

MODEL EVALUATION OF THE
CONTACT STABILIZATION PROCESS
BY LABORATORY STUDIES

by

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INTRODUCTION

The activated sludge method of wastewater treatment has been practiced in the United States since 1917 (1). The conventional process, as originally developed, has undergone significant changes due primarily to experience accumulated from years of successful operation. Early design improvements and process modifications had a predominantly empirical basis derived from operational data of existing treatment plants. In the late 1950's it was recognized that further significant advancements would come only from a better understanding of the kinetics and mechanisms of the biological sludge. This has resulted in the development of several mathematical descriptions of the kinetics and operational characteristics of the activated sludge process (2-6). These models, however, have been applied almost exclusively to the design of single reactor systems with varying degrees of mixing of the reactor contents (7). A two reactor system, such as contact stabilization is affected by interactions between the reactors and has a larger number of independent variables. A more comprehensive description of the microbial kinetics and reactor characteristics is therefore required for its rational design.

Jatko (8), based on a combination of the single reactor models of McKinney (2), Eckenfelder (3) and Lawrence (5), developed a mathematical model of the contact stabilization process. Application of the model, however, required knowledge of several kinetic coefficients that were not evaluated by established laboratory techniques.

The objective of this study was to evaluate the model by typical laboratory activated sludge procedures. A complete mixed activated sludge reactor was operated and the necessary kinetic coefficients of the model

were determined from the operational data analysis. A design example using the experimentally determined kinetic coefficients is also presented.

LITERATURE REVIEW

The objective of an activated sludge process is to remove soluble and nonsettleable particulate organics from a wastewater stream and to convert this material into a flocculant microbial suspension. Classically, this was accomplished by mixing the wastewater with a biological culture in a long, narrow aeration basin with a volume sufficient to provide a 6- to 8-hr. contact period between the two components. The microbial mass was then separated from the liquid stream in a final clarifier. A portion of this biological sludge was wasted and the remainder returned to the head of the aeration tank. Such a process arrangement was termed conventional activated sludge treatment.

Because of deficiencies inherent in the conventional process, numerous modifications to the original process scheme have been proposed. A number of these modifications and their advantages have been discussed (9). A modification that has been in extensive use is the contact stabilization process.

In the contact stabilization process, which is presently designed specially for treatment of wastewater containing a large percentage of nonsettleable particulate organics, the wastewater enters a contact tank, where it is aerated and mixed thoroughly with the mixed liquor suspended solids (MLSS) at a hydraulic detention time of approximately 0.5 to 3 hours. The contents of the contact tank then flow to a final clarifier where effluent is either discharged to the environment or undergoes additional treatment. The settled microbial solids are then transported to a stabilization tank to be aerated between 3 to 6 hours before being returned to the contact tank. A schematic flow diagram of a typical process is shown in Figure 1.

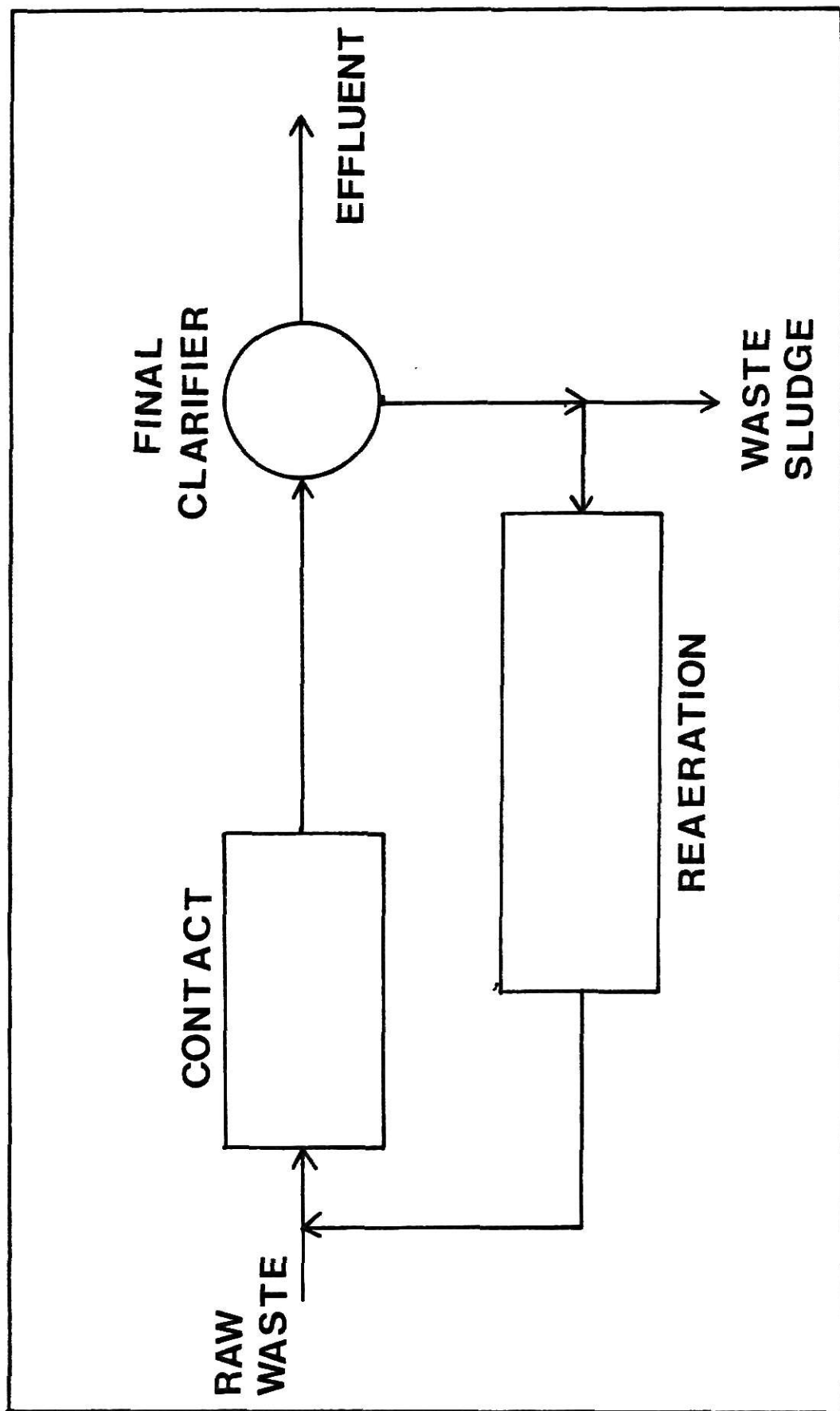


Figure 1. Flow Scheme for the Contact Stabilization Activated Sludge Process

The contact stabilization modification to the activated sludge process was developed independently by Ullrich and Smith (10) and Eckenfelder and Hood (11) as reported by Weston (12). The basis for providing two separate aeration basins was based on the change in 5-day biochemical oxygen demand (BOD_5) concentration observed when aerating a raw wastewater-activated sludge mixture under batch conditions. A typical relationship of the change in BOD_5 concentration with aeration time for a raw wastewater-activated sludge mixture is shown in Figure 2 as reported by McKinney (13). From this type of plot the basis for two aeration basins was formed. In the first aeration basin adsorption of the particulate organics was speculated to occur on the activated sludge floc particles. Because this was observed to occur quickly, a short aeration basin hydraulic detention was used. The release of BOD_5 and subsequent utilization then could occur in a second aeration basin of longer hydraulic detention time.

Several mechanisms have been advanced to explain the manner of non-settleable particulate organics removal for aerobic treatment processes. It is generally believed that particulate organic matter are adsorbed onto the surface of the microbial mass. Soluble organic matter is then released into solution resulting from an enzymatic breakdown of the particulate organics. Biodegradation of the soluble organics then occurs.

The mechanisms of the contact stabilization process have been studied by several investigators. Smallwood (14) used radioactivity labeled particulate algae and soluble nutrient broth and glucose. He found that the algae were adsorbed but the soluble compounds were not. Banerji, et. al. (15) showed that rapid removal of colloidal size starch molecules was due to adsorption. Jones (16) studied the mechanism of physical entrapment of particulate substrates. He concluded that the rapid removal

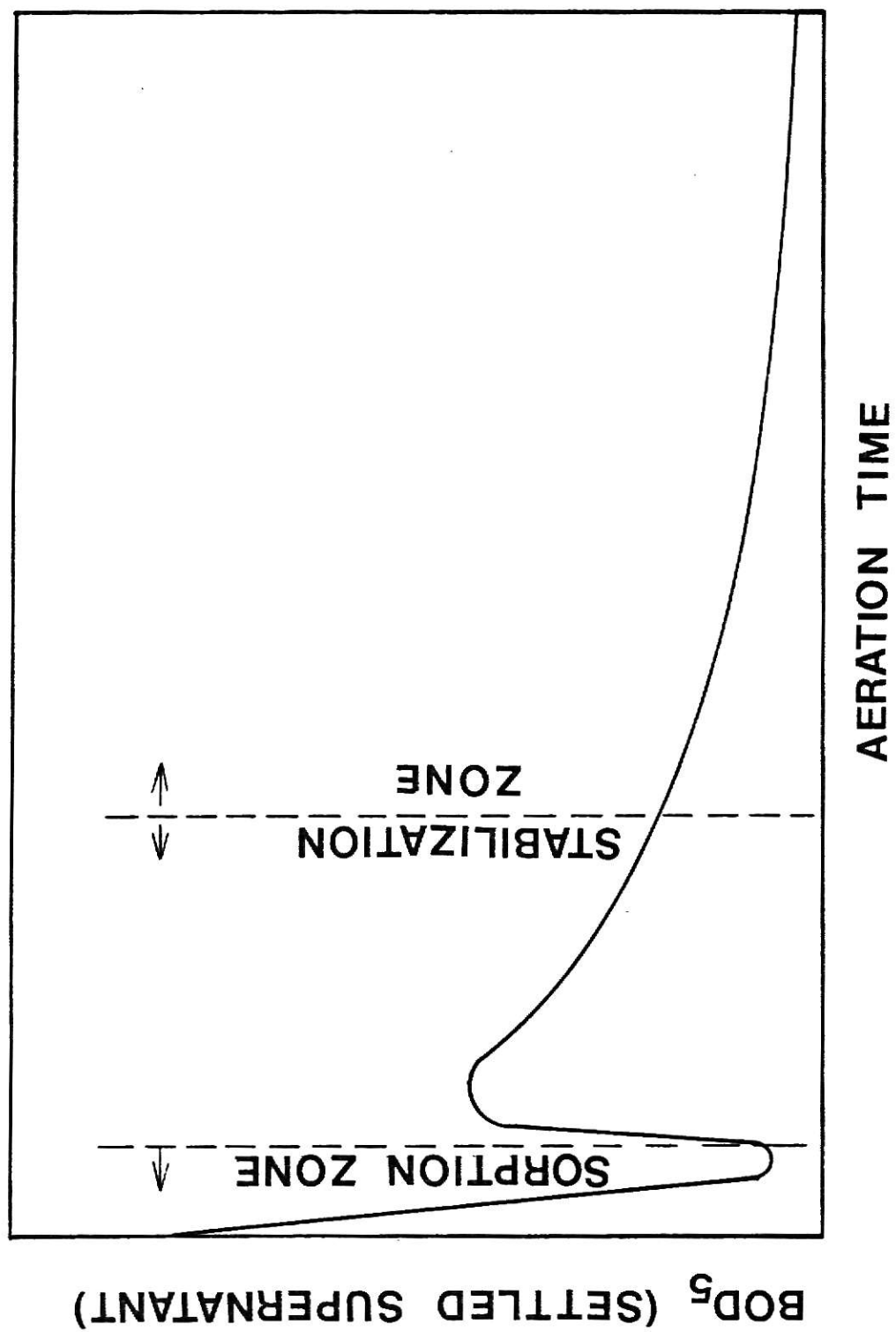


Figure 2. BOD_5 Removal in Contact Stabilization Process

reaction was a function of the nature of the particulate material, the mixing velocity, and the concentration of biological solids in the flocculant form. Although the removal rate was not determined, it appeared to increase with the percentage of particulate BOD_5 in the wastewater.

