EFFECT OF SLUDGE AGE ON THE TREATABILITY OF SLAUGHTERHOUSE WASTEWATER

By

SUTHIRAK SUJARITTANONTA

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Oklahoma State University

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Thesis Approved:

Don F Kincannon
Thesis Adviser

Richard D. DeVries

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

In a world of expanding population and rapidly increasing urban-industrial development, water is one of the most important factors responsible for the general good health enjoyed by the population.

As human populations multiply and industrialization increases and diversifies, pollution of the environment becomes more critical. One of the greatest problems is pollution of natural waters with industrial wastewaters.

Industrial wastewaters can impair the quality of a receiving water if the discharge to a receiving water exceeds the assimilative capacity of the stream.

Because of the problems associated with industrial wastes, the use of wastewater treatability studies is increasing. Engineers must understand the general approach and methodology involved in treatability studies, the procedures of laboratory and pilot plant studies, and the translation of experimental data into design parameters.

This investigation was conducted to study the effect of sludge age on the treatment of slaughterhouse wastewaters using sludge age as the controlling parameter.

CHAPTER II

LITERATURE REVIEW

Slaughterhouse Waste Treatment

Slaughterhouse waste is similar to domestic waste in regard to composition. No toxic components are known to be present; therefore these wastes should be amenable to the processes commonly employed for the treatment of domestic wastes (1). However, the total organic content of slaughterhouse wastes is considerably higher than that of domestic wastes.

In the treatment of slaughterhouse wastes, the first stage of treatment should be within the slaughterhouse itself, where the strength of the waste can be reduced to the lowest possible value by utilization of all feasible salvage operations. The content of the mixed waste depends upon good housekeeping, plant operations, and plant recovery practices (2).

Reducing the quantity or strength of waste can be profitable in large slaughterhouse operations. These include the recovery of grease, blood, and paunch manure. Grease recovery is usually accomplished by means of baffled basins or traps on waste lines. Blood recovery occurs during the killing operation (3). Paunch manure is recovered in the dry state or, if it is mixed with wastewater, it can be removed by vibrating screens or rotary screens.

Screening by rotary wire mesh screen removes coarse materials such as flesh, floating solids, and paunch manure, which can interfere with the treatment process. Removals of nine percent suspended solids on a 20-mesh screen and 19 percent on a 30-mesh screen have been reported. There was no appreciable reduction in the BOD of the waste. A sedimentation basin is necessary, in addition to screening, for the removal of settleable solids. Removals of 63 percent of suspended solids and 35 percent of the BOD by sedimentation have been reported (3).

Biological treatment has been used satisfactorily for the treatment of slaughterhouse wastes. Among these are activated sludge, trickling filter, and anaerobic digesters.

Activated sludge has been used satisfactorily in the treatment of slaughterhouse wastes. In many cases, slaughterhouse wastes and domestic wastes are combined for treatment. Studies have been made by Wernitznig (4) on the treatment of slaughterhouse waste by the activated sludge process under non-steady state conditions. A process efficiency of 93 percent was obtained. Poppe (5) in 1972 studied the combined treatment of slaughterhouse wastes and domestic wastes with and without the addition of biocatalysts. It was found that the addition of biocatalysts had no appreciable effect on the treatment of slaughterhouse wastes.

Trickling filters have also been used for treating slaughterhouse wastes. BOD removals of 95 percent have been reported by using trickling filter following use of a septic tank (6). Bradney, Nelson, and Bragsted (1) described the operation of a trickling filter at the city of Sioux Falls, South Dakota. BOD removals of 97.4 percent using a PVC trickling filter combined with an aerobic lagoon and chlorine contact

have been reported by Baker and White (7).

Studies were made by Stover (8) on the treatment of slaughterhouse wastes by the bio-disc process. The process was found to be feasible for the treatment of slaughterhouse wastes. BOD removals of 93 percent have also been reported using the bio-disc process to treat the effluent from anaerobic lagoons treating slaughterhouse wastes (9).

Anaerobic digestion of slaughterhouse wastes has also been shown to be successful. BOD reductions of 95 percent to 98 percent are attainable with low loadings (10). The operation of the anaerobic digester process in the treatment of slaughterhouse wastes has been described by Steffen (6).

Lagooning of slaughterhouse wastes has been used successfully where sufficient land is available. Sufficient available land is necessary, as the holding time in a lagoon is a big factor in BOD removals (11). Wymore and White (12) studied the treatment of slaughterhouse wastes using anaerobic lagoons followed by aerated lagoons. BOD removals of more than 95 percent were reported.

Slaughterhouse waste treatment processes other than biological treatment have been attempted. Delaporte (13) described the operation of sand filters for the treatment of wastes from small slaughterhouses. BOD removals of 95 percent during summer-autumn operation, and 85 percent during winter-spring operation using two-stage sand filtration were reported (2).

Granstrom (14) has conducted experiments on chemical coagulation using alum and chlorine as the coagulants. It was found that alum and chlorine, if used in sufficient quantities, will appreciably reduce the BOD and color, and provide improved clarification. BOD reductions of

96 percent were reported.

The precipitation of proteins from slaughterhouse wastes has been studied. It has been shown that chlorine has the property of coagulating and precipitating the proteins in slaughterhouse wastes. Studies on the removal of proteins from a slaughterhouse waste by lignin sulphonic acid were conducted by Tonseth and Berridge (15). BOD removals of 70 to 90 percent were reported.

Sludge Age

The activated sludge process utilizes a continuous culture of microorganisms in which a mixed microbial population grows on a mixture of organic and inorganic substances. The sludge age or mean cell residence time, Θ_c, is one of the parameters on which the operation of an activated sludge plant can be based. The sludge age is determined by calculating the total mass of microorganisms in the process, and dividing by the rate at which microorganisms are wasted from the process. For a process operating at steady state conditions, sludge age is the reciprocal of microorganism specific growth rate.

In 1968, Jenkins and Garrison (16) studied the control of the activated sludge process by sludge age. To use sludge age as the controlling parameter, sampling of the influent, mixed liquor, effluent, and return sludge is required. It was shown that effluent quality and nitrification can be regulated by controlling the sludge age. They concluded that sludge age is a kinetically rational basis for the control, operation, and design of activated sludge plants.

Walker (17) described a hydraulic method of controlling sludge age in the activated sludge process. The solids level in the activated

sludge process adjusts automatically to the influent BOD when the sludge age is controlled hydraulically. The solids level increases if the influent substrate concentration increases.

Lawrence and McCarty (18) have also introduced a unifying parameter defined as sludge age, Θ_c, which they concluded is a particularly useful parameter because of its basic relationship to bacterial growth rate and the ease of use in design calculations and in the operation of biological treatment processes. They also introduced an operation safety factor which is defined as sludge age, Θ_c, divided by a minimum sludge age, Θ_c^m, the process can maintain. They also suggested that sludge age be used as an independent parameter in biological treatment control and design, because sludge age is related to the performance of continuous biological processes employing suspensions of microorganisms in a fundamental way.

Sherrard and Lawrence (19) proposed that sludge age be used as the basis for comparing process parameters under different conditions of operation. They showed that the effluent waste concentration, treatment efficiency, cell concentration, sludge production, and sludge settling data are all functions of sludge age.

Sherrard and Schroeder (20) reported on the effect of sludge age in the activated sludge process. They found that operating the activated sludge process at a low sludge age resulted in low mixed liquor suspended solids, high sludge production, and high inorganic nutrient removal.

Sherrard, Schroeder, and Lawrence (21) developed a mathematical model for the completely mixed activated sludge process. Observed yield coefficient (Y_{obs}), food to microorganism ratio (F/M), specific

utilization (U), cell concentration at various hydraulic detention times (θ), and various influent substrate concentrations, sludge production, and treatment efficiency have all been shown to be a function of sludge age.

Stall (22) studied the effect of sludge age on phosphorous removal efficiency in the activated sludge process. Operation of the activated sludge process at a low sludge age increased the phosphorous removal efficiency.

Metcalf and Eddy, Inc. (23) suggested the use of sludge age in design and operational control because of the ease in use and accuracy. They based their suggestion upon the fact that to control the growth rate of microorganisms and their degree of waste stabilization, a specified percentage of microorganisms in the system can be wasted each day. Thus, the control of the system is effected by wasting microorganisms.

CHAPTER III

MATERIALS AND METHODS

To study the treatability of slaughterhouse wastes under steady state conditions, two bench scale units (biological reactors) were operated under closely controlled conditions for approximately six months.

