EVALUATION OF THE BUSCH METHOD FOR ACTIVATED SLUDGE TREATMENT PROCESS DESIGN

By

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To my wife, Mary, and our three children, Ronald, Suzanne, and Daniel, I would like to dedicate this thesis.

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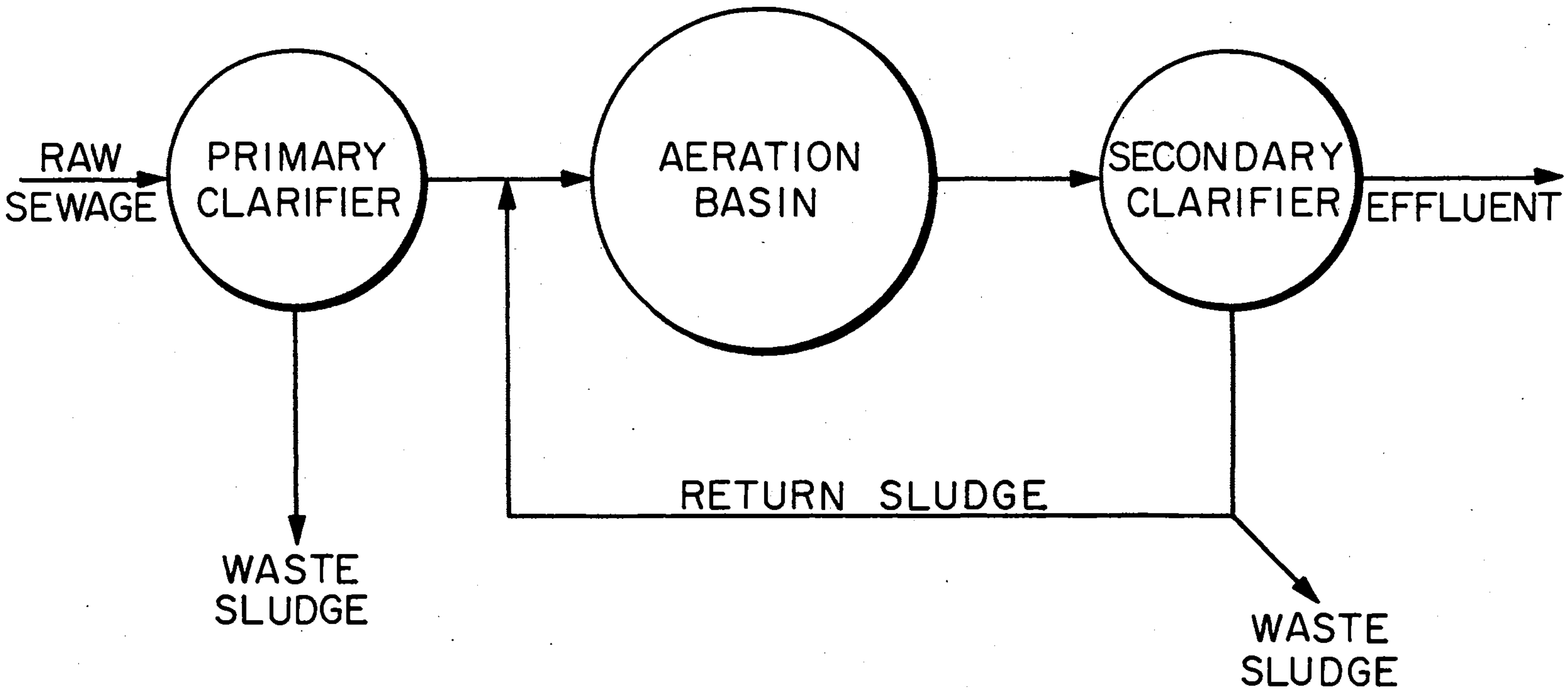
CHAPTER I

INTRODUCTION

In recent years, the design of both domestic and industrial sewage facilities using the activated sludge process has become increasingly popular. A flow diagram of the activated sludge process, which has been defined as a fluidized bed biological reactor (1) is shown in Figure 1. In this process, raw sewage enters the primary clarifier from where the settled effluent then enters the aeration basin. Microorganisms in the aeration basin use part of the organic matter in the sewage for energy and use the remainder for synthesis of new cellular material. Flow from the aeration basin enters the secondary clarifier, where there is a solids-liquid separation. The supernatant liquid is either given additional treatment or is discharged directly to a receiving stream, etc. A portion of the settled sludge in the secondary clarifier is recycled to the aeration basin in order to maintain the desired mean cell residence time, and the remainder of the sludge is wasted.

To properly design the components of an activated sludge treatment process for treatment of a biodegradable industrial waste, it is helpful to run a pilot plant study in the laboratory with a bench-scale unit. Recent trends have been directed toward the operation of bench-scale units under steady state conditions to obtain design and operational criteria. Steady state conditions are characterized by nearly constant measurements of influent chemical oxygen demand (COD), effluent COD, and

Figure 1. Flow Diagram of the Activated Sludge Process


RAW SEWAGE
PRIMARY CLARIFIER
AERATION BASIN
SECONDARY CLARIFIER
EFFLUENT
RETURN SLUDGE
WASTE SLUDGE
WASTE SLUDGE

aeration basin and effluent suspended solids. Steady state conditions are attained by wasting that amount of biomass which increases per unit time due to bacterial growth.

The use of steady state, continuous flow, model treatment units has been shown to be capable of providing reliable design criteria (2). A distinct disadvantage of the use of steady state studies is the time required to run a treatability study. Usually five to six months are required to obtain reliable design data. With an ever increasing industrial technology being developed and with the advent of new and more complex biodegradable industrial wastes, it would be helpful if reliable data could be gathered in a much shorter time period.

One design method that uses continuous flow of waste into the aeration basin which has the potential of being useful in obtaining design criteria in shorter time periods has been described by Busch (3). His design method is based on the concept of operating a bench scale activated sludge unit under non-steady state conditions. His method for obtaining design criteria takes approximately five weeks instead of five months.

From 1961, when Busch first presented his design concept to the present, very little investigation has been made of the activated sludge process under non-steady state conditions and, as a result, very little additional information is available concerning this proposed method of sewage treatment design. The purpose of this research is to study the Busch design method to verify whether or not it can be used to provide reliable design data and to offer any new ideas as to improve the method. and

The remaining chapters of this study are devoted to a detailed presentation of Busch's non-steady state treatability study. In Chapter II, a review of pertinent literature is presented. Chapter III comprises the materials and methods used in this investigation. The results obtained and a discussion of these results are presented in Chapter IV; the conclusions drawn from these results are presented in Chapter V. Finally, the recommendations for future study are proposed in Chapter VI.

CHAPTER II

LITERATURE REVIEW

To evaluate the Busch method for designing waste treatment facilities and to obtain information concerning sludge settling characteristics in the activated sludge process, literature reviews were conducted and are presented separately.

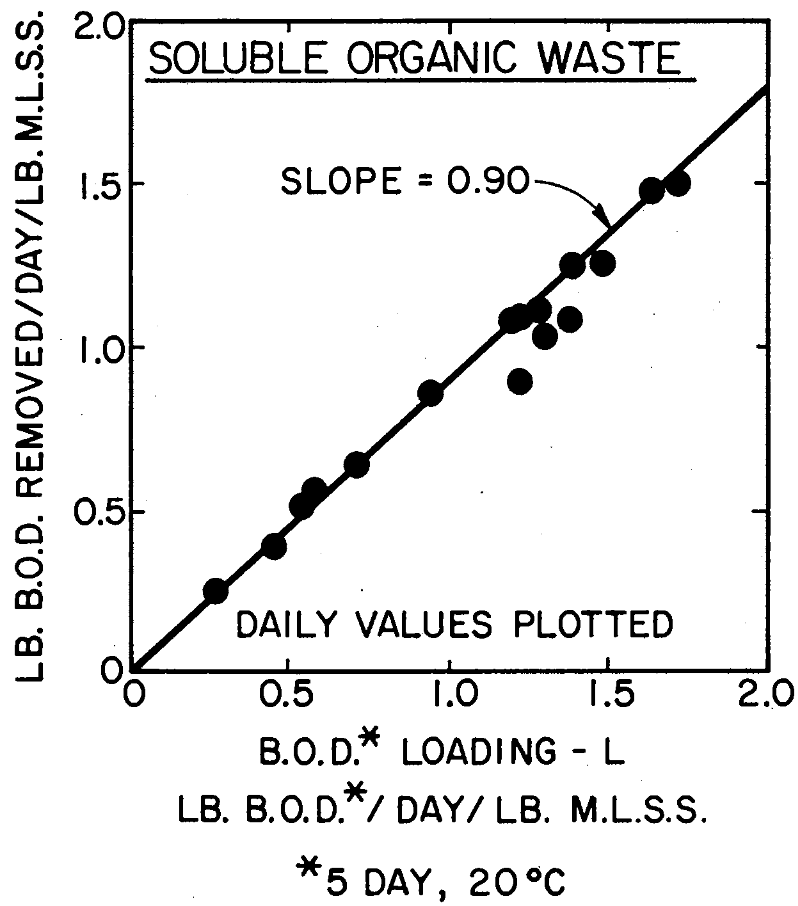
A. Busch Design Method

In 1961, Busch (3) stated that in a completely mixed reactor, continuous flow studies in conjunction with batch aeration using organisms from the continuous flow system can yield all necessary design criteria for aerobic bio-oxidation under non-steady state conditions. In 1963, Busch (4) further reported that his design method as shown in his original study could be used as design criteria for bio-oxidation of petrochemical wastes. Busch's design concept was derived using data from only one test, which was conducted over an 18-day period. The substrate used in the test was described only as a soluble organic waste.

Busch's theory is that by not intentionally wasting any of the mixed liquor suspended solids (MLSS), the increasing MLSS each day will produce a different loading and a different solids age. From the data obtained during an 18-day experiment, three important curves can be derived that can be used for the design of activated sludge components.