The advantages of the contact stabilization process over that of the conventional activated sludge were reported by Grich (17):

- 1) Separating the adsorption and oxidation processes that occur in the same unit in conventional practice into different units affords greater flexibility in the control of the process, because each is then independently controlled.
- 2) The need for reduced aeration time results in smaller tank capacities, less aera, and lower capital expenditure.
- 3) It is more capable of handling shock loadings by virtue of the reservoir of sludge contained in the sludge reaeration unit. In conventional practice a shock load is introduced into the entire contents of sludge under aeration. In the contact stabilization process, however, the effects of this shock load are only felt in the aerator, which is consistently being fed by a supply of non-affected sludge from the reaeration unit.

However, the last advantage was disclaimed by Thirumurthi (18). He compared the contact stabilization process with the high rate activated sludge process and concluded that the contact stabilization process has a lower potential to absorb the fluctuating hydraulic and organic loads.

Until recently, there have been few attempts to mathematically describe these mechanisms and their kinetics in the contact stabilization

process. Jatko (8), based on a combination of the single reactor models of McKinney, Eckenfelder and Lawrence, developed a mathematical model of the contact stabilization process.

JATKO'S MODEL (8)

The model was based on the following assumptions:

1. There are no microbial solids in the raw wastewater.
2. No microbial activity takes place in the final clarifier.
3. Complete mix conditions exist in both the contact and reaeration tanks.
4. Steady state conditions exist throughout the system.
5. The rate of removal of total and soluble substrate follows first order reaction kinetics.
6. The soluble substrate in the raw wastewater that is removed during the contact period is also metabolized during that period. All of the particulate substrate in the raw wastewater is removed during the contact period but is metabolized during the reaeration period.
7. The effect of metabolism of the exogenous substrate entering the reaeration tank is negligible relative to the effects of the sorbed and endogenous substrates.
8. The cell yield and endogenous decay coefficients for soluble and particulate substrate are equal.

Material Balance and Design Equations

The design equations were developed from mass balances for substrate and microbial solids performed around the contact and reaeration tanks. The notation is indicated and defined in Appendix I.

A mass balance for the net rate of change in substrate around the contact tank yields the following expression:

$$\left[\begin{array}{c} \text{Rate of} \\ \text{change in} \\ \text{substrate} \\ \text{mass in} \\ \text{contact} \\ \text{tank} \end{array} \right] = \left[\begin{array}{c} \text{Substrate} \\ \text{in raw} \\ \text{waste-} \\ \text{water} \end{array} \right] + \left[\begin{array}{c} \text{Substrate} \\ \text{in reaer-} \\ \text{ation} \\ \text{tank} \\ \text{recycle} \end{array} \right] - \left[\begin{array}{c} \text{Total} \\ \text{substrate} \\ \text{removed} \\ \text{in} \\ \text{contact} \end{array} \right] - \left[\begin{array}{c} \text{Substrate} \\ \text{lost} \\ \text{in} \\ \text{effluent} \end{array} \right]$$

or

$$\left(\frac{dS}{dt} \right) V_C = QS_o + QRS_e - \left(\frac{dS}{dt} \right)_t V_C - (1 + R)QS_e \quad (1)$$

At steady state conditions equation (1) can be rewritten for first order substrate removal kinetics as:

$$0 = QS_o + QRS_e - K_t X_C S_e V_C - QS_e - QRS_e \quad (2)$$

Since $V_C/Q = t_C$, equation (2) can be rearranged after substitution to yield the total effluent substrate concentration.

$$S_e = \frac{S_o}{K_t X_C t_C + 1} \quad (3)$$

Term S_e includes only the soluble and particulate substrates not removed from the raw wastewater. Since all of the influent particulate substrate is removed during the contact phase, S_e represents the soluble substrate concentration in the effluent from the final clarifier. Any additional oxygen demand exerted by the carry over of microbial solids from the clarifier must be added to the demand exerted by the remaining substrate, that is,

$$(S_e)_T = S_e + f(X_e) \quad (4)$$

$$(S_e)_T = (S_e)_p + (S_e)_s + f(X_e) \quad (4a)$$

$$(S_e)_T = (S_e)_s + f(X_e) \quad (4b)$$

A mass balance for the net rate of change in microbial solids around the reaeration tank yields the following expression:

$$\left[\begin{array}{c} \text{Rate of change} \\ \text{in microbial} \\ \text{mass in re-} \\ \text{aeration tank} \end{array} \right] = \left[\begin{array}{c} \text{Microbial mass} \\ \text{in influent} \\ \text{to reaeration} \\ \text{tank} \end{array} \right] + \left[\begin{array}{c} \text{Growth from} \\ \text{metabolism} \\ \text{of particulate} \\ \text{substrate} \end{array} \right] - \left[\begin{array}{c} \text{Microbial} \\ \text{mass lost in} \\ \text{effluent from} \\ \text{reaeration tank} \end{array} \right]$$

or

$$\left(\frac{dX}{dt} \right) V_R = RQX_U + \left[Y \left(\frac{dS}{dt} \right)_p - k_d X_R \right] V_R - RQX_R \quad (5)$$

Equation (5) can be written for a finite time period as

$$\left(\frac{\Delta X}{\Delta t} \right) V_R = RQX_U + \left[Y \left(\frac{\Delta S}{\Delta t} \right)_p - k_d X_R \right] V_R - RQX_R \quad (6)$$

The term $\left(\frac{\Delta S}{\Delta t} \right)_p$ represents the rate of metabolism of the particulate substrate removed during the contact period. This can be expressed as:

$$\left(\frac{\Delta S}{\Delta t} \right)_p = \frac{(S_o)_p - (S_e)_p}{t_R} \quad (7)$$

Since $(S_e)_p = 0$, equation (7) becomes

$$\left(\frac{\Delta S}{\Delta t} \right)_p = \frac{(S_o)_p}{t_R} \quad (7a)$$

and the materials balance can be rewritten for steady state and first order substrate removal conditions as

$$0 = RQX_U + Y \left[\frac{(S_o)_p}{t_R} \right] V_R - k_d X_R V_R - RQX_R \quad (8)$$

Solving for the reaeration tank volume yields:

$$V_R = \frac{RQ[X_U - X_R + Y(S_o)_p]}{k_d X_R} \quad (9)$$

Alternatively, equation (9) can be rearranged after appropriate substitutions to determine the mixed liquor solids concentration in the reaeration tank.

$$X_R = \frac{X_U + Y(S_o)_p}{k_d t_R + 1} \text{-----} (10)$$

A mass balance for the net rate of change in microbial solids around the contact tank yields the following expression:

$$\left[\begin{array}{c} \text{Rate of change} \\ \text{in microbial} \\ \text{mass in} \\ \text{contact tank} \end{array} \right] = \left[\begin{array}{c} \text{Microbial mass} \\ \text{in recycle from} \\ \text{reaeration tank} \end{array} \right] + \left[\begin{array}{c} \text{Growth from} \\ \text{metabolism of} \\ \text{soluble} \\ \text{substrate} \end{array} \right] - \left[\begin{array}{c} \text{Microbial} \\ \text{mass lost in} \\ \text{effluent from} \\ \text{contact tank} \end{array} \right]$$

or

$$\left(\frac{dX}{dt} \right) V_C = RQX_R + \left[Y \left(\frac{dS}{dt} \right)_s - k_d X_C \right] V_C - (1 + R)QX_C \text{-----} (11)$$

Equation (11) can be written for first order substrate removal and steady state conditions as

$$0 = RQX_R + YK_s X_C (S_e)_s V_C - k_d X_C V_C - QX_C - RQX_C \text{-----} (12)$$

Substituting $S_e = (S_e)_s$, equation (12) can be solved for the volumetric recycle ratio.

$$R = \frac{(k_d V_C + Q - YK_s S_e V_C) X_C}{Q(X_R - X_C)} \text{-----} (13)$$

The mean cell residence time (MCRT) or sludge age, θ_c , has been defined as (5)

$$\theta_c = \frac{\text{Total microbial mass under aeration}}{\text{Total microbial mass withdrawn daily}}$$

The daily loss of microbial solids includes solids lost intentionally through sludge wasting and those lost unintentionally by carry over from

the final clarifier. The sludge age can thus be calculated from equation (14).

$$\theta_c = \frac{X_C V_C + X_R V_R}{(Q - Q_W) X_e + Q_W X_U} \quad (14)$$

Rearranging equation (14) and solving for the sludge wasting rate yields

$$Q_W = \frac{X_C V_C + X_R V_R - Q X_e \theta_c}{(X_U - X_e) \theta_c} \quad (15)$$

If the microbial solids lost in the effluent are small relative to the underflow solids concentration then equation (15) can be reduced to

$$Q_W = \frac{X_C V_C + X_R V_R}{\theta_c X_U} \quad (15a)$$

The oxygen uptake rate in each tank is a function of the substrate removed and the cell mass synthesized. The general expression for the oxygen utilization rate is

$$N_{O_2} = \left(\frac{dS}{dt} \right)_L - 1.4 \left(\frac{dX}{dt} \right) \quad (16)$$

For the contact tank, equation (16) can be expressed as

$$(N_{O_2})_C = \left[\frac{(S_o)_s - (S_e)_s}{t_C} \right] - 1.4 \left\{ \frac{Y[(S_o)_s - (S_e)_s]}{t_C} - k_d X_C \right\} \quad (17)$$

and for the reaeration tank it is

$$(N_{O_2})_R = \left[\frac{(S_o)_p}{t_R} \right] - 1.4 \left[\frac{Y(S_o)_p}{t_R} - k_d X_R \right] \quad (18)$$

where the substrate concentrations are expressed as their ultimate oxygen demand. Table I summarizes the design relationships.