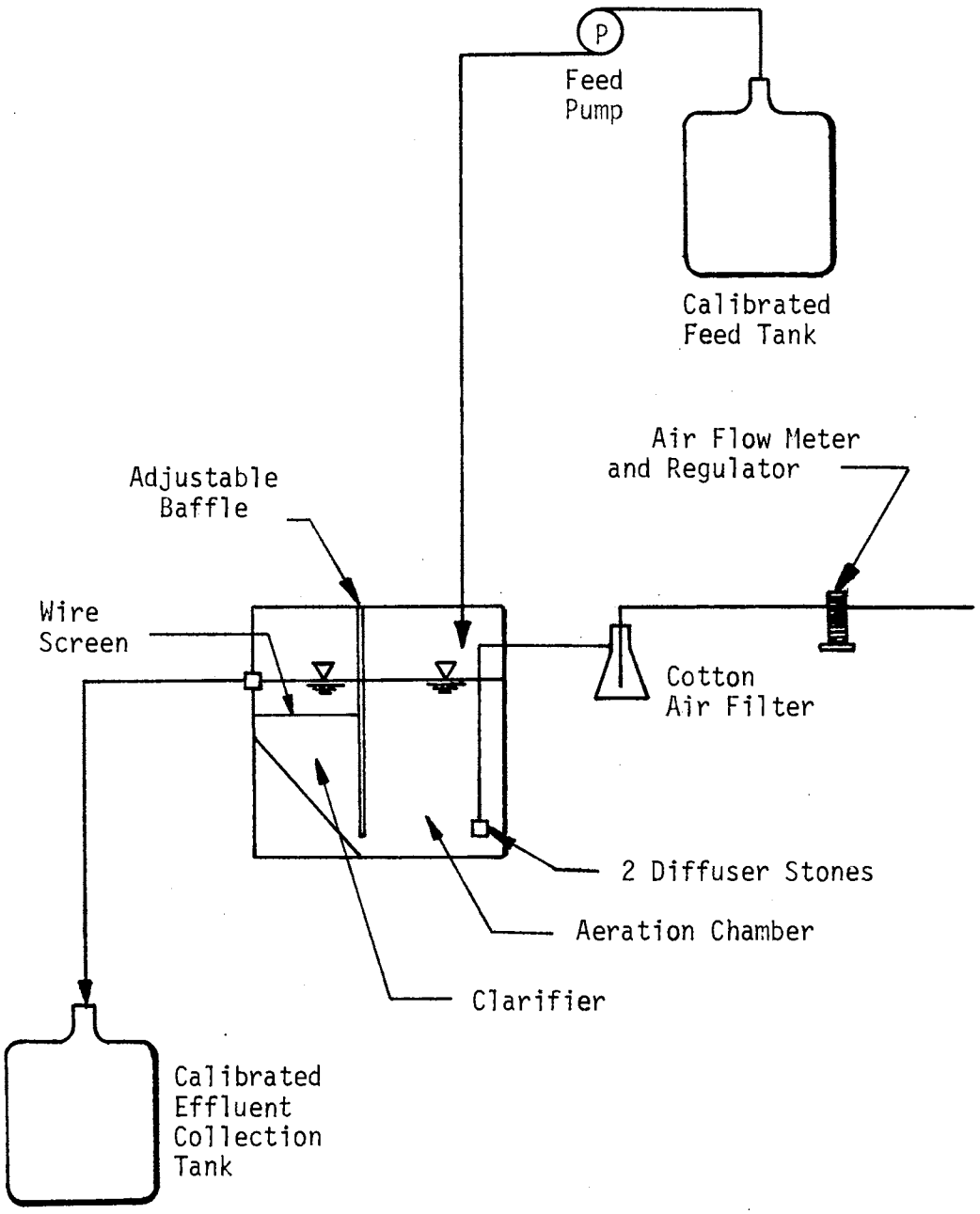
For ease of presentation, a description of the apparatus used, the feed solution, experimental and analytical procedures, and methods of data analysis are presented separately.

Laboratory Apparatus

A schematic diagram of the laboratory apparatus used in the experimental investigation is shown in Figure 1. Two bench scale units of equal volume were used to perform nine continuous flow steady state studies. The biological reactors were rectangular, and made of one-fourth inch thick Plexiglass. An adjustable baffle separated the reactor into two compartments: aeration chamber and clarifier. The volume of the aeration basin and the clarifier could be varied by positioning the adjustable baffle. The volume of the aeration basin, clarifier, total reactor, and hydraulic detention time based on total reactor volume for both reactors are listed in Table I.

A feed rate of 15 liters/day was supplied to the reactors by means of a Milton Roy dual, positive displacement pump (Mini pump, Model MM2-B-96R). The pumping rate was checked weekly by means of a graduated

Figure 1. Experimental Activated Sludge Unit With Internal Sludge Recycle


P
Feed
Pump
Calibrated
Feed Tank
Air Flow Meter
and Regulator
Adjustable
Baffle
Wire
Screen
Cotton
Air Filter
2 Diffuser Stones
Aeration Chamber
Clarifier
Calibrated
Effluent
Collection
Tank

cylinder and timer.

TABLE I

REACTOR DIMESIONS AND HYDRAULIC DETENTION TIMES

	Aeration Chamber Volume (liters)	Clarifier Volume (liters)	Total Reactor Volume (liters)	Hydraulic Detention Time (hrs)
Reactor A	9.2	2.7	11.9	19.0
Reactor B	9.4	2.5	11.9	19.0

Air was supplied through two porous diffusers. An air flow rate of between 4.0 and 4.5 liters per minute was monitored through a Gelman air flow meter to provide good mixing and sufficient oxygen for the microorganisms. The position of two porous diffusers was adjusted to provide a good recycle. A cotton filter was placed between the air flow meter and the air diffusers to prevent oil from entering the air lines and biological reactor which could contaminate the biological population.

The mixed liquor suspended solids were wasted daily from the total reactor after removing the baffle and allowing the entire volume to mix. The wastage rates of the microorganisms were 750, 1000, and 2000 ml/day.

Feed Solution

The chemical composition of wastewater and nutrients is listed in

Table II. The wastewaters were designed to have chemical oxygen demands of approximately 460, 1100, and 1570 milligrams per liter (mg/l). A buffer solution was used to maintain the pH between 6.0 and 7.0.

The wastewater had beef blood as the carbon source. This waste was obtained during beef slaughtering operations at Ralph's Packing Company, Perkins, Oklahoma. An 18-liter container was used to collect the beef blood. About 10 liters were collected directly from slaughtered animals and then diluted immediately with hot water. After returning to the laboratory, the blood was placed in 2-liter glass containers, and samples were taken to determine chemical oxygen demand in each container. The values of chemical oxygen demand varied from less than 10,000 mg/l to over 70,000 mg/l. This depended upon the dilution required to prevent the blood from coagulating. Because the chemical oxygen demands were very high and varied, the chemical oxygen demand of the feed was not as consistent as a synthetic waste would be.

Experimental and Analytical Procedures

The microorganisms for this study were obtained from a unit operated by Wernitznig (1) in the bioengineering laboratories. His unit was also fed a beef blood waste. The biological reactor was operated on a batch basis until the microorganism concentration had built up to approximately 1600 mg/l, then the biological reactor was operated as a continuous flow system. Table III shows the parameters which were monitored on a daily and weekly basis. A batch unit was also operated so that microorganisms would be available for following experiments.

The biological reactor was operated by selecting the sludge age as the operational parameter. Microorganisms were wasted on a daily basis.

TABLE II

COMPOSITION OF WASTEWATER

	Stock Conc. per 2 liters (grams)	Quantity used per 15 liters (ml)	Final Conc. in 15 liters (mg/l)
Beef Blood	*	*	*
KH_2PO_4 (Experiments 1-9)	105.4	100.0	531.33
K_2HPO_4 (Experiments 1-9)	214.0	100.0	713.33
$MgSO_4 \cdot 7H_2O$			
Experiments 1-3	20.0	75.0	50.00
Experiments 4-6	20.0	150.0	100.00
Experiments 7-9	20.0	225.0	150.00
$MnSO_4 \cdot H_2O$			
Experiments 1-3	2.0	75.0	5.00
Experiments 4-6	2.0	150.0	10.00
Experiments 7-9	2.0	225.0	15.00
$CaCl_2$			
Experiments 1-3	1.5	75.0	3.75
Experiments 4-6	1.5	150.0	7.50
Experiments 7-9	1.5	225.0	11.25
$FeCl_3 \cdot 6H_2O$			
Experiments 1-3	0.1	75.0	0.25
Experiments 4-6	0.1	150.0	0.50
Experiments 7-9	0.1	225.0	0.75
$(NH_4)_2SO_4$			
Experiments 1-3	200.0	40.0	266.67
Experiments 4-6	200.0	80.0	533.33
Experiments 7-9	200.0	120.0	800.00

*Amount of beef blood was dependent on substrate concentration of various stock concentrations.

The amount to be wasted depends upon the volume of the biological reactor and the desired value of the sludge age.

TABLE III

PARAMETER MONITORED ON A DAILY OR WEEKLY BASIS

	Daily	Weekly
1. Feed		
A. Chemical oxygen demand	*	
B. pH		*
2. Filtered Effluent		
A. Chemical oxygen demand	*	
3. Unfiltered Effluent		
A. Suspended solids concentration	*	
B. pH		*
4. Biological Reactor		
A. Microorganism concentration	*	
B. pH	*	
C. Temperature		*

The feed was prepared daily, according to the proportions shown in Table II. A 20-ml sample was taken for the chemical oxygen demand concentration. The feeds were designed to have three different chemical oxygen demands, averaging 460 mg/l for experiments 1-3, 1100 mg/l for experiments 4-6, and 1570 mg/l for experiments 7-9.

The effluent sample from the effluent line was collected in a

50-ml graduated cylinder. A 25-ml sample was filtered through a 45 μ membrane filter for filtrate chemical oxygen demand determination.

A 25-ml sample was taken from the mixed effluent collection tank and filtered through a 45 μ membrane filter to determine effluent suspended solids concentration. A 50-ml sample was taken if the effluent suspended solids concentration was less than 10 mg/l, to provide better accuracy.

After plugging the effluent line, the wire screen and baffle were removed and the entire mixed liquor suspended solids was well mixed. A glass tube extending into the center of the biological reactor was used to waste the mixed liquor suspended solids from the total reactor by siphoning. A 25-ml sample was taken from the wasted mixed liquor suspended solids filtered through a 45 μ membrane filter to determine total reactor suspended solids concentration. The baffle was replaced, and after sufficient settling in the clarifier, the wire screen was replaced and the plug in the effluent line was removed. The pH of mixed liquor suspended solids was checked daily, and the temperature was checked weekly.

The suspended solids concentrations were determined by filtering the sample through 45 μ membrane filters (Millipore Filter Corp., Bedford, Mass.). An analytical balance (Mettler Instrument Corporation Balance No. 1-910) was used to weigh the filters. The temperature was measured with a Sargent-Welch thermometer, and pH was measured by a Beckman Expandomatic 55-2 pH meter.

