# THE EFFECT OF GROWTH RATE ON EFFLUENT SUSPENDED SOLIDS IN ACTIVATED SLUDGE SYSTEMS

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Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1978

THE EFFECT OF GROWTH RATE ON EFFLUENT SUSPENDED SOLIDS IN ACTIVATED SLUDGE SYSTEMS

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Dedicated to my parents with

love and appreciation

## ACKNOWLEDGMENTS

I am pleased to express my gratitude and sincere appreciation to my adviser, Dr. D. F. Kincannon, for his advice and assistance during the course of this study. His knowledge, guidance, understanding, and patience throughout my graduate career at Oklahoma State University will always be remembered.

I would like to express my gratitude to Dr. A. F. Gaudy, Jr., Dr. R. N. DeVries, and Dr. Marcia Bates for their guidance, encouragement, and friendship and for serving as committee members.

To my colleagues, Reddy, Manikam, Chen, Tortorelli, Blachly, Vanmeter, Bates, Jett, Neafus, Chelus, Whang, Vasu, Torabian, Chattergee, Hamm, Bartle, and other graduate students in the bioenvironmental engineering program a special thanks for their friendship and assistance.

Much appreciation and love is extended to the author's parents for their support, love, and encouragement; the author feels that words are not sufficient to express his respect for these two important people in his life. Appreciation and love are extended to my sister and brothers for their love and affection; in particular, Mr. Surrender, my brother, is acknowledged for his constant support and encouragement. To him I owe very much.

Acknowledgment is also extended to friends, particularly Mr. Venkatesham, and relatives at home for their constant concern for me. To Fred Cervantes, Leslie, Laura, Nancy, Judd, Susheelprem and Payne, an

honorable mention for their friendship. Special thanks are due Mrs. Grayce Wynd for her affection, friendship, and for her careful and accurate typing of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# CHAPTER I

## INTRODUCTION

The thrust to clean up the environment has been accelerated in the last decade due to increasingly stringent legislation. In consequence, much time, money and research have been expended to modify and develop wastewater treatment systems to enhance the efficiency and effectiveness of pollution control facilities. With the new Environmental Protection Agency regulations for waste treatment plant effluent suspended solids, the clarification function has become a critical consideration. The Environmental Protection Agency has set limits on both effluent suspended solids and effluent BOD; effluent suspended solids contribute to both effluent suspended solids and effluent BOD.

The performance of a secondary wastewater treatment system is dependent not only on the performance of the biological solids in removing BOD, but it is also dependent on the performance of the system in retaining the biological solids in the system. The removal of the biological solids from the activated sludge treatment plant is by gravity settling in the secondary clarifier. The secondary clarifier in an activated sludge system has two functions. One is the clarification function, and the second is to provide a concentrated sludge to return to the aeration basin. Some treatment plants perform both functions efficiently and economically by monitoring zeta potential. To optimize the effluent system in reducing effluent solids, the zeta

potential value is maintained constant by adding cationic additives. The performance of the secondary clarifier in an activated sludge system could be enhanced greatly by increased knowledge of the effects of the many variables which affect the performance of the secondary clarifier. In the present study, the effect of sludge age and zeta potential on the clarification function of the secondary clarifier in an activated sludge system was investigated.

# CHAPTER II

# LITERATURE REVIEW

## Sludge Age

It is well known that sludge age, or specific growth rate, affects certain characteristics of biological solids such as sludge yield and BOD removal. Sludge age may have a gross effect on the settling properties of activated sludge biological solids. If, in fact, sludge age does have a significant effect on the settling properties of activated sludge, the relationship between sludge age and the various settling properties of an activated sludge could be of great significance both to the treatment plant designer and the operator.

Overflow area, volume, and sludge removal rate can be varied to meet the desired operational characteristics of a secondary clarifier for the activated sludge system. Once the plant has been built and is in operation, the only clarifier control variable open to the treatment plant operator is the sludge removal rate. The solids loading on the secondary clarifier may be reduced by wasting more solids from the system. Decreasing the mixed liquor suspended solids decreases sludge age, and sludge age does affect the settling characteristics of the activated sludge biological solids.

In 1967, Ford and Eckenfelder (1) ran three bench scale activated sludge units with different wastes. Their data suggest that sludge age does in fact affect the settling characteristics of activated sludge

biological solids. In 1971, Bisogni and Lawrence (2) ran several bench scale activated sludge units simultaneously, varying only the sludge ages of the units; the sludge ages of the units varied from 0.25 days to 12 days. They found that effluent suspended solids increased from a minimum at a sludge age of one day to a maximum at a sludge age of three days. The effluent suspended solids then decreased to a minimum at a sludge age of six days, and again increased with increasing sludge age. They also found that the zone settling velocity and sludge volume index varied with sludge age. The effluent suspended solids data suggest a complex relationship between sludge age and clarification.

## Flocculation

The mechanism of bacterial flocculation is not yet established, but bacterial flocculation can be classified into three types: natural flocculation, autoflocculation, and chemical flocculation. Natural flocculation was supposed to be due to the collision of bacteria with impurities present in the wastes. Arden and Lockett in 1914 proposed the idea of natural flocculation. In aerated organic wastes, natural slimes are developed, and this results in the subsequent formation of zoogloeal flocs. These flocs consist of organisms, food, and slime materials (3, 4).

Colloidal characteristics of the cells is said to be the reason for autoflocculation. Negative charges on the bacterial surface set up force between electrostatic repulsion and van der Waal's attraction, and when the latter predominates, autoflocculation results. In 1925, Theriault and Clark (5) and Miller (6) set forth the fundamental

concept of chemical flocculation. They said that there must be present a certain minimum quantity of aluminium ($Al^{+++}$) or ferric ($Fe^{+++}$) cations. There should be present an anion of strong coagulating power and pH must be carefully adjusted.

According to Dubos (7), most bacteria are found to have definite capsules, and it appears that bacteria are joined at the capsular surface. Abramson (8) found that bacteria had a definite electrokinetic potential, and that the reduction of this potential resulted in agglutination of the bacteria. It was shown by McCalla (9) in 1940 that bacteria adsorbed positive ions from solution as a result of their negative surface charge. The chemical composition of the slime layer is believed to be responsible for the electrical charge on the bacteria, which is predominantly polysaccharide.

Buswell and Long (10) in 1923 proposed that activated sludge flocs were composed of a synthetic gelatinous matrix in which filamentous and unicellular bacteria are embedded and on which various protozoa feed and crawl. The purification is attained by digestion and assimilation by the organisms in the sewage and subsequent resynthesis of organic matter into the living material of organisms. Buswell also stated that activated sludge is made up of zoogloeal floc and that the protozoa on this floc are responsible for the major portion of the purification of the sewage.

Heukelekian and Littman (11) and other investigators felt that the bacteria were bound together by a gelatinous material surrounding each cell. The work of Dunbar, Theriault, Cavel, Buswell, Baly, and others (12) showed that the colloidal matter in sewage was adsorbed by the slimes, but none agreed on the mechanisms involved. Theriault

believed that the gelatinous matrix of activated sludge was a biogeolitic substance and that the organic materials were adsorbed onto the sludge by an ion exchange process. Electrical charge was the theory of Cavel and others. Cavel felt that the slimes were positively charged as they adsorbed negative colloids. This idea was disproved by Buswell, who showed that both the colloid and slime had negative charges.

McKinney and Weichlein (13) in 1953 noted that floc formation has some relation with bacterial metabolic activities. Complete metabolism of the organic waste was related to floc formation. Again in 1952, McKinney (14) came up with another theory on floc formation. He said that floc formation was due to the collisions between cells and bacterial surface charges. McKinney further said that the overall surface potential has been reduced with respect to the surface area in contact. Again in 1956, McKinney (15) maintained that floc formation was dependent on the energy of bacteria but not on the surface charge. He said van der Waal's forces would overcome low energy systems and floc results.

In 1964, Tanney and Stumm (16) proposed that biological self-flocculation results from the interaction of naturally produced polyelectrolytes. In 1965, Crabtree, Boyle, McCoy, and Rohlich (17) pointed out that bacterial flocculation is not absolutely related to slimes. They proposed that bacterial flocculation is due to the accumulation of polymer poly-β-hydroxybutyric acid (PHB). They observed that the rapid accumulation of PHB by zoogloea was associated intimaterly with the flocculation of the organism.

## Zeta Potential

The stability of the colloid system or emulsion is dependent upon adsorption of ions (or polymers) from the bulk of the suspending liquid. There are three methods by which the colloid can be stabilized; one method is mutual repulsion due to high zeta potential; the second method is adsorption of a small lyophilic colloid on a larger electro-negative colloid. The third and last method is steric hindrance due to adsorption of an oriented nonionic polyelectrolyte. Colloids are electro-negative in tap water in the pH range of 5 to 10, and such colloids have zeta potential in the range of -14 to -30 millivolts. The zeta potential must be less electro-negative for coagulation. According to Brinton and Lauffer (18), the zeta potential of bacteria ranges between -22 to -76 mv in wastes with pH equal to 7.3.

According to Selye (19), vigorous microbial activity on an aqueous organic colloid system leads to lowering of zeta potential, and subsequent agglomeration results in sedimentation. According to Riddick (20), the action of microorganisms on the colloidal organic waste leads to lowering of zeta potential, and subsequent agglomeration results in sedimentation according to Stoke's law. Abramson (21) notes that most colloids are electro-negative in water at low ionization in the pH range around neutrality. According to Salle (22), the end products of intense microbial activity lead to agglomeration. Salle also noted that microbial decomposition takes place by decarboxylation wherein carbon dioxide leaves as gas and hydrogen is left. The removal of carboxyl radical reduces the electro-negative charge on the surface of a particle, which results in agglomeration and subsequent sedimentation.

Kupec, Smatla, Jaromir, and Milan (23) measured the zeta potential during evaluation of compositions formed during biological purification of tannery wastewaters by activated sludge. Carlson (24) removed colloidal particles from wastewater by passing the liquid through a flow path, determining the zeta potential and then adjusting the zeta potential to a predetermined value to cause flocculation and coagulation. Additives used included inorganic electrolytes $FeCl_3$ or alum, or synthetic polyelectrolytes. Grutsch and Mallatt (25) optimized the effluent system of the activated sludge process by a chemical treatment approach.

## Sedimentation

Sedimentation is a widely used physical process in wastewater treatment plants to remove undesirable solids from the carrying water. In order to separate solids from the carrying water by sedimentation, certain conditions must be met. First, the solids must be of greater density than the water; second, the solids must either be of sufficient particle size to allow gravity settling to occur or be capable of agglomeration into sufficiently large particles for gravity settling to occur. These requirements are due to the nature of the sedimentation operation and the physical laws governing it.

In wastewater treatment, sedimentation has two functions. First, the solids are separated from the bulk of the water, producing clarified supernatant. Second, the solids are allowed to settle further after separation from the bulk of the liquid to reduce the water content of the solids. In wastewater treatment, these two functions are important.

There are four classifications of sedimentation as defined by Fitch (26). The four classifications are not quite distinct, but they do provide a basis for design procedure. Camp (27) came up with a refined version of Hazen's analysis along with design procedure and equation. Fitch (28, 29) later showed that both overflow rate and detention time influence solids removal. Talmadge and Fitch (30) described an equation for clarification in an activated sludge secondary clarifier. It does not account for removal of dispersed growth or very small floc particles which are removed with increased detention time in the clarifier. It is simply the equation describing the required overflow rate for the initial gross removal of floc particles in the secondary clarifier.

Temperature would affect the settling rate of activated sludge by changing the viscosity of the water. Temperature, stirring, and other physical and chemical variables should be controlled.

# CHAPTER III

## MATERIALS AND METHODS

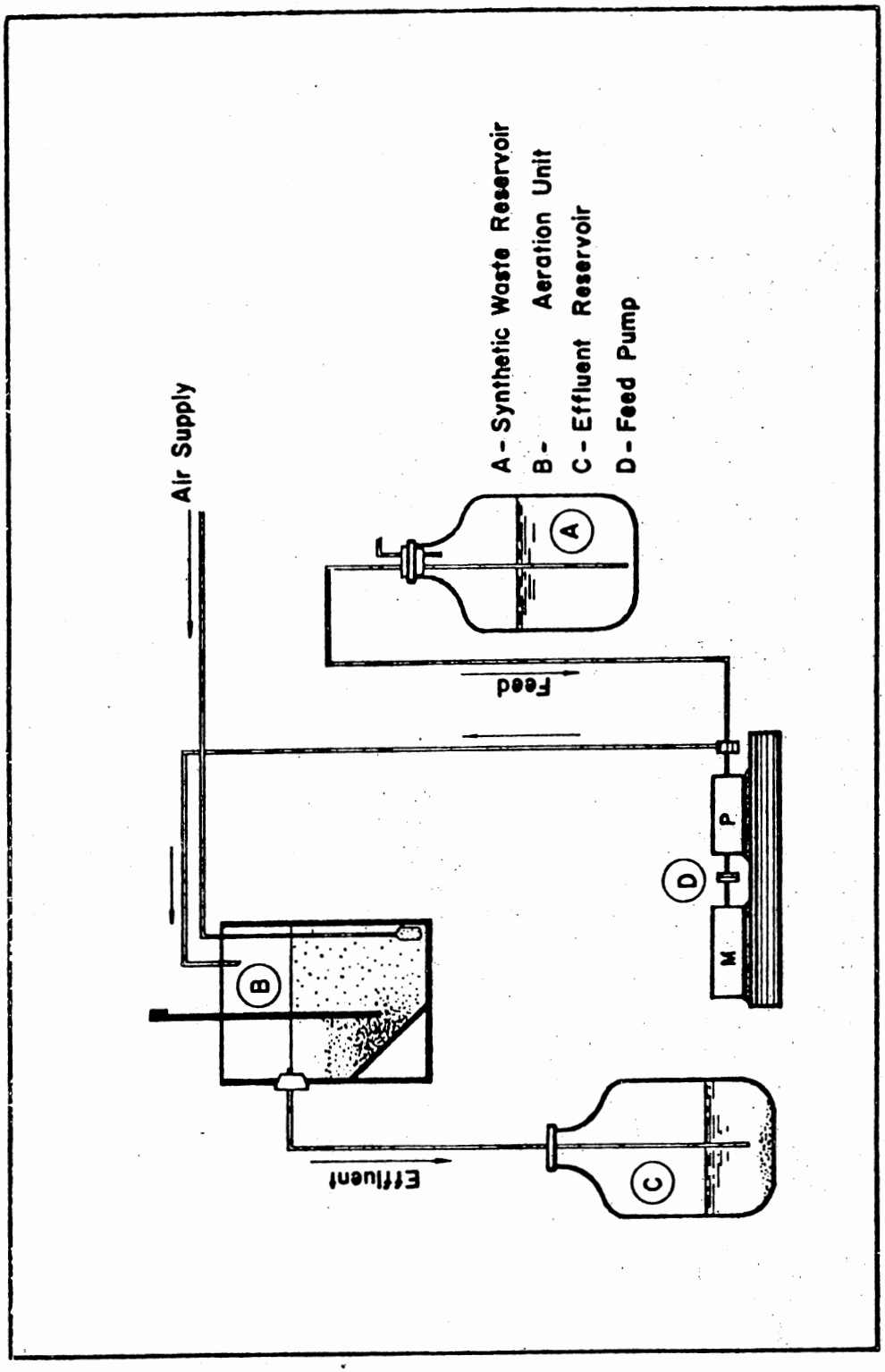
To study the performance and the characteristics of the effluent of the activated sludge biomass of various ages, a bench scale activated sludge unit was operated under closely controlled conditions. For ease of presentation, the experimental laboratory apparatus, the feed solution, initial startup, daily protocol, analytical procedures and methods of analysis used to carry out the objetives of this study are described separately.