TABLE I.
SUMMARY OF DESIGN RELATIONSHIPS

Design Characteristic	Design Equation
Effluent Substrate Concentration (neglects oxygen demand of microbial solids) - mg/l	$S_e = \frac{S_o}{K_t X_C t_C + 1} \text{-----} (3)$
Volume of Reaeration Tank - gal	$V_R = \frac{RQ[X_U - X_R + Y(S_o)_P]}{k_d X_R} \text{-----} (9)$
Microbial Solids Concentration in Reaeration Tank - mg/l	$X_R = \frac{X_U + Y(S_o)_P}{k_d t_R + 1} \text{-----} (10)$
Sludge Recycle Ratio	$R = \frac{(k_d V_C + Q - YK_s S_e V_C)X_C}{Q(X_R - X_C)} \text{-----} (13)$
Sludge Age or MCRT - days	$\theta_c = \frac{X_C V_C + X_R V_R}{(Q - Q_W)X_e + Q_W X_U} \text{-----} (14)$
Sludge Wasting Rate - gpd	$Q_W = \frac{X_C V_C + X_R V_R - QX_e \theta_c}{(X_U - X_e) \theta_c} \text{-----} (15)$
Oxygen Utilization Rate in Contact Tank - mg/l-hr	$(N_{O_2})_C = \frac{(S_o)_s - (S_e)_s}{t_C}$ $- 1.4 \left\{ \frac{Y[(S_o)_s - (S_e)_s]}{t_C} - k_d X_C \right\} \text{---} (17)$
Oxygen Utilization Rate in Reaeration Tank mg/l-hr	$(N_{O_2})_R = \left[\frac{(S_o)_P}{t_R} \right] - 1.4 \left[\frac{Y(S_o)_P}{t_R} - k_d X_R \right] \text{---} (18)$

EVALUATION

Application of the mathematical model described requires knowledge of the following kinetic coefficients: K_t , K_S , Y and k_d . These terms can be evaluated in bench scale, complete mixed activated sludge reactors (19). Extensive data were collected and analyzed and the necessary kinetic coefficients calculated. Using these determined kinetic coefficients and the model, a treatment process for a typical wastewater was designed. The design characteristics, such tankage and oxygen requirements, recycle ratios, hydraulic detention times, etc., were then compared to those of existing treatment plants that are known to be effective. Similarity of design characteristics would suggest that the design formulae are reasonable.

It should be also noted that total and soluble substrate removal rate constants can be evaluated if the influent soluble BOD_5 is measured in addition to the conventional operating parameters. It is not necessary, therefore, to operate a separate series of reactors using only the soluble portion of the wastewater as a feed source. A single activated sludge reactor was used in this study.

PROCEDURES

ANALYTICAL PROCEDURES AND EQUIPMENT

Biochemical Oxygen Demand

Five-day biochemical oxygen demand (BOD_5) determinations were run on synthetic wastes and daily composite final effluents primarily according to the methods listed in Standard Methods (20). The amount of sample added to the 300-ml BOD bottle must be determined. To make this calculation, one should understand that dilution water at room temperature contains approximately 8 mg/l of DO. Consequently, if the oxygen demand of the sample to be tested is greater than 8 mg/l, dilution has to be made. It is desirable to have at least 2 mg/l of initial oxygen left unused after 5-day incubation at 20°C. Depletion of 50 percent is most desirable. In this test, 3, 6 and 200 ml of samples were used to get the desired total and soluble synthetic wastes and soluble final effluents respectively.

Three 300-ml BOD bottles were filled half full with dilution water. Then, using a large-tipped volumetric pipet, the desired amount of sample was placed into the three 300-ml BOD bottles. Each bottle was filled with straight dilution water and the stoppers were inserted. Two bottles with the diluted sample and two with the dilution water were incubated in Precision Scientific Model 815 Incubator for 5 days at 20°C. A dissolved oxygen determination on both remaining bottles was run and was recorded. Dissolved oxygen was measured by Yellow Springs Model 51A Oxygen Meter.

The tests to determine soluble BOD_5 , were performed on synthetic waste filtered on 47 mm, 0.45 millipore membrane filter. Final effluent

was filtered in 11 cm Whatman no. 40 filter paper. Filter papers were supported in buchner funnels and thoroughly washed with distilled water. Vacuum was provided by an aspirator.

The tests run on synthetic waste were seeded by using 1-2 ml of final effluent per liter of dilution water. Dilution water was prepared according to Standard Methods (20) and aerated with laboratory compressed air and porous diffuse stones for 24 hours and thus assumed to be saturated with dissolved oxygen.

Chemical Oxygen Demand

Chemical oxygen demand (COD) determinations were run as described in Standard Methods (20) for ten milliliter samples, using 0.25 N standard potassium dichromate solution and 0.10 N standard ferrous ammonium sulfate titrant. Tests were run on synthetic wastes to determine the biodegradability of the waste. The same sample has to be used for BOD₅ and COD test.

The equipment consisted of 250 ml erlenmyer flasks with ground-glass 24/40 necks, 300 mm Pyrex condensers with 24/40 ground-glass joints, and a Lindberg Hevi-Duty Type H-5 Heater.

Mixed Liquor (Volatile) Suspended Solids

Mixed liquor suspended solids (MLSS) were determined by Millipore Filter Technique as described in Standard Methods (20). Whatman 934 AH, 4.25 cm glass fiber filter papers were placed in aluminum dishes and then dried in a Matheson Scientific Oven at 103°C for at least 2 hours. The filters and dishes were removed from the oven and placed in dessicators, cooled to room temperature, and weighed on a Mettler Type H6 Analytical Balance. After weighing, the filters were placed on the ground-glass

filter holder. Using a volumetric pipet, the sample (25 mL) was centrifuged and then was added to the filter and the vacuum was applied. Upon completion of the filtration, the filters were placed back in the dishes and dried in the oven at 103°C again for one hour. The cooling and weighing procedure was followed as above.

If mixed liquor volatile suspended solids (MLVSS) was to be determined, it is required to utilize porcelain crucibles instead of aluminum dishes. Following the second weighing, the crucibles, ashless filter papers, and dried solids were placed in a Thermolyne Model F-A1730 Muffle Furnace and burned at 550°C for fifteen minutes. The crucibles and ashes were then cooled to room temperature, first in air and then in desiccators, and weighed using the Mettler Balance. Initial weights were determined on the crucibles while the sample was being filtered.

Sludge Volume Index

The sludge volume index (SVI) is defined as the volume in mL occupied by 1 g of activated sludge after settling for 30 min. The determinations were obtained as described in Standard Methods (20). By allowing a well-mixed liquor sample to settle 1,000 mL graduated cylinder (with graduation lines 10 mL apart) for 30 min. At the end of 30 min. recorded the volume occupied by the sludge to nearest 5 mL. The calculation was as follows:

$$SVI = \frac{\text{mL of settled sludge in 30 min.} \times 1,000}{\text{mg/L of suspended solids in mixed liquor}}$$

pH

The pH determinations were obtained using a Corning Scientific Model 10 pH Meter. Tests were run on synthetic wastes, final effluents and mixed liquor suspended solids.

Dissolved Oxygen (DO)

Dissolved oxygen measurements in the pilot plant aeration tank were obtained using a Yellow Springs Model 57 Oxygen Meter. The DO probe was immersed in the mixed liquor and recorded. If the DO in the aeration tank was less than 2 mg/l, the compressed air flow rate was adjusted to maintain DO at 2 mg/l.

DO determinations for the BOD₅ examinations were run using a Yellow Spring Model 51A Oxygen Meter. The results were occasionally checked with the azide modification of the basic Winkler method as described in Standard Methods (20).

EXPERIMENTAL PROCEDURES

Activated Sludge Reactor

To evaluate the kinetic coefficients in the model advocated by Jatko (8), two completely mixed activated sludge reactors were operated concurrently with two different sludge ages. Each reactor was designed for a flow rate of 14.8 litres per day. The photograph of the activated sludge reactor and the experiment system are shown in Figure 3 and 4. The flow diagram of the reactor is shown in Figure 5.

The reactor was rectangular in shape having the dimensions 30x15x29 cm and was filled to the 23 cm depth. This gave a volume of the reactor 9.8 litres. It was divided into two sections by an adjustable baffle. The first section was used for the aeration basin having a volume of 6.9 litres and giving a detention time of 11 hours. The second part was used for the settling basin having a volume of 2.9 litres. The aeration basin was aerated using laboratory compressed air and three porous diffuser stones. The diffusers were located about 2 cm from the bottom and spaced equally