Feed and effluent chemical oxygen demand determinations were made in accordance with Standard Methods (24). When the chemical oxygen demand exceeded 1000 mg/l, dilution of the samples was required. The

dilute method was used for effluent chemical oxygen demand determinations for better accuracy.

Methods of Data Analysis

The data obtained from this investigation were analyzed by mathematical relationship for the completely mixed activated sludge process as presented by Sherrard, Schroeder, and Lawrence (21).

Efficiency of wastewater treatment or COD removal efficiency was determined by the relationship

$$E = \frac{(C_o - C)}{C_o} \times 100 \qquad (1)$$

where

E = COD removal efficiency, percent

C_o = influent substrate concentration, mg/l

C = effluent substrate concentration, mg/l

Sludge age or mean cell residence time was determined by the relationship

$$\Theta_c = \frac{VX}{Q_w X + Q_{eff} X_{eff}} \qquad (2)$$

where

Θ_c = sludge age, days

V = volume of total biological reactor, liters

X = microorganism concentration in total biological reactor and wasted mixed liquor suspended solids, mg/l

Q_w = wasted mixed liquor suspended solids flow rate, liters/day

Q_{eff} = effluent liquid flow rate, liters/day

X_{eff} = microorganism concentration in effluent liquid, mg/l

Net microbial growth was determined by the relationship

$$R_g = \frac{X}{\theta_c} \tag{3}$$

where

R_g = net microbial growth, mg/l/day

An observed yield coefficient was determined by the relationship

$$Y_{obs} = \frac{Q_w X + Q_{eff} X_{eff}}{Q(C_o - C)} \tag{4}$$

where

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

Q = influent flow rate, liters/day

The rate of substrate utilization was determined by the relationship

$$-R_{su} = \frac{R_g}{Y_{obs}} \tag{5}$$

where

$-R_{su}$ = rate of substrate utilization, mg COD/l/day

The rate of substrate utilization per unit weight of microorganisms or specific utilization can be determined by the relationship

$$U = \frac{-R_{su}}{X} \tag{6}$$

where

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

The microorganism constant yield coefficient and microorganism maintenance energy coefficient were determined by plotting specific growth rate versus specific utilization rate. The equation is

$$\frac{1}{\Theta_c} = YU - b \tag{7}$$

where

Y = microroganism constant yield coefficient, mg/mg

b = microorganism maintenance energy coefficient, $days^{-1}$

The other method used was a plot of the reciprocal of observed yield versus the sludge age. The equation is

$$\frac{1}{Y_{obs}} = \frac{1}{Y_{max}} + \frac{b\Theta_c}{Y_{max}} \tag{8}$$

where

Y_{max} = intercept of the line at the vertical axis

The total reactor microorganism concentration was determined by the relationship

$$X = \frac{Y(C_o - C)}{1 + b\Theta_c} \frac{\Theta_c}{\Theta} \tag{9}$$

where

Θ = hydraulic detention time, days

Waste sludge production was calculated according to the following expression

$$P_x = \frac{VX}{\Theta_c} \tag{10}$$

or

$$P_x = \frac{YQ(C_o - C)}{1 + b\Theta_c} \tag{11}$$

where

P_x = waste sludge production, mg/day

CHAPTER IV

RESULTS

The laboratory activated sludge units were operated under steady state conditions for approximately six months, using sludge age as the operating parameter. Data were collected in sludge ages of 4.6 days to 15.0 days. Influent substrate concentrations of 460, 1100, and 1570 mg/l were fed to the system. The hydraulic detention time was maintained at 19.0 hours. Summary of the "steady state" data for the nine experimental runs is found in Tables IV, V, and VI. Raw data for each of the nine experimental runs are found in the Appendix.

COD Removal Performance

COD removal efficiencies of the activated sludge process utilizing a slaughterhouse wastewater are shown in Figure 2. Removal efficiencies from each of the nine experimental runs are plotted as a function of sludge age. As shown, COD removal efficiency is nearly constant over the range of process operating conditions (Θ_c from 4.6 days to 15.0 days) regardless of the influent COD concentration. The COD removal efficiency exceeded 91 percent in all of the experimental runs.

Figure 3 shows the effluent concentration for the sludge ages studied. It can be seen that the effluent COD was constant for this study. Thus, sludge age and influent COD have no effect on the effluent COD in the range of sludge ages of 4.6 to 15.0 days.

TABLE IV

SUMMARY OF STEADY STATE DATA FOR LABORATORY REACTOR, INFLUENT COD = 460 mg/l

	Substrate Concentration			Biol. Sol. Conc.					
Θ_c (days)	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total React. (mg/l)	Effl. (mg/l)	$1/\Theta_c$ ($days^{-1}$)	Y_{obs} (mg/mg)	U ($days^{-1}$)	Sludge Prod. (mg/day)
10.3	446	32	92.8	1790	20	0.10	0.33	0.30	2069
12.4	475	33	93.0	2363	35	0.08	0.34	0.24	2269
4.6	460	40	91.3	869	39	0.22	0.36	0.62	2243

TABLE V

SUMMARY OF STEADY STATE DATA FOR LABORATORY REACTOR, INFLUENT COD = 1100 mg/l

	Substrate Concentration			Biol. Sol. Conc.					
Θ_c (days)	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total React. (mg/l)	Effl. (mg/l)	$1/\Theta_c$ ($days^{-1}$)	Y_{obs} (mg/mg)	U ($days^{-1}$)	Sludge Prod. (mg/day)
5.4	1191	46	96.2	1962	29	0.19	0.25	0.74	4292
11.1	1043	30	97.1	4363	23	0.09	0.31	0.29	4681
15.0	1066	33	96.9	5207	15	0.07	0.27	0.25	4176

TABLE VI

SUMMARY OF STEADY STATE DATA FOR LABORATORY REACTOR, INFLUENT COD = 1570 mg/l

	Substrate Concentration			Biol. Sol. Conc.					
Θ_c (days)	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total React. (mg/l)	Effl. (mg/l)	$1/\Theta_c$ ($days^{-1}$)	Y_{obs} (mg/mg)	U ($days^{-1}$)	Sludge Prod. (mg/day)
5.5	1537	38	97.5	3049	33	0.18	0.29	0.63	6542
11.2	1525	31	98.0	5586	23	0.09	0.26	0.34	5913
15.0	1648	33	98.2	7471	22	0.07	0.25	0.27	5919