### Experimental Laboratory Apparatus

A schematic diagram of the activated sludge unit with other apparatus used in this experimental investigation is shown in Figure 1. The aeration tank was a bench scale unit having a volume of 6.5 liters. The tank was rectangular in shape and made of one-fourth inch thick plexiglass with internal recycle of bacterial cells serving as the aeration tank and secondary clarifier. An adjustable baffle was used to separate the aeration and settling compartments. A feed rate of 19.6 liters/day was set. The feed was mixed every day in a five-gallon glass bottle. The bottle volume was marked in one-liter graduations to twenty liters.

Air was supplied to the aeration tank through four porous diffuser stones at a total rate of approximately $7.5 \pm 0.5$ cubic feet per hour.

Figure 1. Experimental Activated Sludge Unit


A - Synthetic Waste Reservoir
B - Aeration Unit
C - Effluent Reservoir
D - Feed Pump
Air Supply
Feed
Effluent
A
B
C
D
P
M

A Gelman airflow meter was used to monitor the airflow. This compressed air was adequate to provide thorough and complete mixing and to supply sufficient oxygen for the microorganisms, but also created required movement to recycle solids from the settling tank compartment. A glass cotton filter was placed between the diffusers and the air outlet to prevent any oil in the airlines from entering the experimental unit. The temperature was maintained at $23 \pm 2^{o}C$. During the summer, when operation of the unit was initiated, temperature control was no problem. However, the temperature in the laboratory began to fluctuate with the onset of winter.

The feed was supplied to the reactor by means of a Milton Roy dual positive displacement pump (Mini-pump Model MM2-B-96R). The feed rate was checked daily by reading the volume pumped during the previous twenty-four hours. If the pumping rate was incorrect, a graduated cylinder and timer were used to adjust the pumping rate. The feed lines were disinfected by pumping a one-percent solution of Clorox for at least one hour, followed by tap water to cleanse the lines of the disinfectant. One of the feed lines was being disinfected while the other was being used.

## Feed Composition

The composition of the synthetic waste used in this study is given in Table I. Glucose was used as the carbon and energy source in these studies. The synthetic wastewater fed to the aeration tank was designed to have a chemical oxygen demand (COD) of 300 mg/l. Other required nutrients contained in the feed are shown in Table I. The feed pH was maintained at approximately $7.6 \pm 0.2$. The pH of the system was

monitored daily using a Beckman Expandomatic SS-2 pH-meter. Tap water was used in making the feed solution.

TABLE I

COMPOSITION OF SYNTHETIC WASTE

| Constituent | Stock Solution Concentration (g/l) | Feed Concentration (mg/l) |
|---|---|---|
| Glucose | 200 | 300 |
| $(NH_4)_2$ | 100 | 150 |
| $MgSO_4$ | 10 | 15 |
| $FeCl_3$ | 0.05 | 0.075 |
| $MnSO_4$ | 1.0 | 1.5 |
| $CaCl_2$ | 0.75 | 1.125 |
| $KH_2PO_4$ | 38.75 | 116.25 |
| $K_2HPO_4$ | 124.5 | 373.5 |
| Tap water | | to volume |

## Initial Startup

The original inoculum for this activated sludge was obtained from the primary clarifier effluent of the municipal sewage treatment plant at Stillwater, Oklahoma. The unit was operated on a batch basis until the solids concentration had built up to approximately 3000 mg/l. The

microorganisms were batch fed on a once-a-day basis for three weeks. One third of the total volume was wasted from the supernatant after allowing the cells to settle for an hour each day and again made up to the volume with tapwater.

Once the biological solids concentration reached approximately 3000 mg/l, the unit was switched to continuous flow operating conditions. Sludge age was selected as the controlling parameter of operation. The selected sludge age was maintained by wasting biological solids from the aeration tank. Microorganisms were wasted daily at the same time. The amount to be wasted was computed using equations to be discussed later. The experimental unit was operated continuously at four sludge ages--thirteen days, eight days, five days, and two days.

## Daily Protocol

The use of sludge age as the operational parameter required periodic measurement of biological solids concentration and substrate concentration. Effort was made to develop operating procedures leading to efficient and accurate collection of data. Table II shows the parameters which were monitored and recorded daily. Twenty-ml samples of the fresh feed ($S_i$) was removed for chemical oxygen demand (COD) determination. A 50-ml effluent sample was pipetted for the determination of effluent solids concentration ($X_e$). From this filtrate, a 20-ml sample was removed for the determination of chemical oxygen demand ($S_e$).

Another 100-ml effluent sample was collected in a beaker for the determination of zeta potential, specific conductance, pH, and temperature. Each day before changing the feed, the effluent line was plugged

and the feed was shut off momentarily. The dividing baffle was then lifted and the contents of the total system were allowed to mix completely. Then a 25-ml sample was pipetted from the unit for determination of mixed liquor solids concentration ($X_R$) in the total system, and the dividing baffle was again replaced. The settling chamber effluent plug was removed and the feed restarted. The unit was then back on continuous flow operation. The pH was monitored daily in the feed, mixed liquor solids, and effluent.

TABLE II

PARAMETERS MONITORED DAILY

(1) Feed

a) chemical oxygen demand
b) pH

(2) Filtered Effluent

a) chemical oxygen demand

(3) Unfiltered Effluent

a) suspended solids concentration
b) zeta potential
c) specific conductance
d) temperature
e) pH

(4) Mixed Liquor

a) suspended solids
b) pH
c) temperature

## Analytical Methods

In the present study, chemical oxygen demand, biological solids concentration, pH, temperature, zeta potential, and specific conductance were monitored daily.

### Chemical Oxygen Demand

Chemical oxygen demand (COD) determination is an important method to measure the oxygen equivalent of the organic matter in a sample. The principle of the COD test is based upon the fact that all organic components with a few exceptions can be totally oxidized to $CO_2$ and $H_2O$ by the action of the strong oxidizing agent, potassium dichromate, under acid conditions. In spite of the fact that the chief limitation of the COD test is its inability to differentiate between biologically oxidizable and biologically inert organic matter, it is widely used in research work because of the speed with which results can be obtained and its helpfulness in indicating the presence of biologically resistant organic substances (31).

The dichromate reflux method has been selected for the chemical oxygen demand determination in the bioengineering laboratory of the Oklahoma State University because it has advantages over other oxidants in reproducibility and applicability to a wide variety of samples (31). The detailed procedures for running the COD test are given in Standard Methods (32).

### Biological Solids Concentration

Concentration of the biological solids were determined by filtering

the appropriate volume through membrane filters (0.45 μ pore size, Millipore Filter Corp., Bedford, Mass.). The filter pads were placed in light weight aluminum tare pans and dried at 103°C in a drying oven for two hours. Then the filter pads were cooled to room temperature in a calcium carbonate desiccator and the initial weights of the pans were determined. The samples were filtered with the aid of a vacuum pump. Filtrate samples were taken at this point for COD determination. After filtration, the pans were replaced in the drying oven for two hours at 103°C, cooled in the calcium carbonate desiccator, and weighed to determine the biological solids concentration.

pH

The pH of the mixed liquor suspended solids and effluent were monitored daily using a Beckman Expandomatic SS-2 pH-meter. The pH was maintained at 7.6 $\pm$ 0.2 by means of a phosphate buffer system. Periodic standardization of the meter at pH values of 4, 7, and 10 ensured accuracy of the readings.

Temperature

Temperatures of the effluent and mixed liquor suspended solids were monitored with a Curtin laboratory thermometer. In the case of effluent, temperature was monitored before and after measuring zeta potential, since applied voltage, while measuring zeta potential, may increase the temperature and hence average temperature was taken into consideration.

## Zeta Potential and Specific Conductance

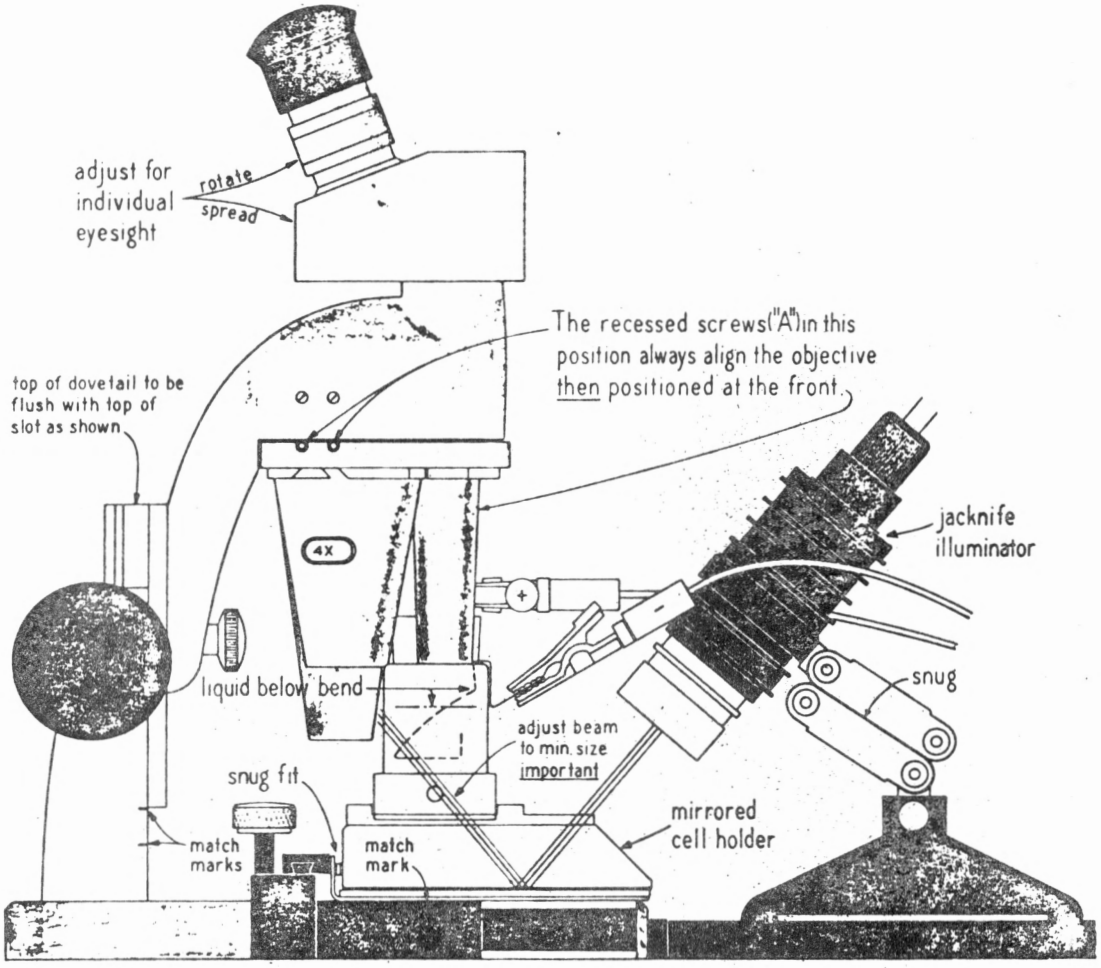
Zeta potential and specific conductance of the effluent were monitored daily using a Zeiss Zetameter, as shown in Figure 2 (Zeta-Meter Inc., New York). About 100 ml of effluent was collected after thorough shaking of the effluent bottle. Then temperature was monitored with a laboratory thermometer. About 3/4ths of the cell tube was filled with effluent and a voltage of 100 volts was applied across the two ends of the cell tube. Voltage of 100 volts was selected for accurate measurement of time during movement of the particles. The lower the voltage, the slower the movement of the particles; the higher the voltage, the faster the movement of the particles. Under the influence of applied voltage, negative particles move to the positive direction and positive particles move to the negative direction. The zeta potential and specific conductance were computed using equations to be discussed later. Once the zeta potential and specific conductance were monitored, the temperature of the effluent in the cell tube was measured again. Average temperature was used for temperature correction in computing zeta potential and specific conductance.

## Methods of Data Analysis

The data obtained in the present study were analyzed by means of the mathematical relationships for a completely mixed, activated sludge process presented by Lawrence and McCarty (33, 34).

Lawrence and McCarty have made use of the mean cell residence time, $\Theta_c$, a parameter that is mathematically equivalent to the reciprocal of net microbial growth rate, $\mu_n$, as the primary system parameter to

Figure 2. Zeiss Zetameter


adjust for individual eyesight
rotate
spread
The recessed screws("A")in this position always align the objective then positioned at the front.
top of dovetail to be flush with top of slot as shown
4X
jacknife illuminator
liquid below bend
snug
adjust beam to min. size important
snug fit
mirrored cell holder
match marks
match mark

control treatment plant design.

COD removal efficiency was calculated by means of the equation:

$$E = \frac{(S_i - S_e)}{S_i} \times 100 \qquad (1)$$

where

$E$ = COD removal efficiency, percent

$S_i$ = influent COD concentration, mg/l

$S_e$ = effluent COD concentration, mg/l

Sludge age or mean cell residence time was calculated by means of the equation:

$$\Theta_c = \frac{VX}{F_w X + (F - F_w)X_e} \qquad (2)$$

where

$\Theta_c$ = sludge age, days

$V$ = volume of aeration tank, liters

$X$ = aeration tank solids concentration, mg/l

$F_w$ = waste flow rate, liters/day

$F$ = flow rate through system, liters/day

$X_e$ = effluent solids concentration, mg/l

The observed yield coefficient was calculated by means of the equation:

$$Y_o = \frac{F_w X + (F - F_w)X_e}{F(S_i - S_e)} = \frac{\Delta X/\Delta t}{\Delta S/\Delta t} \qquad (3)$$

where

$Y_o$ = observed yield coefficient, mg/mg

The specific utilization of substrate was calculated using the equation:

$$U = \frac{F(S_i - S_e)}{VX} = \frac{\Delta S/\Delta t}{X} \tag{4}$$

U = specific utilization, $days^{-1}$.

