165 mg/1. Initial pH = 7.00.							
0	0	1045	-	-	6.55	444	100
200	0.178	1015	-	-	6.20	366	83
300	0.267	1000	841	833	6.20	347	78
400	0.356	66	558	532	6.10	302	68
500	0.444	58	236	227	6.00	188	42
600	0.533	65	103	103	6.50	81	18
700	0.622	53	69	69	6.40	22	5

Table 1 (Continued)

Dose	Dose / MLVSS	SVSS	SVI	Hour / SVI	pH	$OU \times 10^6$	%OU
Alum run.	MLVSS = 1950 mg/l.	MLSS = 2000 mg/l.		Initial pH = 7.00.			
0	0	1785	-	-	6.80	90	100
200	0.103	1800	105	85	6.00	96	107
300	0.154	1733	125	100	5.20	6	7
400	0.205	1005	110	93	4.00	4	5
500	0.256	1130	85	75	3.40	3	3
600	0.308	1314	75	65	3.30	4	4
700	0.359	1315	70	55	3.25	3	3
Ferric chloride run.	MLVSS = 1965 mg/l.		MLSS = 2000 mg/l.	Initial pH = 7.00.			
0	0	1850	-	-	6.70	172	100
200	0.102	1855	70	60	5.50	99	57
300	0.153	1445	93	80	4.25	13	7
400	0.204	354	70	63	3.15	10	6
500	0.255	76	98	78	2.90	8	5
600	0.305	69	80	65	2.75	8	5
700	0.356	65	63	53	2.60	6	3
Cationic polymer run.	MLVSS = 2185 mg/l.		MLSS = 2310 mg/l.	Initial pH = 7.30.			
0	0	2000	-	-	7.10	345	100
200	0.092	1985	-	-	7.20	337	98
300	0.137	140	396	329	7.20	166	48
400	0.183	79	91	84	7.25	61	18
500	0.229	60	58	56	7.20	34	10
600	0.275	55	43	41	7.20	31	9
700	0.320	63	37	37	7.15	28	8

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Table 1 (Continued)

Dose	Dose/MLVSS	SVSS	SVI	Hour SVI	pH	$OU \times 10^6$	%OU
Alum run. MLVSS = 3155 mg/l. MLSS = 3215 mg/l. Initial pH = 7.40.							
0	0	3035	-	-	7.15	174	100
200	0.063	2915	-	-	6.60	153	88
300	0.095	2790	-	-	5.95	8	4
400	0.127	2880	-	-	4.90	8	4
500	0.159	2645	-	-	4.65	5	3
600	0.190	2900	-	-	4.50	4	2
700	0.222	2655	-	-	4.45	4	2
Ferric chloride data. MLVSS = 3220 mg/l. MLSS = 3280 mg/l. Initial pH = 7.40.							
0	0	2940	-	-	7.10	102	100
200	0.062	2940	-	-	6.20	61	60
300	0.093	2915	-	-	5.20	12	12
400	0.124	2190	-	-	4.35	3	3
500	0.155	1780	-	-	3.75	3	3
600	0.186	-	-	-	3.55	2	2
700	0.217	-	-	-	3.40	3	3
Cationic polymer data. MLVSS = 3050 mg/l. MLSS = 3170 mg/l. Initial pH = 7.20.							
0	0	2700	-	-	6.80	358	100
200	0.064	2475	-	-	6.80	241	67
300	0.096	2470	-	-	6.60	143	40
400	0.128	2420	-	-	6.60	71	20
500	0.160	2358	-	-	6.60	37	10
600	0.192	-	-	-	6.60	29	8
700	0.224	-	-	-	6.60	20	5

Table 1 (Continued)

	Dose	Dose/MLVSS	SVSS	SVI	Hour/SVI
Ferric chloride run. MLVSS = 3050 mg/l. MLSS = 3170 mg/l.					
	0	0	2900	-	-
	600	0.197	2935	-	321
	700	0.230	2265	318	315
	800	0.262	840	313	279
	900	0.295	435	207	179
	1000	0.328	200	93	82
	1100	0.360	197	84	75
Cationic polymer run. MLVSS = 3050 mg/l. MLSS = 3170 mg/l.					
	0	0	2900	-	-
	600	0.197	1935	115	60
	700	0.230	838	110	110
	800	0.262	50	100	100
	900	0.295	44	115	115
	1000	0.328	46	120	120
	1100	0.361	94	115	115

Table 2 - Settling data recorded as the volume (ml) indicated by the sludge-supernatant interface. No settling occurred in any uncoagulated control sample.