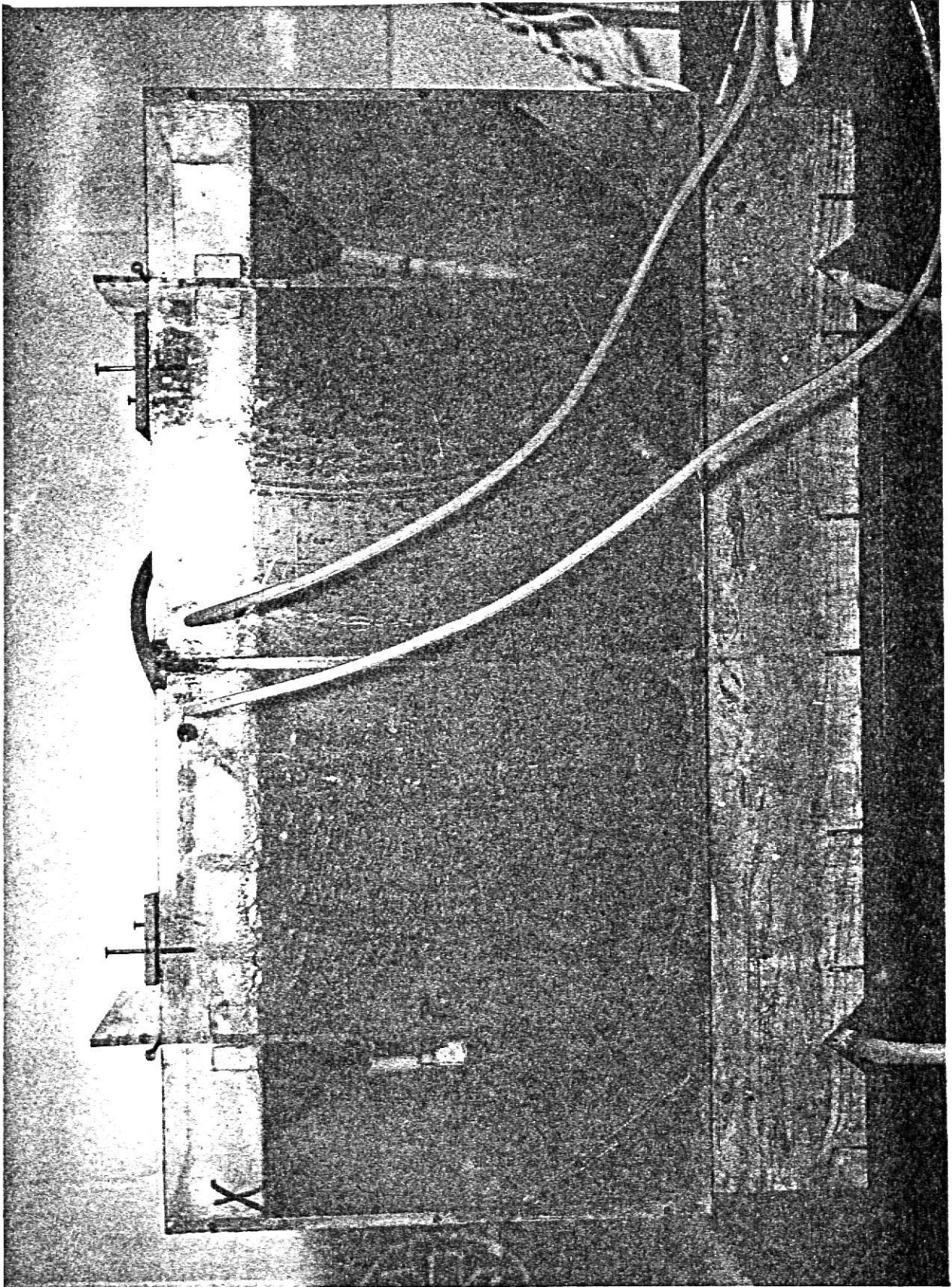


Figure 3. Photograph of the Activated Sludge Reactor

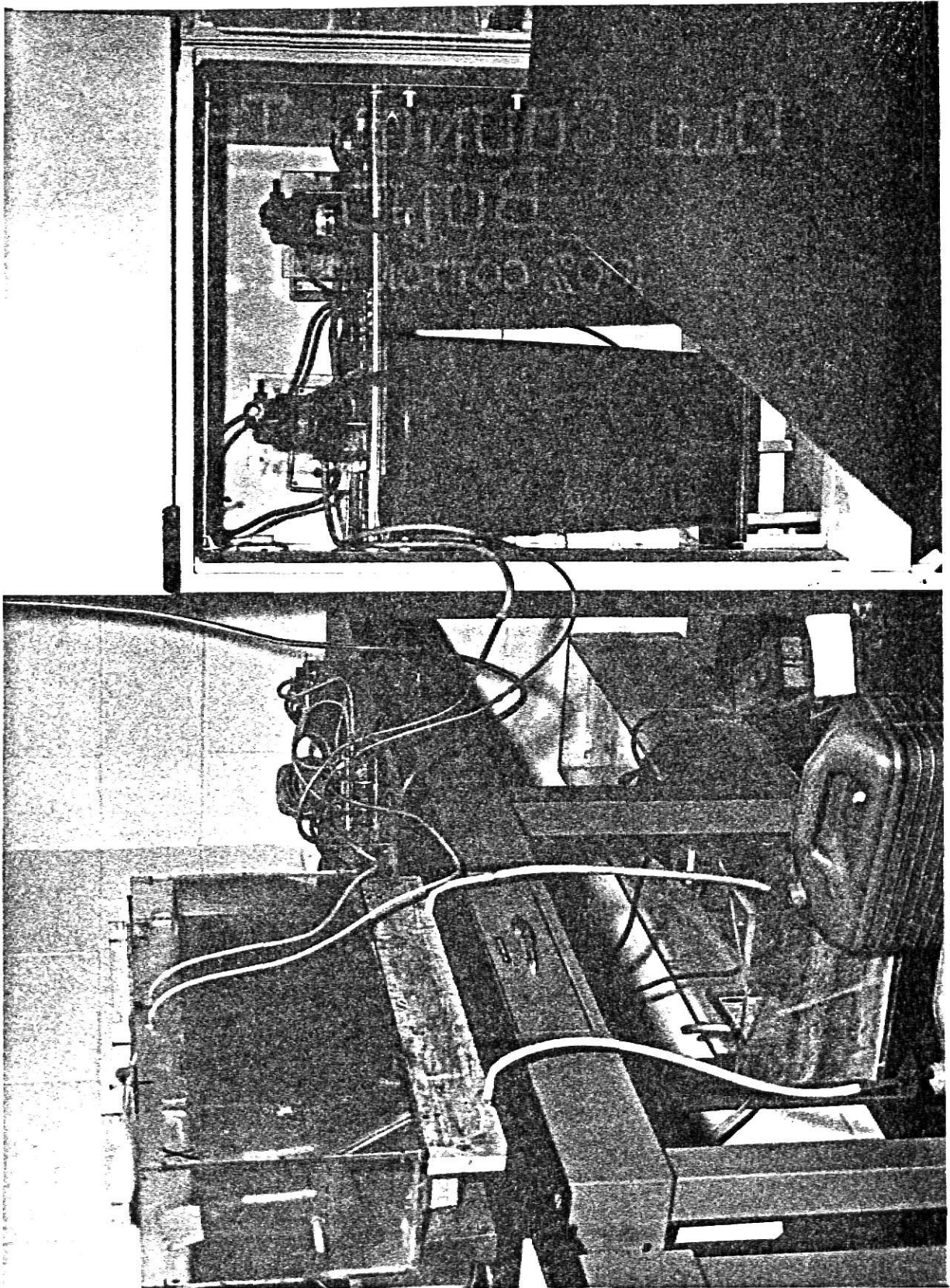


Figure 4. Photograph of the Experimental Activated Sludge System

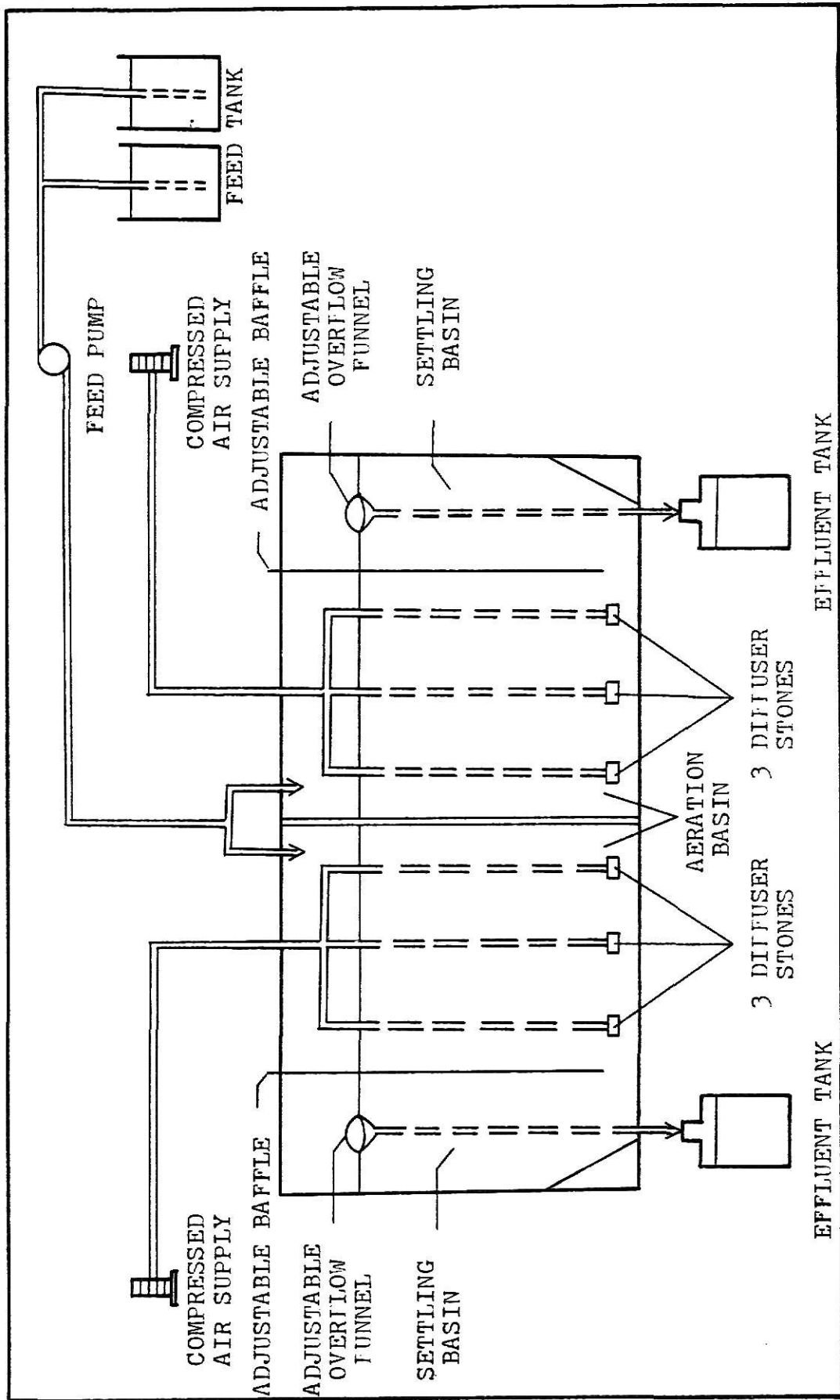


Figure 5. Flow Diagram of the Activated Sludge Reactor, Internal Cell Recycle

along the 20 cm side wall of the basin. An adjustable overflow funnel was placed in the settling basin and effluents were collected by a gravity flow to a 5-gallon effluent tank.

The synthetic waste used for this study was made of starch, peptone, skim milk and dog food. The stock solution and its characteristics is shown listed in Table II. Stock solution was prepared every two days and stored in a refrigerated tank in which the temperature was maintained at 4 to 6°C. Mixing was accomplished by a propeller. Influent waste was pumped by a feed pump with a controlling timer at 14.8 litres per day.

Test Procedures

The substrate removal rate constants, K_t and K_s , the sludge yield coefficient Y , and the endogenous decay coefficient k_d , were evaluated using acclimated sludge operated over a working range of sludge age values. For this study, five different specific sludge ages (4, 6, 8, 12 and 16 days) were used. Operation at any specific sludge age was continued until a steady state condition existed for the mixed liquor volatile suspended solids and effluent BOD_5 concentrations. The following procedure was used (19):

1. An acclimated culture of microorganisms was obtained by feeding the synthetic waste for a period of one month to microorganisms (or sludge) obtained from Manhattan Sewage Treatment Plant.

2. Each reactor was filled with the acclimated sludge at the pre-determined volume to have an initial desired VSS concentration.

3. The air was turned on and the reactor contents were completely mixed. The air was not be metered, but it was controlled in:

- (a) The air flow rate was not excessive to the point of breaking the biological floc or causing undue turbulence.

TABLE II.
STOCK SOLUTION AND ITS CHARACTERISTICS
USED FOR THIS STUDY

Constituent	Amount Used
Starch	2.1 gm
Peptone	4.1 gm
Skim Milk	4.1 gm
Nutrient Broth	2.6 gm
Ammonium Sulfate $[(\text{NH}_4)_2\text{SO}_4]$	3.8 gm
Potassium Chloride (KCL)	69 mg
Calcium Chloride $(\text{CaCl}_2 \cdot 2\text{H}_2\text{O})$	91 mg
Magnesium Sulfate (MgSO_4)	51 mg
Ferrous Sulfate $(\text{FeSO}_4 \cdot 7\text{H}_2\text{O})$	94 mg
Sodium Phosphate Dibasic $(\text{Na}_2\text{HPO}_4)$	17.6 gm
Sodium Carbonate (Na_2CO_3)	+
Dog Food	9.4 gm
Tap Water	30 l

+ Varied to maintain neutral pH.

Total $\text{BOD}_5 = 367 \text{ mg/l}$

Soluble $\text{BOD}_5 = 256 \text{ mg/l}$

Solubility Index $\text{SI}_o = 70\%$

Total COD = 680 mg/l

Soluble COD = 451 mg/l

- (b) The air flow was sufficient to provide a dissolved oxygen concentration of not less than 2 mg/l in the aeration basin.

4. The sliding baffle was adjusted to provide a 1-2 cm slot opening at the bottom. Subsequent baffle adjustment was made as desired according to the sludge blanket height in the settling zone and the sludge interchange rate between the aeration and settling basins.