The true yield coefficient and the maintenance energy coefficient (or decay coefficient) were determined graphically by plotting the experimentally derived values of observed growth rate versus the specific utilization. The relevant equations are:

$$\mu_n = \frac{1}{\Theta_c} \tag{5}$$

$$\mu_n = Y_t U - K_d \tag{6}$$

where

$\mu_n$ = net specific growth rate, $day^{-1}$

$Y_t$ = true yield coefficient, mg/mg

$K_d$ = maintenance energy coefficient, $day^{-1}$

The true yield coefficient and the decay coefficient were also determined graphically by plotting the observed yield coefficient versus sludge age. The relevant equation describes a straight line relationship of the form:

$$\frac{1}{Y_o} = \frac{K_d}{Y_t}\Theta_c + \frac{1}{Y_t} \tag{7}$$

where

$Y_o$ = observed yield coefficient, mg/mg

$Y_t$ = true yield coefficient, mg/mg

$K_d$ = decay coefficient, $day^{-1}$

$\Theta_c$ = sludge age, days

The microorganism concentration in the aeration tank was estimated using the equation:

$$X = \frac{\Theta_c F Y_t (S_i - S_e)}{V(1 + K_d \Theta_c)} \tag{8}$$

Waste sludge production was calculated using the equation:

$$X_w = F_w X + (F - F_w) X_e \tag{9}$$

where

$X_w$ = waste sludge production, mg/day

The formula for determining specific conductance with the Riddick Zeta-Meter cell is:

$$SC = \frac{K \cdot I}{E} \tag{10}$$

where

SC = specific conductance of the sample in micromhos/cm

K = cell constant, which for the cell tube averages about 65

I = current in microamps

E = voltage in volts

Absolute electrophoretic mobility (EM) may be determined in any temperature, but it should always be corrected to and reported at 25°C.

$$EM = \frac{10\mu}{Vt} \qquad (11)$$

where

EM = absolute electrophoretic mobility

$\mu$ = tracking distance in microns, depending upon objective employed

t = average time per full-scale division, sec

V = voltage applied, in volts

Later on, the zeta potential is determined from the EM-ZP curves.

# CHAPTER IV

## RESULTS

The results of this study are presented below. The observed operational parameters of the experimental activated sludge unit are presented in order to provide a basis for evaluating the other parameters.

The performance data of the activated sludge unit at a sludge age of thirteen days are presented in Figure 3. The performance data of the activated sludge unit at subsequent sludge ages of eight, five, and two days are presented in Figures 4, 5, and 6, respectively. As seen in Figure 3, the effluent suspended solids changed significantly after the sixteenth day, and the maximum effluent suspended solids at the sludge age of thirteen days was found to be 75 mg/l. Corresponding change in zeta potential and specific conductance are also observed in Figure 3.

In Figure 4, the maximum effluent suspended solids at the sludge age of eight days was found to be 150 mg/l, and there is a clear change in the specific conductance as the effluent suspended solids increased. Also seen in Figure 4, the effluent COD went up with increasing effluent suspended solids.

In Figure 5, the effluent suspended solids at the sludge age of five days seems to be maintained consistently at low level. There is a marked change in the effluent suspended solids at the sludge age of two days in Figure 6. The maximum effluent suspended solids was found to be 125 mg/l.

Figure 3. Operational Performance of Activated Sludge Unit at a Sludge Age of Thirteen Days

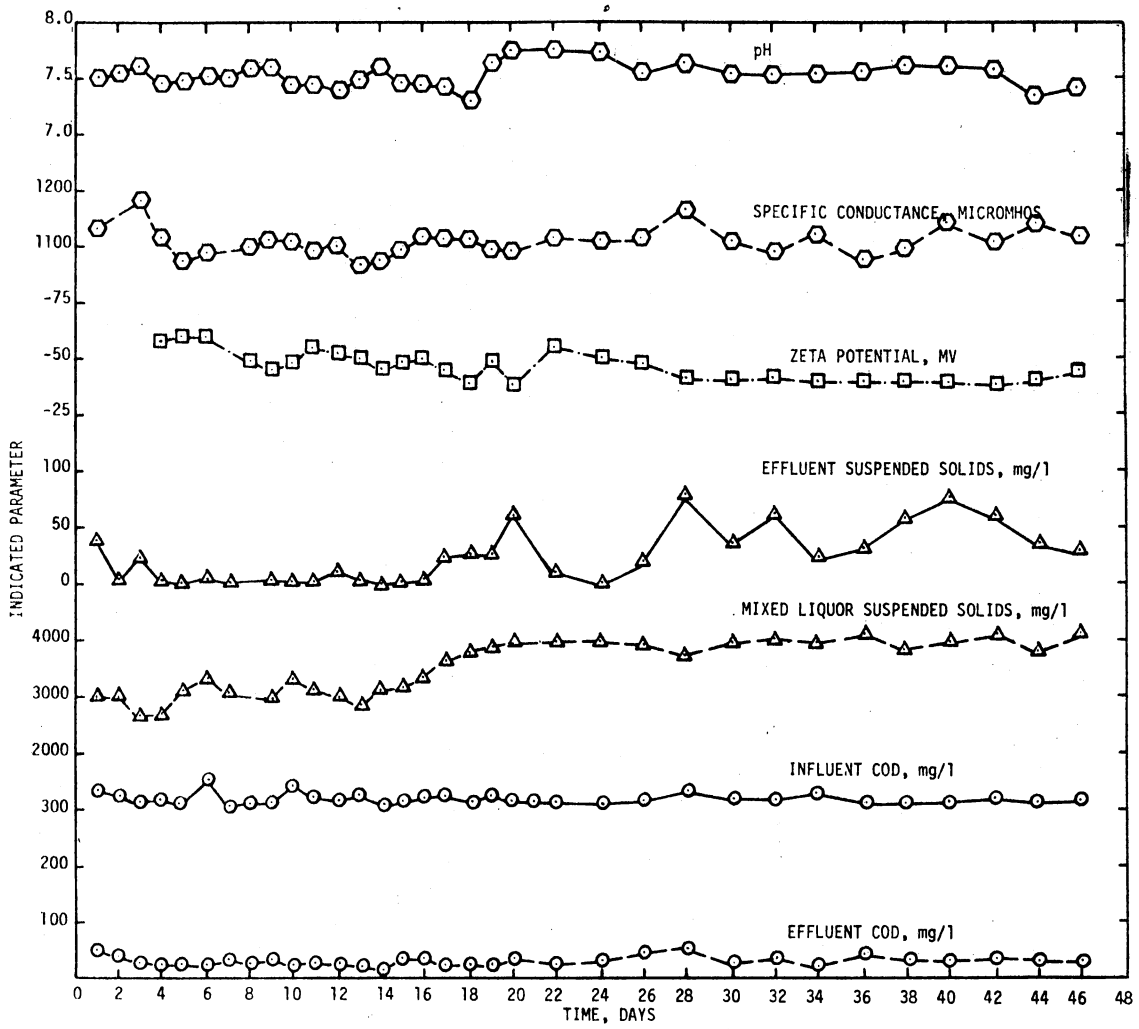

pH
SPECIFIC CONDUCTANCE, MICROMHOS
ZETA POTENTIAL, MV
EFFLUENT SUSPENDED SOLIDS, mg/l
MIXED LIQUOR SUSPENDED SOLIDS, mg/l
INFLUENT COD, mg/l
EFFLUENT COD, mg/l
INDICATED PARAMETER
TIME, DAYS
8.0
7.5
7.0
1200
1100
-75
-50
-25
100
50
0
4000
3000
2000
300
200
100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48

Figure 4. Operational Performance of Activated Sludge Unit at a Sludge Age of Eight Days

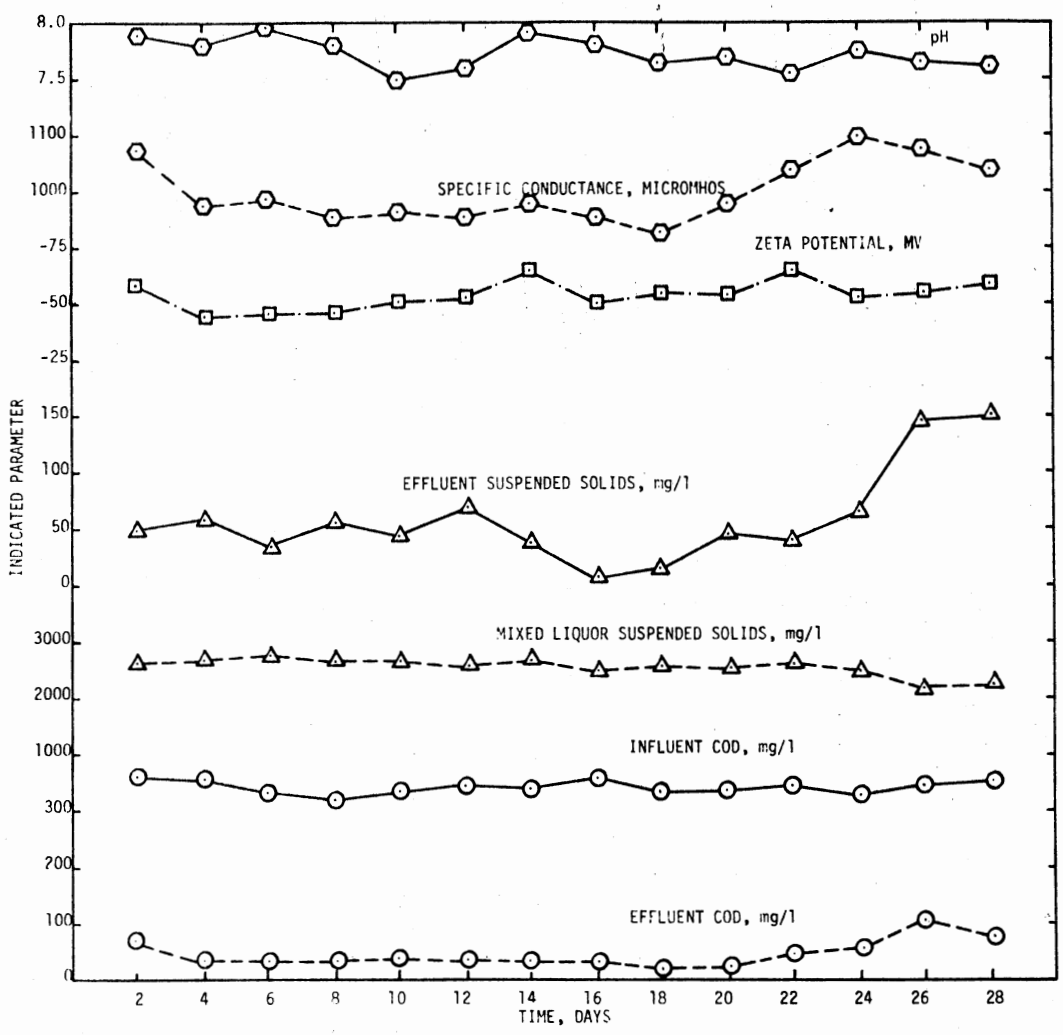

8.0
7.5
1100
1000
-75
-50
-25
150
100
50
0
3000
2000
1000
300
200
100
0
INDICATED PARAMETER
pH
SPECIFIC CONDUCTANCE, MICROMHOS
ZETA POTENTIAL, MV
EFFLUENT SUSPENDED SOLIDS, mg/l
MIXED LIQUOR SUSPENDED SOLIDS, mg/l
INFLUENT COD, mg/l
EFFLUENT COD, mg/l
2
4
6
8
10
12
14
16
18
20
22
24
26
28
TIME, DAYS

Figure 5. Operational Performance of Activated Sludge Unit at a Sludge Age of Five Days

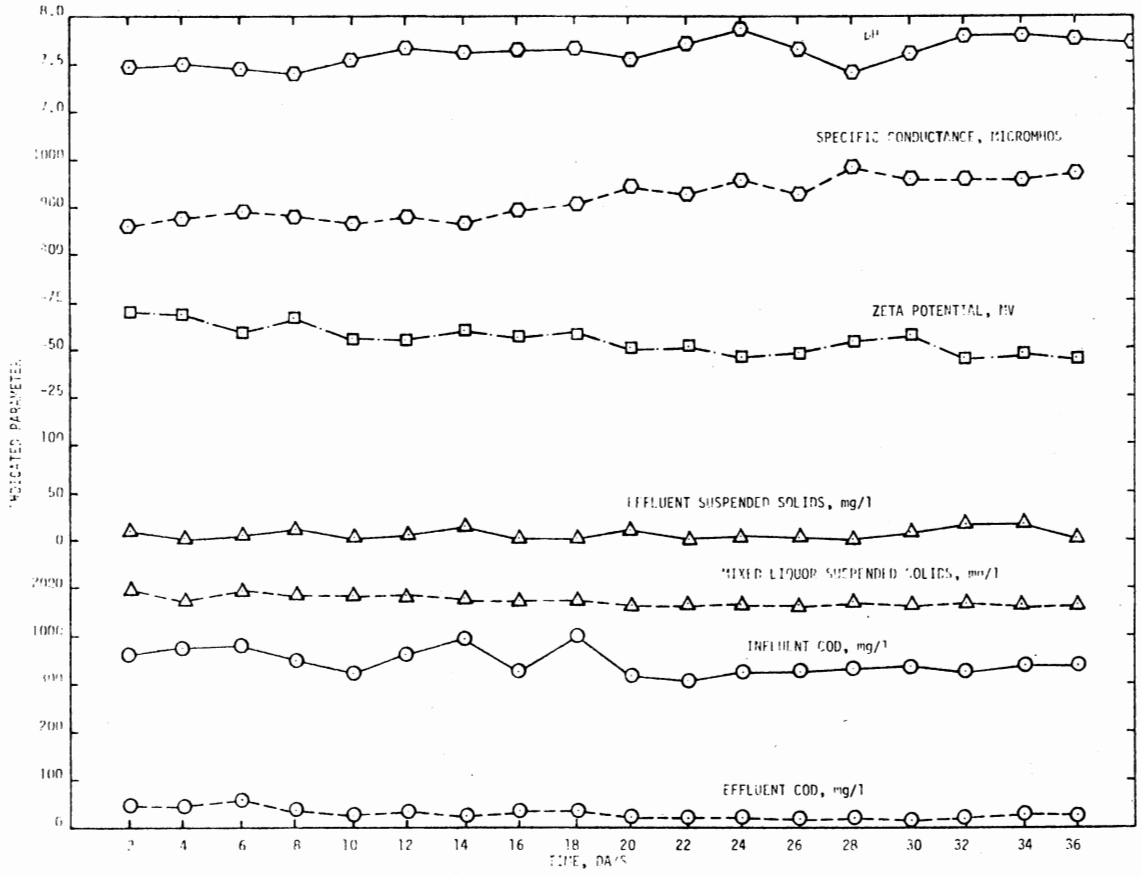
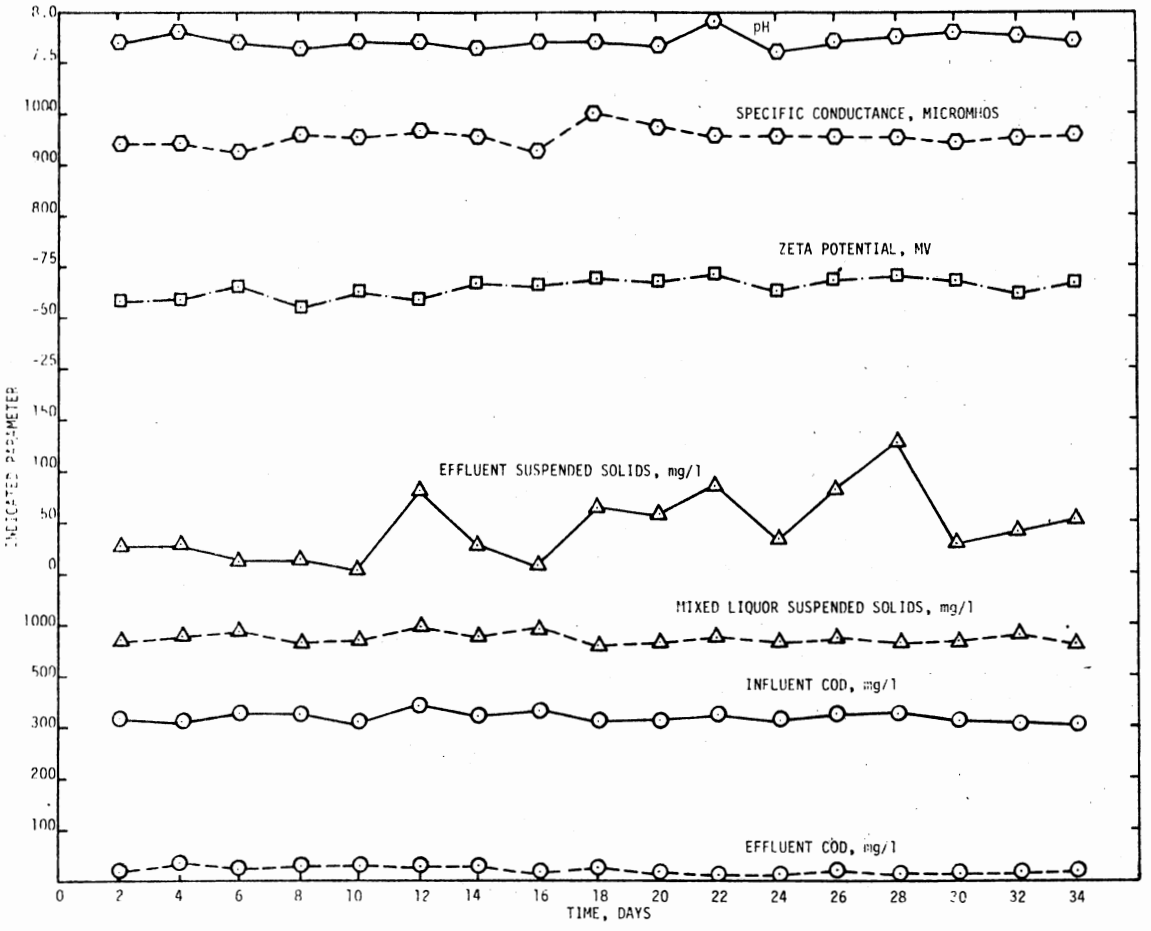