	Coagulant Dose (mg/l)					
Time (min)	200	300	400	500	600	700

Ferric chloride run.   MLVSS = 1000 mg/l.

Time (min)	200	300	400	500	600	700
0	1000	1000	1000	1000	1000	1000
1			890	160	205	830
2			390	115	170	660
3		915	320	100	155	435
4			280		150	300
5		695	260	95	140	255
7		410	220	90		185
10		345	190	90	130	165
15		285	170	85	125	145
20		255	150	80	120	130
25		240	145	80	120	120
30		230	140	75	115	115
35		220	135	75	115	115
40		210	130	75	110	110
45		205	130	75	110	110
50		200	125	75	110	110
55		195	125	75	105	105
60	1000	190	120	75	105	105

Alum run.   MLVSS = 960 mg/l.

Time (min)	200	300	400	500	600	700
0	1000	1000	1000	1000	1000	1000
4			970			
6			940			
10			830			
12			700			850
15			590			650
20			440		800	410
25			395	600	500	335
30			360	400	360	300
35			340	350	325	285
40			320	340	295	270
45			310	330	280	260
50			295	300	270	250
55			290	280	260	240
60	1000	1000	285	270	250	235

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Table 2 (Continued)

Time (min)	Coagulant Dose (mg/l)					
	200	300	400	500	600	700

Cationic polymer run. MLVSS = 1125 mg/l.

Time (min)	200	300	400	500	600	700
0	1000	1000	1000	1000	1000	1000
1				500	120	80
2			930	430	120	80
3			910	390	120	80
4			890		120	80
5			870	350	120	80
7			830	330	120	80
10			780	310	120	80
15			720	290	120	80
20			680	285	120	80
25			670	280	120	80
30		980	650	275	120	80
35		980	645	275	120	80
40		980	640	270	120	80
45		975	635	270	120	80
50		975	630	270	120	80
55		975	625	265	120	80
60	1000	970	620	265	120	80

Ferric chloride run. MLVSS = 1965 mg/l.

Time (min)	200	300	400	500	600	700
0	1000	1000	1000	1000	1000	1000
2			330			
3		400	290			260
4				550	380	210
5		330	235	400	310	200
7		285	210	355	265	175
10		250	190	290	230	160
12		240				
15	150	225	170	255	200	145
20	145	205	150	225	180	135
25	140	195	145	205	170	130
30	140	185	140	195	160	125
35	135	180	140	185	155	120
40	130	170	135	175	150	115
45	130	170	135	170	145	110
50	125	165	130	165	140	110
55	125	165	130	160	135	105
60	120	160	125	155	130	105

Table 2 (Continued)

Time (min)	Coagulant Dose (mg/l)					
	200	300	400	500	600	700

Alum run.   MLVSS = 1950 mg/l.

Time (min)	200	300	400	500	600	700
0	1000	1000	1000	1000	1000	1000
5			330	300		
7				265		210
8					210	
10			300	230	200	185
15		340	265	205	180	165
20		290	245	190	170	150
25	230	265	230	180	160	145
30	210	250	220	170	150	140
35	200	240	210	165	145	135
40	190	230	205	160	140	130
45	185	220	200	155	140	125
50	180	210	195	155	135	120
55	175	205	190	150	135	115
60	170	200	185	150	130	110

Cationic polymer run.   MLVSS = 2185 mg/l.

Time (min)	200	300	400	500	600	700
0	1000	1000	1000	1000	1000	1000
1				190	130	110
2				180	120	100
3			330	170	115	95
4			310			
5			295	160	110	90
7			275	155	110	
10			255	150	110	90
11		980				
15		975	235	145	105	90
20		970	225	140	105	85
25		940	220	140	100	85
30		915	210	135	100	85
35		895	205	135	100	85
40		850	205	135	95	85
45		825	200	130	95	85
50		800	200	130	95	85
55		780	190	130	95	85
60	1000	760	185	130	95	85

Table 2 (Continued)

			Coagulant Dose (mg/1)			
Time (min)	600	700	800	900	1000	1100

Ferric chloride run. MLVSS = 3050 mg/1.

Time	600	700	800	900	1000	1100
0	1000	1000	1000	1000	1000	1000
2				980	550	540
5				940	410	380
7					380	340
10				890	350	315
15			970	820	320	285
20		980	965	770	300	275
25		975	960	710	290	270
30		970	955	665	285	255
35	990	970	940	630	270	250
40	990	970	920	610	265	240
45	985	970	900	595	260	240
50	985	965	880	580	255	235
55	980	965	860	570	250	230
60	980	960	850	545	250	230

Cationic polymer run. MLVSS = 3050 mg/1.