Figure 2 is a loading vs. removal curve, and the slope relates to

Figure 2. Loading vs. Removal Curve

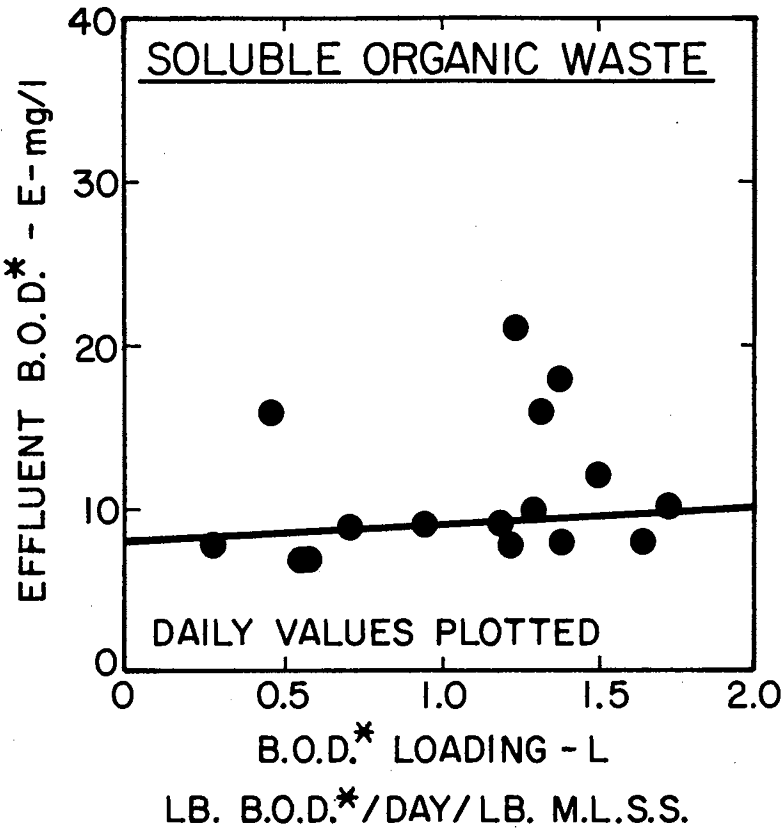

SOLUBLE ORGANIC WASTE
SLOPE = 0.90
DAILY VALUES PLOTTED
LB. B.O.D. REMOVED/DAY/LB. M.L.S.S.
2.0
1.5
1.0
0.5
0
0
0.5
1.0
1.5
2.0
B.O.D.* LOADING - L
LB. B.O.D.*/ DAY/ LB. M.L.S.S.
*5 DAY, 20°C

the plant efficiency. This curve is of little use in formulating process design criteria. Figure 3 is an effluent loading curve which is very useful in that it shows a minimum attainable effluent BOD. Figure 4 is a plot of observed yield vs. sludge age, and is probably the most important curve required in the design of an activated sludge treatment plant. By knowing the amount of sludge that will be produced for a particular sludge age, waste sludge handling facilities can be adequately designed. Comparative curves of solids age vs. observed yield have been derived under steady state conditions by Stall (1) and Sherrard, Schroeder, and Lawrence (5) using a bacto-peptone substrate.

Busch (6) reported in 1959 that bench scale experimental data often do not agree well with pilot plant or full scale results. He further stated that if the bench scale study is to be properly evaluated, then there must be a positive control over suspended solids. Also, a hydraulic loading similar to full scale requirements must be used. In his design method there is no control over a non-steady state biological population, as there is no wastage of mixed liquor. He also states in his design method that the hydraulic detention time selected in the plant design is governed solely by the optimum combination of MLSS concentration and economic tankage volume.

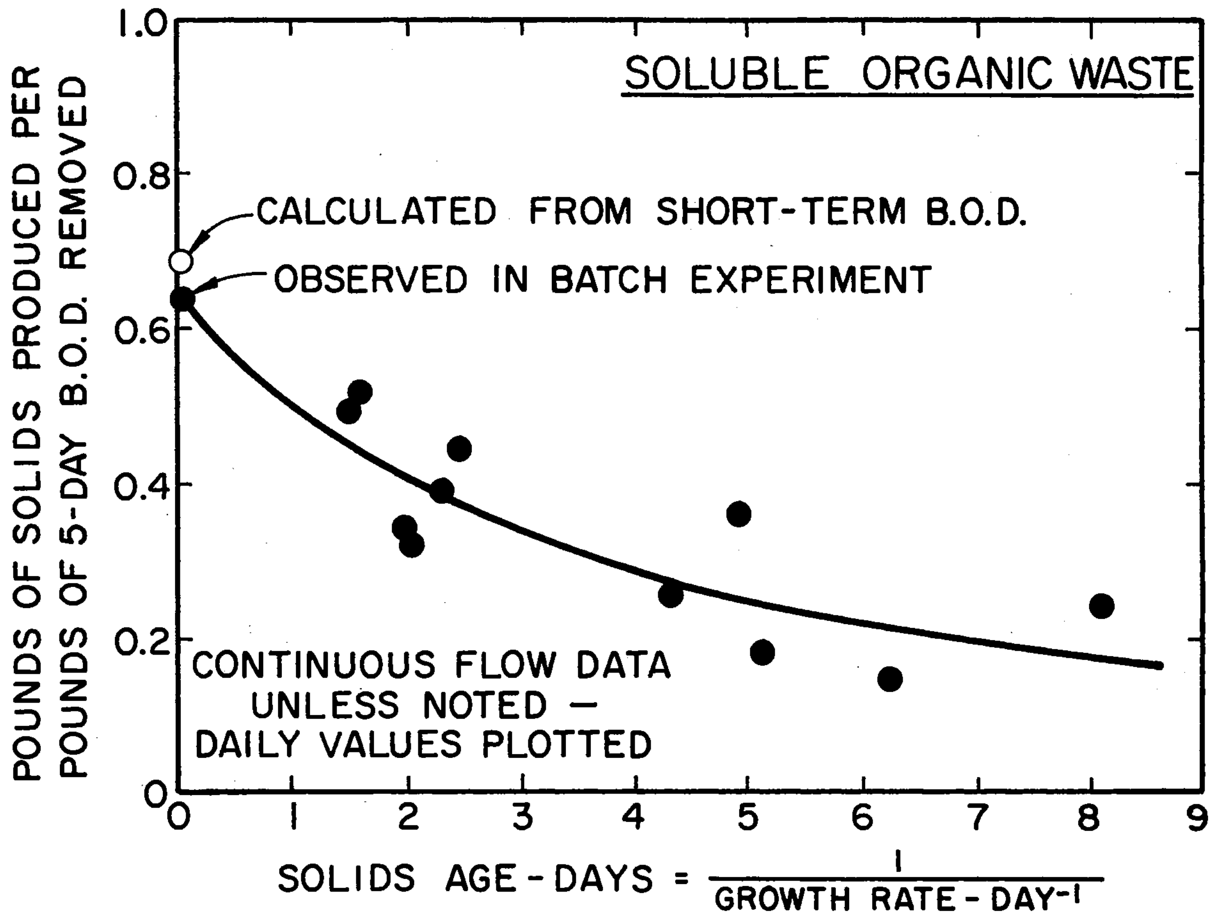
In 1959, Busch (7) also attempted to study food population equilibria in a similar non-steady state bench scale study, and concluded that even after 103 days, a food-population equilibrium was never attained and the biological solids showed cyclic fluctuations in concentrations and settling characteristics.

Figure 3. Effluent Loading Curve


SOLUBLE ORGANIC WASTE
DAILY VALUES PLOTTED
EFFLUENT B.O.D.* - E - mg/l
0
10
20
30
40
0
0.5
1.0
1.5
2.0
B.O.D.* LOADING - L
LB. B.O.D.*/DAY/LB. M.L.S.S.

*5 DAY, 20°C

Figure 4. Solids Production vs. Solids Age


SOLUBLE ORGANIC WASTE
CALCULATED FROM SHORT-TERM B.O.D.
OBSERVED IN BATCH EXPERIMENT
CONTINUOUS FLOW DATA
UNLESS NOTED —
DAILY VALUES PLOTTED
POUNDS OF SOLIDS PRODUCED PER
POUNDS OF 5-DAY B.O.D. REMOVED
1.0
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
SOLIDS AGE - DAYS = 1 / GROWTH RATE - DAY-1

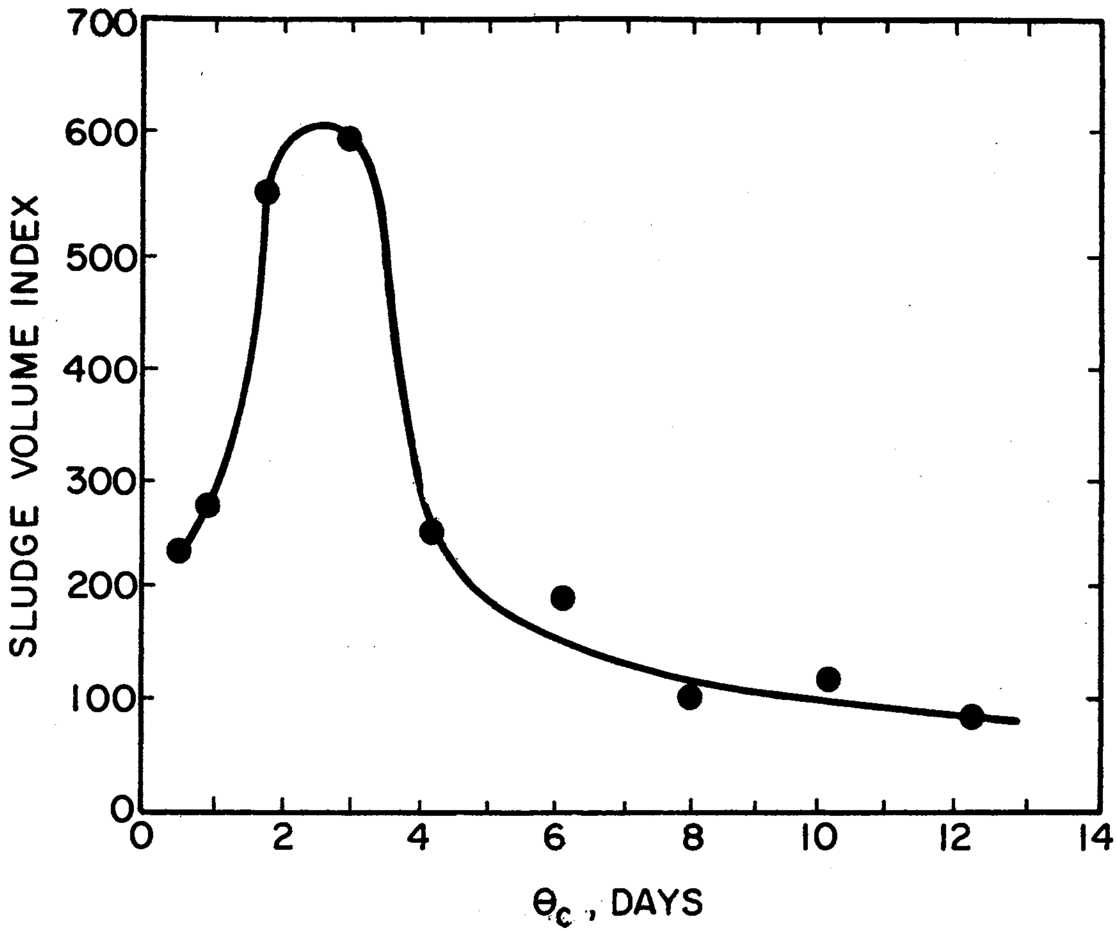
B. Activated Sludge Characteristics

As reported by Dick and Vesilind (8), the sludge volume index (SVI) which is defined as the volume in ml occupied by one gram of activated sludge after settling the aerated liquor for 30 minutes, has become the standard measure of the physical characteristics of activated sludge solids. The most common use of this parameter has been in monitoring waste treatment plant operation and in comparing the settling characteristics of various sludges. For this reason it is important that the SVI be considered when running a pilot plant study. Dick and Vesilind also reported that temperature affects the SVI to a considerable extent.