SPECIFIC CONDUCTANCE, MICROMHOS
ZETA POTENTIAL, MV
EFFLUENT SUSPENDED SOLIDS, mg/l
MIXED LIQUOR SUSPENDED SOLIDS, mg/l
INFLUENT COD, mg/l
EFFLUENT COD, mg/l
INDICATED PARAMETER
TIME, DAYS
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36

Figure 6. Operational Performance of Activated Sludge Unit at a Sludge Age of Two Days


pH
SPECIFIC CONDUCTANCE, MICROMHOS
ZETA POTENTIAL, MV
EFFLUENT SUSPENDED SOLIDS, mg/l
MIXED LIQUOR SUSPENDED SOLIDS, mg/l
INFLUENT COD, mg/l
EFFLUENT COD, mg/l
INDICATED PARAMETER
TIME, DAYS
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
100
200
300
500
1000
50
100
150
-25
-50
-75
800
900
1000
7.5
8.0

The COD removal efficiencies for the activated sludge unit are presented in Figure 7. The removal efficiency is presented as a function of sludge age and specific growth rate. As seen in Figure 7, the percentage COD removed was 91 percent and was constant over the range of specific growth rate investigated.

The effluent COD is shown in Figure 8 as a function of sludge age and specific growth rate. As can be seen, the effluent COD varied little over the range of sludge ages investigated.

The mixed liquor suspended solids concentrations are presented versus sludge age and specific growth rate in Figure 9. The points are the observed values of mixed liquor suspended solids concentration at each sludge age or specific growth rate. The mixed liquor suspended solids calculated was based on equation (8). As can be seen in Figure 9, the mixed liquor suspended solids increased with increasing sludge age, which was predicted by equation (8). Excess sludge was wasted once a day and mixed liquor suspended solids concentration was determined before sludge wasting.

Specific utilization is shown in Figure 10 as a function of sludge age and specific growth rate. Specific utilization decreased with increasing sludge age, as expected.

An average value of observed yield was calculated for each sludge age. The relationship between observed yield, sludge age, and specific growth rate is shown in Figure 11. The observed yield increased with decreasing sludge age, as expected.

The specific utilization as a function of specific growth rate is shown in Figure 12. The true yield coefficient and the decay coefficient were derived from Figure 12 using equation (11). The true yield

Figure 7. Percent COD Removed versus Growth Rate

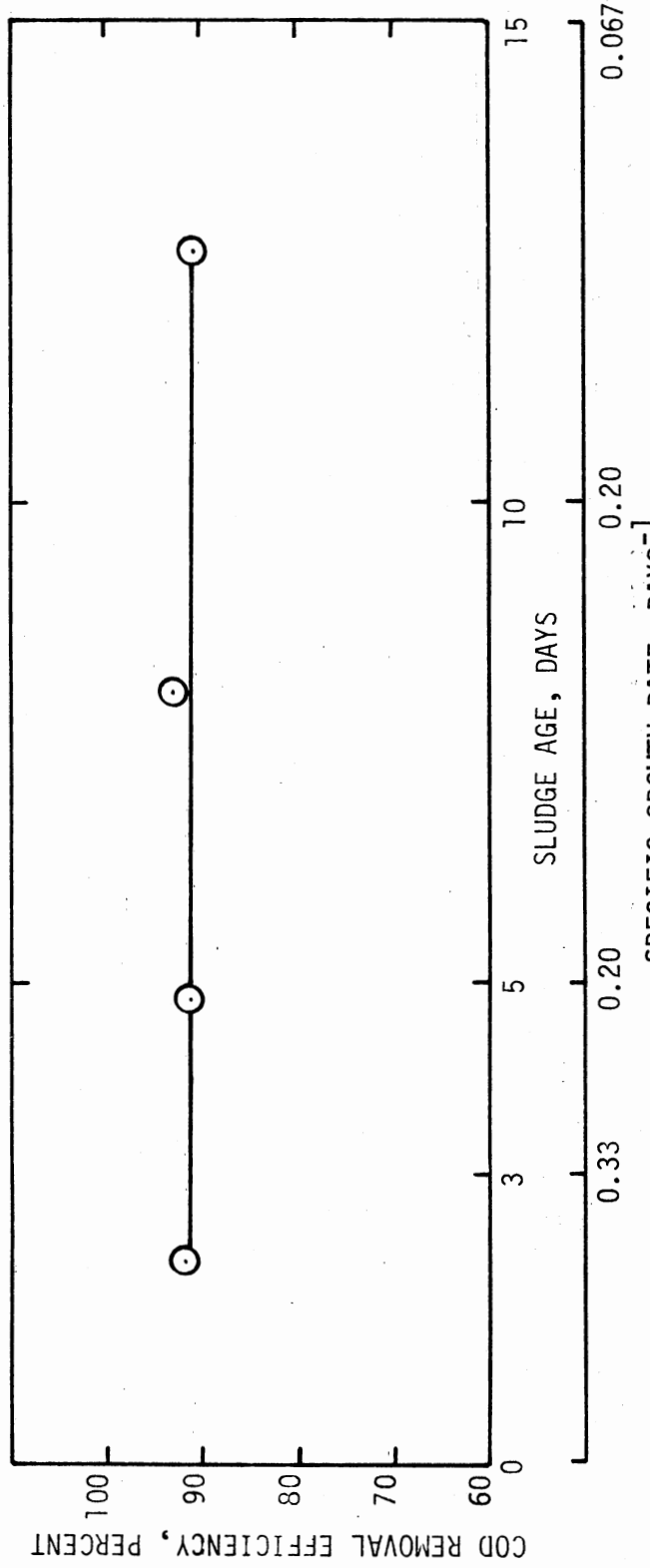

COD REMOVAL EFFICIENCY, PERCENT
100
90
80
70
60
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.20
0.067
SPECIFIC GROWTH RATE; DAYS$^{-1}$

Figure 8. Effluent COD versus Growth Rate

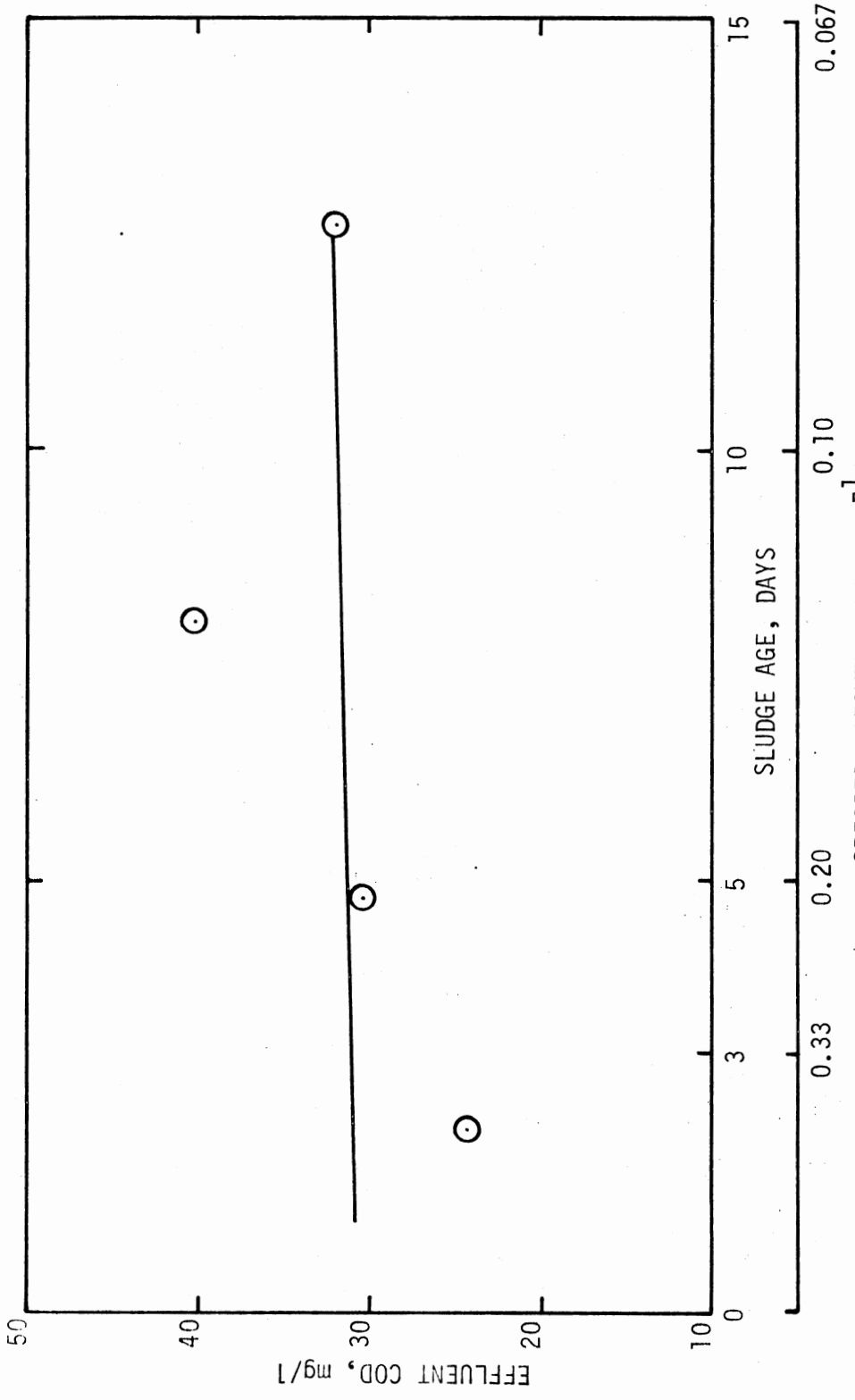

EFFLUENT COD, mg/l
50
40
30
20
10
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0.067
SPECIFIC GEOWTH RATE, DAY$^{-1}$

Figure 9. Mixed Liquor Suspended Solids versus Growth Rate

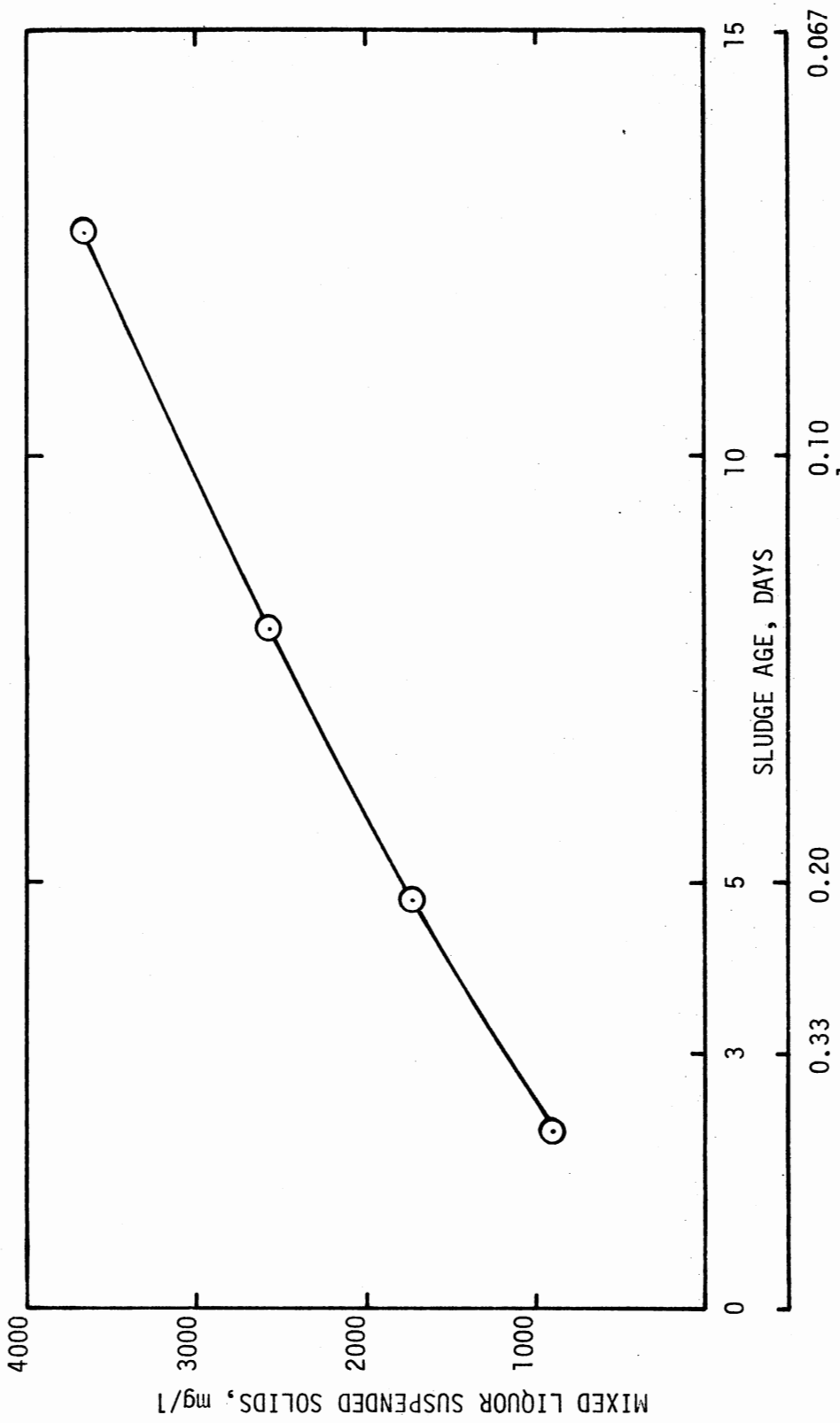

MIXED LIQUOR SUSPENDED SOLIDS, mg/l
4000
3000
2000
1000
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0.067
SPECIFIC GROWTH RATE, DAYS$^{-1}$