5. The feed pump was started at a flow rate of 14.8 litres per day.

6. Continuous flow-through systems were maintained until steady-state condition existed. This was assumed once the VSS of the aeration basin and the BOD_5 of the effluent were stabilized. One or two weeks were required before this occurred. The VSS of the aeration basin were measured daily. (The effluent tube was plugged, the baffle was pulled, and the VSS of the completely mixed contents was measured. Once the sample had been withdrawn, the baffle was reinserted, the effluent tube was unplugged and operations were resumed.) A constant level of VSS was maintained by wasting solids daily buildup. The amount of wasting solids is listed in Table III. After wasting the required amount of solids, the same amount of distilled water was refilled.

7. Once steady state condition was achieved, the analytical and sampling schedule was established and is shown in Table IV. This schedule was continued for two weeks, or until such time as consistent results were obtained.

8. The sludge age was changed and the procedure 6 and 7 was repeated.

The laboratory glassware and the sample bottles were cleaned in hot detergent water and rinsed completely in hot tap water, and again rinsed two or three times with distilled water. The glassware was also cleaned in chromic acid solution as necessary. All pipets were cleaned in chromic

TABLE III
THE AMOUNT OF SOLIDS TO BE WASTED
AT DIFFERENT SLUDGE AGES

Sludge Age (days)	Waste Volume (%)	Waste Volume (litres)
4	25.0	2.45
6	16.7	1.63
8	12.5	1.23
12	8.3	0.82
16	6.3	0.61

1. The volume of the reactor is 9.8 litres.
2. The microbial solids lost in the effluent are negligible.

TABLE IV
ANALYTICAL AND SAMPLING SCHEDULE

Analysis	Frequency	Inflow ¹ Waste	Mixed ² Liquor	Effluent ³
BOD ₅ , mg/l (filtered and unfiltered samples)	3/week daily	X		X
SS, VSS, mg/l	daily		X	
Dissolved Oxygen, mg/l	daily		X	
pH	daily	X	X	X
SVI	3/week		X	

1. Sample to be withdrawn from influent feed line.
2. Sample to be withdrawn from the unbaffled reactor.
3. Sample to be withdrawn from effluent tank.

acid solution and rinsed completely with cold tap water, and again rinsed two or three times with distilled water. Standard chemical solutions were made up as specified in Standard Methods (20). The room temperature was controlled at $20 \pm 2^{\circ}\text{C}$.

RESULTS AND DISCUSSION

In a completely mixed system, the soluble substrate in the effluent is approximately equal to that in the aeration tank, and a material balance under steady state conditions can be developed (19):

$$QS_o - Q(S_e)_s = \left(\frac{dS}{dt}\right)V \quad (19)$$

where

Q = volumetric flow rate of raw wastewater

V = tank volume

S_o = total substrate concentration in raw wastewater

$(S_e)_s$ = concentration of soluble substrate remaining in effluent

t = hydraulic residence time in aeration tank

$\frac{dS}{dt}$ is a function of the substrate remaining according to first-order removal kinetics:

$$\frac{dS}{dt} = K X (S_e)_s \quad (20)$$

the following relationship results:

$$\frac{S_o - (S_e)_s}{X t} = K (S_e)_s \quad (21)$$

where

K = removal rate (first-order reaction kinetics)

X = average MLVSS in aeration tank.

With the relationship described above, the measurement of the influent total and soluble substrate concentrations for the whole waste will provide the necessary kinetic data. The total and soluble substrate removal rate coefficients, K_t , K_s were evaluated from the following linear relationships:

$$q_t = \frac{(S_o)_s - (S_e)_s}{Xt} = K_t (S_e)_s - y \text{ ----- (22)}$$

$$q_s = \frac{(S_o)_s - (S_e)_s}{Xt} = K_s (S_e)_s - y \text{ ----- (23)}$$

where

q_t = specific total substrate utilization rate

q_s = specific soluble substrate utilization rate

y = non-biodegradable BOD_5

The cell yield coefficient, Y , and the endogenous decay coefficient, k_d , were evaluated from an empirical relationship between microbial growth and substrate removal in a biological system (21)

$$\frac{dX}{dt} = Y \left(\frac{dS}{dt} \right) - k_d X \text{ ----- (24)}$$

On a finite basis, this equation can be redefined as a linear relationship.

$$\frac{\Delta X}{\Delta t} = Y \left(\frac{\Delta S}{\Delta t} \right) - k_d X \text{ ----- (25)}$$

or

$$\frac{\Delta X / \Delta t}{X} = Y \left(\frac{\Delta S / \Delta t}{X} \right) - k_d \text{ ----- (26)}$$

or

$$\mu = \frac{1}{\theta_c} = Y q_t - k_d \text{ ----- (27)}$$

where

$\frac{dX}{dt}$ = net microbial growth

$\frac{dS}{dt}$ = substrate utilization rate

μ = specific growth rate

θ_c = mean cell residence time of sludge age

With these linear relationships described above, the required kinetic coefficients were evaluated from the activated sludge reactor operation data which were listed in Appendix II - Table VIII. The calculations of values for evaluation of these kinetic coefficients were listed in Tables V, VI, and VII, respectively. The results were plotted in Figures 6, 7 and 8.

Linear regression analysis of the data shown in Figures 6 and 7 indicated that $K_t = 0.12$ and $K_s = 0.082$ l/mg-day on a BOD_5 basis. The correlation coefficients for these two groups of data were 0.94. Again the linear regression analysis of the data shown in Figure 8 indicated that $Y = 0.48$ mgVSS/mg BOD_5 and $k_d = 0.051$ /day. The results are closely to the reports by Pearson (22). The correlation coefficient of the values of Y and k_d was 0.98. The details of statistical analysis were listed in Appendix II - Tables IX, X and XI. These determined kinetic coefficients were then used in the following design example.

TABLE V
CALCULATION OF VALUES FOR EVALUATION OF K_t

θ_c (days)	S_o (mg/l)	$(S_e)_s$ (mg/l)	$X(VSS)$ (mg/l)	t (days)	$q_t = \frac{S_o - (S_e)_s}{Xt}$ (day ⁻¹)	F/M $\frac{1bBOD_5/day}{(1bMLVSS)}$
4	367	4.8	1,200	0.466	0.648	0.46
6	367	3.8	1,940	0.466	0.402	0.29
8	367	3.0	2,233	0.466	0.350	0.25
12	367	2.4	2,550	0.466	0.307	0.22
16	367	1.7	3,010	0.466	0.260	0.18

TABLE VI
CALCULATION OF VALUES FOR EVALUATION OF K_s

θ_c (days)	$(S_o)_s$ (mg/l)	$(S_e)_s$ (mg/l)	$X(VSS)$ (mg/l)	t (days)	$q_s = \frac{(S_o)_s - (S_e)_s}{Xt}$ (day ⁻¹)	F/M $\frac{1bBOD_5/day}{(1bMLVSS)}$
4	256	4.8	1,200	0.466	0.449	0.46
6	256	3.8	1,940	0.466	0.279	0.29
8	256	3.0	2,233	0.466	0.243	0.25
12	256	2.4	2,550	0.466	0.213	0.22
16	256	1.7	3,010	0.466	0.181	0.18

TABLE VII
CALCULATION OF VALUES FOR EVALUATION OF Y AND k_d

θ_c	S_o	$(S_e)_s$	X(VSS)	t	$q_t = \frac{S_o - (S_e)_s}{Xt}$	$1/\theta_c$
(days)	(mg/l)	(mg/l)	(mg/l)	(days)	(day ⁻¹)	(day ⁻¹)
4	367	4.8	1,200	0.466	0.648	0.250
6	367	3.8	1,940	0.466	0.402	0.167
8	367	3.0	2,233	0.466	0.350	0.125
12	367	2.4	2,550	0.466	0.307	0.083
16	367	1.7	3,010	0.466	0.260	0.063