To show the sludge settling characteristics as a function of sludge age at steady state conditions, Bisogni and Lawrence (9) plotted SVI as a function of solids age, as shown in Figure 5. Changing the solids age from one to two days will cause the SVI to increase by 100 percent, and changing it from three to four days will reduce the SVI by 100 percent. After four days there is less pronounced reduction in the SVI value. Busch (6) stated that by increasing or decreasing the sludge age, a culture with better settling characteristics will be produced.

In one of the few investigations made of sludge settling characteristics under non-steady state conditions, Busch (7) reported that there were large fluctuations in a curve of SVI plotted against time in days that the test was run. The median SVI for one gram glucose feed per day was 272 as compared to a six-gram glucose feed per day having a median SVI of 1250. Median SVI values for intermediate feeds were erratic and did not plot in a straight line relationship. The daily SVI values ranged from a low of less than 50 to a high of over 3000. Also, for

Figure 5. Sludge Volume Index as a Function of Solids Age



700
600
500
400
300
200
100
0
SLUDGE VOLUME INDEX
0
2
4
6
8
10
12
14
θc , DAYS

very low or very high solids concentrations, the SVI loses any significance. Busch further reported that while using surface loadings of 150 and 1440 gallons per day per square foot, that although the SVI values were of the same order of magnitude, settling characteristics of the populations were markedly different.

CHAPTER III

MATERIALS AND METHODS

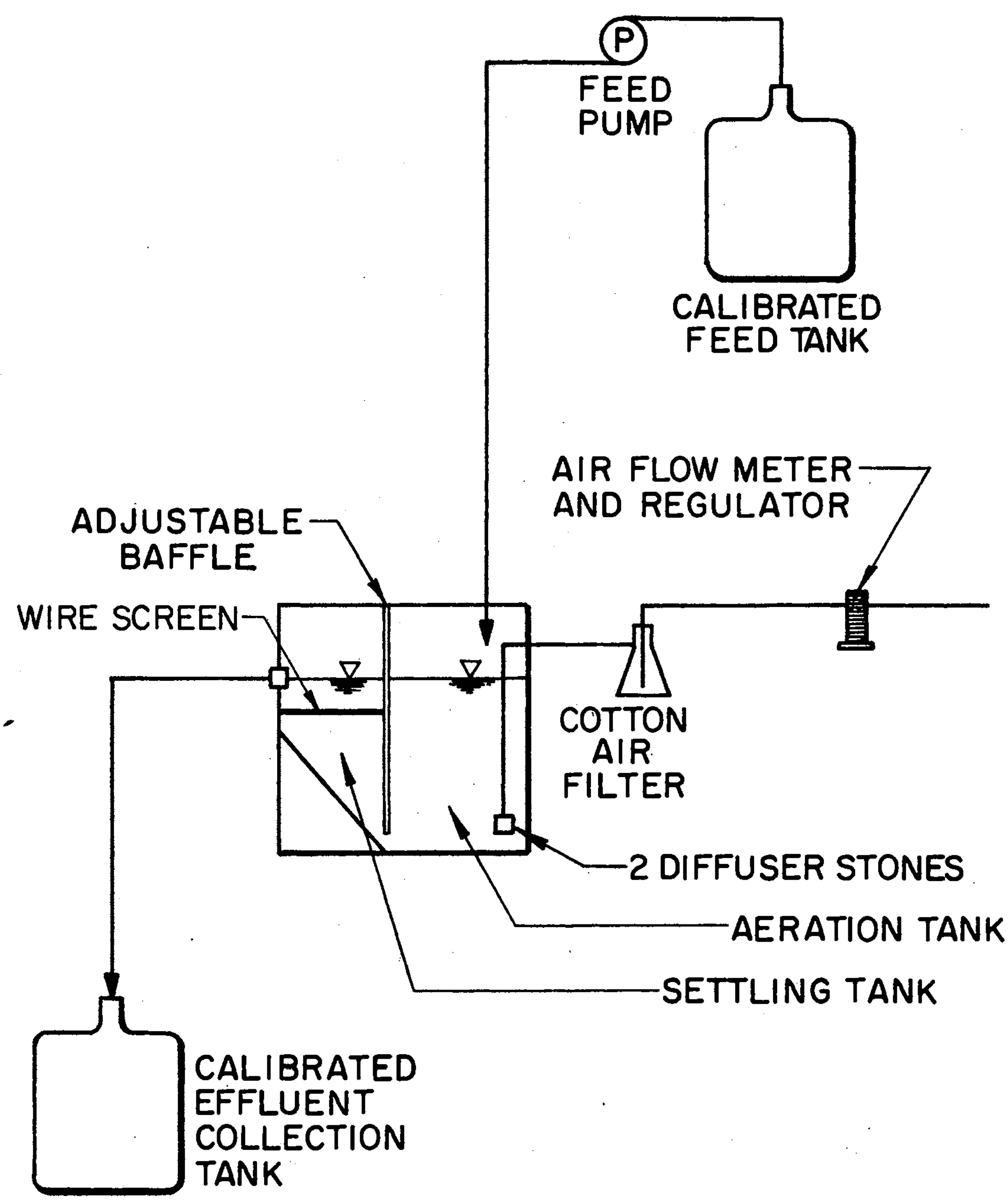
To evaluate the Busch method for design of the activated sludge treatment process, a bench scale unit was operated under controlled conditions for approximately seven months. Analytical procedures were conducted in accordance with procedures outlined in *Standard Methods* (10).

A description of the apparatus used, the feed solution, the bacterial population, daily protocol, temperature, analytical procedures, and methods of data analysis are presented separately for ease of presentation.

A. Laboratory Apparatus

An illustration of the type of model laboratory apparatus herein referred to as the reactor, which was used in this investigation, is shown in Figure 6. Experimental use of this type of reactor was also reported by Gaudy, et al. (11) in 1971. Two laboratory units were used in the present study to perform five continuous flow experiments. Reactor A was used for the first four experiments and a similar unit (Reactor B) with a slightly larger volume was used for experiment 5. The reactors were made of ¼" plexiglass and were covered on three outside surfaces with aluminum foil to keep sunlight from penetrating the reactor to preclude algal growth. The reactors had two compartments (an aeration basin and a settling basin) which were separated by an

Figure 6. Experimental Bench-scale Activated Sludge Unit with Internal Recycle


FEED
PUMP
CALIBRATED
FEED TANK
AIR FLOW METER
AND REGULATOR
ADJUSTABLE
BAFFLE
WIRE SCREEN
COTTON
AIR
FILTER
2 DIFFUSER STONES
AERATION TANK
SETTLING TANK
CALIBRATED
EFFLUENT
COLLECTION
TANK

adjustable baffle. The volumes of the aeration and settling basins, the total reactor volume (which was considered to be that volume where bacterial growth occurred) and hydraulic detention times based on the total reactor volume for both reactors are listed in Table I. Mean cell residence time was controlled independently of hydraulic detention time by internal recycling. Solids which passed from the aeration basin were drawn back into the aeration basin by suction provided by the air diffusers.

TABLE I

REACTOR DIMENSIONS AND HYDRAULIC DETENTION TIMES

	Aeration Basin Volume (Liters)	Settling Basin (Liters)	Total Volume (Liters)	System Hydraulic Detention Time (Hours)
Reactor A	7.8	3.4	11.2	14.9
Reactor B	8.5	3.7	12.2	16.3

Continuous synthetic and industrial waste water was supplied to the respective reactors by means of a Milton Roy dual, positive displacement pump (Mini-pump, Model MM2-b-96R). The pumping rate of 18 liters per day was checked weekly.

Compressed air with an air flow rate of between 3.8 and 4.2 liters per minute was supplied to the reactors through two porous diffuser stones. The amount of air varied during the day depending on the total air requirements throughout the laboratory; however, this did not pose any problems, since the minimum rate of 3.8 liters per minute contained sufficient oxygen for bacterial growth, recycling of solids, and good mixing. With the use of compressed air there exists the possibility of oil entering the air lines and subsequently getting into the reactor. If the oil were to get into the reactor, it could contaminate the biological population and therefore to preclude this from happening, a cotton filter was placed between the air flow meter and the air diffusers.

B. Feed Solution

The chemical composition of both the synthetic and industrial wastes is listed in Table II. The carbon sources for both wastes are discussed below. The various nutrients (magnesium sulfate, ferric chloride, manganese sulfate, calcium chloride and ammonium sulfate) are also listed in Table II. A phosphate buffer solution was used as a means of controlling the pH in the aeration basin for all five experiments. This buffer plus the normal buffering effect of the tap water maintained the pH between 6.8 and 7.1.

1. Synthetic Waste. The synthetic waste had bacto-peptone as the carbon source with an average chemical oxygen demand (COD) of 311 milligrams per liter (mg/l) for experiments No. 1 and No. 3, and 627 mg/l for experiment No. 2. A concentrated stock solution was made for each experiment, and 100-ml samples were prepared and were kept frozen until their use. For this reason, the COD values of the feed were almost always the same for each daily run, and the variance that did occur can be attributed to the inaccuracies in running the COD test.