Figure 10. Specific Utilization versus Specific Growth Rate

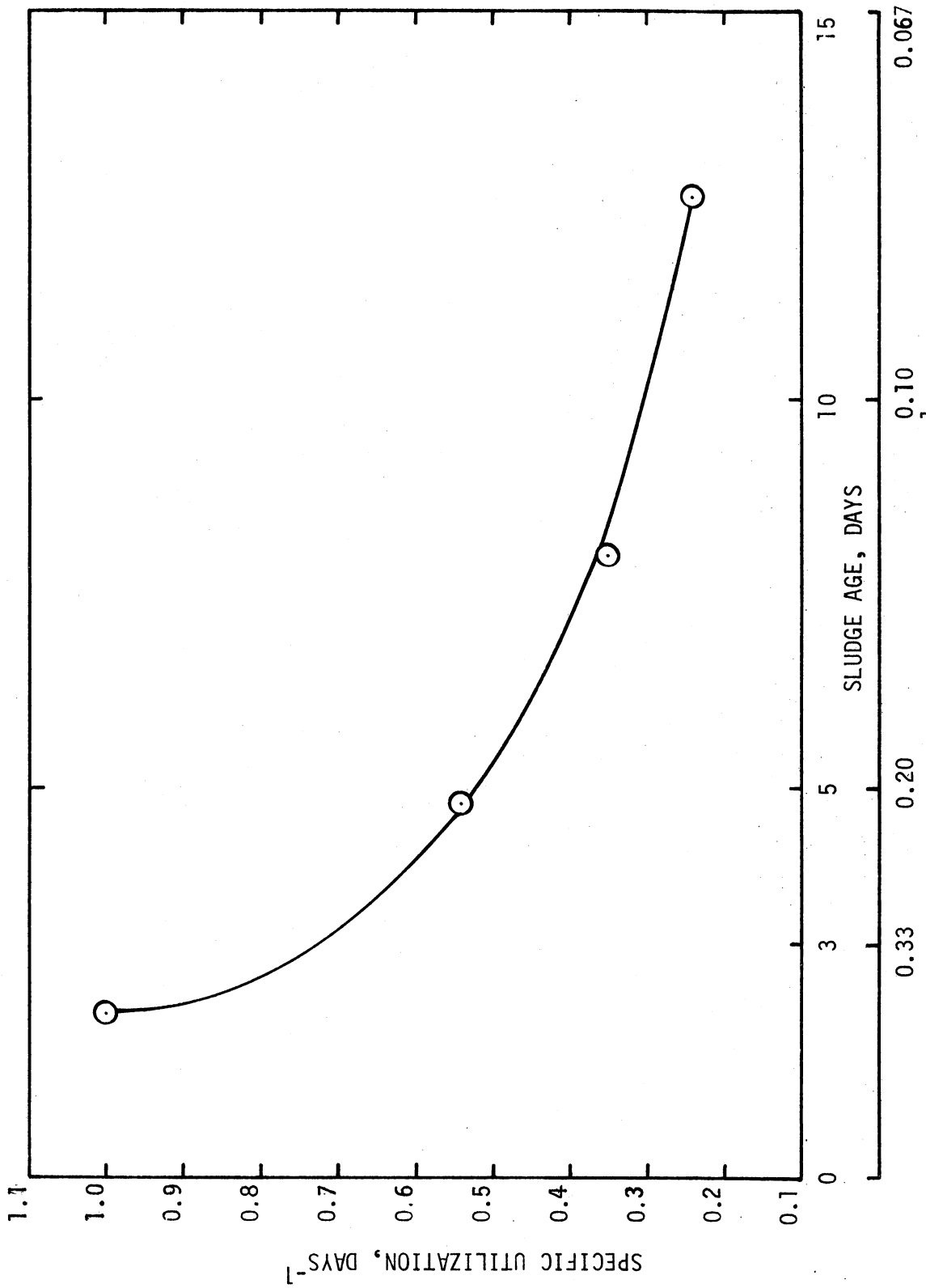

SPECIFIC UTILIZATION, DAYS$^{-1}$
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0.067
SPECIFIC GROWTH RATE, DAYS$^{-1}$

Figure 11. Observed Yield Coefficient versus Growth Rate

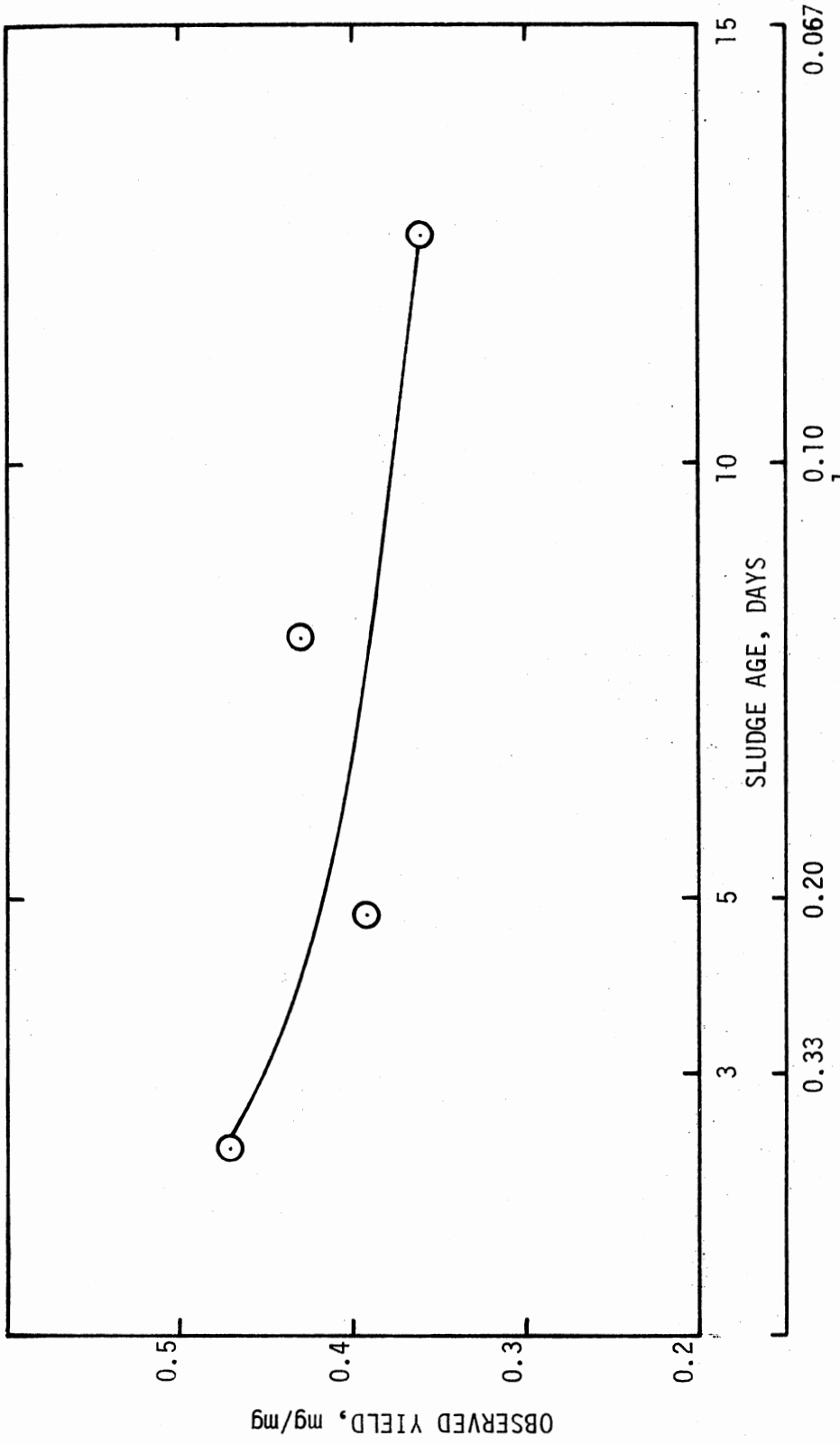
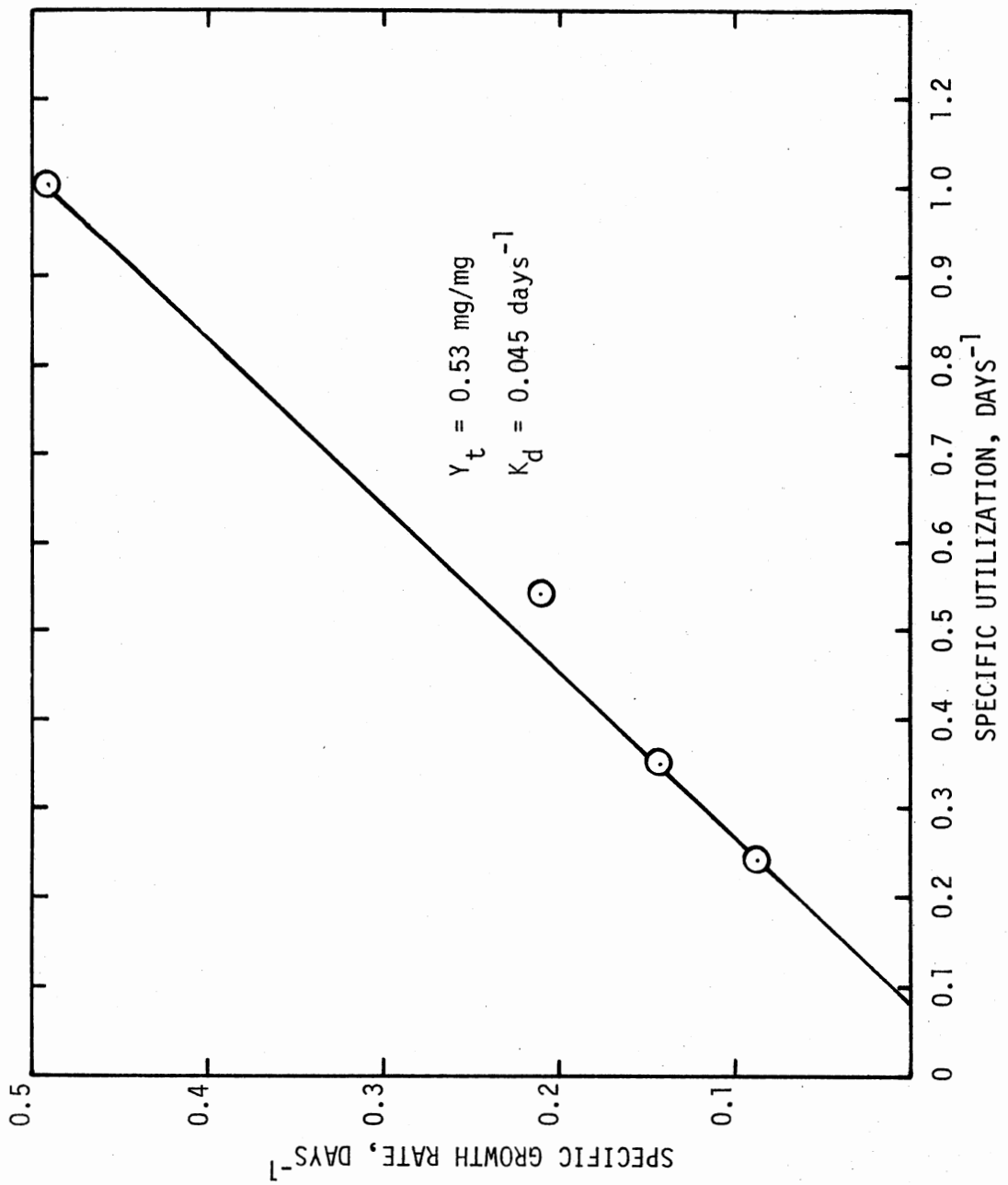

OBSERVED YIELD, mg/mg
0.5
0.4
0.3
0.2
SLUDGE AGE, DAYS
15
10
5
3
SPECIFIC GROWTH RATE, DAYS$^{-1}$
0.067
0.10
0.20
0.33

Figure 12. Specific Growth Rate versus Specific Utilization


SPECIFIC GROWTH RATE, DAYS$^{-1}$
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
SPECIFIC UTILIZATION, DAYS$^{-1}$
$Y_t$ = 0.53 mg/mg
$K_d$ = 0.045 days$^{-1}$

coefficient was found to be 0.53 mg/mg, and the decay coefficient was found to be 0.045 $days^{-1}$.

The reciprocal of the observed yield versus sludge age and specific growth rate is shown in Figure 13. The true yield coefficient and decay coefficient were again determined, using equation (7). The true yield coefficient was found to be 0.52 mg/mg, and the decay coefficient was found to be 0.047 $days^{-1}$.

Excess sludge production is presented as a function of sludge age and specific growth rate in Figure 14. As can be seen, sludge production decreased with increasing sludge age, as predicted by the mean cell residence time.

An average value of pH was calculated for each sludge age. The relationship between pH, sludge age, and specific growth rate is shown in Figure 15. The pH was constant over the range of sludge ages investigated.