Figure 2. COD Removal Efficiencies versus Sludge Age

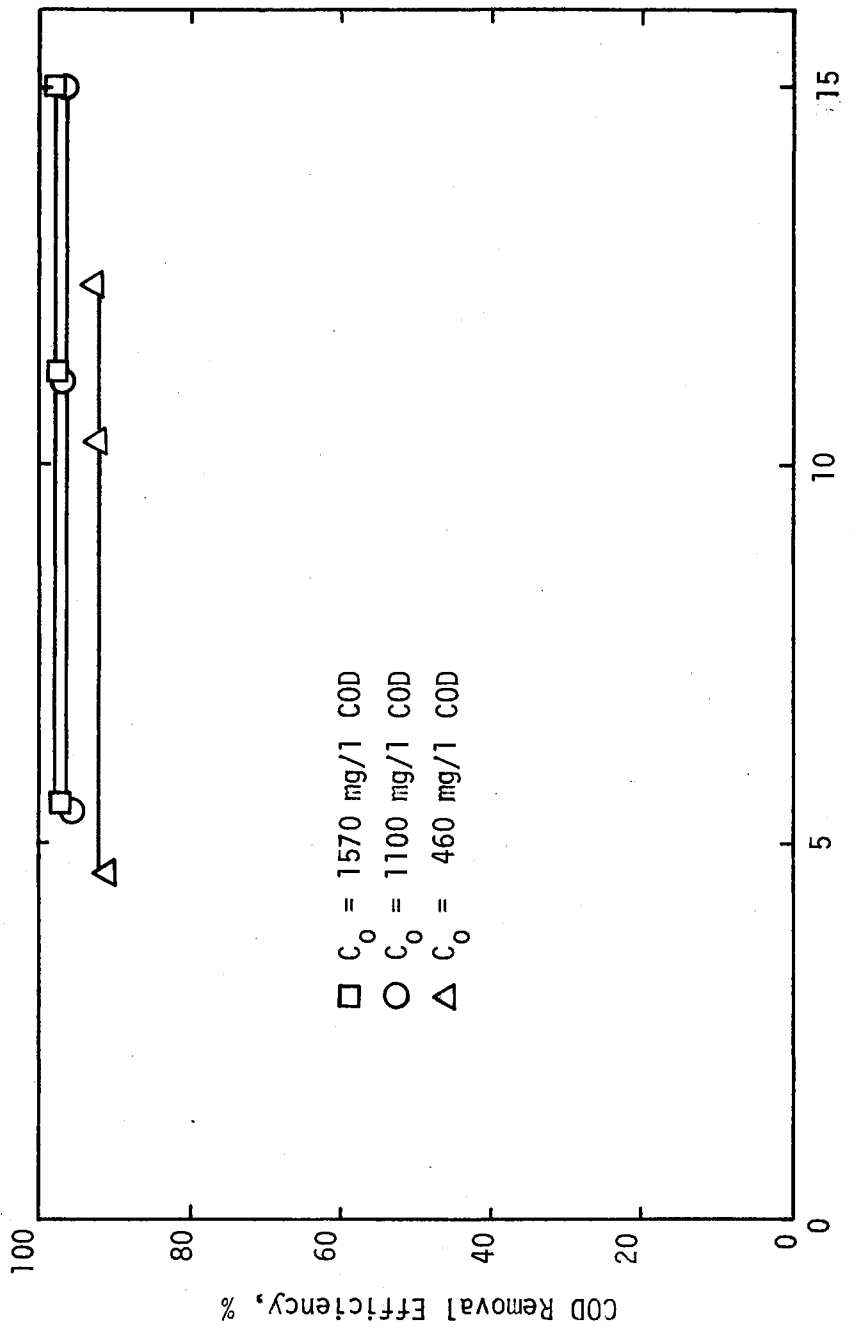
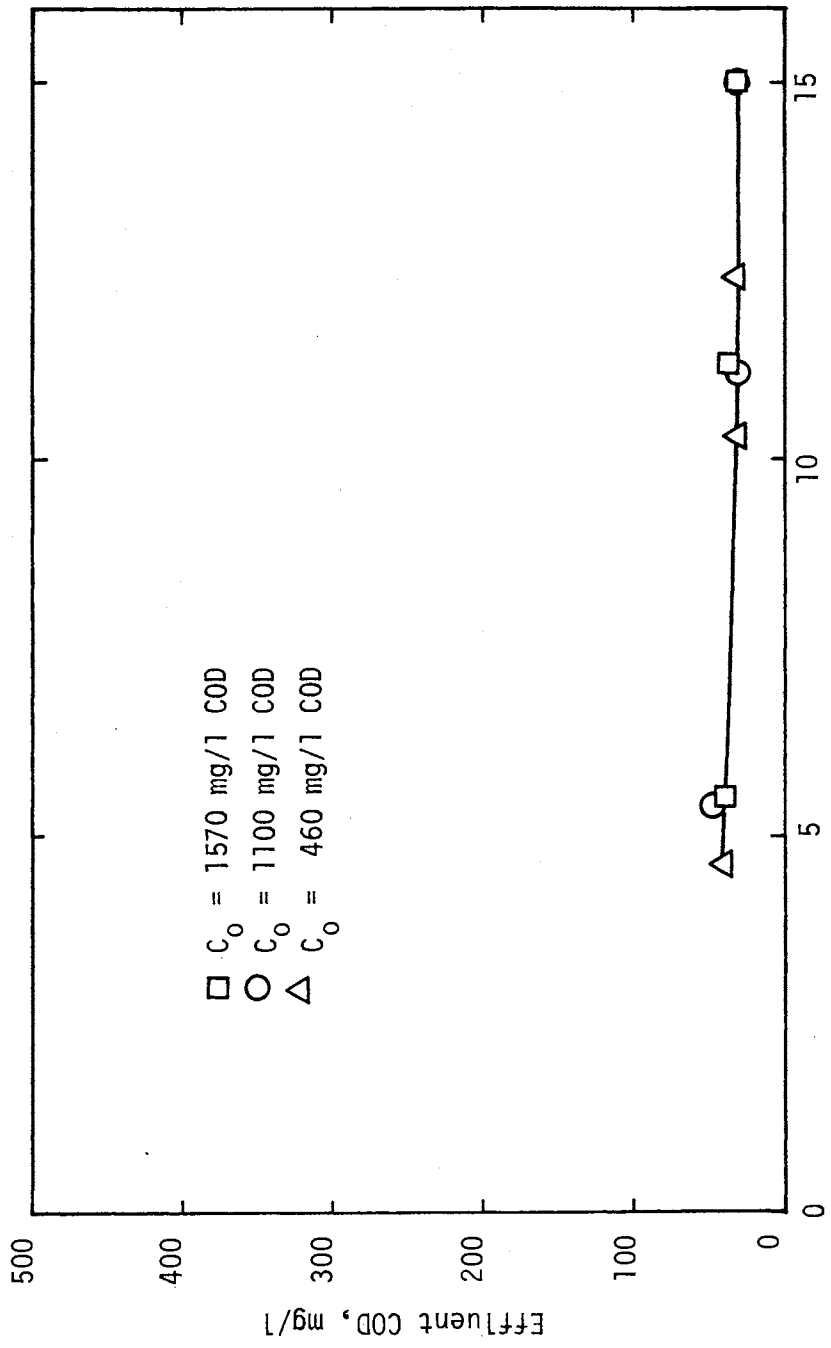

COD Removal Efficiency, %
100
80
60
40
20
0
0
5
10
15
Sludge Age, Days
□ C_o = 1570 mg/l COD
○ C_o = 1100 mg/l COD
△ C_o = 460 mg/l COD

Figure 3. Effluent COD versus Sludge Age


Effluent COD, mg/l
500
400
300
200
100
0
0
5
10
15
Sludge Age, Days
C_o = 1570 mg/l COD
C_o = 1100 mg/l COD
C_o = 460 mg/l COD

Specific Utilization

A relationship between the specific utilization and sludge age is shown in Figure 4. Specific utilization is the ratio of the substrate utilized per day and the microorganism concentration. As shown, the specific utilization decreased from 0.7 $days^{-1}$ at Θ_c = 5 days to 0.26 $days^{-1}$ at Θ_c = 15 days. It can also be seen that the specific utilization rate was not a function of the substrate concentration.

Observed Yield

An observed yield coefficient was calculated at each sludge age. The relationship between observed yield and sludge age is illustrated in Figure 5. As shown, the observed yield decreased as the sludge age increased. The linear relationship of the data was obtained according to an equation of the form

$$\frac{1}{\Theta_c} = YU - b$$

The specific growth rate, $1/\Theta_c$, as a function of specific utilization, is plotted in Figure 6. The slope of the straight line passed through the experimental datum points represents maximum yield, Y_{max}, and the intercept represents the maintenance energy coefficient, b. The value of Y_{max} = 0.326 mg/mg, and b = 0.009 $days^{-1}$ was obtained.

The observed yield data was also linearized by using the relationship

$$\frac{1}{Y_{obs}} = \frac{1}{Y_{max}} + \frac{b\Theta_c}{Y_{max}}$$

Figure 4. Specific Utilization versus Sludge Age

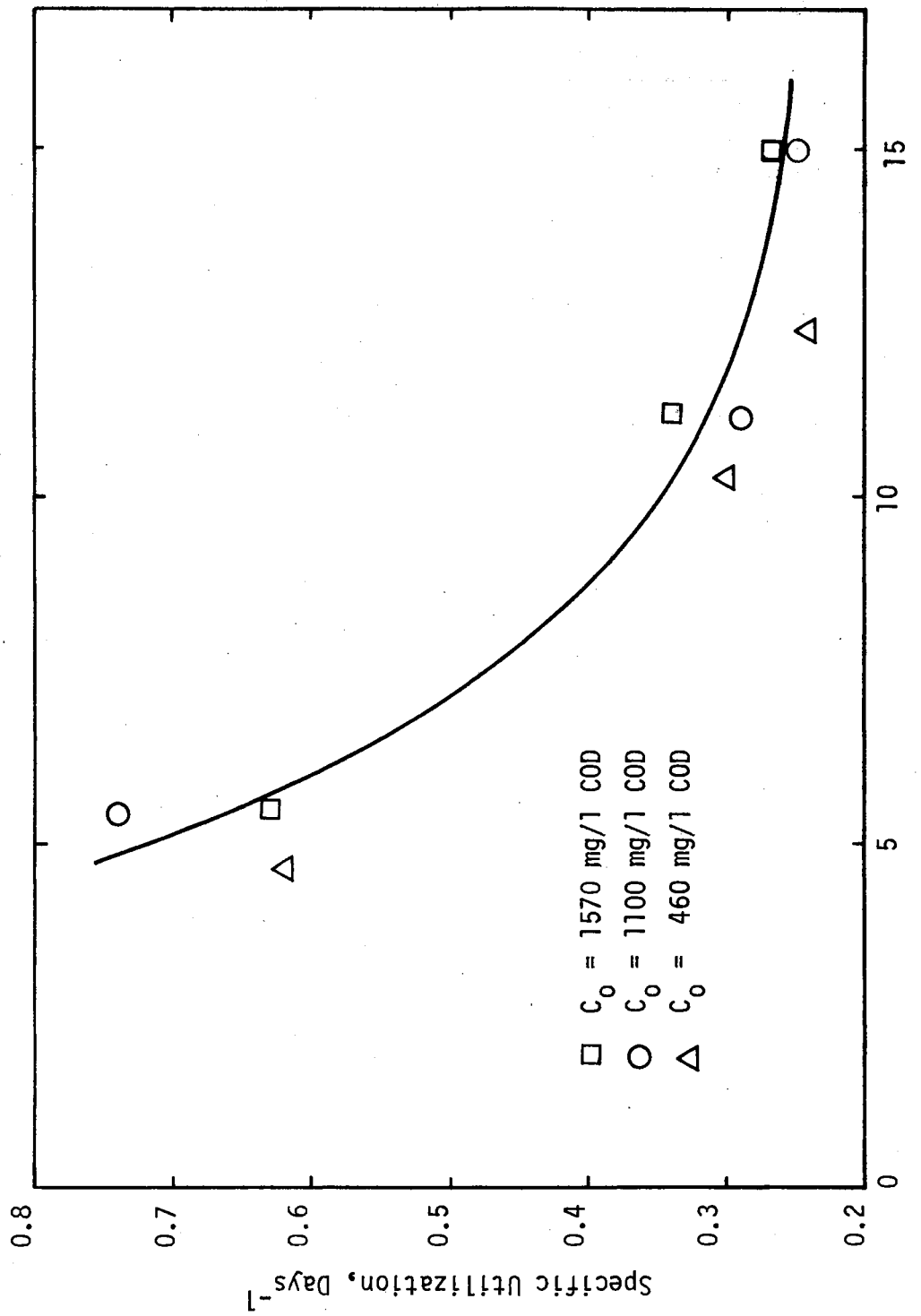

Specific Utilization, Days^{-1}
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
5
10
15
Sludge Age, Days
C_o = 1570 mg/l COD
C_o = 1100 mg/l COD
C_o = 460 mg/l COD

