A DESIGN EVALUATION ON BIOLOGICAL ROTATING CONTACTOR (RBC) TREATING MUNICIPAL WASTEWATER

By

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A DESIGN EVALUATION ON ROTATING BIOLOGICAL CONTACTOR (RBC) TREATING MUNICIPAL WASTEWATER

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CHAPTER I

INTRODUCTION

The rotating biological contactor (RBC) is one of the newest methods of aerobic biological wastewater treatment. It is being considered for wastewater treatment in many municipalities and industries. The rotating biological contactor process has operational characteristics similar to both the activated sludge process and the biological filter process. It has been used to treat different types of wastewater, to upgrade existing treatment facilities, and, also, to achieve nitrification.

Stable performance, good settling characteristics, low sludge production and the absence of recycle are all the characteristic of RBC's. They handle a wide range of flows, and are easy to operate and install.

Due to the imposed Federal and State regulations on stream standards, ammonia-nitrogen (NH_3-N) removal is required for some treatment plants. Today, in addition to the removal of organic carbon, nitrification should be considered as one of the major criteria in designing a wastewater treatment plant.

This research was conducted to: (i) evaluate different design parameters and models for the RBC scale-up treating municipal wastewater, (ii) study the feasability of using a RBC for domestic wastewater treatment, (iii) provide a means to predict when nitrification will occur and at what rate, and (iv) evaluate whether this 1.0 meter pilot unit can be used for treatability studies with or without any limitation to the scale-up.

CHAPTER II

LITERATURE REVIEW

The rotating biological contactor (RBC) for wastewater treatment was first conceived in Germany by Weigard in 1900. In 1920, investigators experimented with using rotating wood surfaces, which were impractical to manufacture and deteriorated. Nothing further developed in Europe until the late 1950's. Research work on RBC processes was begun at Stuttgart University, West Germany. Investigators conducted experiments with plastic flat discs rotating in wastewater. In 1959 the J. Conard Stengelin Co. in Tuttlingen, West Germany, began to manufacture expended-polystyrene discs 2m and 3m in diameter for use in wastewater treatment plants. After 1960, further development of the RBC process was undertaken by the Allis-Chalmer Company. The first commercial installation in the U.S. went into operation at a small cheese factory in 1969. (1,2,3)

Autorol Corp (Milwaukee, Wis.) bought the RBC technology from Allis-Chalmers in 1970, and in 1972 developed a more compact disc. It consisted of a series of parallel flat expended honey combed configuration of polystyrene sheets, which provided more surface area for a given volume. (1) Presently there are several companies which offer RBC's for commercial applications and today, in the United States, there are 250 RBC installations heating municipal, industrial wastewater (2,5).

Historically RBC systems have been used for the treatment of wastewater for organic removal. Later the system was expanded to include both nitrification and denitrification (4).

RBC's are comparable to such conventional aerobic process as biological filters and activated sludge, since they all employ the same wastewater purification mechanisms.

Both the RBC process and the biological filter process are fixed film biological reactors. However, the microbial mass in the RBC system is passed through the wastewater, where as the wastewater is passed over the microbial mass with the biological filter.

The RBC process is somewhat similar to the activated sludge process in that both have a suspended culture of biomass in the mixed liquor and posses aeration. However, with the RBC's, the part of the bio-mass that is in suspension in the mixed liquor is very small in comparison to the amount of biological growth supported by the disc surfaces and therefore, would contribute only marginally to the overall treatment.

Opatken (7) has studied different kinetic reaction rates of secondary treatment by utilizing Friedman's (8) data. These include

Zero Order Kinetic

$$C_n = k\theta + C_{inf} \qquad (1)$$

where

C_n = soluble substrate concentration at the "n" stage, mg/l

k = reaction rate constant, mg/l

θ = reaction time after n stages, hr

C_{inf} = influent soluble substrate concentration to RBC system, mg/l

The equation implies that the concentration of substrate removal is identical for equal time intervals.

First Order Kinetics

$$\ln \frac{C_n}{C_{inf}} = kt \tag{2}$$

It shows that the percent removal is constant for equal time intervals.

Second Order Kinetics

$$r = \frac{\Delta C}{\Delta t} = kC_n^2 \tag{3}$$

where

$r = \frac{\Delta C}{\Delta t}$ = rate of disappearance of substrate concentration, mg/l

k = reaction rate constant, l/mg . hr.