Time	600	700	800	900	1000	1100
0	1000	1000	1000	1000	1000	1000
1			110	130	130	120
2		270	100	120	120	115
5		200	100	115	120	115
7		185	100	115	120	115
10		170	100	115	120	115
15		145	100	115	120	115
20		130	100	115	120	115
25		115	100	115	120	115
30	115	110	100	115	120	115
35	110	110	100	115	120	115
40	100	110	100	115	120	115
45	90	110	100	115	120	115
50	80	110	100	115	120	115
55	70	110	100	115	120	115
60	60	110	100	115	120	115

Table 3 - Dissolved oxygen uptake data for various coagulants and dosages.

	Coagulant Dose (mg/l)						
Time (min)	0 DO (mg/l)	200 DO (mg/l)	300 DO (mg/l)	400 DO (mg/l)	500 DO (mg/l)	600 DO (mg/l)	700 DO (mg/l)
Alum run. MLVSS = 960 mg/l.							
0	6.700	5.500	5.500	5.575	7.900	7.725	7.500
1	6.175	4.750	4.700	5.525			
2	5.600	3.875	3.900		7.875	7.700	7.475
3	5.100	2.975		5.450			
4	4.575	2.100	2.300		7.850	7.700	7.450
5	4.050	1.275	1.525	5.350			
6	3.575	0.625	0.800		7.825	7.700	7.425
7	3.075			5.250			
8	2.600				7.800	7.675	7.400
9				5.175			
10					7.775	7.675	7.400
11				5.050			
12					7.750	7.675	7.375
13				4.975			
15				4.900	7.700	7.650	7.350
Ferric chloride run. MLVSS = 1000 mg/l.							
0	5.500	7.300	7.300	7.350	7.400	7.200	7.100
1	4.775						
2	4.100	7.275	7.275				7.025
3	3.425			7.325	7.350	7.125	
4	2.825	7.225	7.250				
5	2.225						6.975
6	1.700	7.200		7.325	7.300	6.950	

Table 3 (Continued)

Time (min)	Coagulant Dose (mg/l)						
	0 DO (mg/l)	200 DO (mg/l)	300 DO (mg/l)	400 DO (mg/l)	500 DO (mg/l)	600 DO (mg/l)	700 DO (mg/l)

Ferric chloride run. MLVSS = 1000 mg/l. (Continued)

Time (min)	0	200	300	400	500	600	700
8							6.925
9				7.300	7.250		
10		7.175	7.275			6.900	
11							6.900
12		7.150		7.325	7.200	6.825	
14		7.125					6.825
15				7.300	7.125	6.750	
16		7.100					
17							6.775
20				7.300	7.025	6.650	6.750

Cationic polymer run. MLVSS = 1125 mg/l.

Time (min)	0	200	300	400	500	600	700
0	6.800	4.950	6.500	7.000	7.200	7.300	8.500
1	6.325	4.725	6.250	6.675	7.000	7.200	
2	5.825	4.425	5.900	6.350	6.800	7.100	8.450
3	5.350	4.050	5.500	6.000	6.600	7.000	
4	4.900	3.675	5.125	5.650	6.400	6.900	8.425
5	4.400	3.225	4.725	5.300	6.175	6.825	
6	3.900	2.800	4.325	4.975	5.950	6.725	8.400
7	3.400	2.400	3.900	4.600	5.725	6.650	
8	2.850	1.875	3.500	4.275	5.500	6.575	8.350
10							8.300
12							8.250
14							8.200
16							8.150

Table 3 (Continued)