Figure 5. Observed Yield versus Sludge Age

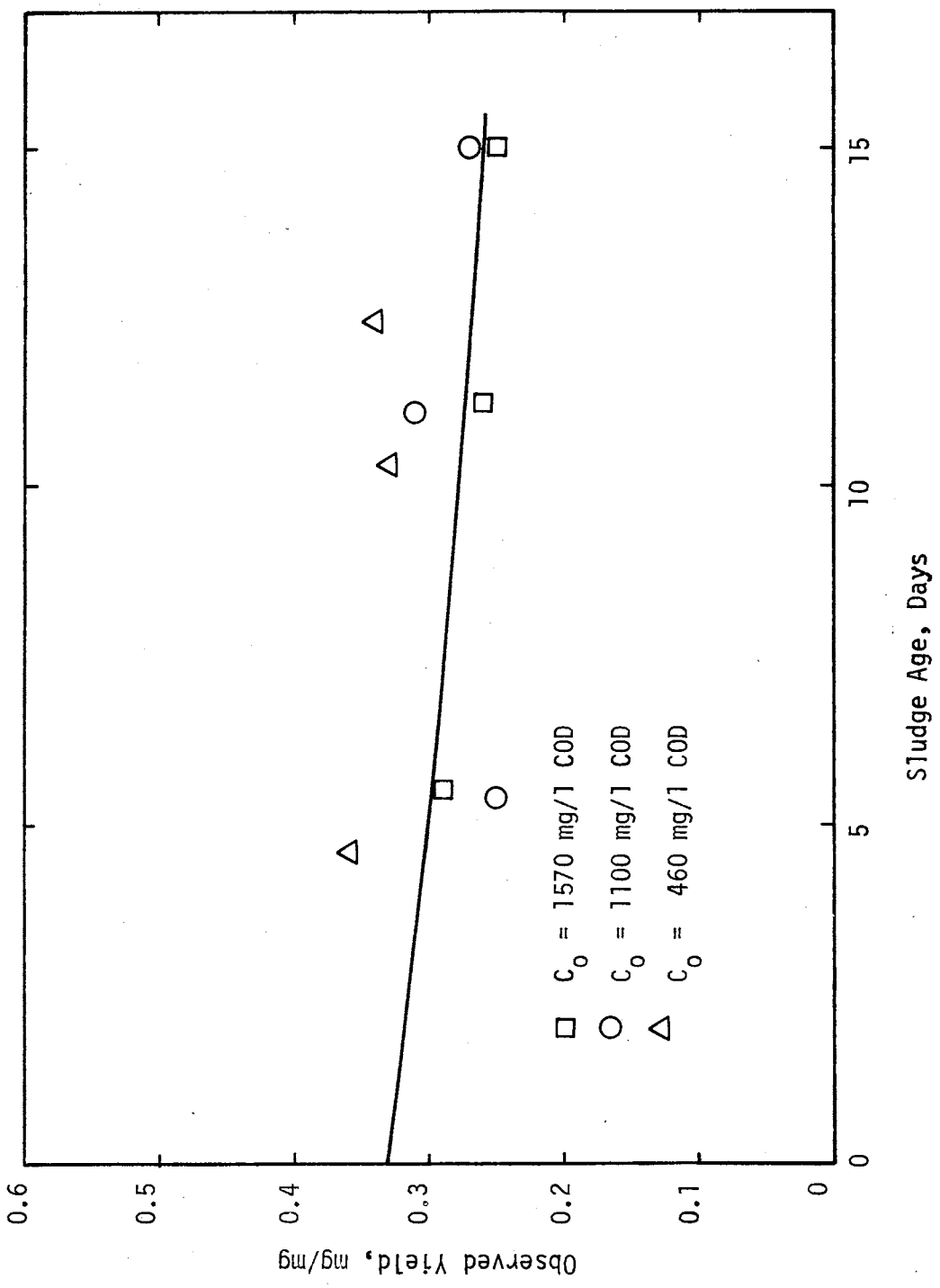
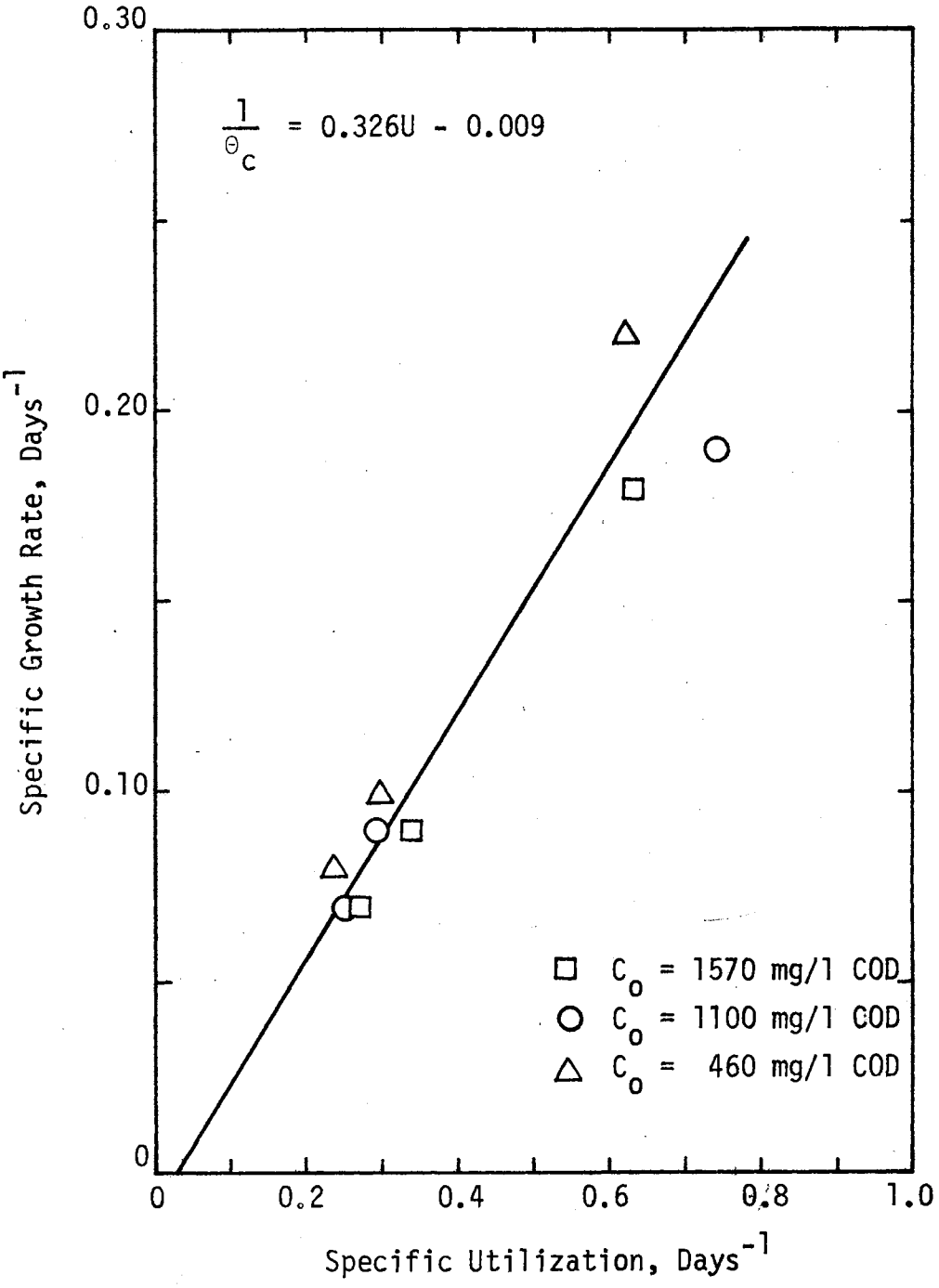

Observed Yield, mg/mg
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
Sludge Age, Days
C_o = 1570 mg/l COD
C_o = 1100 mg/l COD
C_o = 460 mg/l COD

Figure 6. Specific Growth Rate versus Specific Utilization Rate


0.30
0.20
0.10
0
0
0.2
0.4
0.6
0.8
1.0
$\frac{1}{\Theta_c}$ = 0.326U - 0.009
Specific Growth Rate, Days^{-1}
Specific Utilization, Days^{-1}
□ C_o = 1570 mg/l COD
○ C_o = 1100 mg/l COD
△ C_o = 460 mg/l COD

The observed yield coefficient as a function of sludge age was shown in Figure 7. The value of Y_{max} = 0.323 mg/mg, and b = 0.008 $days^{-1}$ was obtained.

Total Reactor Microorganism Concentration

As shown in Figure 8, the total reactor microorganism concentration predicted by equation (9) is plotted as a function of sludge age. The actual reactor microorganism concentrations obtained from the nine experimental runs are shown as the plotted points. It can be seen that the difference between the experimental values and calculated values is less than 11 percent, except for a sludge age of 15.0 days and influent COD of 460 mg/l, and for a sludge age of 11.2 days and influent COD of 1570 mg/l. There, the differences are 13.9 percent and 13.7 percent, respectively. The total reactor microorganism concentration increased as sludge age increased. As shown, to maintain a given sludge age, the total reactor microorganism concentration must be doubled when the influent COD concentration is doubled.