Specific conductance is shown in Figure 16 as a function of sludge age and specific growth rate. An average value of specific conductance was calculated for each sludge age, using equation (10). Specific conductance increased with increasing sludge age.

An average value of zeta potential was calculated for each sludge age using equation (11). An effluent sample was used in measuring zeta potential and specific conductance. The relationship between zeta potential, sludge age, and specific growth rate is shown in Figure 17. As can be seen, zeta potential decreased with increasing sludge age.

The effluent suspended solids varied in a complex fashion with sludge age and specific growth rate. Effluent suspended solids is shown in Figure 18 as a function of sludge age and specific growth rate. The

Figure 13. Reciprocal of Observed Yield versus Growth Rate

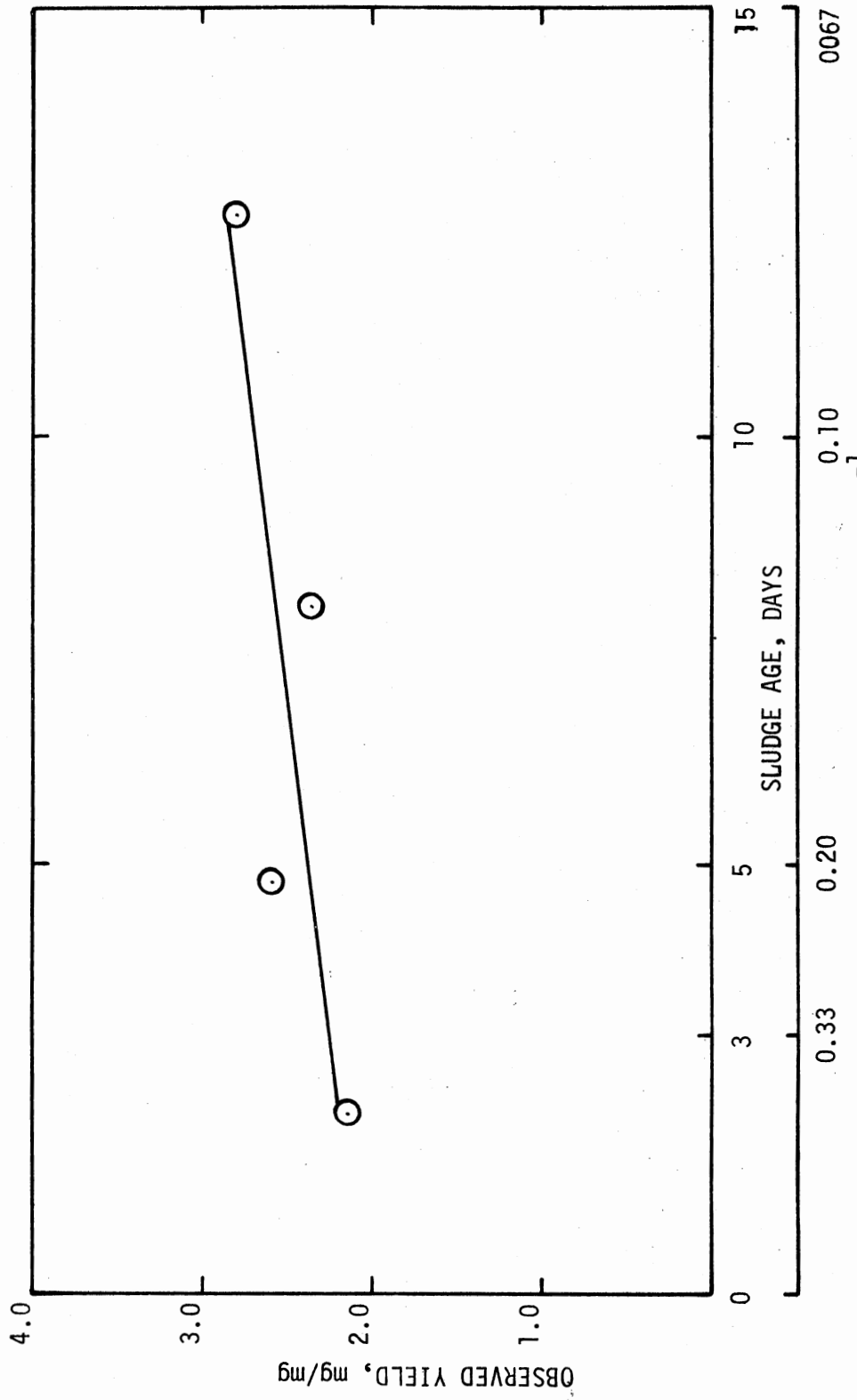

OBSERVED YIELD, mg/mg
4.0
3.0
2.0
1.0
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0067
SPECIFIC GROWTH RATE, DAYS$^{-1}$

Figure 14. Sludge Production versus Growth Rate

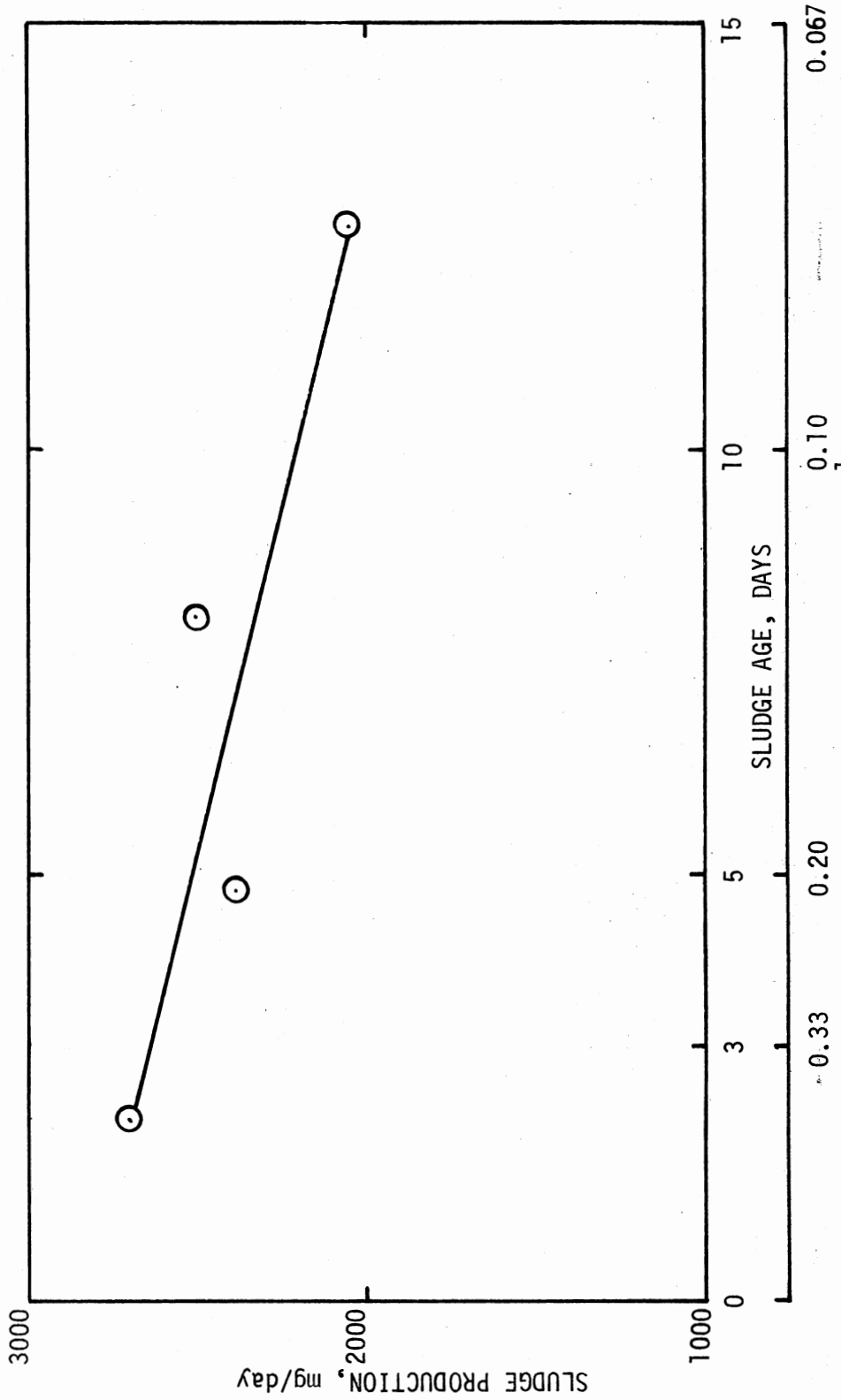

SLUDGE PRODUCTION, mg/day
3000
2000
1000
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0.067
SPECIFIC GROWTH RATE, DAYS$^{-1}$

Figure 15. pH versus Growth Rate

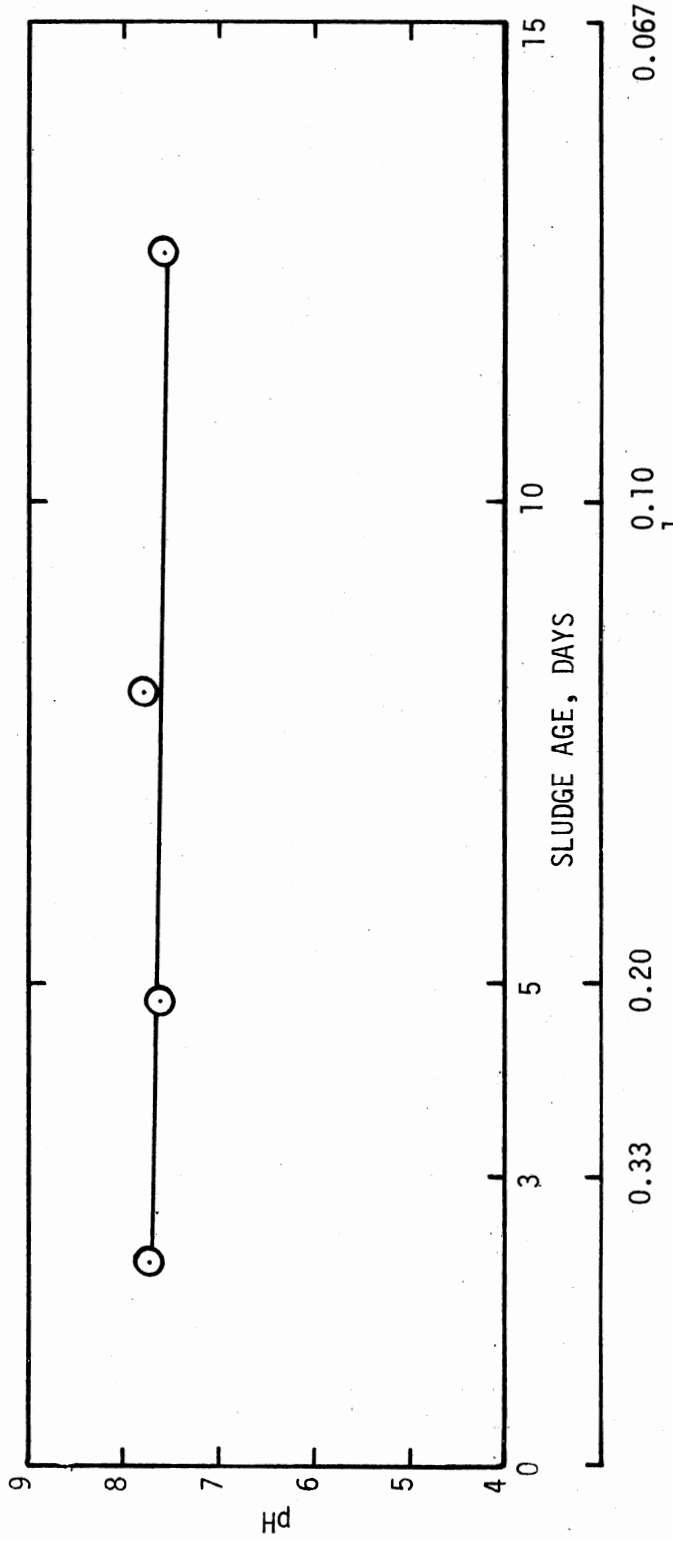

pH
9
8
7
6
5
4
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0.067
SPECIFIC GROWTH RATE, DAYS$^{-1}$

Figure 16. Specific Conductance versus Growth Rate

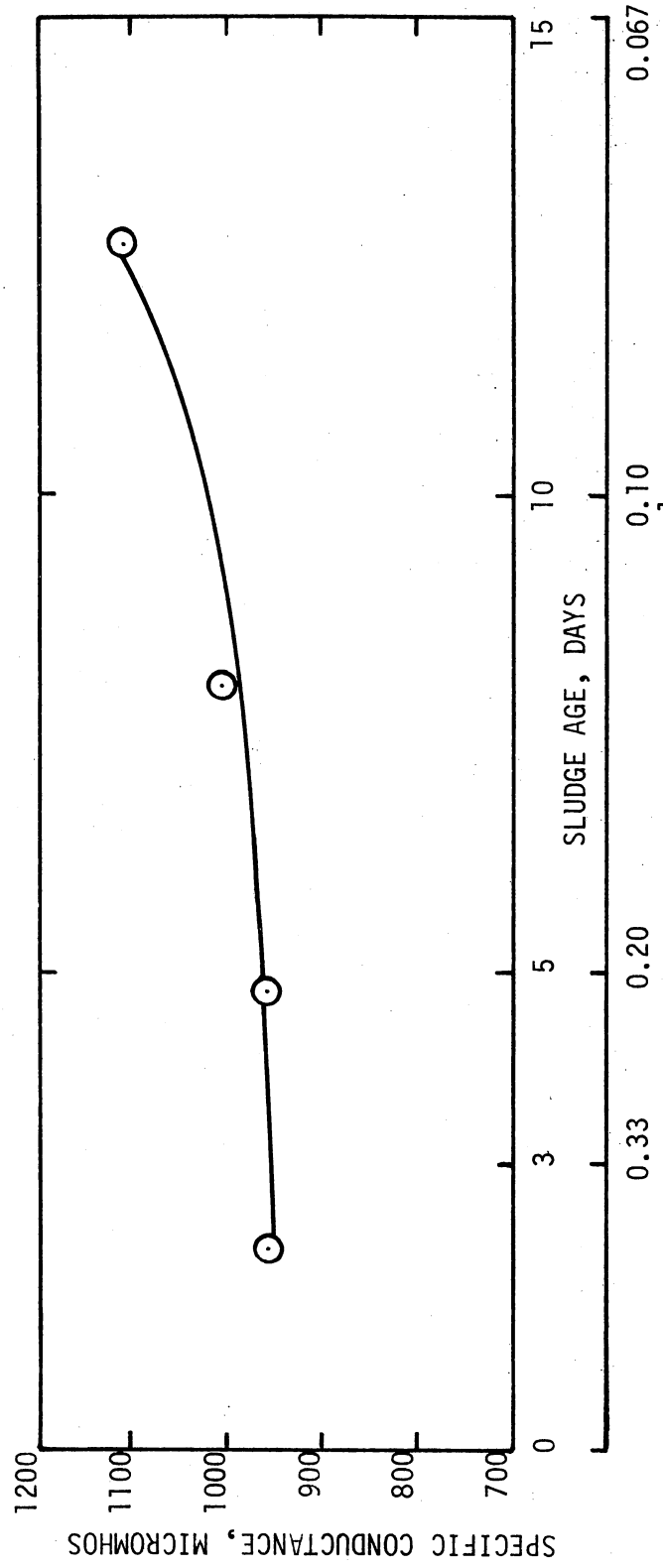

SPECIFIC CONDUCTANCE, MICROMHOS
1200
1100
1000
900
800
700
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0.067
SPECIFIC GROWTH RATE, DAYS$^{-1}$