TABLE II

WASTEWATER COMPOSITION OF SYNTHETIC AND INDUSTRIAL WASTES

		Stock Concen. per 2 l (grams)	Quantities used per 18 l (ml)	Final Concen. per 18 l (mg/l)
I.	Synthetic Waste			
	Carbon Source: Bacto-Peptone			
	Experiments 1 and 3*	103.2	100.0	286.67
	Experiment 2**	103.2	200.0	573.33
II.	Industrial Waste			
	Carbon Source: Beef and Blood			
	Experiments 4 and 5***	****	****	****
	KH_2PO_4 (Experiments 1-5)	105.4	100.0	292.78
	K_2HPO_4 (Experiments 1-5)	214.0	100.0	594.44
	$(NH_4)_2SO_4$			
	Experiments 1, 3, 4, 5	200.0	45.0	250.00
	Experiment 2	200.0	90.0	500.00
	$MgSO_4 \cdot 7H_2O$			
	Experiments 1, 3, 4, 5	20.0	90	50.00
	Experiment 2	20.0	120	66.67
	$FeCl_3 \cdot 6H_2O$			
	Experiments 1, 3, 4, 5	0.1	90	0.25
	Experiment 2	0.1	120	0.33
	$MnSO_4 \cdot H_2O$			
	Experiments 1, 3, 4, 5	2.0	90	5.00
	Experiment 2	2.0	120	6.67
	$CaCl_2$			
	Experiments 1, 3, 4, 5	1.5	90	3.75
	Experiment 2	1.5	120	5.00

*Average COD of waste = 311 mg/l
**Average COD of waste = 627 mg/l
***Average COD of waste = 315 mg/l
****Amount of beef blood which was added was dependent on the COD of the various stock concentrations

2. Industrial Waste. This waste had beef blood as the carbon source. The beef blood was diluted with tap water to an average COD of 323 mg/l. This waste was obtained during beef slaughtering operations at Ralph's Packing Company, Perkins, Oklahoma . About five liters of beef blood were collected directly from a slaughtered animal and were immediately diluted by about 50 percent with hot water. After returning to the laboratory, the blood was placed in 2-liter glass containers. The COD values of the various containers varied from less than 14,000 mg/l to over 35,000 mg/l. This variance was caused by the additional dilution required to prevent the blood from coagulating. Because of these varying CODs and the fact that the CODs were so high, the daily COD of the feed in the reactor was not as consistent as when using the synthetic waste.

C. Bacterial Population

The initial seed of microorganisms was obtained from Stall (1). Since these microorganisms were fed the same bacto-peptone, it was not necessary to acclimate them to the feed for the first three experiments. The bacteria were initially grown in a batch unit and then approximately 1000 mg/l of the mixed liquor suspended solids were transferred to the continuous flow reactor. The reactor was run for approximately one week in order for the bacteria to become acclimated to the continuous flow process. The MLSS was then reduced to about 1000 mg/l and monitoring of the daily parameters, as shown in Table III, was initiated. Table III also shows those parameters which were monitored on a weekly basis. A batch unit was kept in simultaneous operation so that bacteria would be available for following experiments.

TABLE III

PARAMETERS MONITORED ON A DAILY OR WEEKLY BASIS

	Daily	Weekly
1. Feed		
A. Chemical Oxygen Demand	x	
B. pH		x
2. Biological Reactor		
A. Microorganism Concentration	x	
B. Temperature		x
C. pH	x	
D. Sludge Volume Index	x	
3. Unfiltered Effluent		
A. Suspended Solids Concentration	x	
B. pH		x
4. Filtered Effluent		
Chemical Oxygen Demand	x	

For the industrial waste experiments the bacteria, which were being fed bacto-peptone in a batch unit, were slowly acclimated to the beef blood. During a two-week period, the amount of bacto-peptone was slowly decreased every day while the amount of beef blood was increased. After the two-week period, the batch unit was fed only the beef blood. Again, as was done with the first experiment, bacteria were transferred to the continuous flow reactor and were acclimated to this condition for about five days prior to monitoring the daily parameters, as shown in Table III.

D. Daily Protocol

1. Feed. After the 18-liter feed solution was prepared with the concentrations shown in Table II, a 20-ml sample was taken for a COD analysis. The pH was checked weekly to be 7.1.

2. Effluent. A 50-ml sample was collected at the discharge line from the reactor and was then filtered through a 45 μ filter pad. From the filtrate, a 20-ml sample was taken for the COD analysis. The COD determination was made of the discharge effluent rather than from the effluent collection tank, since the biological solids which were in the effluent collection tank further metabolized the organic matter in the tank and the results would be lower than the results actually obtained by measuring at the effluent discharge. This was imperative for experiments No. 4 and No. 5 when the solids concentrations in the effluent ranged between 60-100 mg/l.

After the effluent collection tank was well mixed, a 25-ml sample was taken and filtered through a 45 μ filter pad in order to determine the concentration of suspended solids. When the solids concentrations were less than 10 mg/l, a 50-ml sample was used to provide better accuracy when running this test.

3. Biological Solids. After plugging the effluent discharge line, the baffle and wire screen were removed and the entire MLSS was well mixed. A 600-ml sample was collected and placed on a magnetic stirrer. A 25-ml sample was then taken from the 600 ml of MLSS. This sample was then filtered through a 45 μ filter pad in order to determine the suspended solids concentration. The remaining MLSS were returned to the

reactor, the tank was again well mixed, and 1000 ml of the MLSS was then placed in a 1000-ml graduated cylinder. The contents of the cylinder were aerated for one minute and were then allowed to settle for 30 minutes. The volume of solids was recorded in order to determine the sludge volume index (SVI), and the entire 1000 ml was returned to the reactor. The baffle was replaced and as soon as there was sufficient settling in the clarifier side of the reactor, the wire screen was replaced and the plug on the effluent line was removed. The pH was checked daily, and the temperature was checked weekly.

E. Temperature

During the course of this investigation there was no control over the room temperature in which the reactors were located or of the temperature of the feed solution. Although the daily temperatures of the tap water which was used for the feed solution varied by as much as 10^{o}F during the various experiments, by the time the feed reached the reactor it was near room temperature. During some of the experiments, the temperature of the laboratory and therefore also the temperature of the feed solution and the reactor temperature varied by 5-10^{o}F, and this may have caused some of the problems which are described in Chapter IV.

F. Analytical Procedures

The following methods and equipment were used to measure the chemical oxygen demand, suspended solids concentration, pH, and temperature during this research.

Feed and effluent COD determinations were made in accordance with Standard Methods (10). The standard method was used for the feed and the dilute method was used for the effluent, except when the effluent value exceeded 100 mg/l (experiments 2 and 3). In these instances, the standard method was also used for effluent determinations.

The suspended solids concentrations were determined by filtering the 25-ml samples through .45 μ pore size filters (Millipore Filter Corp., Bedford, Mass.). The filters were weighed on a Mettler Instrument Corporation balance (No. 1-910). The pH was determined using a Beckman Expandomatic 55-2 pH meter, and the temperature was measured with a Sargent-Welch thermometer.

G. Methods of Data Analysis

The following mathematical relationships were used for data analysis. The observed yield coefficient (Y_{obs}) was calculated according to the following expression:

$$Y_{obs} = \frac{(V)(X-X_o) + (Q_{eff})(X_{eff})}{Q(C_o - C)} \qquad (1)$$

where

Y_{obs} = observed yield coefficient

V = total reactor volume, liters

X = MLSS after 24 hours, mg/l

X_o = initial MLSS, mg/l

Q_{eff} = effluent flow rate, liters per day

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

Q = influent flow rate, liters per day

C_o = influent substrate concentration, mg/l

C = effluent substrate concentration, mg/l

The mean cell residence time (sludge age or Θ_c) was calculated according to the following expression:

$$\Theta_c = \frac{(V)(X_a)}{(X - X_o)(V) + (Q_{eff})(X_{eff})} \tag{2}$$

where

X_a = average MLSS over a 24-hour period

mg/l and all other terms are as previously defined.

The percent COD removal efficiency was calculated according to the following expression:

$$E = \frac{100(C_o - C)}{C_o} \tag{3}$$

where

E = % COD removal efficiency

and all other terms are as previously defined.

CHAPTER IV

RESULTS AND DISCUSSION

Laboratory activated sludge units were operated under non-steady state conditions over a period of approximately six months. Tabular raw data for each of the five experimental runs are found in the Appendix.

In evaluating Busch's design method, the three design curves which Busch reported as being necessary for design criteria were plotted separately for the synthetic and industrial wastes and are discussed below:

A. Synthetic Waste

Shown in Figure 7 is a plot of COD loading vs. specific utilization. This data does plot as a straight line relationship, and therefore does correspond to Busch's design curve (Figure 2). The slope of the line indicates a process efficiency of 84 percent. Figure 8 is a plot of COD loading vs. effluent COD, and does and does not agree with Busch's curve (Figure 3). Data from the two experiments where there was a filamentous biological population, plots as unrelated random points and therefore a straight line cannot be drawn connecting the points. Data obtained in the first experiment where there was a non-filamentous biological population does plot as a straight line relationship and does coincide with Busch's design curve. The microorganisms for experiment one also became filamentous; however, not until after 25

Figure 7. COD Loading vs. Specific Utilization Curve (Synthetic Waste)