Sludge Production

The relationship between sludge production and sludge age is shown in Figure 9. The curves represent calculated values obtained from the solution of equation (10). The actual sludge productions from the nine experimental runs are shown as plotted points. The difference between calculated values and experimental values is less than 12.0 percent. As shown, the sludge production was gradually increased as sludge age decreased from 15.0 days to 0.3 days, and decreased rapidly when the sludge age was less than 0.3 days. The gradual change in sludge

Figure 7. Reciprocal of Observed Yield versus Sludge Age

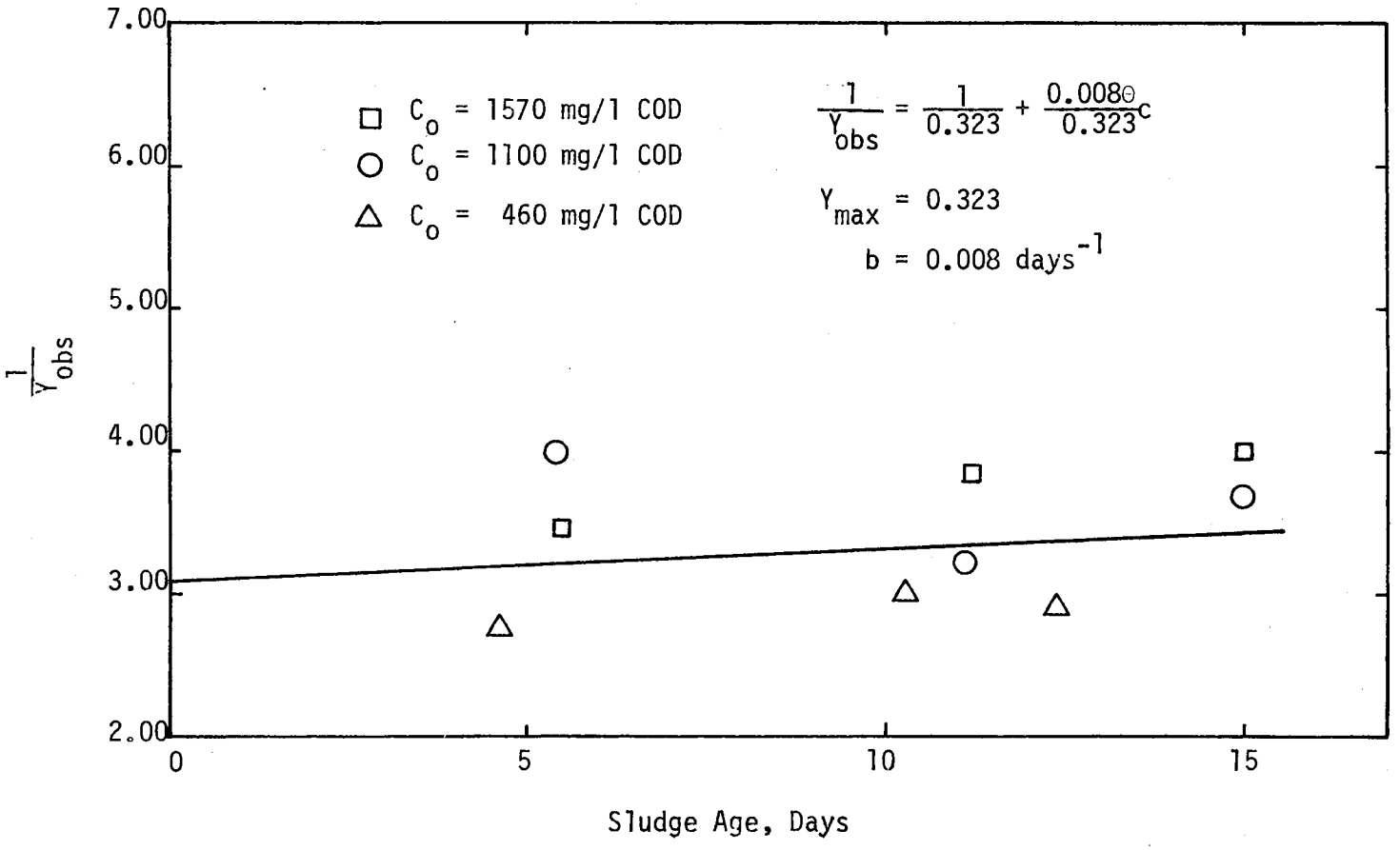

7.00
6.00
5.00
4.00
3.00
2.00
0
5
10
15
$\frac{1}{Y_{obs}}$
Sludge Age, Days
□ C_o = 1570 mg/l COD
○ C_o = 1100 mg/l COD
△ C_o = 460 mg/l COD
$\frac{1}{Y_{obs}} = \frac{1}{0.323} + \frac{0.008\Theta}{0.323}c$
Y_{max} = 0.323
b = 0.008 days^{-1}

Figure 8. Total Reactor Microorganism Concentration versus Sludge Age

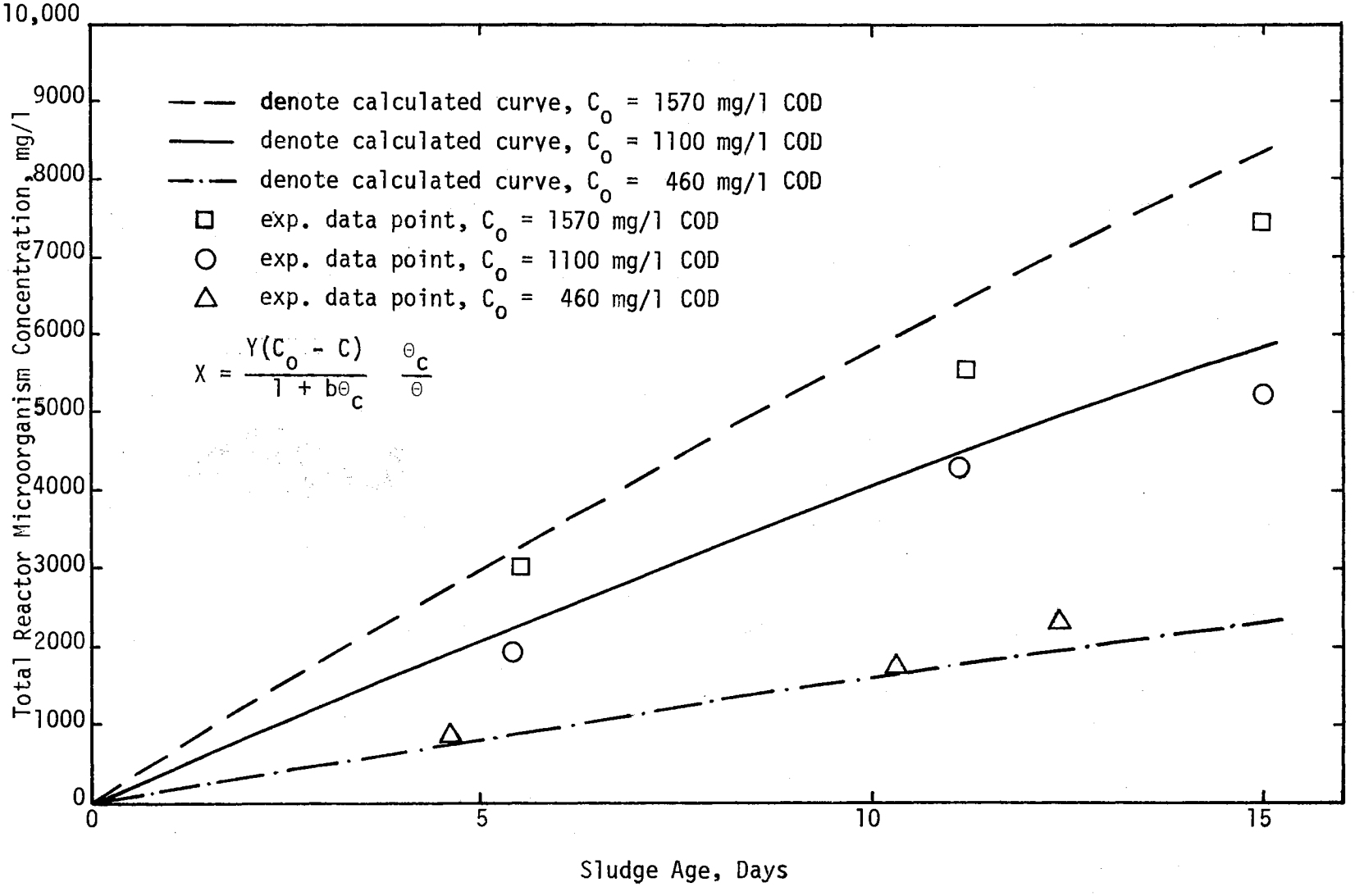
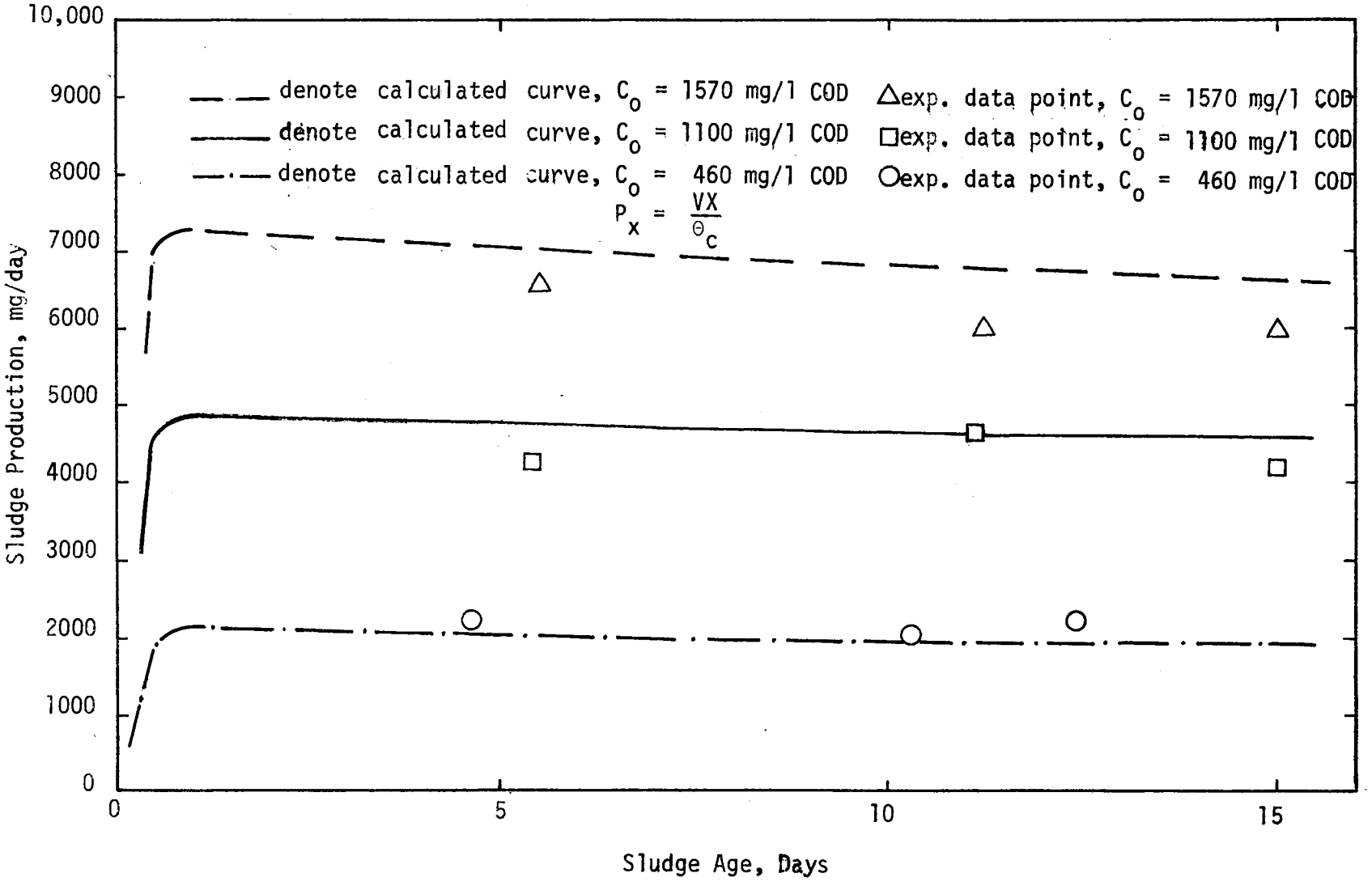