C_n^2 = the square of soluble substrate concentration in the nth stage, $(mg/l)^2$

ΔC = $(C_{n-1} - C_n)$ the difference in soluble substrate concentration of the influent into a stage from the concentration within that stage, mg/l

Δt = reaction time, hr

In considering a RBC system, a mass balance of carbonaceous substrate removal may be written as follows. (6)

mass of substrate into the volume = mass of substrate out of volume = mass of subtrate consumed

$$FS_i = FS_e + \left(\frac{ds}{dtA}\right)_G A \quad (4)$$

where

F = flow rate, million gallon per day, MGD

S_i = influent $SBOD_5$ concentration, mg/l

S_e = effluent $SBOD_5$ concentration, mg/l

A = surface area of volume, 1000 ft^2

$\left(\frac{ds}{dtA}\right)_G$ = specific substrate utilization, lb $SBOD_5$/day/1000 ft^2

The surface area of a RBC can be equated to the mass of microorganisms in activated sludge. By assuming an active film thickness, the mass of microorganisms can be determined. (6)

Kincannon and Stover (3) have compared the substrate utilization rate, $\left(\frac{ds}{dtA}\right)_G$, from different mathematical description, proposed by several investigators, for RBC's. These include:

Kornegay and Andrew (9)
$$\frac{ds}{dtA} = \frac{PS_e}{K_m + S_e} \quad (5)$$

Schroeder (10)

$$\frac{ds}{dtA} = \frac{f\ h\ k_o\ S_e^{\ 2}}{k_m + S_e} \tag{6}$$

Friedman (8)

$$\frac{ds}{dtA} = \frac{k\ S_e^{\ 2}}{k_m + S_e} \tag{7}$$

Eckenfelder (11)

$$\frac{ds}{dtA} = k_e S_e \tag{8}$$

Kincannon and Stover (3)

$$\frac{ds}{dtA} = \frac{U_m \frac{FS_i}{A}}{k_B + \frac{FS_i}{A}} \tag{9}$$

where

p = area capacity constant, lbs/ft^2/day

k_m = saturation constant, mg/l

S_e = substrate concentration at a point of measurement, mg/l

f = proportionality constant, lbs/ft^3

h = effective depth of the biomass, ft

k_o = maximum removal rate, (mg/l day)$^{-1}$

S_i = influent substrate concentration to any stage, mg/l

k = removal rate constant, $\frac{\text{lbs/day/ft}^2}{\text{mg/l}}$

k_1 = Eckenfelder's removal rate, $\frac{\text{lbs/day/ft}^2}{\text{mg/l}}$

U_m = maximum specific substrate removal rate, lbs/day/1000 ft^2

k_B = proportionality constant, lbs/day/1000 ft^2

Substrate concentration is a function of removal rate for the first four models, whereas Stover and Kincannon's expression is a function of loading. In addition to substrate concentration and organic loading, hydraulic loading has been considered as one of the major design parameters for RBC's. Friedman (8) mentions that the determination of the required area of RBC media is normally based on hydraulic loading criteria. Pilot studies are conducted to provide a correlation between effluent quality and hydraulic loading conditions and that hydraulic loading which obtains the desirable effluent from a pilot unit is selected and used for prototype design. Units are usually reported in gallons per day per square foot (gpdsf) of disc surface, and the required media area increased as a safety factor for design.

RBC processes treating municipal wastewater have been shown to be efficient in both carbon and ammonia-nitrogen removal (4,13,14,15). Removal of organic carbon is independent of the ammonia-nitrogen concentration, though the nitrification process is dependent on the BOD concentration (4,12,13,14,15,16). The importance of nitrogen control in wastewater effluent is due to its impact on receiving streams. Ammonia-nitrogen exerts an additional oxygen demand, is responsible for algae blooms and is toxic to biotic life.

Temperature has a signficant influence on carbon removal and nitrification in RBC units (18). By using the municipal wastewater at Hyrum, Utah, Pano and Middlebrooks (17) have found that the overall carbon removal efficiencies are 80 percent, 85 percent, and 90 percent for 5°C, 15°C and 20°C, respectively. The overall ammonia-nitrogen removal ranges from 87 percent to 98 percent at 15°C, and from 91 to 99 organic loading rates increase, the overall ammonia removal decreases.

Oxygen transfers has a significant impact on treatment efficiency. Stover and Kincannon (3) have shown that around 1.5 to 2.0 lbs SBOD/day/1000 ft^2 the full scale systems started becoming oxygen transfer limited instead of biochemical reaction rates limited. At a certain loading condition, the RBC becomes saturated with BOD, and the removal rate does not increase with increasing BOD loadings. The system is said to become oxygen limited at these loading conditions and exhibits apparent zero-order kinetics. Stover and Kincannon (3) have also found that the rotational speed and oxygen transfer capabilities are not proportional to the RBC diameter. It means that smaller diameter systems transfer more oxygen, and they achieve higher removal efficiency than larger system. In order to effectively accomplish scale-up of RBC's from pilot data, the oxygen transfer capabilities and limitations of the full scale system must be defined.