| Time (min) | Coagulant Dose (mg/l) | | | | | | |
	0 DO (mg/l)	200 DO (mg/l)	300 DO (mg/l)	400 DO (mg/l)	500 DO (mg/l)	600 DO (mg/l)	700 DO (mg/l)
Alum run. MLVSS = 1950 mg/l.							
0	4.400	7.050	5.675	5.200	5.475	5.575	5.300
1	4.200	6.925					
2	4.100	6.775	5.650	5.175	5.475	5.575	5.300
3	3.925	6.600					
4	3.775	6.400	5.625	5.150	5.450	5.550	5.275
5	3.600	6.200					
6	3.400	6.000	5.600	5.125	5.450	5.525	5.275
7	3.225	5.800					
8	3.025	5.575	5.575	5.125	5.425	5.525	5.275
10			5.550	5.100	5.425	5.525	5.250
12			5.525	5.100	5.400	5.500	5.250
14			5.500	5.075	5.400	5.500	5.225
16			5.475	5.075	5.375	5.475	5.225
Ferric chloride run. MLVSS = 1965 mg/l.							
0	7.700	8.650	8.600	7.900	8.125	7.625	7.125
1	7.400						
2	7.050	8.350	8.550	7.850	8.100	7.600	7.100
3	6.725						
4	6.400	8.025	8.500	7.800	8.050	7.575	7.100
5	6.025						
6	5.675	7.650	8.450	7.775	8.000	7.550	7.075
7	5.300						
8	4.950	7.225	8.400	7.725	7.975	7.525	7.025

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Table 3 (Continued)

Time (min)	Coagulant Dose (mg/l)						
	0 DO (mg/l)	200 DO (mg/l)	300 DO (mg/l)	400 DO (mg/l)	500 DO (mg/l)	600 DO (mg/l)	700 DO (mg/l)

Ferric chloride run. MLVSS = 1965 mg/l. (Continued)

Time (min)	0	200	300	400	500	600	700
10		6.825	8.350	7.700	7.950	7.500	7.000
12		6.425	8.300	7.650	7.925	7.475	7.000
14		6.000	8.250	7.600	7.900	7.425	6.975
16		5.600	8.200	7.575	7.875	7.400	6.975

Cationic polymer run. MLVSS = 2185 mg/l.

Time (min)	0	200	300	400	500	600	700
0	4.900	4.900	6.350	7.375	7.475	7.400	7.350
1	4.400	4.200	6.000				
2	3.550	3.500	5.675	7.150	7.350	7.275	7.275
3	2.800	2.625	5.300				
4	2.050	1.775	4.975	6.900	7.200	7.150	7.150
5	1.375	1.150	4.625				
6	0.750	0.500	4.275	6.625	7.050	7.000	7.025
7			3.900				
8			3.575	6.375	6.900	6.900	6.900
10				6.100	6.775	6.750	6.800
12				5.850	6.600	6.600	6.675
14				5.600	6.450	6.475	6.525
16				5.300	6.300	6.350	6.400

Alum run. MLVSS = 3155 mg/l.

Time (min)	0	200	300	400	500	600	700
0	4.850	4.200	5.400	5.050	7.125	6.050	6.800
1	4.175	3.725	5.150				
2	3.500	3.250	4.900	5.025			
3	2.850	2.800	4.625		7.100	6.000	6.800

Table 3 (Continued)

Time (min)	Coagulant Dose (mg/l)						
	0 DO (mg/l)	200 DO (mg/l)	300 DO (mg/l)	400 DO (mg/l)	500 DO (mg/l)	600 DO (mg/l)	700 DO (mg/l)

Alum run. MLVSS = 3155 mg/l. (Continued)

Time (min)	0	200	300	400	500	600	700
4	2.200	2.300	4.300	4.975			
5	1.675	1.825	4.150				
6	1.225	1.325	3.900	4.925	7.025	5.975	6.775
7	0.750	0.850	3.650				
8		0.400	3.425				
9					7.000	5.925	6.725
10				4.850			
12				4.800	6.975	5.900	6.700
14				4.750			
15					6.900	5.825	6.650
16				4.700			
18				4.650	6.850	5.800	6.600
20				4.600	6.800	5.775	6.575

Ferric chloride run. MLVSS = 3220 mg/l.

Time (min)	0	200	300	400	500	600	700
0	5.500	4.300	6.300	6.575	8.000	8.025	7.850
1	5.175	4.100					
2	4.825		6.225				
3	4.425	3.700		6.525	7.975	8.025	7.800
4	4.150	3.475	6.175				
5	3.800	3.275					
6	3.075	3.050	6.100	6.500	7.975	8.000	7.775
7	3.425	2.850					
8	2.825	2.675	6.000				
9				6.475	7.950	7.975	7.700
10			5.925				
12			5.850	6.450	7.925	7.975	7.675

Table 3 (Continued)