10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
Total Reactor Microorganism Concentration, mg/l
Sludge Age, Days
denote calculated curve, C_o = 1570 mg/l COD
denote calculated curve, C_o = 1100 mg/l COD
denote calculated curve, C_o = 460 mg/l COD
exp. data point, C_o = 1570 mg/l COD
exp. data point, C_o = 1100 mg/l COD
exp. data point, C_o = 460 mg/l COD
$X = \frac{Y(C_o - C)}{1 + b\Theta_c} \frac{\Theta_c}{\Theta}$

Figure 9. Sludge Production versus Sludge Age


10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
Sludge Production, mg/day
Sludge Age, Days
denote calculated curve, C_o = 1570 mg/l COD
denote calculated curve, C_o = 1100 mg/l COD
denote calculated curve, C_o = 460 mg/l COD
$P_x = \frac{VX}{\Theta_c}$
exp. data point, C_o = 1570 mg/l COD
exp. data point, C_o = 1100 mg/l COD
exp. data point, C_o = 460 mg/l COD

production results from the relatively small change in observed yield and because the efficiency of treatment is nearly constant over the range of process operation. Thus, the effect of sludge age on sludge production is relatively small. Sludge production was affected by influent COD. The amount of sludge produced was higher at higher influent COD values.

CHAPTER V

DISCUSSION

The purpose of this investigation was to study the effect of sludge age on the treatability of a slaughterhouse wastewater. By varying the sludge wasting rate, the sludge age was varied between 4.6 and 15.0 days.

One of the problems encountered in the treatment of a slaughterhouse wastewater is insufficient BOD reduction. A BOD removal of 87 percent and a COD removal of 78 percent by an anaerobic lagoon was reported by Enders, Hammer, and Weber (25). Stover (8) showed that the bio-disc process can remove 74 percent of the COD of a slaughterhouse wastewater. A BOD removal of 74 percent and a COD removal of 73 percent by a PVC trickling filter treating a slaughterhouse wastewater was reported by Baker and White (7). Wernitznig (4) found that a slaughterhouse wastewater can significantly alter the settling and filtering characteristics of the microorganisms in the activated sludge process.

The most obvious result obtained from this investigation was that the COD removal efficiency of the activated sludge process treating the slaughterhouse wastewater was consistently high. In all experimental runs, COD removals of over 90 percent were obtained. The effluent COD concentrations were less than 50 mg/l regardless of influent COD concentrations. The BOD_5 concentration is lower than the COD concentration. Thus, the effluent quality meets the effluent quality standard

established by EPA, which says that the effluent BOD_5 concentration shall not exceed 50 mg/l for a slaughterhouse wastewater treatment plant.

The relationship between aeration basin cell concentration and sludge age is very important in the operation of an activated sludge plant. In this investigation, the total reactor volume (aeration basin and secondary clarifier) was used to determine the aeration basin solids because of the variation of microorganism concentration in the secondary clarifier. The total reactor microorganism concentration was increased as the sludge age and influent COD concentration increased. The total reactor microorganism concentration was doubled when the influent COD concentration was doubled. From this investigation, the total reactor microorganism concentration obtained from nine experimental runs was very slightly different from the calculated value of the total reactor microorganism concentration. These small differences in experimental values and calculated values of total reactor microorganism concentration showed that the biological treatment process of slaughterhouse wastewater can be described by the sludge age kinetics even though slaughterhouse wastewaters are a very complex substrate. Since the slaughterhouse wastewater treatment process follows the biological growth kinetics, it is possible to predict the total reactor microorganism concentration at any operational sludge age. The ability to predict aeration basin microorganism concentrations is very important to the design engineer and treatment plant operator.

Sludge handling is one of the critical problems in the wastewater treatment plant. Thus, the relationship between sludge production and sludge age is also important. In this investigation, sludge production was insignificantly affected by sludge age. The small increase in

sludge production as sludge age decreased is attributed to relatively small microorganism maintenance energy coefficient. Therefore, the sludge production from an activated sludge plant treating a slaughterhouse wastewater will not vary with sludge age. Prediction of sludge production at any sludge age is possible, since the biological treatment process of slaughterhouse wastewater follows sludge age kinetics.

A very low microorganism maintenance energy coefficient was observed in these studies, i.e., 0.009 $days^{-1}$, compared to domestic wastes, 0.07 $days^{-1}$ (23). Results of this investigation illustrate the feasibility of the activated sludge process treating slaughterhouse wastewater. Sludge age can be used successfully as a design and operational parameter. These studies provide definite data to assist the engineer in designing a slaughterhouse wastewater treatment plant and making decisions when solving slaughterhouse wastewater problems.

CHAPTER VI

CONCLUSIONS

Based upon the results of this investigation using the continuous flow activated sludge unit treating slaughterhouse waste, the following conclusions can be drawn:

1. The activated sludge process provided high treatment efficiency for the treatment of slaughterhouse blood waste.

2. The effect of sludge age on the effluent quality is insignificant over the range of normal operation.

3. Using sludge age as an operational parameter was feasible for the activated sludge process treating slaughterhouse blood waste.

4. The microorganism concentration in the aeration basin can be predicted by sludge age kinetics.

5. The slaughterhouse blood waste has a low microorganism maintenance energy coefficient which is responsible for a gradual change in total reactor microorganism concentration and insignificant change in sludge production over the operational sludge age.

6. The activated sludge process is feasible for the treatment of slaughterhouse wastewater if the operation is properly controlled.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

Based on the findings of this study, the following suggestions are made for future treatability studies on slaughterhouse wastewaters:

1. Conducted studies to determine the feasibility of other biological treatments on slaughterhouse wastewater.

2. Perform studies to determine the effect of other operational parameters on the treatment of slaughterhouse wastewater.

3. Study the effect of sludge age on nitrification in the treatment of slaughterhouse wastewater.

4. Conduct studies to determine the effect of shock loading on the treatment of slaughterhouse waste.

5. Perform detailed chemical analyses on slaughterhouse waste before and after biological treatment processes.

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APPENDIX

TABLE VII

RAW DATA FOR Θ_c = 10.3 DAYS AND C_o = 446 mg/l

	COD			Biol. Solids								
Date	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	Θ_c (days)	$1/\Theta_c$ ($days^{-1}$)	R_g (mg/l/day)	Y_{obs} (mg/mg)	$-R_{su}$ (mg COD/l/day)	U ($days^{-1}$)	P_x (mg/day)
1974												
3-21	459	32	93.0	1624	12	10.8	0.09	150	0.26	577	0.36	1784
3-22	465	42	91.0	1628	8	11.1	0.09	147	0.27	544	0.33	1739
3-23	467	29	93.8	1664	8	11.1	0.09	150	0.27	556	0.33	1778
3-24	425	32	92.5	1716	24	9.9	0.10	173	0.35	494	0.29	2056
3-25	439	34	92.3	2524	30	10.2	0.10	247	0.48	515	0.20	2935
3-26	441	30	93.2	1740	28	9.7	0.10	179	0.34	526	0.30	2127
3-27	427	27	93.7	1636	30	9.4	0.11	174	0.34	512	0.31	2064
Avg.	446	32	92.8	1790	20	10.3	0.10	174	0.33	532	0.30	2069