CHAPTER III

MATERIAL AND METHODS

RBC Studies

The RBC pilot plant consisted of 5 sequential stages, or compartments separated by baffles, allowing for the flow of wastewater from one stage to the next. Each stage consisted of 20 discs, 3.28 ft. in diameter and fabricated of ultra-thin sheets of polyethylene. With a sinusoidal surface configuration, the discs generated a great deal of turbulence. The deformation increased the area of the disc by an average of 50% over a flat disc area. The sheets were thermoformed, spot welded, and provided by the Enviroquip, Inc. The basin was 3.67 ft. wide and 11.67 ft. long, and made of carbon steel, with a liquid capacity of 314 gal. The discs were mounted on a steel shaft, 4 in. wide, 4 in. height, 11.67 ft. long, equipped with a sprocket and chain drive which was driven by an AC motor and speed controlled to provide different rotational speeds. During this pilot study, the motor rotated the disc at a constant speed of 1 ft/sec. Forty percent of the disc surface area was submerged in the liquid. Since the specific area for the media was 38.8 ft^2 of media/ft^3 of media, the surface area provided by each stage was 560 sq. ft. The total surface area of the polyethylene medium available for microbial growth was therefore 2800 sq. ft. Figure 1 shows the RBC reactor and Figure 2 shows a detail of the rotating media.