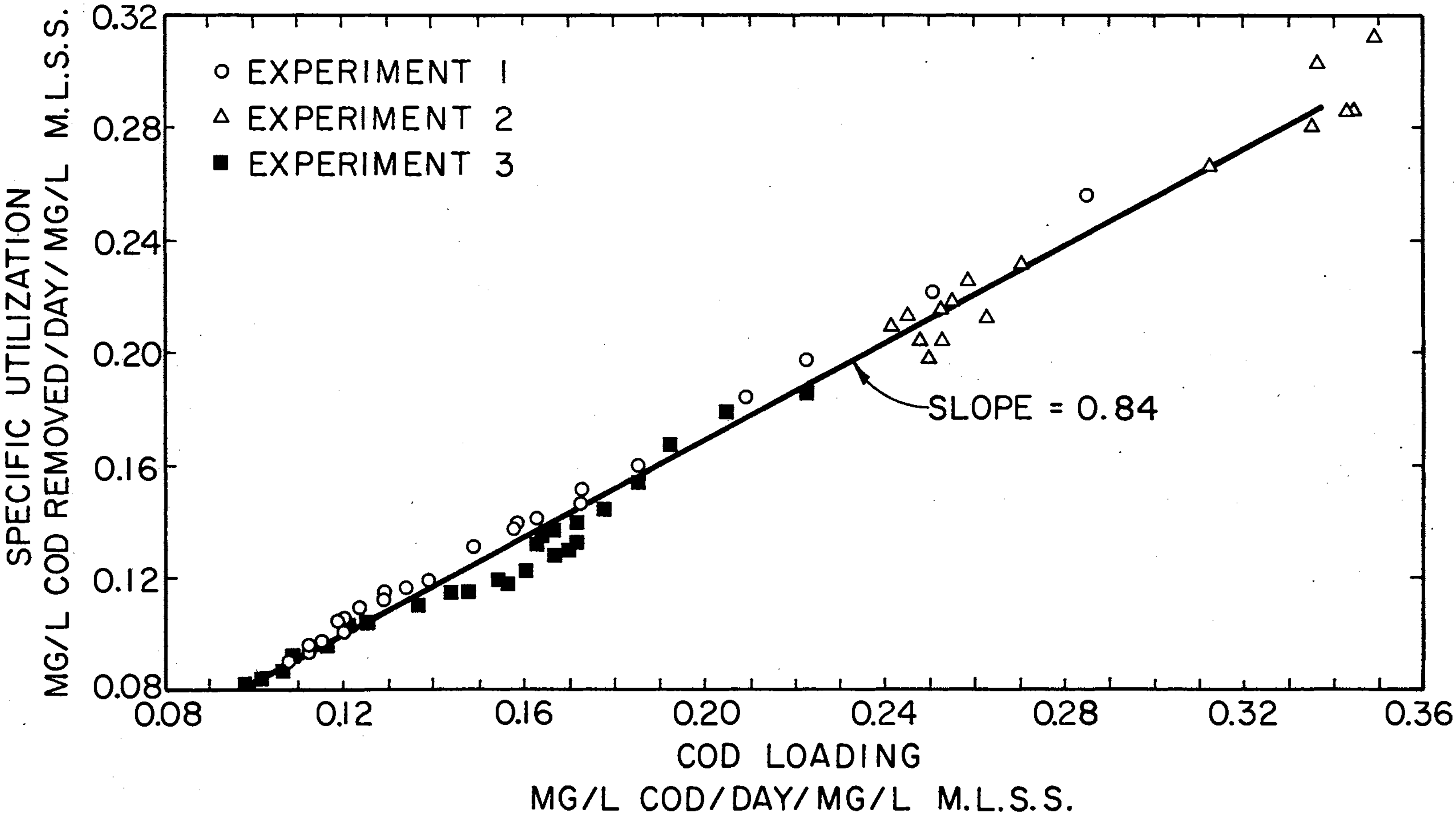
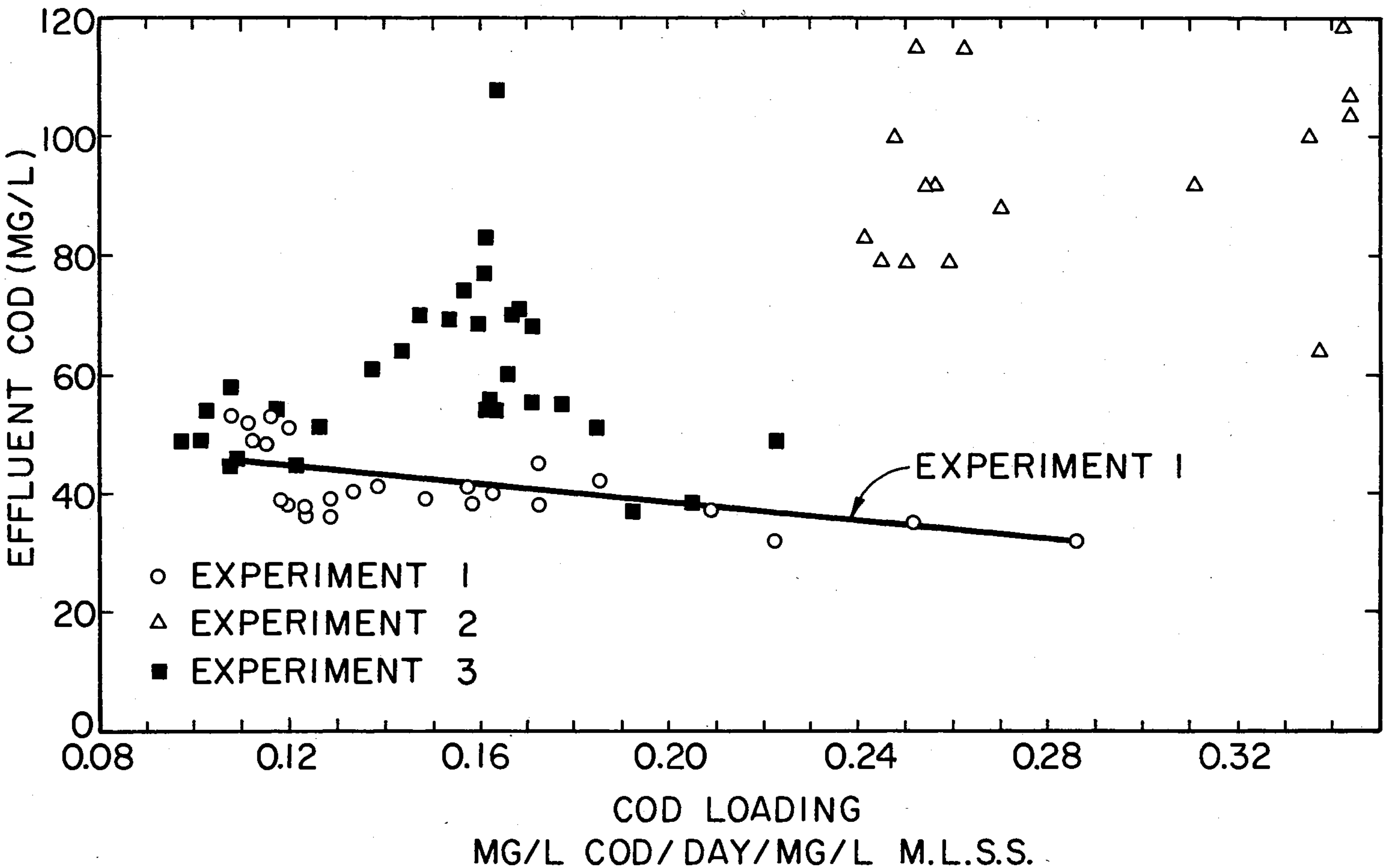

SPECIFIC UTILIZATION
MG/L COD REMOVED/DAY/MG/L M.L.S.S.
0.32
0.28
0.24
0.20
0.16
0.12
0.08
○ EXPERIMENT 1
△ EXPERIMENT 2
■ EXPERIMENT 3
SLOPE = 0.84
0.08
0.12
0.16
0.20
0.24
0.28
0.32
0.36
COD LOADING
MG/L COD/DAY/MG/L M.L.S.S.

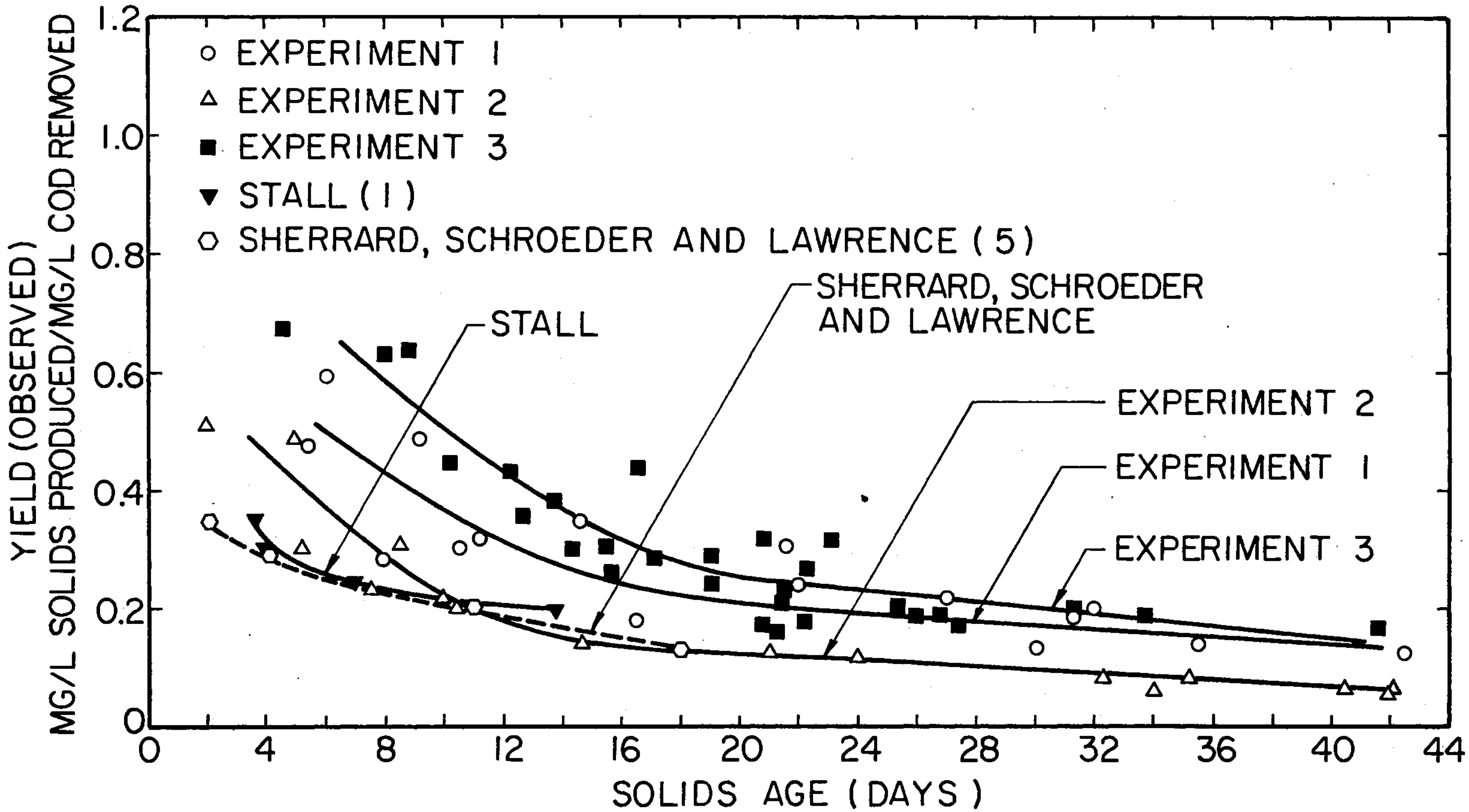
Figure 8. Effluent Loading Curve (Synthetic Waste)


EFFLUENT COD (MG/L)
120
100
80
60
40
20
0
0.08
0.12
0.16
0.20
0.24
0.28
0.32
COD LOADING
MG/L COD/ DAY/MG/L M.L.S.S.
EXPERIMENT 1
EXPERIMENT 1
EXPERIMENT 2
EXPERIMENT 3

days of operation, and by that time the experiment had been terminated. Figure 9 is a plot of Y_{obs} vs. Θ_c and probably is the most important curve. The data from each experiment compares favorably with Busch's design curve (Figure 4) in appearance. However, when compared to two other curves which were derived under steady state conditions using a similar substrate, differences are found to exist. As can be readily seen from the data points, no single curve can be drawn, and thus the reproducibility of the design method was not found to exist. The curves have much less variance at high Θ_cs (above 40 days) than at lower Θ_cs, and the variance becomes quite significant at values of Θ_c less than 20 days. Also, the values of Θ_c are two or more times greater than those normally used in treatability studies conducted under steady state conditions. These larger values of Θ_c can be most likely attributed to the low concentrations of microorganisms found in the clarifier effluent.