TABLE VIII

RAW DATA FOR Θ_c = 12.4 DAYS AND C_o = 475 mg/l

Date	COD			Biol. Solids		Θ_c	$1/\Theta_c$	R_g	Y_{obs}	$-R_{su}$	U	P_x
	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	(days)	($days^{-1}$)	(mg/l/day)	(mg/mg)	(mg COD/l/day)	($days^{-1}$)	(mg/day)
1974	469	30	93.6	2402	36	12.3	0.08	195	0.35	557	0.23	2318
4-18	478	40	91.6	2420	34	12.5	0.08	194	0.35	554	0.23	2296
4-20	490	38	92.2	2324	40	119	0.08	195	0.34	574	0.25	2316
4-21	468	28	94.0	2404	40	12.0	0.08	200	0.36	556	0.23	2376
4-22	476	33	93.1	2308	26	13.0	0.08	178	0.32	556	0.24	2106
4-23	468	31	93.4	2320	32	12.5	0.08	186	0.34	547	0.24	2201
Avg.	475	33	93.0	2363	35	12.4	0.08	191	0.34	557	0.24	2269

TABLE IX

RAW DATA FOR Θ_c = 4.6 DAYS AND C_o = 460 mg/l

Date	COD			Biol. Solids		Θ_c	$1/\Theta_c$	R_g	Y_{obs}	$-R_{su}$	U	P_x
	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	(days)	($days^{-1}$)	(mg/l/day)	(mg/mg)	(mg COD/l/day)	($days^{-1}$)	(mg/day)
1974												
5-23	442	36	91.9	976	52	4.4	0.23	222	0.43	516	0.53	2631
5-24	438	47	89.3	924	40	4.6	0.22	201	0.41	490	0.53	2382
5-25	414	35	91.5	888	25	5.0	0.20	177	0.37	478	0.54	2106
5-26	4o7	36	92.8	880	40	4.6	0.22	191	0.32	597	0.68	2269
5-27	489	42	91.4	788	40	4.5	0.22	175	0.31	565	0.72	2077
5-28	481	44	90.4	756	36	4.5	0.22	168	0.30	560	0.74	1992
Avg.	460	40	91.3	869	39	4.6	0.22	189	0.36	534	0.62	2243

TABLE X

RAW DATA FOR Θ_c = 5.4 DAYS AND C_o = 1191 mg/l

	COD			Biol. Solids								
Date	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	Θ_c (days)	$1/\Theta_c$ ($days^{-1}$)	R_g (mg/l/day)	Y_{obs} (mg/mg)	$-R_{su}$ (mg COD/l/day)	U ($days^{-1}$)	P_x (mg/day)
1974												
5-29	1160	40	96.6	2028	20	5.6	0.18	362	0.26	1392	0.70	4295
5-30	1192	41	96.6	1928	48	5.1	0.80	378	0.26	1454	0.75	4484
5-31	1216	48	96.1	1864	40	5.2	0.19	358	0.24	1492	0.79	4251
6- 1	1208	52	95.7	1948	28	5.4	0.19	361	0.25	1444	0.75	4278
6- 2	1208	50	95.9	2024	12	5.7	0.18	355	0.24	1479	0.72	4211
6- 3	1176	40	96.6	2020	40	5.3	0.19	381	0.27	1411	0.71	4520
6- 4	1176	49	95.8	1924	12	5.7	0.18	338	0.24	1408	0.74	4003
Avg.	1191	46	96.2	1962	29	5.4	0.19	362	0.25	1440	0.74	4292

TABLE XI

RAW DATA FOR Θ_c = 11.1 DAYS AND C_o = 1043 mg/l

Date	COD			Biol. Solids		Θ_c	$1/\Theta_c$	R_g	Y_{obs}	$-R_{su}$	U	P_x
	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	(days)	($days^{-1}$)	(mg/l/day)	(mg/mg)	(mg COD/l/day)	($days^{-1}$)	(mg/day)
1974												
6-15	1072	35	96.7	4300	28	10.9	0.09	394	0.30	1313	0.31	4679
6-16	1076	26	97.6	4312	20	11.9	0.09	388	0.29	1338	0.31	4607
6-17	1068	27	97.5	4296	16	11.3	0.09	380	0.29	1310	0.30	4509
6-18	1072	31	97.1	4444	28	10.9	0.09	408	0.31	1316	0.30	4835
6-19	978	30	96.9	4384	26	11.0	0.09	399	0.34	1174	0.27	4727
6-20	1032	31	97.0	4332	20	11.1	0.09	390	0.31	1258	0.29	4629
6-21	1001	29	97.1	4476	22	11.1	0.09	403	0.33	1221	0.27	4782
Avg.	1043	30	97.1	4363	23	11.1	0.09	395	0.31	1276	0.29	4681

TABLE XII

RAW DATA FOR Θ_c = 15.0 DAYS AND C_o = 1066 mg/l

Date	COD			Biol. Solids		Θ_c	$1/\Theta_c$	R_g	Y_{obs}	$-R_{su}$	U	P_x
	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	(days)	($days^{-1}$)	(mg/l/day)	(mg/mg)	(mg COD/l/day)	($days^{-1}$)	(mg/day)
1974												
6-28	1126	25	97.8	5164	28	14.3	0.07	361	0.26	1388	0.27	4683
6-29	1047	22	97.9	4856	8	15.3	0.07	317	0.24	1321	0.27	3764
6-30	1039	21	98.0	5456	2	15.7	0.06	348	0.27	1289	0.24	4121
7- 1	1039	29	97.2	5488	4	15.6	0.06	352	0.28	1257	0.23	4172
7- 2	1016	45	95.6	5664	24	14.6	0.07	388	0.32	1213	0.21	4601
7- 3	1063	52	95.1	4656	24	14.4	0.07	323	0.25	1292	0.28	3835
7- 4	1135	35	96.9	5168	12	15.1	0.07	342	0.25	1368	0.26	4059
Avg.	1066	33	96.9	5207	15	15.0	0.07	347	0.24	1304	0.25	4176

TABLE XIII

RAW DATA FOR Θ_c = 5.5 DAYS AND C_o = 1537 mg/l

Date	COD			Biol. Solids		Θ_c	$1/\Theta_c$	R_g	Y_{obs}	$-R_{su}$	U	P_x
	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	(days)	($days^{-1}$)	(mg/l/day)	(mg/mg)	(mg COD/l/day)	($days^{-1}$)	(mg/day)
1974	1485	27	98.2	3228	32	5.6	0.18	576	0.31	1858	0.58	6836
6-14	1515	35	97.7	3060	24	5.6	0.18	546	0.29	1883	0.62	6481
6-16	1561	59	96.2	2968	28	5.6	0.18	530	0.28	1893	0.64	6286
6-17	1542	33	97.9	3044	18	5.7	0.18	534	0.28	1907	0.63	6334
6-18	1498	39	97.4	3140	34	5.5	0.18	571	0.31	1842	0.59	6771
6-19	1599	34	97.9	2872	48	5.3	0.19	542	0.27	2007	0.70	6427
6-20	1560	39	97.5	3032	50	5.4	0.19	561	0.29	1934	0.64	6659
Avg.	1537	38	97.5	3049	33	5.5	0.18	551	0.29	1903	0.63	6542

TABLE XIV

RAW DATA FOR Θ_c = 11.2 DAYS AND C_o = 1525 mg/l

Date	COD			Biol. Solids		Θ_c	$1/\Theta_c$	R_g	Y_{obs}	$-R_{su}$	U	P_x
	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	(days)	($days^{-1}$)	(mg/l/day)	(mg/mg)	(mg COD/l/day)	($days^{-1}$)	(mg/day)
1974												
6-29	1488	34	97.7	5400	8	11.6	0.09	466	0.25	1864	0.35	5521
6-30	1480	37	97.5	5936	22	11.3	0.09	525	0.29	1810	0.30	6230
7- 1	1590	32	98.0	5624	34	10.9	0.09	516	0.26	1985	0.35	6119
7- 2	1472	27	98.2	5820	40	10.8	0.09	539	0.29	1859	0.32	6391
7- 3	1551	27	98.3	5540	18	11.3	0.09	490	0.25	1960	0.35	5815
7- 4	1551	28	98.2	5552	12	11.5	0.09	483	0.25	1932	0.35	5726
7- 5	1543	32	97.9	5232	26	11.1	0.09	471	0.25	1884	0.36	5590
Avg.	1525	31	98.0	5586	23	11.2	0.09	499	0.26	1899	0.34	5913

TABLE XV

RAW DATA FOR Θ_c = 15.0 DAYS AND C_o = 1648 mg/l

Date	COD			Biol. Solids		Θ_c	$1/\Theta_c$	R_g	Y_{obs}	$-R_{su}$	U	P_x
	Feed (mg/l)	Effl. (mg/l)	Remov. Effic. (%)	Total System (mg/l)	Effl. (mg/l)	(days)	($days^{-1}$)	(mg/l/day)	(mg/mg)	(mg COD/l/day)	($days^{-1}$)	(mg/day)
1974												
7-21	1693	37	97.8	7944	28	14.8	0.07	537	0.26	2065	0.26	6366
7-22	1709	32	98.1	7044	26	14.8	0.07	476	0.22	2164	0.31	5645
7-23	1686	34	98.0	7804	18	15.1	0.07	517	0.25	2068	0.26	6129
7-24	1505	30	98.0	7092	14	15.2	0.07	467	0.25	1868	0.26	5534
Avg.	1648	33	98.2	7471	22	15.0	0.07	467	0.25	2041	0.27	5951

VITA

Suthirak Sujarittanonta

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF SLUDGE AGE ON THE TREATABILITY OF SLAUGHTERHOUSE WASTEWATER

Major Field: Bioenvironmental Engineering

Biographical:

Personal Data: Born on June 30, 1949, in Lopburi, Thailand, the son of Luang Suthipakayapibul and Mrs. Sopis Sujarittanonta.

Education: Graduated from Triam Udom Suksa School, Bangkok, Thailand, in May, 1967; received the Bachelor of Science degree in Civil Engineering from Oklahoma State University, Stillwater, Oklahoma, in December, 1973; completed requirements for the Master of Science degree at Oklahoma State University in December, 1974.

Membership in Professional Societies: Water Pollution Control Federation, American Society of Civil Engineering.