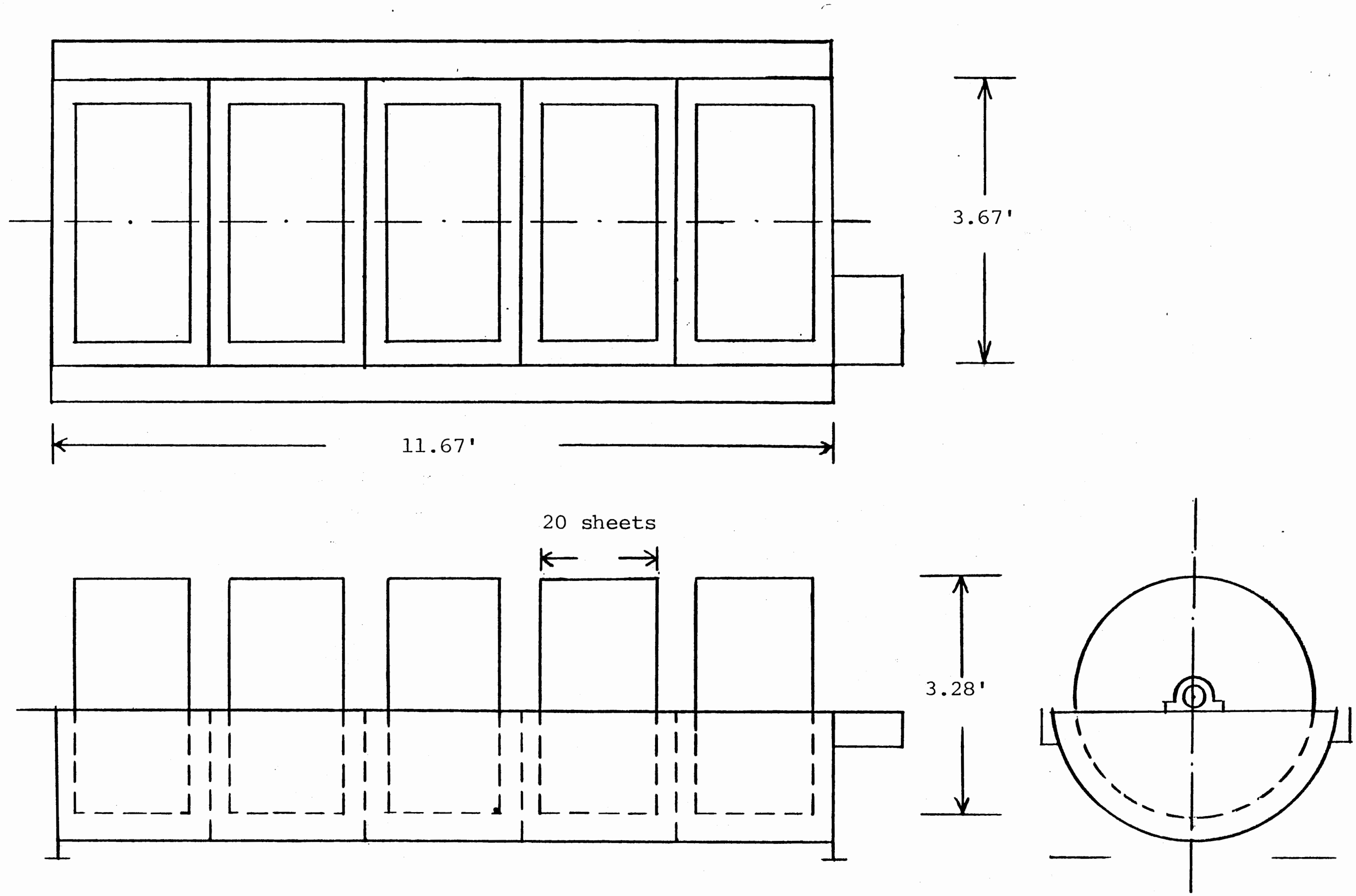

Figure 1. Pilot Scale RBC Tank Dimensions

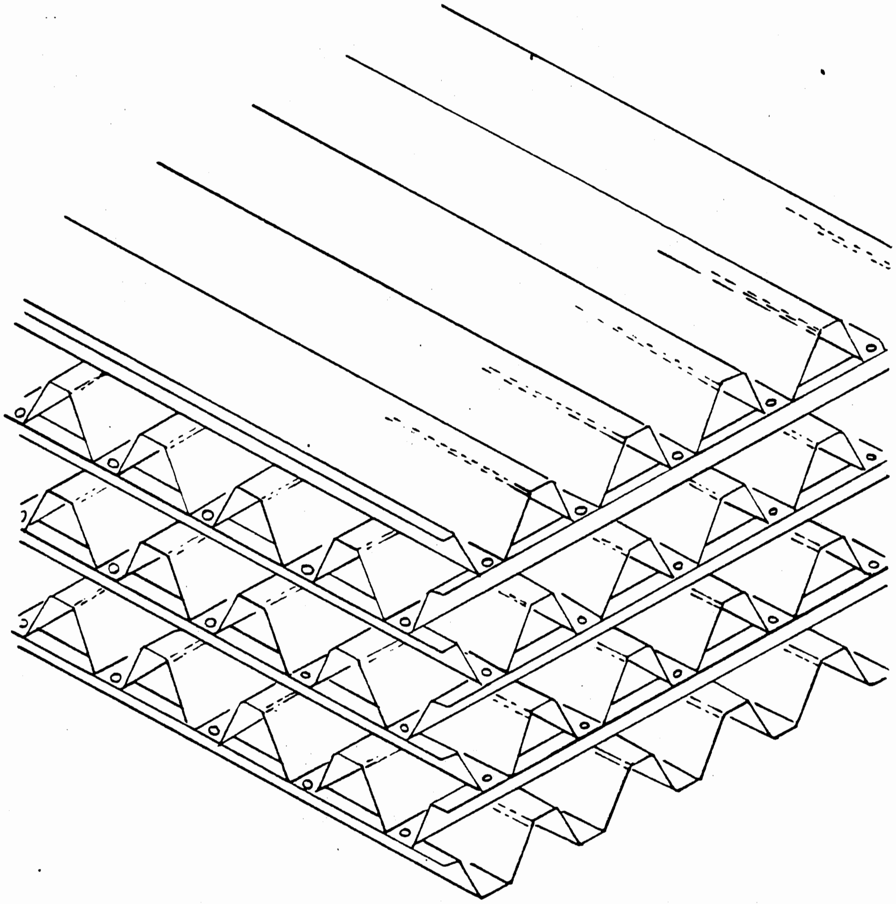

Figure 2. Media Detail

The pilot plant was fed with domestic wastewater continually. No initial seed was added in the start up due to the existence of different microbial populations already in the wastewater.

The wastewater was directly pumped from the sewage line into a holding tank, which was 2.5 ft. diameter, 4 ft. height and had a capacity of 147 gallons. It was placed at the head of the RBC unit. Figure 3 shows the holding tank and Figure 4 shows a detail of the pilot plant. The wastewater was then pumped into the basin by utilizing a teel pump (MODEL #1P610). It flowed from the first stage through each of the next four stages and out of the effluent overflow line. Prior to the experimental periods, the system was operated for a sufficient length of time to allow the unit to stabilize before sampling began. Experiments were conducted in a controlled temperature pilot plant at 23 ± 3°C.