For experiment 1, the sludge settling characteristics remained virtually unchanged. The SVI was nearly constant for all MLSS concentrations and sludge ages, and therefore a plot of SVI vs. Θ_c was a straight line rather than a curve similar to that shown in Figure 5, which was obtained under steady state conditions using a synthetic substrate. For experiments 2 and 3, the SVI increased on a daily basis with the increasing filamentous biological population. Also during these two experiments, after reaching a maximum SVI value in a period of 16-20 days, the SVI value became smaller with increasing MLSS concentrations. The SVI had no relationship to the effluent quality, since the same effluent microorganism concentration was obtained at SVIs of 30 and 300.

Figure 9. Solids Production vs. Solids Age (Synthetic Waste)

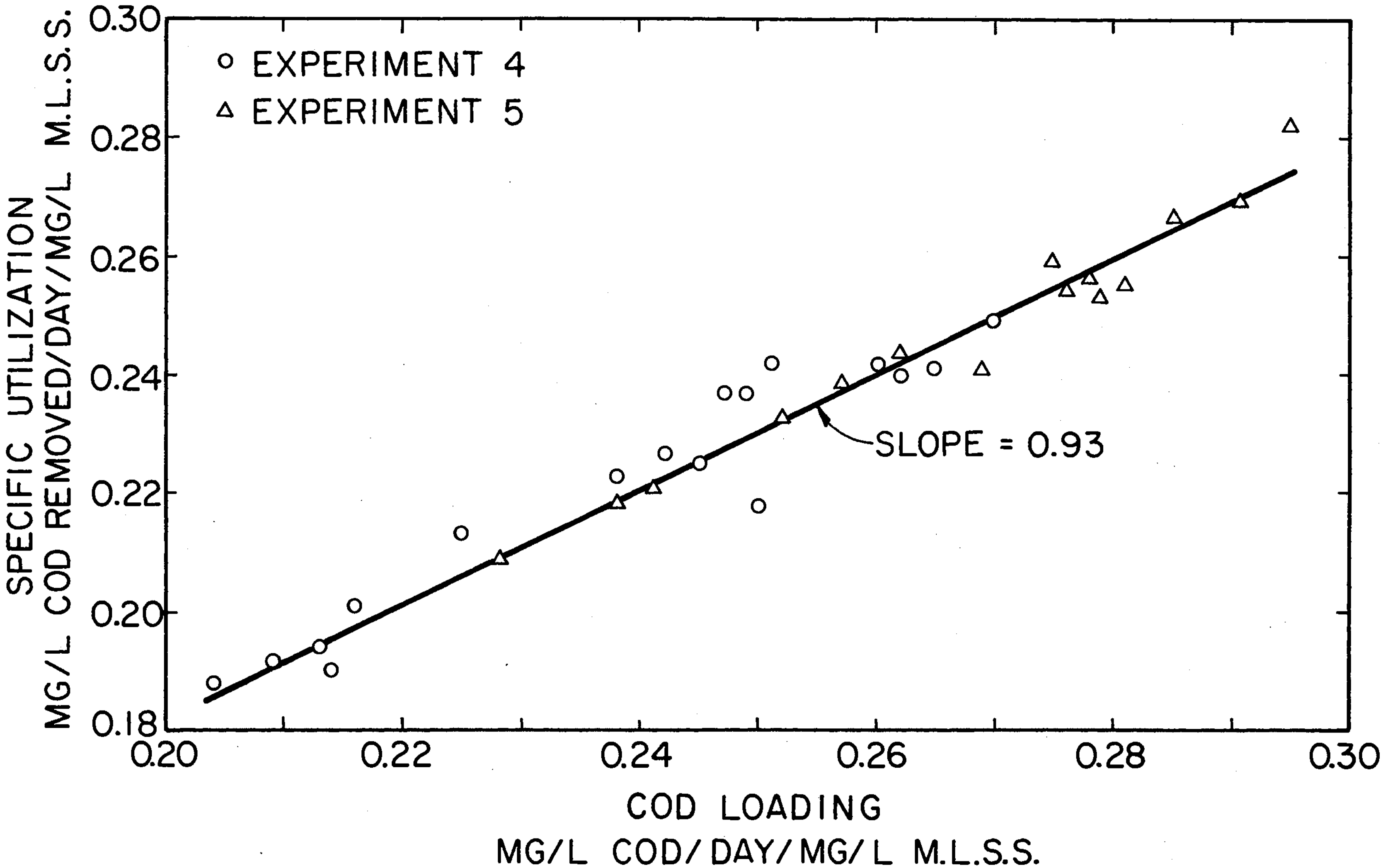


YIELD (OBSERVED)
MG/L SOLIDS PRODUCED/MG/L COD REMOVED
1.2
1.0
0.8
0.6
0.4
0.2
0
0
4
8
12
16
20
24
28
32
36
40
44
SOLIDS AGE (DAYS)
EXPERIMENT 1
EXPERIMENT 2
EXPERIMENT 3
STALL (1)
SHERRARD, SCHROEDER AND LAWRENCE (5)
STALL
SHERRARD, SCHROEDER AND LAWRENCE
EXPERIMENT 2
EXPERIMENT 1
EXPERIMENT 3

B. Industrial Waste

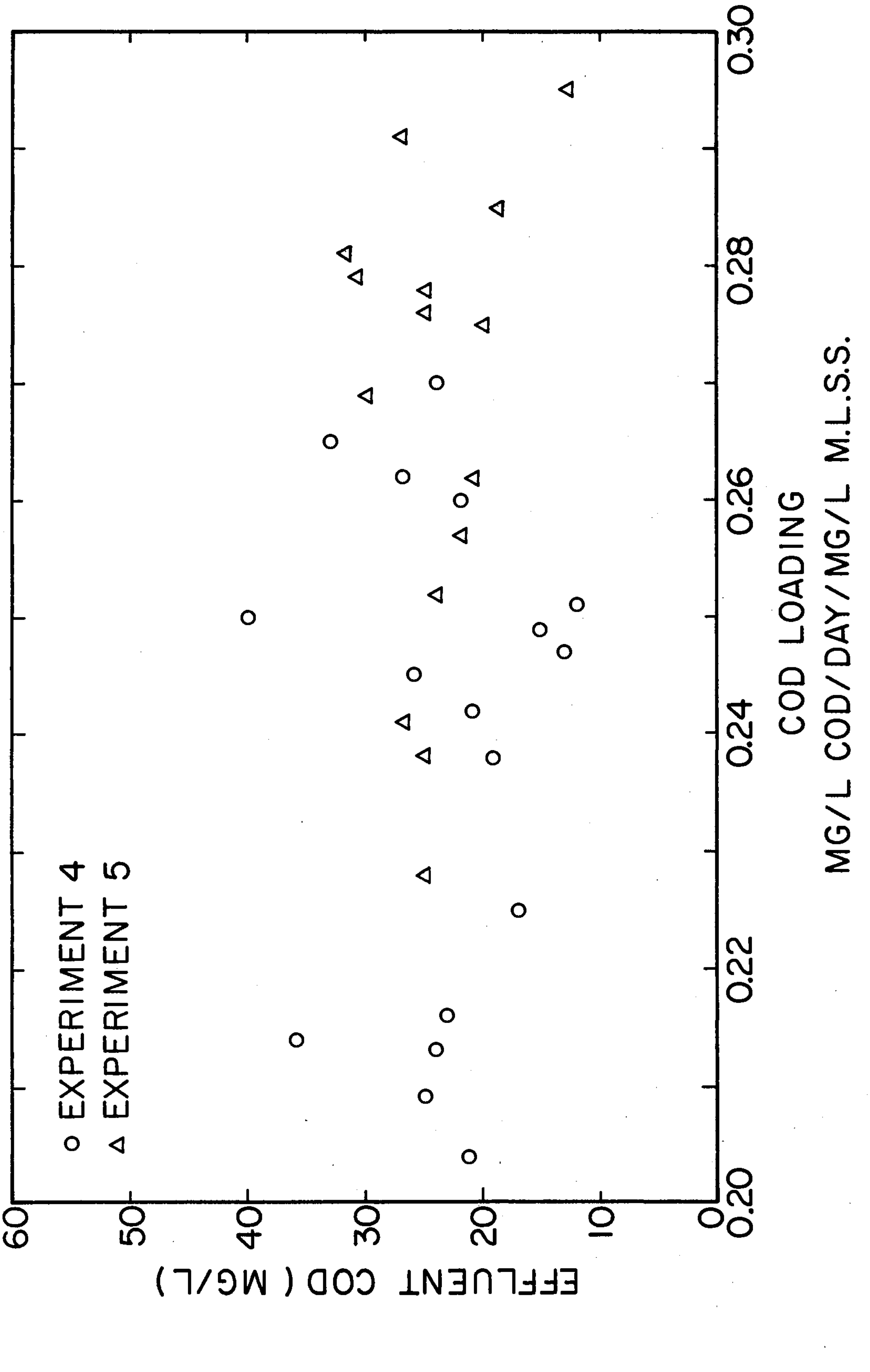
Similar plots to those described above for the bacto-peptone waste were made for the beef blood waste. Shown in Figure 10 is a plot of COD loading vs. specific utilization. The data was found to be linear, and process efficiency of 93 percent was obtained. Figure 11 is a plot of COD loading vs. effluent COD. A problem exists in plotting this data as a linear relationship due to the random scattering of the data points. Figure 12, which is a plot of Y_{obs} vs. Θ_c, does plot as a single curve for both experiments, thus reproducibility is obtained. Values of Θ_c obtained are similar to those found in practice, and this can be attributed to the fact that the inadvertent wastage of microorganisms in the effluent was much higher than for the synthetic waste. Comparative steady state curves using this substrate are not available. As was the case in experiment 1, a plot of SVI vs. Θ_c was linear. The effluent quality varied throughout both experiments, and filtering characteristics of both the effluent and MLSS solids changed from one day to the next.