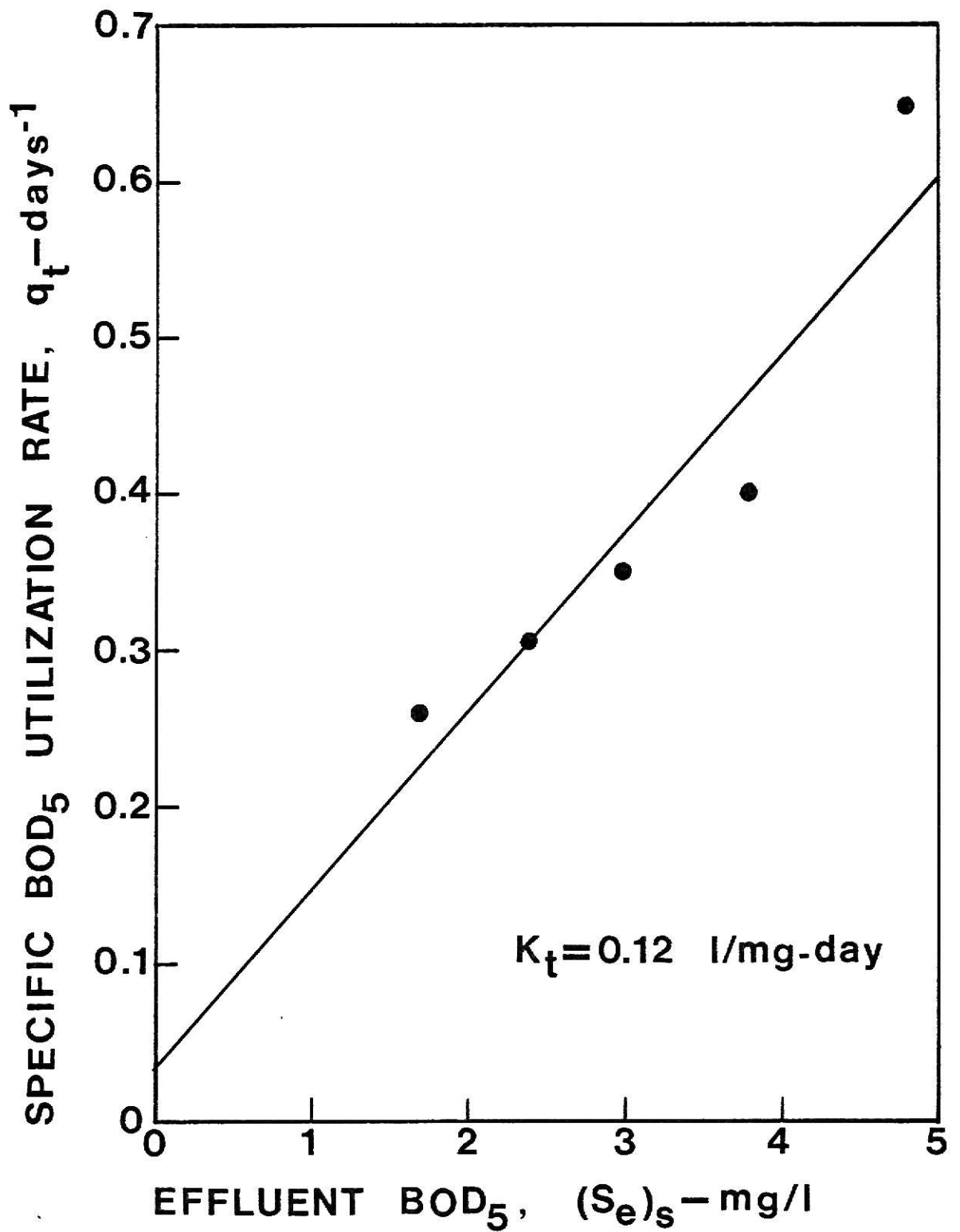


Figure 6. Specific Total BOD₅ Utilization Rate Versus Effluent Soluble BOD₅

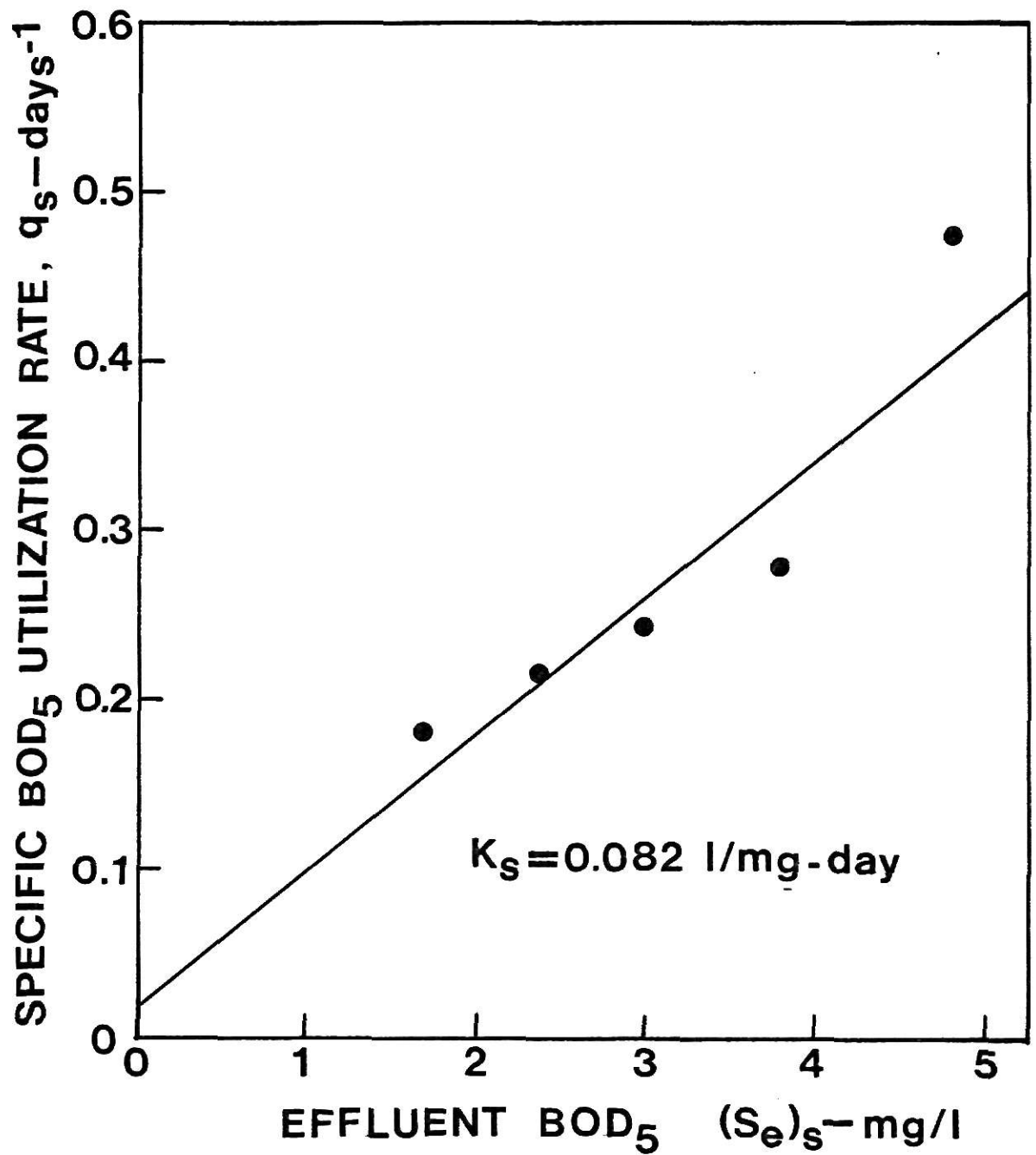


Figure 7. Specific Soluble BOD₅ Utilization Rate Versus Effluent Soluble BOD₅

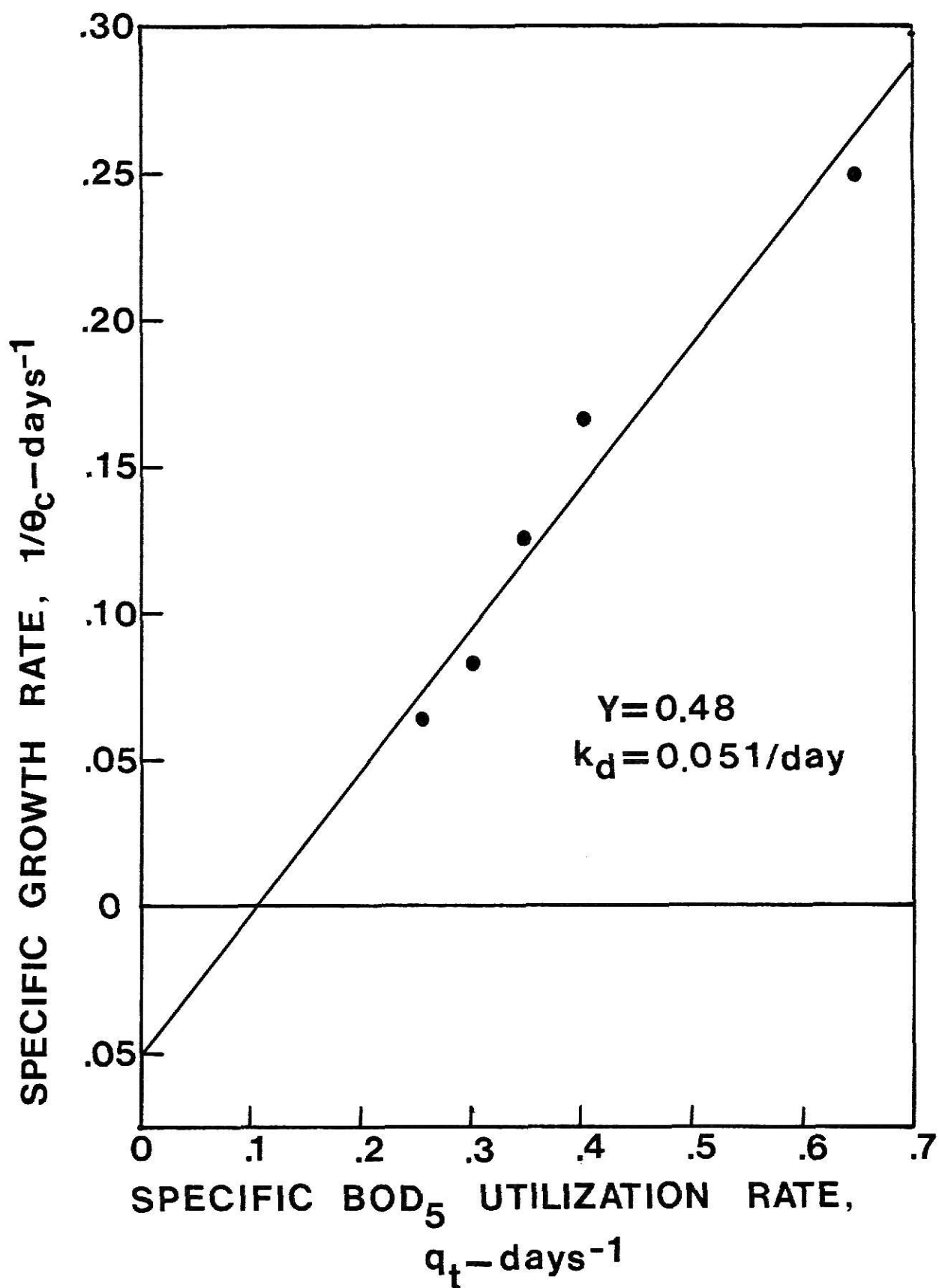


Figure 8. Specific Growth Rate Versus Specific Total BOD₅ Utilization Rate

DESIGN EXAMPLE

Wastewater Characteristics

$$S_o = 367 \text{ mg BOD}_5/\ell$$

$$(S_o)_s = 256 \text{ mg BOD}_5/\ell$$

$$(S_o)_p = 111 \text{ mg BOD}_5/\ell$$

$$\text{BOD}_5/\text{BOD}_u = 0.68$$

$$Q = 5.0 \text{ mgd}$$

Nutrients for biological growth are adequate.

Kinetic Coefficients

$$Y = 0.48 \text{ mg VSS/mg BOD}_5$$

$$k_d = 0.051/\text{day}$$

$$K_t = 0.12 \text{ } \ell/\text{mg VSS-day}$$

$$K_s = 0.082 \text{ } \ell/\text{mg VSS-day}$$

Design Parameters

$$(S_e)_T = 32 \text{ mg BOD}_5/\ell$$

$$X_C = 3,000 \text{ mg VSS}/\ell$$

$$t_R = 5 \text{ hr}$$

$$X_e = 20 \text{ mg VSS}/\ell \text{ (65\% are biodegradable)}$$

$$\theta_c = 10 \text{ days}$$

$$(\text{SVI})_C = 150 \text{ ml/gm VSS}$$

$$\text{Temperature} = 20^\circ\text{C}$$

Hydraulic regime of reactor = complete mix.

[Data were taken from the recommendations by Metcalf and Eddy (23)]

1. Estimate the soluble BOD_5 in the effluent

Effluent Total BOD_5 = Influent soluble BOD_5 escaping treatment +
 BOD_5 of effluent biological solids

$$32 = (S_e)_s + 20(0.65)(1.4)(0.68)$$

$$(S_e)_s = 20 \text{ mg/l soluble } BOD_5$$

This would mean that the biological treatment efficiency based on soluble BOD_5 would be

$$E_s = \frac{367 - 20}{367} (100) = 94.6\%$$

The overall plant efficiency would be

$$E_{\text{overall}} = \frac{367 - 32}{367} (100) = 91.3\%$$

2. Determine the contact tank hydraulic residence time, t_c , by rearranging equation (3) to yield

$$t_c = \frac{S_o - (S_e)_s}{K_t (S_e)_s X_C} = \frac{367 - 20}{(0.12)(20)(3,000)} = 0.0482 \text{ days}$$

$$= 1.16 \text{ hr} = 69 \text{ min.}$$

Volume of the contact tank

$$V_C = (t_c)Q = (0.0482)(5.0)(10^6) = 241,000 \text{ gal}$$

3. Determine the mixed liquor solids concentration in the reaeration tank from equation (10).

$$X_R = \frac{X_U + Y(S_o)_p}{k_d t_R + 1}$$

The value of X_U can be approximated from operational data by the expression

$$X_U = \frac{10^6}{(SVI)_C}$$

From settling test, $(SVI)_C = 150 \text{ ml/gm VSS}$

$$X_U = \frac{10^6}{150} = 6,667 \text{ mg VSS/l}$$

$$X_R = \frac{6,667 + (0.48)(111)}{(0.051)(5/24) + 1} = 6,650 \text{ mg VSS/l}$$

4. Determine the sludge recycle ratio for the design value of X_R from equation (13)

$$\begin{aligned} R &= \frac{(k_d V_C + Q - YK_s(S_e)_s V_C)X_C}{Q(X_R - X_C)} \\ &= \frac{[(0.051)(0.241) + 5 - (0.48)(0.082)(20)(0.241)](3,000)}{5(6,650 - 3,000)} \\ &= 0.79 \end{aligned}$$

$$RQ = (0.79)(5.0) = 3.96 \text{ mgd}$$

5. Determine the volume of the reaeration tank for the design value of X_R from equation (9)

$$\begin{aligned} V_R &= \frac{RQ[X_U - X_R + Y(S_o)_p]}{k_d X_R} \\ &= \frac{(3.96)(10^6)[6,667 - 6,650 + (0.48)(111)]}{(0.051)(6,650)} \\ &= 821,000 \text{ gal} \end{aligned}$$

or since

$$V_R = RQt_R = (3.96)(10^6)(0.2083) = 825,000 \text{ gal}$$

(The difference in the V_R values is due to the accumulation of round-off errors)