Time (min)	Coagulant Dose (mg/l)						
	0 DO (mg/l)	200 DO (mg/l)	300 DO (mg/l)	400 DO (mg/l)	500 DO (mg/l)	600 DO (mg/l)	700 DO (mg/l)
Ferric chloride run. MLVSS = 3220 mg/l. (Continued)							
14			5.775				
15				6.425	7.900	7.950	7.650
16			5.700				
18				6.400	7.900	7.925	7.625
20				6.375	7.900	7.900	7.625
Cationic Polymer run. MLVSS = 3050 mg/l.							
0	5.500	6.400	6.850	7.600	8.000	7.800	6.000
1	4.200	5.575	6.350	7.325			
2	2.800	4.700	5.800		7.725	7.600	5.875
3	1.500	3.725	5.300	6.775			
4	0.400	2.800	4.750	6.525	7.500	7.375	5.700
5		1.875	4.225	6.250			
6		1.025	3.700	5.975	7.225	7.150	5.575
7		0.325	3.200	5.725			
8				5.500	6.975	6.925	5.400
10					6.700	6.700	5.300
12					6.475	6.500	5.125
14					6.225	6.300	5.000
16					5.875	6.100	4.875

Table 4 - Settling and dissolved oxygen uptake data for buffered
coagulant runs at MLVSS concentrations approximately
equal to 1000 mg/l. Settling data is presented as the
volume indicated by the sludge-supernatant interface.

Time (min)	500 mg/l Alum Interface volume (ml)	500 mg/l Ferric chloride Interface volume (ml)
0	1000	1000
6		90
7	120	
8		85
10	115	85
15	115	85
20	115	80
25	110	80
30	110	80
35	105	80
40	105	75
45	100	75
50	100	75
55	100	75
60	100	70

Dissolved oxygen uptake for buffered coagulant runs.
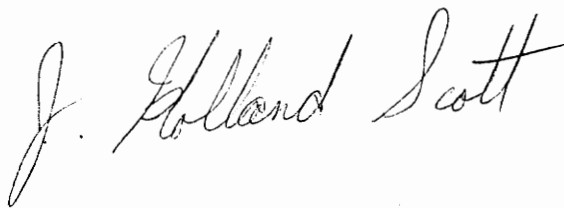
Time (min)	0 mg/l Control	0 mg/l Control	500 mg/l Alum	500 mg/l Alum	500 mg/l $FeCl_3$	500 mg/l $FeCl_3$
0	5.650	6.300	6.000	4.400	7.500	4.200
1	5.400	6.000	5.600	3.900	7.175	3.575
2	5.100	5.700	5.125	3.250	6.900	2.900
3	4.800	5.425	4.700	2.650	6.650	2.300
4	4.500	5.100	4.300	2.050	6.400	1.650
5	4.225	4.775	3.925	1.475	6,150	1.075
6	3.975		3.550		5.900	
7	3.700		3.200		5.600	
8	3.400		2.800		5.325	
	pH=7.60	pH=7.00	pH=7.65	pH=7.10	pH=7.55	pH=7.05

VITA

J. Holland Scott was born in Nassawadox, Virginia on December 13, 1953. He received his primary and secondary education at Onancock High School in Onancock, Virginia.

In September of 1971 Mr. Scott entered Virginia Polytechnic Institute and State University in persuit of a Bachelor of Science degree in Civil Engineering. In December of 1975 the requirements for this degree were completed and it was awarded in June of 1976.

Mr. Scott is presently completing his studies for the Master's degree in Sanitary Engineering at Virginia Polytechnic Institute and State University.

COAGULATION STUDY OF A
BOUND WATER BULKED SLUDGE

by

J. Holland Scott

(ABSTRACT)

The objective of this research was to determine the
coagulation effects of alum, ferric chloride, and cationic
polymer when the coagulants are added to a sludge which
has bulked due to a high bound water content. The effect
of coagulant addition upon microbial metabolism was studied
using dissolved oxygen uptake.

Coagulant dosages ranging from 200 mg/l to 700 mg/l
were added to 1000 mg/l and 2000 mg/l mixed liquor volatile
suspended solids (MLVSS) concentration sludges, while
dosages ranging from 200 mg/l to 1100 mg/l were added to
3000 mg/l MLVSS concentration sludges. The settling param-
eters studied included settling curves, half-hour and hour
sludge volume indexes, and supernatant volatile suspended
solids.

It was discovered that while good separation of
microbial solids could be accomplished through the use of
ferric chloride and a synthetic cationic polymer, alum
coagulation was ineffective and coagulation addition in

the range of dosages used brought about a reduction in the dissolved oxygen uptake rate of the microorganisms. The data presented includes dissolved oxygen uptake rates, uptake rates expressed as a percentage of the uptake rate in the coagulated sample, and supernatant pH.