Figure 10. COD Loading vs. Specific Utilization Curve (Industrial Waste



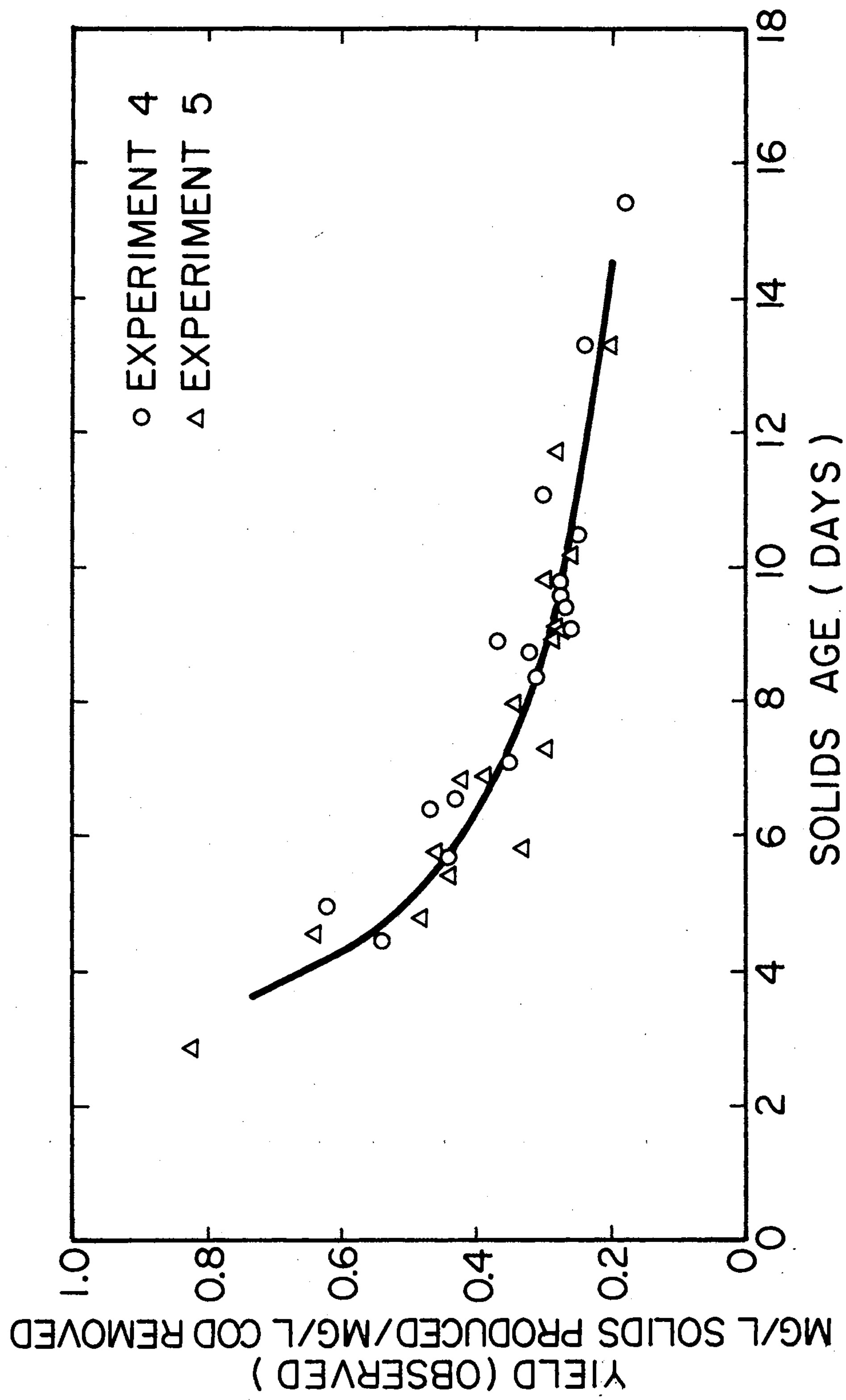
EXPERIMENT 4
EXPERIMENT 5
SLOPE = 0.93
SPECIFIC UTILIZATION
MG/L COD REMOVED/DAY/MG/L M.L.S.S.
0.18
0.20
0.22
0.24
0.26
0.28
0.30
0.20
0.22
0.24
0.26
0.28
0.30
COD LOADING
MG/L COD/ DAY/ MG/ L M.L.S.S.

Figure 11. Effluent Loading Curve (Industrial Waste)



EXPERIMENT 4
EXPERIMENT 5
EFFLUENT COD (MG/L)
0
10
20
30
40
50
60
0.20
0.22
0.24
0.26
0.28
0.30
COD LOADING
MG/L COD/DAY/MG/L M.L.S.S.

Figure 12. Solids Production vs. Solids Age (Industrial Waste)



EXPERIMENT 4
EXPERIMENT 5
SOLIDS AGE (DAYS)
YIELD (OBSERVED)
MG/L SOLIDS PRODUCED/MG/L COD REMOVED
0
2
4
6
8
10
12
14
16
18
0.2
0.4
0.6
0.8
1.0

CHAPTER V

CONCLUSIONS

Based on the results of this investigation, the following conclusions are made:

1. There is insufficient data available to ascertain whether or not the Busch design method can provide reliable design data for sewage treatment facilities; however, the method does have the potential to provide reliable design data in a much shorter period of time than under steady state conditions. Comparative curves obtained using a similar bacto-peptone substrate under steady state conditions did not coincide with those obtained under non-steady state conditions during this investigation.

2. Daily values of observed yield and sludge age were governed to a large extent by the effluent microorganism concentration, and COD removal was of only secondary importance.

3. The sludge settling characteristics which were measured in terms of the SVI were virtually unchanged by increasing MLSS concentrations and mean cell residence times, except when the microorganism population became predominately filamentous.

4. The following problems may be encountered in running a pilot plant study under non-steady state conditions:

(A) Using a bacto-peptone substrate during the experiment, filamentous microorganisms can become the predominant biological population.

(B) Settling and filtering characteristics of the microorganisms can be altered significantly when using a beef blood substrate.

CHAPTER VI

RECOMMENDATIONS FOR FUTURE STUDY

Based on the findings of this study, the following suggestions are made for future treatability studies of the activated sludge process:

1. Conduct waste treatment experiments using a beef blood substrate under steady state conditions, and compare the results with those obtained in this study under non-steady state conditions.

2. Carry out an investigation using a soluble organic substrate other than bacto-peptone or beef blood, and operate the bench scale reactor under both steady and non-steady state conditions to compare the results.

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APPENDIX

RAW DATA FOR EACH OF FIVE NON-STEADY STATE EXPERIMENTS

TABLE IV

RAW DATA FOR EXPERIMENT NUMBER 1 (Synthetic Waste)

Date	Biological Solids: Beginning MLSS (mg/l)	Biological Solids: Ending MLSS (mg/l)	Biological Solids: ΔMLSS (mg/l)	Biological Solids: Average MLSS (mg/l)	Biological Solids: Effluent (mg/l)	COD: Feed (mg/l)	COD: Effluent (mg/l)	COD: ΔCOD (mg/l)	Loading mg/l COD/day / mg/l MLSS	Specific Utilization mg/l COD Removal/day / mg/l MLSS	θ_C (days)	Y_{obs}	Sludge Volume after 30 min. Settling (ml)	Sludge Volume Index
(1973)														
10-19	997	1121	124	1059	0.5	303	32	271	.286	.256	7.99	.286	75	67
10-20	1121	1327	206	1224	1.1	307	35	272	.251	.222	5.39	.475	85	64
10-21	1327	1405	78	1366	1.6	303	32	271	.222	.198	16.46	.185	89	64
10-22	1405	1536	131	1471	1.8	307	37	270	.209	.184	10.50	.308	95	62
10-23	1536	1785	249	1661	3.0	307	42	265	.185	.160	6.05	.596	100	56
10-24	1785	1808	23	1797	5.6	311	38	273	.173	.152	55.75	.073	101	56
10-25	1808	1855	47	1832	8.2	315	45	270	.172	.147	30.02	.139	102	55
10-26	1855	1974	119	1915	13.4	311	40	271	.162	.142	13.20	.322	109	55
10-27	1974	2005	31	1990	7.8	315	41	274	.158	.138	45.38	.099	117	58
10-28	2005	2004	-1	2005	5.0	318	38	280	.159	.140	249.50	.018	130	65
10-29	2004	2218	214	2111	1.6	315	39	276	.149	.131	9.25	.488	128	58
10-30	2218	2272	54	2245	5.2	311	41	270	.139	.120	35.55	.143	130	58
10-31	2272	2424	152	2348	2.2	315	40	275	.134	.117	14.60	.352	132	55
11- 1	2424	2448	24	2436	1.5	315	36	279	.129	.115	91.80	.059	138	56
11- 2	2448	2556	108	2502	2.4	322	39	283	.129	.113	21.90	.246	141	55
11- 3	2556	2564	8	2560	2.6	318	36	282	.124	.110	209.56	.027	145	57
11- 4	2564	2621	57	2593	2.1	322	38	284	.124	.110	42.45	.131	152	58
11- 5	2621	2666	45	2644	2.4	318	38	280	.120	.106	53.66	.109	152	57
11- 6	2666	2746	80	2706	3.1	322	39	283	.119	.105	31.36	.187	161	59
11- 7	2746	2837	91	2792	6.7	333	51	282	.120	.101	27.00	.224	170	60
11- 8	2837	2881	44	2859	6.6	333	53	280	.116	.098	51.94	.121	175	61
11- 9	2881	2910	29	2896	8.1	333	48	285	.115	.098	68.54	.092	188	65
11-10	2910	2976	66	2943	12.6	333	49	284	.113	.097	33.73	.189	198	67
11-11	2976	3050	74	3013	12.0	336	52	284	.112	.094	31.90	.204	205	67
11-12	3050	3173	123	3112	11.2	336	53	283	.108	.091	21.62	.310	210	66

TABLE V

RAW DATA FOR EXPERIMENT NUMBER 2 (Synthetic Waste)