6. Determine the sludge wasting rate of the system from equation (15) and the clarifier effluent microbial solids concentration, $X_e = 20 \text{ mg VSS/l}$.

$$\begin{aligned}
 Q_w &= \frac{X_C V_C + X_R V_R - Q X_e \theta_c}{(X_U - X_e) \theta_c} \\
 &= \frac{(3,000)(0.241) + (6,650)(0.821) - 5(20)(10)}{(6,667 - 20)(10)} \\
 &= 0.078 \text{ mgd}
 \end{aligned}$$

7. Determine the oxygen uptake rate and the total oxygen required for organic substrate removal in the contact and reaeration tanks. These oxygen requirements can be determined from equation (17) and (17a) for the contact tank and from equation (18) and (18a) for the reaeration tank.

- a) The oxygen utilization rate in the contact tank is

$$\begin{aligned}
 (N_{O_2})_C &= \frac{(S_o)_s - (S_e)_s}{t_C} - 1.4 \left\{ \frac{Y[(S_o)_s - (S_e)_s]}{t_C} - k_d X_C \right\} \\
 &= \frac{256 - 20}{(0.68)(0.0482)} - 1.4 \left[\frac{(0.48)(256 - 20)}{(0.68)(0.0482)} \right. \\
 &\quad \left. - (0.051)(3,000) \right] \\
 &= 2,576 \text{ mg/l-day} = 107 \text{ mg/l-hr}
 \end{aligned}$$

The specific oxygen utilization rate is therefore 35.8 mg/l-hr-gVSS and the total oxygen required in the contact tank is

$$\begin{aligned}
 W_C &= (N_{O_2})_C (V_C) = (2,576)(0.241)(8.34) \\
 &= 5,178 \text{ lb/day}
 \end{aligned}$$

b) The oxygen utilization rate in the reaeration tank

$$\begin{aligned}
 (N_{O_2})_R &= \frac{(S_o)_P}{t_R} - 1.4 \left[\frac{Y(S_o)_P}{t_R} - k_d X_R \right] \\
 (N_{O_2})_R &= \frac{111}{(0.68)(0.2083)} - 1.4 \left[\frac{(0.48)(111)}{(0.68)(0.2083)} \right. \\
 &\quad \left. - (0.051)(6,650) \right] \\
 &= 732 \text{ mg/l-day} = 30.5 \text{ mg/l-hr.}
 \end{aligned}$$

The specific oxygen utilization rate is 4.6 mg/l-hr-gVSS
and the total oxygen required is

$$\begin{aligned}
 W_R &= (N_{O_2})_R (V_R) \\
 &= (732)(0.821)(8.34) \\
 &= 5,012 \text{ lb/day}
 \end{aligned}$$

8. Check the organic and volumetric loading rate

$$\begin{aligned}
 \text{organic loading} &= \frac{1 \text{ lbBOD}_5}{1 \text{ bMLVSS}} \\
 &= \frac{(367 - 20)(5.0)(8.34)}{[(0.241)(3,000) + (0.821)(6,650)](8.34)} \\
 &= 0.28 \text{ lbBOD}_5/\text{lbVSS-day} \\
 \text{volumetric loading} &= \frac{1 \text{ lbBOD}_5}{1,000 \text{ ft}^3} \\
 &= \frac{(367 - 20)(5.0)(8.34)(7.48)(1,000)}{(0.241 + 0.821)(10^6)} \\
 &= 102 \text{ lbBOD}_5/1,000 \text{ cu ft-day}
 \end{aligned}$$

These two values agree closely with the mean values of 0.28 lbBOD₅/lbVSS-day and 84 lbBOD₅/1,000 cu ft-day reported in Haseltine's (1) survey of treatment plants employing sludge reaeration.

9. Check total oxygen and air requirement.

Oxygen requirement = 10,190 lb/day. Specific weight of air at standard temperature and pressure is 0.0750 lb/cu ft and contains 23.2 percent oxygen by weight, then the theoretical air requirement is

$$\frac{10,190}{(0.075)(0.232)} = 585,632 \text{ cu ft/day}$$

Assume that the oxygen transfer efficiency has been completed to be 4 percent (24). Therefore the requirement is

$$\frac{585,632}{0.04} = 14,641,000 \text{ cu ft/day}$$

the air volume

$$\frac{14,641 \times 10^6 \text{ cu ft/day}}{(367 - 20)(5)(8.34) \text{ lbBOD}_5/\text{day}} = 1,011 \text{ cu ft/lbBOD}_5 \text{ removed.}$$

This value agrees closely with the mean value 989 cu ft/lb BOD₅ removed reported in Haseltine's (1) survey of treatment plant employing sludge reaeration.

CONCLUSION

A completely mixed continuous flow activated sludge reactor was successfully operated using a synthetic waste to evaluate the necessary kinetic coefficients in Jatko's model of the contact stabilization process. With these kinetic determined coefficients and the model, a design for a treatment process for the synthetic waste was also presented. The loading rates and physical characteristics of the proposed plant agreed favorably with those of existing contact stabilization plants that have satisfactory performance records. It can be concluded that Jatko's model is reasonable.

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APPENDIX I

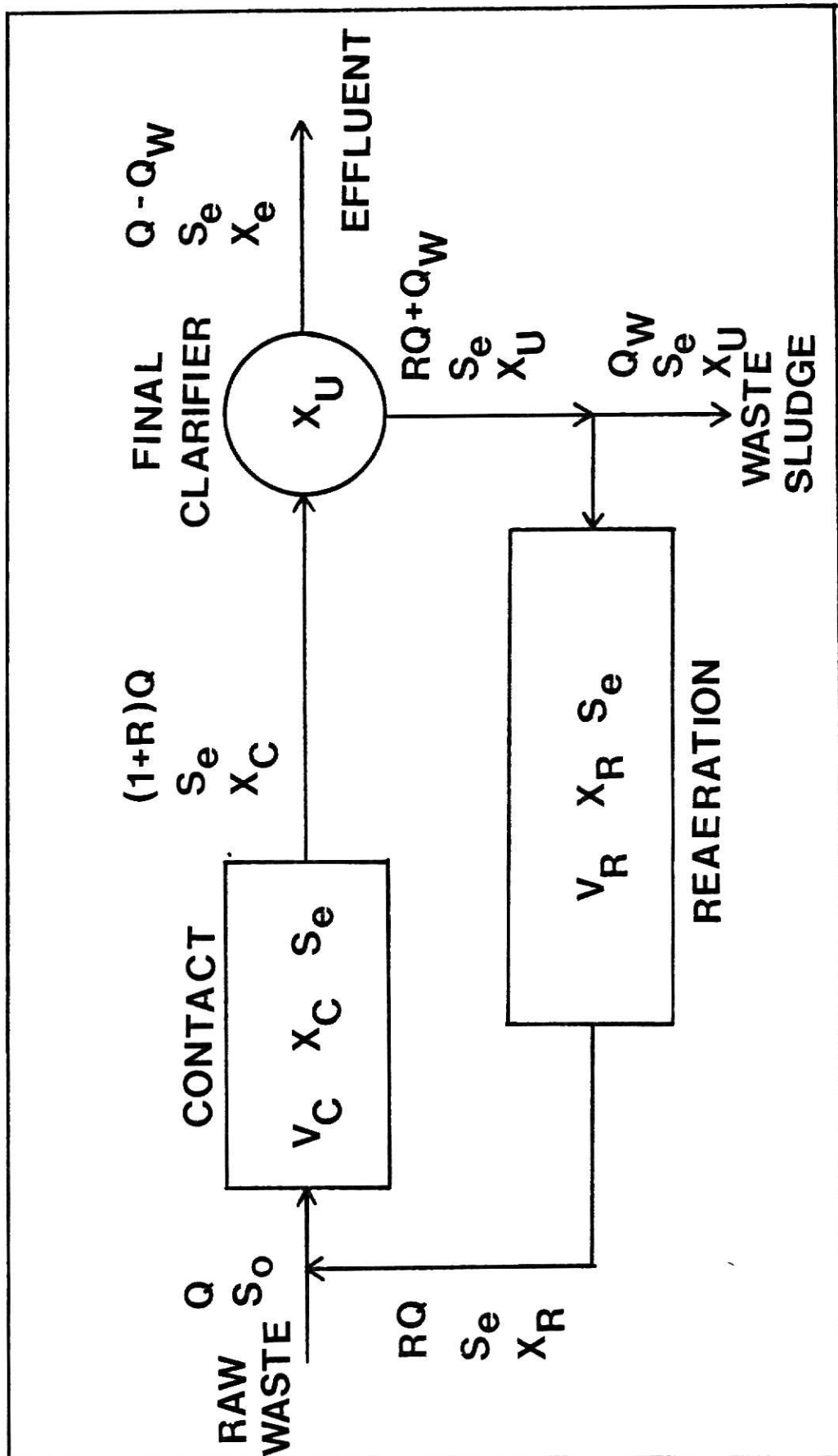


Figure 9. Flow Scheme for the Contact Stabilization Activated Sludge Process

Nomenclature

- f = oxygen demand constant of effluent microbial solids
 k_d = endogenous decay coefficient, T^{-1}
 K_t = first order rate constant for total substrate removal per unit of microbial mass per unit time, $L^3M^{-1}T^{-1}$
 K_s = first order rate constant for soluble substrate removal per unit of microbial mass per unit time, $L^3M^{-1}T^{-1}$
 $(N_{O_2})_C$ = oxygen utilization rate in contact tank, $ML^{-3}T^{-1}$
 $(N_{O_2})_R$ = oxygen utilization rate in reaeration tank, $ML^{-3}T^{-1}$
 q_s = specific soluble substrate utilization rate, T^{-1}
 q_t = specific total substrate utilization rate, T^{-1}
 Q = volumetric flow rate of raw wastewater, L^3T^{-1}
 Q_W = volumetric flow rate of sludge wasting, L^3T^{-1}
 R = sludge recycle ratio
 S_o = total substrate concentration in raw wastewater, ML^{-3}
 $(S_o)_p$ = particulate substrate concentration in raw wastewater, ML^{-3}
 $(S_o)_s$ = soluble substrate concentration in raw wastewater, ML^{-3}
 S_e = total concentration of substrate of raw wastewater origin remaining in effluent from final clarifier, ML^{-3}
 $(S_e)_p$ = concentration of particulate substrate of raw wastewater origin remaining in effluent from final clarifier, ML^{-3}
 $(S_e)_s$ = concentration of soluble substrate remaining in effluent from final clarifier, ML^{-3}
 $(S_e)_T$ = total oxygen demand of effluent from final clarifier, ML^{-3}
 $(SVI)_C$ = sludge volume index of mixed liquor in contact tank, L^3M^{-1}
 t_C = hydraulic residence time in contact tank, T
 t_R = hydraulic residence time in reaeration tank, T