Figure 17. Zeta Potential versus Growth Rate

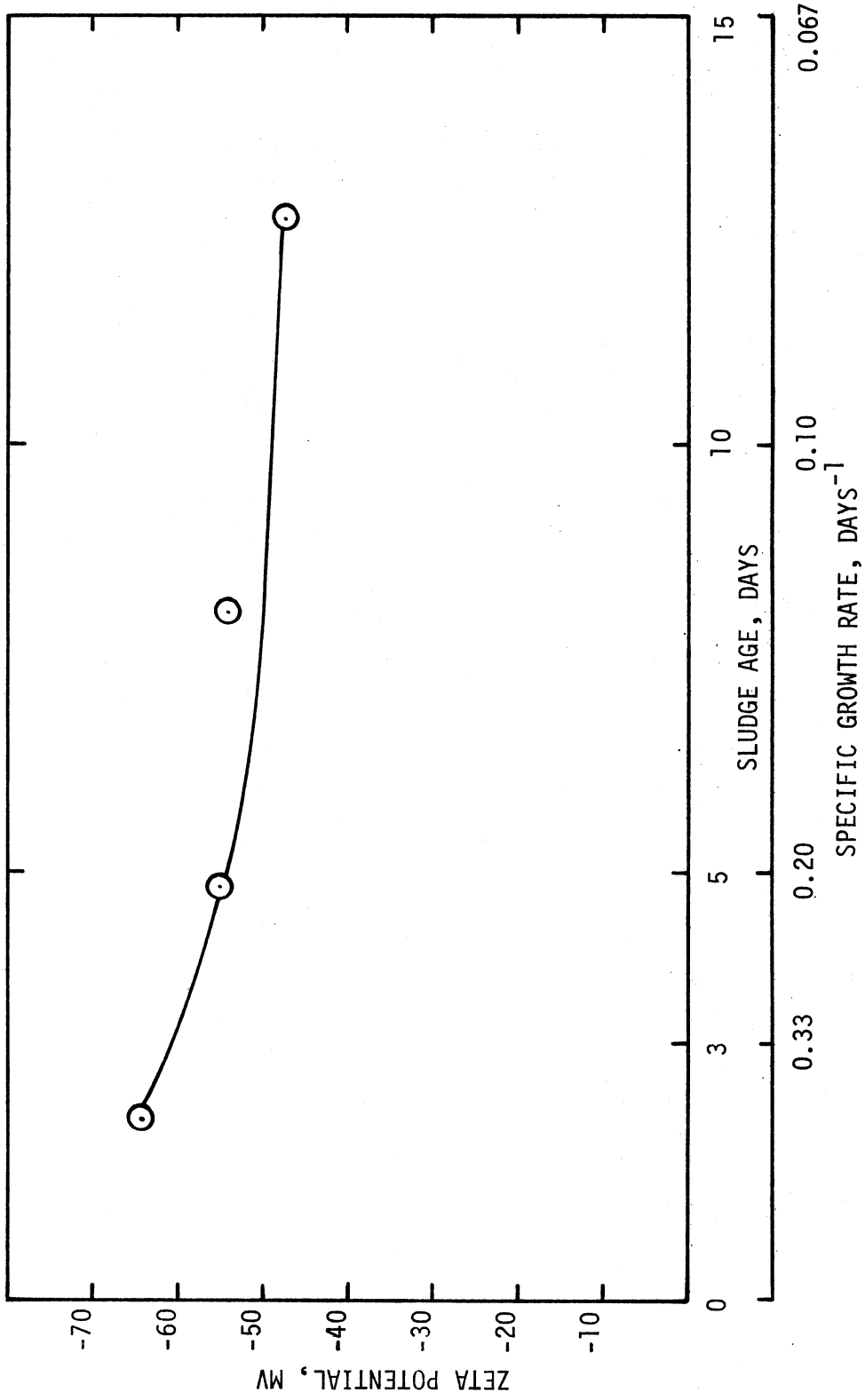
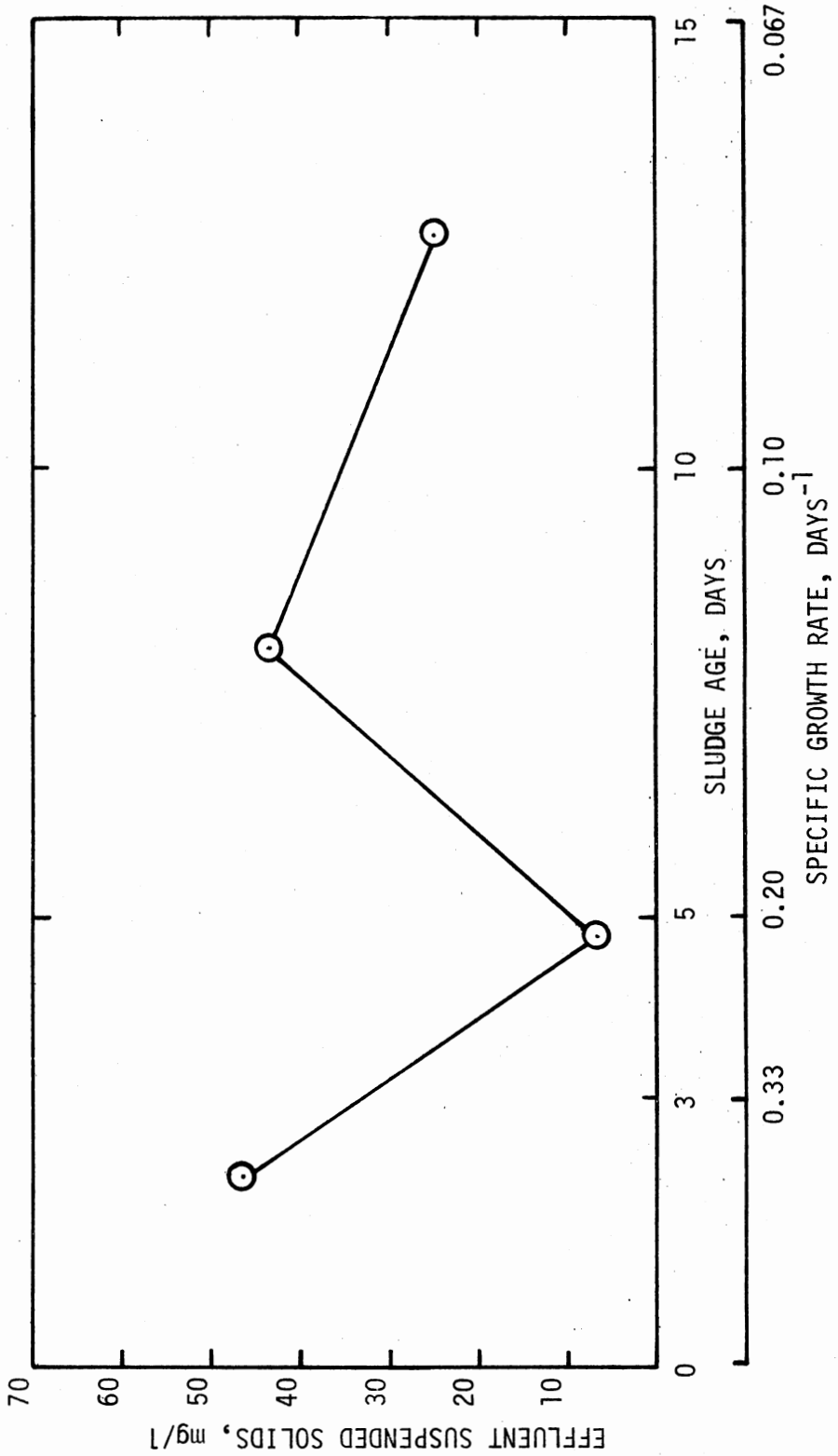

ZETA POTENTIAL, MV
-10
-20
-30
-40
-50
-60
-70
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0.067
SPECIFIC GROWTH RATE, DAYS$^{-1}$

Figure 18. Effluent Suspended Solids versus Growth Rate


EFFLUENT SUSPENDED SOLIDS, mg/l
70
60
50
40
30
20
10
0
3
5
10
15
SLUDGE AGE, DAYS
0.33
0.20
0.10
0.067
SPECIFIC GROWTH RATE, DAYS$^{-1}$

average effluent suspended solids were found to be less at five days sludge age than at two, eight, and thirteen days of sludge ages.

The relationship between specific conductance, zeta potential, and effluent suspended solids is shown in Figures 19 and 20. As seen, specific conductance and zeta potential do vary with effluent suspended solids.

Zeta potential versus mixed liquor suspended solids is shown in Figure 21. Zeta potential seems to be increasing with increasing mixed liquor suspended solids concentration. The relationship between specific conductance and mixed liquor suspended solids is shown in Figure 22. Specific conductance is increasing with increasing mixed liquor suspended solids concentration.