	Biological Solids					COD								
Date	Beginning MLSS (mg/l)	Ending MLSS (mg/l)	ΔMLSS (mg/l)	Average MLSS (mg/l)	Effluent (mg/l)	Feed (mg/l)	Effluent (mg/l)	ΔCOD (mg/l)	Loading $\frac{\text{mg/l COD/day}}{\text{mg/l MLSS}}$	Specific Utilization $\frac{\text{mg/l COD Removal/day}}{\text{mg/l MLSS}}$	θ_C (days)	Y_{obs}	Sludge Volume after 30 min. Settling (ml)	Sludge Volume Index
(1973)														
11-21	949	1429	480	1189	5	629	44	585	.529	.492	1.94	.519	37	26
11-22	1429	1694	265	1562	6	618	63	555	.396	.355	5.20	.307	49	29
11-23	1694	1891	197	1793	12	625	63	562	.349	.313	7.83	.239	53	28
11-24	1891	1860	-31	1876	11	633	64	569	.337	.303	106.96	.020	51	27
11-25	1860	1796	-64	1828	26	629	107	522	.344	.286	44.51	.050	60	33
11-26	1796	1864	68	1830	34	629	104	525	.344	.287	14.64	.145	67	36
11-27	1864	1784	-80	1824	34	625	119	506	.343	.277	34.11	.068	120	67
11-28	1784	1929	145	1857	17	622	100	522	.335	.281	10.35	.205	170	88
11-29	1929	2101	172	2015	14	629	92	537	.312	.267	9.92	.225	330	157
11-30	2101	2501	400	2301	15	622	88	534	.270	.232	4.95	.494	345	138
12- 1	2501	2492	-9	2497	37	639	92	547	.256	.219	42.06	.068	420	169
12- 2	2492	2570	78	2531	25	639	92	547	.252	.216	21.09	.134	450	175
12- 3	2570	2487	-83	2529	38	619	100	519	.248	.205	42.08	.073	515	207
12- 4	2487	2342	-145	2415	44	611	115	496	.253	.205	35.17	.089	760	325
12- 5	2342	2382	40	2362	36	619	115	504	.262	.213	23.93	.121	850	357
12- 6	2382	2391	9	2387	28	619	79	540	.259	.226	44.11	.062	910	381
12- 7	2391	2622	231	2507	30	627	79	548	.250	.219	8.56	.317	930	355
12- 8	2622	2608	-14	2615	30	631	83	548	.241	.210	54.38	.055	940	360
12- 9	2608	2540	-68	2574	40	631	79	552	.245	.214	40.57	.072	950	374
12-10	2540	2564	24	2552	34	639	79	560	.250	.219	32.30	.087	955	373

TABLE VI

RAW DATA FOR EXPERIMENT NUMBER 3 (Synthetic Waste)

	Biological Solids					COD								
Date	Beginning MLSS (mg/l)	Ending MLSS (mg/l)	ΔMLSS (mg/l)	Average MLSS (mg/l)	Effluent (mg/l)	Feed (mg/l)	Effluent (mg/l)	ΔCOD (mg/l)	Loading mg/l COD/day / mg/l MLSS	Specific Utilization mg/l COD Removal/day / mg/l MLSS	θ_C (days)	Y_{obs}	Sludge Volume after 30 min. Settling (ml)	Sludge Volume Index
(1973)														
12-22	1212	1473	261	1343	7	300	49	251	.223	.187	4.45	.675	18	12
12-23	1473	1531	58	1502	7	308	38	270	.205	.180	21.27	.159	20	13
12-24	1531	1592	61	1562	8	300	37	263	.192	.168	20.73	.175	24	15
12-25	1592	1648	56	1620	10	300	51	249	.185	.154	22.09	.180	26	16
12-26	1648	1728	80	1688	16	300	55	245	.178	.145	15.59	.268	28	16
12-27	1728	1820	92	1774	18	304	55	249	.171	.140	14.29	.302	31	17
12-28	1820	1932	112	1876	20	304	55	249	.162	.132	12.63	.360	38	20
12-29	1932	1824	-108	1878	44	304	54	250	.162	.133	27.32	.176	48	26
12-30	1824	1832	8	1828	48	300	54	246	.164	.135	21.42	.215	65	35
12-31	1832	1800	-32	1816	60	304	60	244	.167	.134	19.00	.246	90	50
(1974)														
1- 1	1800	1860	60	1830	72	312	68	244	.171	.133	10.24	.448	150	81
1- 2	1860	1796	-64	1828	68	308	71	237	.169	.130	17.02	.287	220	122
1- 3	1796	1848	52	1822	40	304	70	234	.167	.128	15.44	.309	290	157
1- 4	1848	1820	-28	1834	52	300	108	192	.164	.105	22.11	.271	380	209
1- 5	1820	1892	72	1856	48	298	83	215	.161	.116	12.20	.432	420	222
1- 6	1892	1836	-56	1864	44	302	77	225	.162	.121	26.75	.196	450	245
1- 7	1836	2004	168	1920	40	302	74	228	.157	.119	7.90	.634	460	230
1- 8	2004	2036	32	2020	28	317	68	249	.160	.123	26.02	.192	590	290
1- 9	2036	2092	56	2064	24	317	69	248	.154	.120	21.53	.237	750	359
1-10	2092	2136	44	2114	24	313	70	243	.148	.115	25.33	.211	780	365
1-11	2136	2260	124	2198	20	317	64	253	.144	.115	13.68	.384	820	363
1-12	2260	2360	100	2310	12	317	61	256	.137	.111	18.95	.290	810	343
1-13	2360	2612	252	2486	10	313	51	262	.126	.105	8.80	.637	780	299
1-14	2612	2636	24	2624	10	317	45	272	.121	.104	65.18	.092	660	250
1-15	2636	2704	68	2670	10	313	54	259	.117	.097	31.35	.202	840	310
1-16	2704	2676	-28	2690	12	294	46	248	.109	.092	140.21	.048	840	314
1-17	2676	2792	116	2734	8	294	45	249	.108	.091	20.77	.322	810	290
1-18	2792	2856	64	2824	2	306	58	248	.108	.088	41.54	.169	800	280
1-19	2856	3020	164	2938	6	302	54	248	.103	.084	16.44	.436	790	262
1-20	3020	3012	-8	3016	10	306	49	257	.101	.085	187.91	.039	775	257
1-21	3012	3136	124	3074	4	302	49	253	.098	.082	23.09	.321	770	245

TABLE VII

RAW DATA FOR EXPERIMENT NUMBER 4 (Industrial Waste)

	Biological Solids					COD								
Date	Beginning MLSS (mg/l)	Ending MLSS (mg/l)	ΔMLSS (mg/l)	Average MLSS (mg/l)	Effluent (mg/l)	Feed (mg/l)	Effluent (mg/l)	ΔCOD (mg/l)	Loading mg/l COD/day / mg/l MLSS	Specific Utilization mg/l COD Removal/day / mg/l MLSS	θ_C (days)	Y_{obs}	Sludge Volume after 30 min. Settling (ml)	Sludge Volume Index
(1974)														
1-24	1100	1192	92	1146	18	309	24	285	.270	.249	9.09	.264	20	17
1-25	1192	1252	60	1222	38	306	40	266	.250	.218	9.84	.283	20	16
1-26	1252	1300	48	1276	44	313	26	287	.245	.225	10.55	.257	22	17
1-27	1300	1312	12	1306	36	278	24	254	.213	.194	18.61	.171	23	13
1-28	1312	1340	28	1326	44	270	21	249	.204	.188	13.29	.247	28	21
1-29	1340	1388	48	1364	64	270	18	252	.198	.185	8.88	.373	30	22
1-30	1388	1296	-92	1342	56	325	21	304	.242	.227	15.42	.184	30	23
1-31	1296	1248	-48	1272	84	317	15	302	.249	.237	9.60	.278	31	25
2- 1	1248	1276	28	1262	92	317	12	305	.251	.242	7.10	.359	31	24
2- 2	1276	1344	68	1310	96	324	13	311	.247	.237	5.74	.448	31	23
2- 3	1344	1288	-56	1316	96	313	19	294	.238	.223	8.71	.326	32	25
2- 4	1288	1208	-80	1248	96	324	22	302	.260	.242	8.35	.318	36	30
2- 5	1208	1336	128	1272	88	333	27	306	.262	.240	4.48	.548	38	28
2- 6	1336	1356	20	1346	76	357	33	324	.265	.241	9.40	.273	39	29
2- 7	1356	1428	72	1392	84	313	17	296	.225	.213	6.55	.435	40	28
2- 8	1428	1568	140	1498	92	321	36	285	.214	.190	4.96	.628	45	29
2- 9	1568	1404	-164	1486	88	310	25	285	.209	.192	11.09	.309	48	34
2-10	1404	1488	84	1446	84	313	23	290	.216	.201	6.41	.470	52	35

TABLE VIII

RAW DATA FOR EXPERIMENT NUMBER 5 (Industrial Waste)

	Biological Solids					COD								
Date	Beginning MLSS (mg/l)	Ending MLSS (mg/l)	ΔMLSS (mg/l)	Average MLSS (mg/l)	Effluent (mg/l)	Feed (mg/l)	Effluent (mg/l)	ΔCOD (mg/l)	Loading mg/l COD/day / mg/l MLSS	Specific Utilization mg/l COD Removal/day / mg/l MLSS	θ_c (days)	Y_{obs}	Sludge Volume after 30 min. Settling (ml)	Sludge Volume Index
(1974)														
1-25	876	944	68	910	56	325	28	297	.357	.326	5.81	.343	10	11
1-26	944	1008	64	976	44	313	28	285	.321	.292	7.32	.306	12	12
1-27	1008	1084	76	1046	48	282	30	252	.269	.241	6.86	.395	12	11
1-28	1084	1132	48	1108	48	306	25	281	.276	.254	9.12	.287	20	18
1-29	1132	1228	96	1180	68	309	21	288	.262	.244	5.77	.462	20	16
1-30	1228	1180	-48	1204	36	309	22	287	.257	.238	23.12	.125	25	21
1-31	1180	1104	-76	1142	60	317	25	292	.278	.256	13.28	.205	26	24
2- 1	1104	1064	-40	1084	84	309	19	290	.285	.267	8.91	.290	28	26
2- 2	1064	1032	-32	1048	80	309	13	296	.295	.282	9.01	.270	28	27
2- 3	1032	1096	64	1064	104	324	19	305	.305	.287	4.75	.483	30	27
2- 4	1096	1316	220	1206	108	332	20	312	.275	.259	2.89	.824	35	27
2- 5	1316	1200	-116	1258	112	353	32	321	.281	.255	7.96	.350	38	32
2- 6	1200	1184	-16	1192	80	333	31	302	.279	.253	10.17	.265	38	32
2- 7	1184	1272	88	1228	88	357	27	330	.291	.269	5.43	.447	40	31
2- 8	1272	1244	-28	1258	88	317	24	293	.252	.233	9.80	.300	45	36
2- 9	1244	1388	144	1316	88	313	25	288	.238	.219	4.54	.644	50	36
2-10	1388	1264	-124	1326	80	302	25	277	.228	.209	11.76	.289	51	40
2-11	1264	1396	132	1330	36	321	27	294	.241	.221	6.83	.427	60	43

VITA

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Master of Science

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