V_C = volume of contact tank, L^3

V_R = volume of reaeration tank, L^3

W_C = oxygen required in contact tank, MT^{-1}

W_R = oxygen required in reaeration tank, MT^{-1}

X_C = concentration of microbial mass in contact tank, ML^{-3}

X_R = concentration of microbial mass in reaeration tank, ML^{-3}

X_e = concentration of microbial mass in effluent from final clarifier, ML^{-3}

X_U = concentration of microbial mass in underflow from final clarifier, ML^{-3}

y = non-biodegradable BOD_5 , ML^{-3}

Y = cell yield coefficient of microbial growth

$\left(\frac{dS}{dt}\right)$ = net rate of change in total substrate concentration in contact tank, $ML^{-3}T^{-1}$

$\left(\frac{dS}{dt}\right)_t$ = rate of total substrate removal per unit volume per unit time, $ML^{-3}T^{-1}$

$\left(\frac{dS}{dt}\right)_p$ = rate of metabolism of particulate substrate per unit volume per unit time, $ML^{-3}T^{-1}$

$\left(\frac{dS}{dt}\right)_s$ = rate of metabolism of soluble substrate per unit volume per unit time, $ML^{-3}T^{-1}$

$\left(\frac{dX}{dt}\right)$ = net rate of change in microbial mass concentration in aeration tanks, $ML^{-3}T^{-1}$

θ_c = mean cell residence time (MCRT) of sludge age, T

μ = specific growth rate, T^{-1}

APPENDIX II

DATA ANALYSIS

TABLE VIII

RESULTS COLLECTED FROM ACTIVATED SLUDGE REACTOR OPERATIONS

θ_c (days)	$(S_e)_s$ (mg/l)	MLVSS (mg/l)
4	4.2	1,174
"	4.4	1,165
"	4.3	1,164
"	4.8	1,184
"	5.3	1,195
"	5.0	1,302
"	5.3	1,274
"	5.4	1,226
"	4.0	1,180
"	4.6	1,236
"	5.1	1,093
"	5.0	1,205
TOTAL	57.4	14,398
MEAN	4.8	1,200
6	3.3	1,925
"	3.2	1,912
"	3.4	2,029
"	2.7	2,089
"	4.2	1,793
"	3.6	1,943
"	4.0	1,937

6	4.8	1,793
"	4.2	1,961
"	3.8	1,977
"	4.4	1,909
"	4.0	2,012
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TOTAL	45.6	23,280
MEAN	3.8	1,940
<hr/>		
8	3.6	2,304
"	2.7	2,510
"	4.6	2,359
"	3.6	2,250
"	1.4	2,064
"	1.3	2,280
"	2.4	2,065
"	1.4	2,240
"	4.1	2,246
"	5.0	2,187
"	3.4	2,100
"	2.5	2,191
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TOTAL	36.0	26,796
MEAN	3.0	2,233
<hr/>		
12	1.6	2,388
"	1.9	2,396
"	1.4	2,579
"	1.5	2,666
"	2.5	2,573
"	1.4	2,659

12	2.1	2,441
"	3.4	2,492
"	1.9	2,616
"	3.7	2,736
"	3.6	2,544
"	3.8	2,509
<hr/>		
TOTAL	28.8	30,599
MEAN	2.4	2,550
<hr/>		
16	1.2	2,862
"	2.2	2,949
"	1.4	2,844
"	1.2	2,943
"	1.5	3,045
"	1.9	3,051
"	1.4	3,025
"	2.4	3,059
"	2.2	3,160
"	1.3	3,158
"	2.3	2,943
"	1.4	3,080
<hr/>		
TOTAL	20.4	36,119
MEAN	1.7	3,010
<hr/>		

TABLE IX
LINEAR REGRESSION AND CORRELATION ANALYSIS FOR EVALUATION OF K_t

Effluent BOD ₅ [(S _e) _s], X	4.8	3.8	3.0	2.4	1.7
Specific BOD ₅ Utilization Rate (q _t), Y	0.648	0.402	0.350	0.307	0.260
<hr/>					
ΣX = 15.7	ΣY = 1.967		n = 5		
\bar{X} = 3.14	\bar{Y} = 0.3934				
ΣX ² = 55.13	ΣY ² = 0.86586		ΣXY = 6.8668		
(ΣX) ² /n = 49.298	(ΣY) ² /n = 0.77382		(ΣX)(ΣY)/n = 6.1764		
<hr/>					
Σx ² = 5.832	Σy ² = 0.09204		Σxy = 0.69042		

$$\text{Slope} = b_1 = \Sigma xy / \Sigma x^2 = 0.69042 / 5.832 = 0.118$$

$$\text{Intercept} = b_0 = \bar{Y} - b_1 \bar{X} = 0.3934 - (0.118)(3.14) = 0.0217$$

$$\hat{Y} = b_0 + b_1 X = 0.0217 + 0.118X, \hat{Y} = 0.49 \text{ at } X = 4.0$$

$$\text{Correlation Coefficient} = r = \Sigma xy / \sqrt{(\Sigma x^2)(\Sigma y^2)} = 0.69042 / \sqrt{(5.832)(0.09204)} = 0.94$$

$$\Sigma d_{yx}^2 = \Sigma y^2 - (\Sigma xy)^2 / \Sigma x^2 = 0.0103$$

$$s_{yx}^2 = \Sigma d_{yx}^2 / (n - 2) = 0.00343$$

$$s_{yx} = 0.0586$$

$$s_{b_1} = s_{yx} / \Sigma x^2 = 0.0586 / 5.832 = 0.0243$$

$$t = b_1 / s_{b_1} = 0.118 / 0.0243 = 4.86^*, \text{ d.f.} = 3, (\alpha = 0.05)$$

TABLE X
LINEAR REGRESSION AND CORRELATION ANALYSIS FOR EVALUATION OF K_s

Effluent BOD ₅ [(S _e) _s], X	4.8	3.8	3.0	2.4	1.7
Specific BOD ₅ Utilization Rate (q _s), Y	0.449	0.279	0.243	0.213	0.181
<hr/>					
ΣX = 15.7	ΣY = 1.365		n = 5		
\bar{X} = 3.14	\bar{Y} = 0.273				
ΣX ² = 55.13	ΣY ² = 0.41662		ΣXY = 4.7633		
(ΣX) ² /n = 42.298	(ΣY) ² /n = 0.37265		(ΣX)(ΣY)/n = 4.2861		
<hr/>					
Σx ² = 5.832	Σy ² = 0.04398		Σxy = 0.4772		

$$\text{Slope} = b_1 = \Sigma xy / \Sigma x^2 = 0.4772 / 5.832 = 0.082$$

$$\text{Intercept} = b_0 = \bar{Y} - b_1 \bar{X} = 0.273 - (0.082)(3.14) = 0.0162$$

$$\hat{Y} = b_0 + b_1 X = 0.0162 + 0.082X, \hat{Y} = 0.344 \text{ at } X = 4.0$$

$$\text{Correlation Coefficient} = r = \Sigma xy / \sqrt{(\Sigma x^2)(\Sigma y^2)} = 0.4772 / \sqrt{(5.832)(0.04398)} = 0.94$$

$$\begin{aligned} \Sigma d_{yx}^2 &= \Sigma y^2 - (\Sigma xy)^2 / (\Sigma x^2) = (0.04398) - (0.4772)^2 / (5.832) \\ &= 0.00493 \end{aligned}$$

$$s_{yx}^2 = \Sigma d_{yx}^2 / (n - 2) = 0.00493 / 3 = 0.00164$$

$$s_{yx} = \sqrt{0.00164} = 0.0406$$

$$s_{b_1} = s_{yx} / \Sigma x^2 = 0.0168$$

$$t = b_1 / s_{b_1} = 0.0168 / 0.082 = 4.88^*, \text{ d.f.} = 3, (\alpha = 0.05)$$

TABLE XI

LINEAR REGRESSION AND CORRELATION ANALYSIS FOR EVALUATION OF Y AND k_d

Specific BOD ₅ Utilization Rate (q_t), X	0.648	0.402	0.350	0.307	0.260
Specific Growth Rate ($1/\theta_c$), Y	0.25	0.167	0.125	0.083	0.063

$$\Sigma X = 1.967$$

$$\Sigma Y = 0.688$$

$$n = 5$$

$$\bar{X} = 0.3934$$

$$\bar{Y} = 0.1376$$

$$\Sigma X^2 = 0.86586$$

$$\Sigma Y^2 = 0.117$$

$$\Sigma XY = 0.31475$$

$$(\Sigma X)^2/n = 0.77382$$

$$(\Sigma Y)^2/n = 0.095$$

$$(\Sigma X)(\Sigma Y)/n = 0.27066$$

$$\Sigma x^2 = 0.09204$$

$$\Sigma y^2 = 0.0222$$

$$\Sigma xy = 0.04409$$

$$\text{Slope} = b_1 = \Sigma xy / \Sigma x^2 = 0.04409 / 0.09204 = 0.48$$

$$\text{Intercept} = b_0 = \bar{Y} - b_1 \bar{X} = 0.1376 - (0.48)(0.3934) = -0.051$$

$$\hat{Y} = -0.051 + 0.48X, \hat{Y} = 0.189 \text{ at } X = 0.50$$

$$\text{Correlation Coefficient} = r = \Sigma xy / \sqrt{(\Sigma x^2)(\Sigma y^2)} = 0.04409 / \sqrt{(0.09204)(0.0222)}$$

$$= 0.98$$

$$\Sigma d_{yx}^2 = \Sigma y^2 - (\Sigma xy)^2 / (\Sigma x^2) = 0.0222 - (0.04409)^2 / (0.09204)$$

$$= 0.0108$$

$$s_{yx}^2 = \Sigma d_{yx}^2 / (n - 2) = 0.0108 / 3 = 0.00036$$

$$s_{yx} = \sqrt{0.00036} = 0.01897$$

$$s_{b_1} = s_{yx} / \Sigma x^2 = 0.01897 / 0.09204 = 0.0625$$

$$t = b_1 / s_{b_1} = 0.0625 / 0.48 = 7.68^{**}, \text{ d.f.} = 3, (\alpha = 0.01)$$

MODEL EVALUATION OF THE
CONTACT STABILIZATION PROCESS
BY LABORATORY STUDIES

by

TZER-MIN LEE

B.S., Taipei Institute of Technology, 1968

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

ABSTRACT

A completely mixed continuous flow activated sludge reactor was successfully operated using a synthetic waste to evaluate the necessary kinetic coefficients to be employed in a model of the contact stabilization process. With these coefficients determined a design model for the synthetic waste treatment was also presented. The loading rates and physical characteristics of the proposed plant agreed favorably with those of existing contact stabilization plants that have satisfactory performance records.