Figure 19. Specific Conductance versus Effluent Suspended Solids

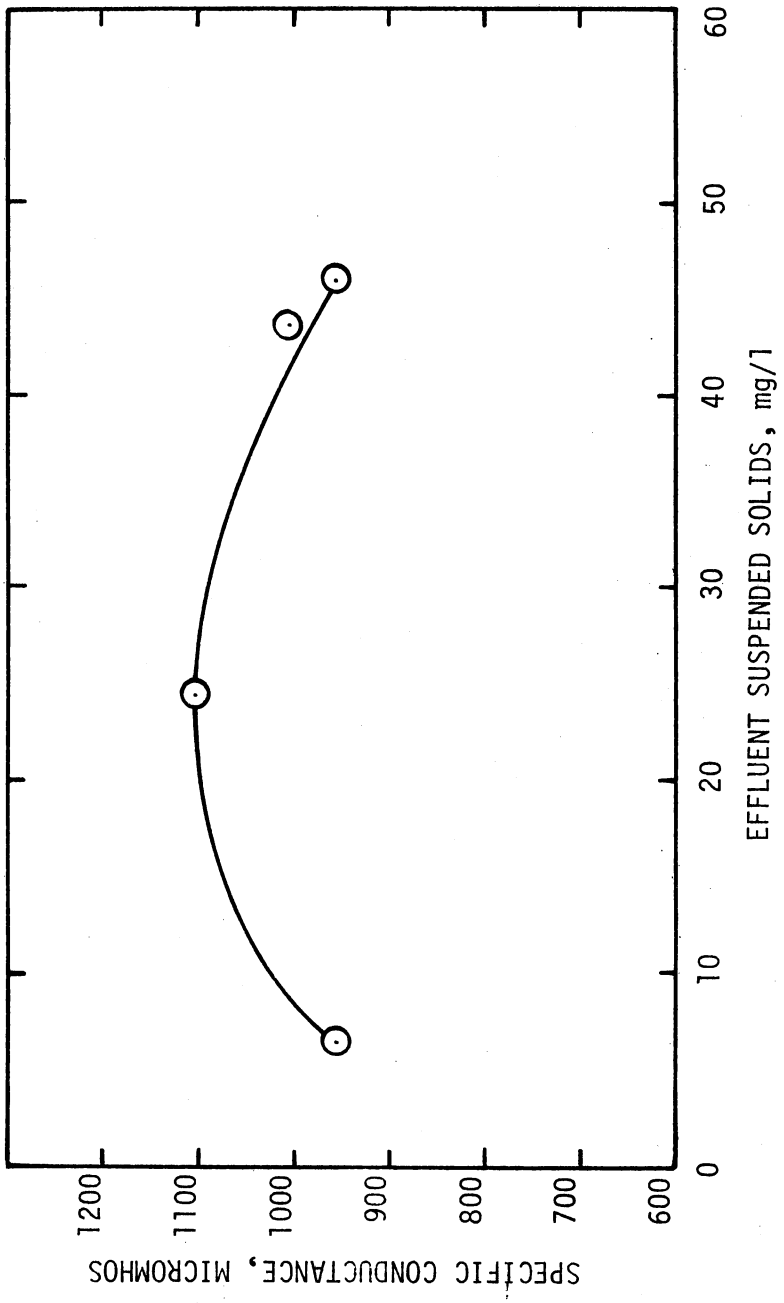

SPECIFIC CONDUCTANCE, MICROMHOS
600
700
800
900
1000
1100
1200
0
10
20
30
40
50
60
EFFLUENT SUSPENDED SOLIDS, mg/l

Figure 20. Zeta Potential versus Effluent Suspended Solids

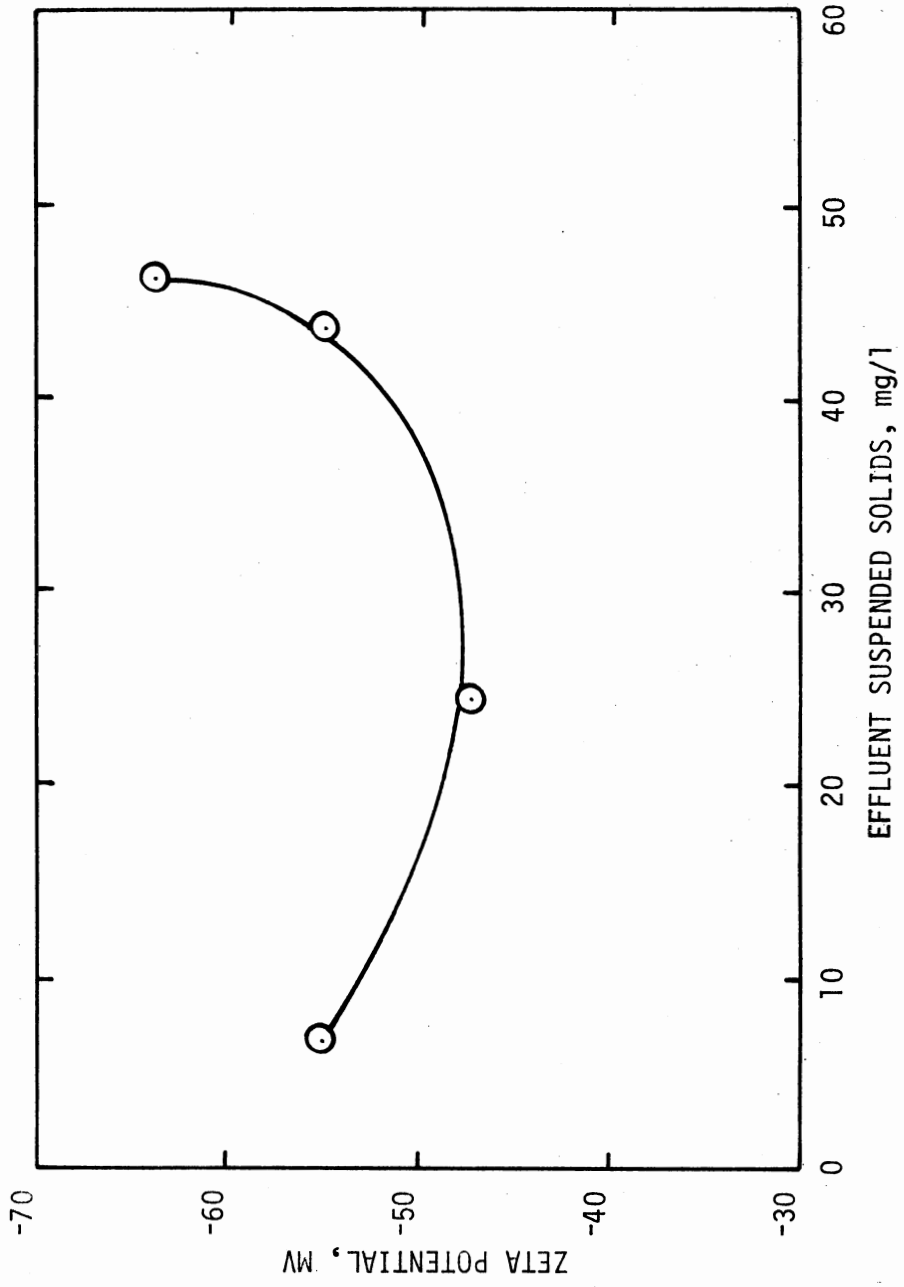

ZETA POTENTIAL, MV
-70
-60
-50
-40
-30
0
10
20
30
40
50
60
EFFLUENT SUSPENDED SOLIDS, mg/l

Figure 21. Zeta Potential versus Mixed Liquor Suspended Solids

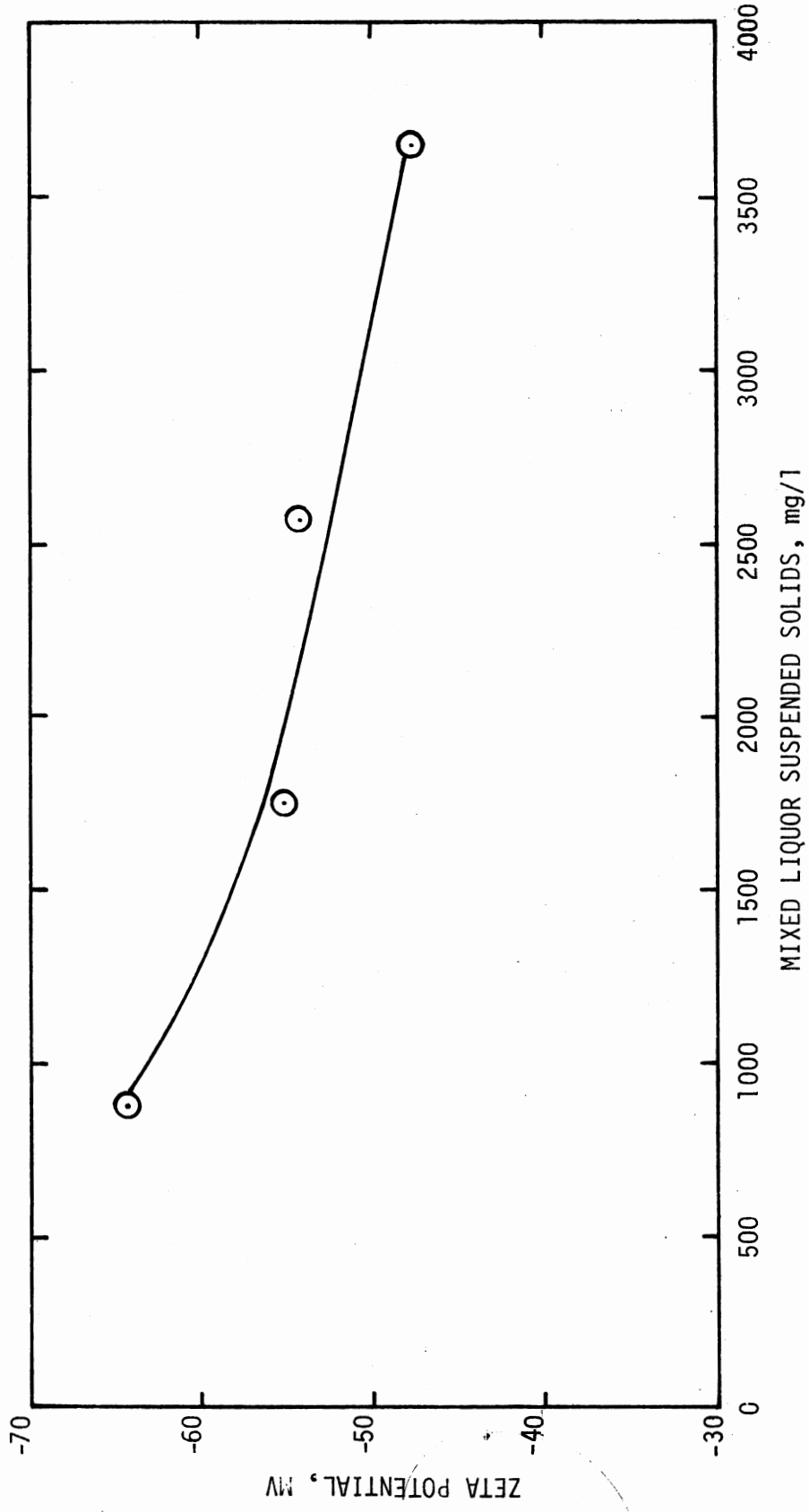
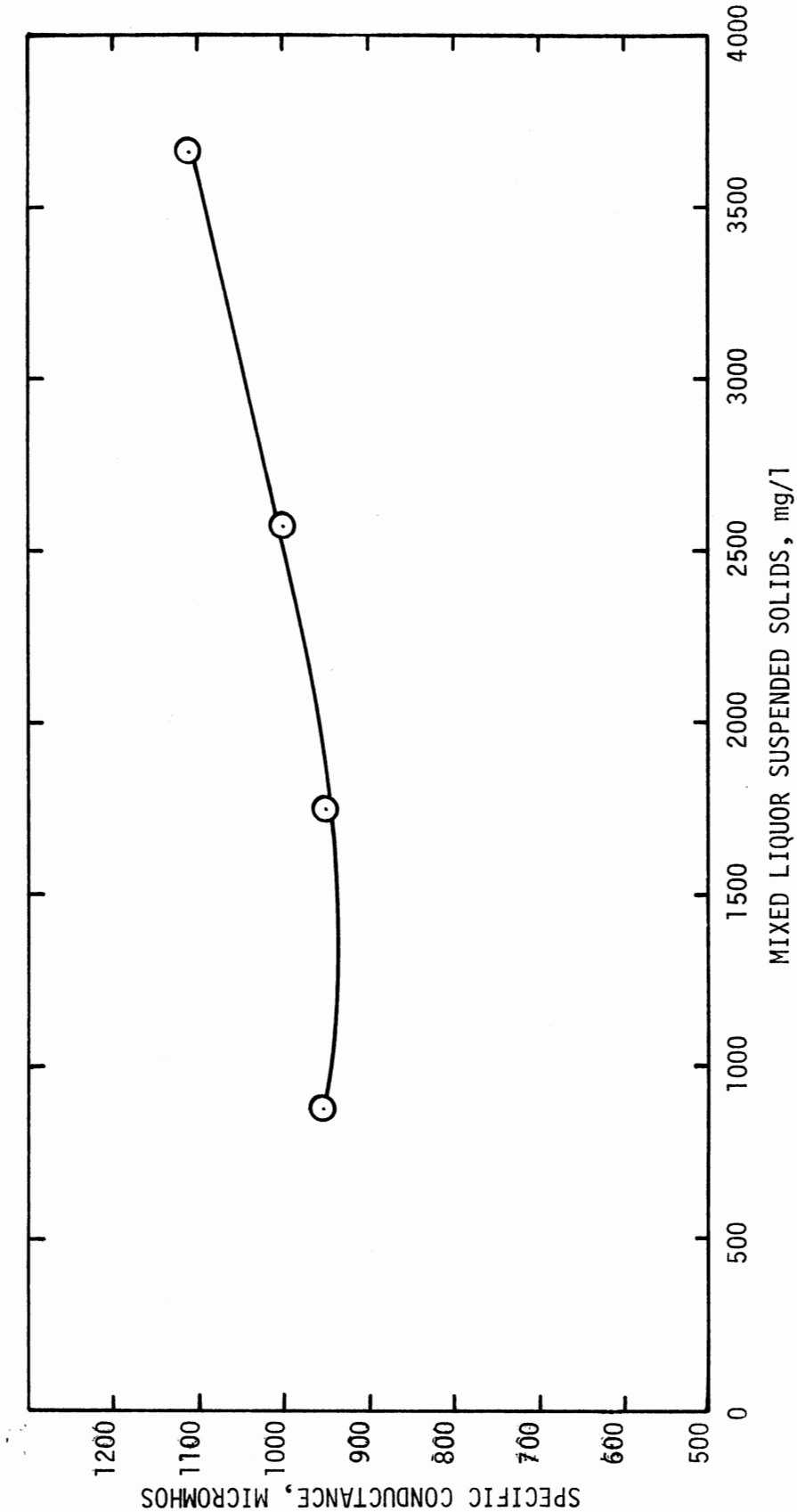

ZETA POTENTIAL, MV
-70
-60
-50
-40
-30
0
500
1000
1500
2000
2500
3000
3500
4000
MIXED LIQUOR SUSPENDED SOLIDS, mg/l

Figure 22. Specific Conductance versus Mixed Liquor Suspended Solids


SPECIFIC CONDUCTANCE, MICROMHOS
500
600
700
800
900
1000
1100
1200
0
500
1000
1500
2000
2500
3000
3500
4000
MIXED LIQUOR SUSPENDED SOLIDS, mg/l

# CHAPTER V

## DISCUSSION

Results describing the operating characteristics of the activated sludge unit used in the present study, as presented in Figures 7 through 14, were fit quite well by the mean cell residence time equations.

An interesting finding with respect to the operating data was the observed relationship between average effluent suspended solids concentration and sludge age Figure 18. This finding is of interest because sludge age apparently has some effect on the clarification function of a secondary clarifier for the activated sludge system. The Environmental Protection Agency has set limits on both effluent suspended solids and effluent BOD. Consequently, these are both important design and operation criteria. Effluent suspended solids contribute to both effluent suspended solids and effluent BOD, as seen in Figure 18.

The average effluent suspended solids concentration was minimum 6.5 mg/l at a sludge age of 4.8 days. At other sludge ages, the average suspended solids concentration varied between 25 and 46 mg/l. The overflow rate and clarifier detention time were constant at all sludge ages. A relationship similar to that found in this study was observed by Bisogni and Lawrence (2), although the absolute values observed in each study were different, which is to be expected. There are differences in seed, overflow rate, and mixed liquor suspended solids in the Bisogni and Lawrence study and in the present study. Also in the present

study, activated sludge solids were wasted once per day and the activated sludge solids concentration measured prior to wasting was the value used in calculating sludge age. Another reason for the difference between the values observed in the present study and the values observed by Bisogni and Lawrence is possibly the differing operating procedures. Regardless of the slight difference between the values observed by Bisogni and Lawrence and values observed in the present study, both studies do suggest that sludge age affects clarification. However, the specific value of the relationship is not clear at this point, and more research needs to be done on the effect of sludge age on clarification of activated sludge.

In the present study, zeta potential and specific conductance of the effluent suspended solids was also measured. The results seem to be quite interesting. It was observed that there is a relationship between zeta potential and sludge age (Figure 17). It was observed that zeta potential increases slightly with increasing sludge age. It was also observed that there is a relationship between specific conductance and sludge age (Figure 16). It is seen that specific conductance increases with increasing sludge age. Thus, it was observed that both zeta potential and specific conductance increase with increasing sludge age. All of the calculations of zeta potential and specific conductance were corrected at a temperature of $25^{o}C$.

It was also observed that there is a relationship between average effluent suspended solids and zeta potential (Figure 20). With increase of effluent suspended solids, zeta potential seemed to be increasing. A relationship similar to this was observed by Riddick (20). Riddick observed that zeta potential increases with increasing effluent suspended solids concentration.

There is also a relationship between average specific conductance and average effluent suspended solids concentration. It was observed that specific conductance decreases with increasing effluent suspended solids concentration. Thus, with an increase in effluent suspended solids concentration, the zeta potential increases and specific conductance decreases. Concurrently, it was also observed that zeta potential and specific conductance increase with increasing sludge age. The studies of Riddick (20) and also the present studies suggest that zeta potential affects clarification.

The most undesirable result of an overloaded secondary clarifier is an increase in effluent suspended solids. Changing the sludge age would also probably result in increased effluent suspended solids. The safest strategy in dealing with an overloaded clarifier and the first strategy to be tried is increasing the return flow. Although this will likely decrease the underflow concentration, so will decreasing the sludge age. Adequate capacity for return flow should be designed into treatment plants and should receive careful consideration by the design engineer.

It seems that sludge age is the independent variable of greatest significance. It is possible that the varying mixed liquor suspended solids concentration was either entirely or at least partially responsible for the variations in effluent suspended solids concentration, zeta potential, and specific conductance (Figures 21 and 22). The most simple means of determining the effect of mixed liquor suspended solids concentration on the above parameters is to maintain a constant sludge age, while varying the feed concentration.

# CHAPTER VI

## CONCLUSIONS

This study has led to the following conclusions, which are valid only within the range of sludge ages and mixed liquor suspended solids concentration with heterogeneous culture.

1. At a constant overflow rate and detention time, the effluent suspended solids concentration will vary with sludge age and specific growth rate.

2. Zeta potential seems to increase slightly with increasing sludge age and specific growth rate.

3. Specific conductance increases with increasing sludge age and specific growth rate.

4. Zeta potential and specific conductance vary with effluent suspended solids and mixed liquor suspended solids concentration in the specific growth rates investigated.

# CHAPTER VII

## SUGGESTIONS FOR FUTURE WORK

The phenomenon of heterogeneous culture is extremely complex. Effluent solids concentration may depend upon a large number of factors, any one of which may predominate according to the peculiar and particular set of environmental conditions in which the heterogeneous culture exists.

All of the experiments of the present study were performed using only glucose as substrate. It would be worthwhile to study effluent solids concentrations with different substrates to determine any possible relation between substrate structure and effluent solids concentration.

It would also be of interest to isolate as many organisms as possible which are present in wastewaters for individual study to determine which increase or decrease effluent solids concentration.

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VITA[2]

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