The variables applied to the system were the influent organic concentration and the hydraulic loading. The average hydraulic loadings investigated were 1.131, 2.314, 3.806 gpd/ft^2. During the summer of 1983, the influent concentrations of wastewater experienced a decreasing value of biological oxygen demand (BOD).

Samples were collected from the influent line, at the end of stages one through four, and from the effluent line. Following collection, the pH and dissolved oxygen (D.O.) of samples were immediately determined. The influent and effluent temperatures were measured in order to determine the temperature drop of the wastewater as it passed through the unit. Also, the thickness of the bio-film was measured in each stage. Total biological oxygen demand (TBOD) for influent and effluent, soluble biological oxygen demand (BOD), soluble chemical oxygen demand (COD),

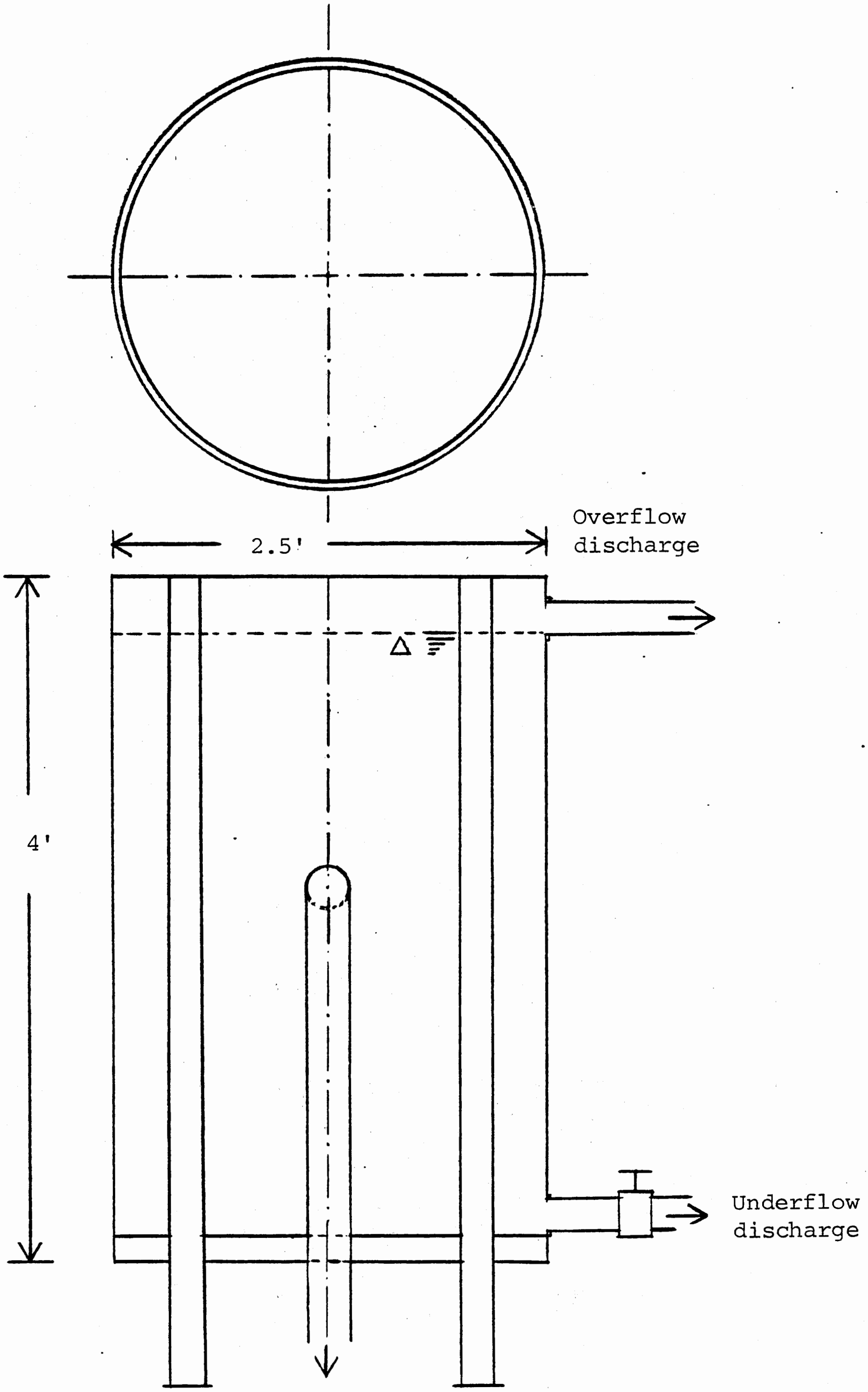

Figure 3. Pilot Holding Tank Dimensions

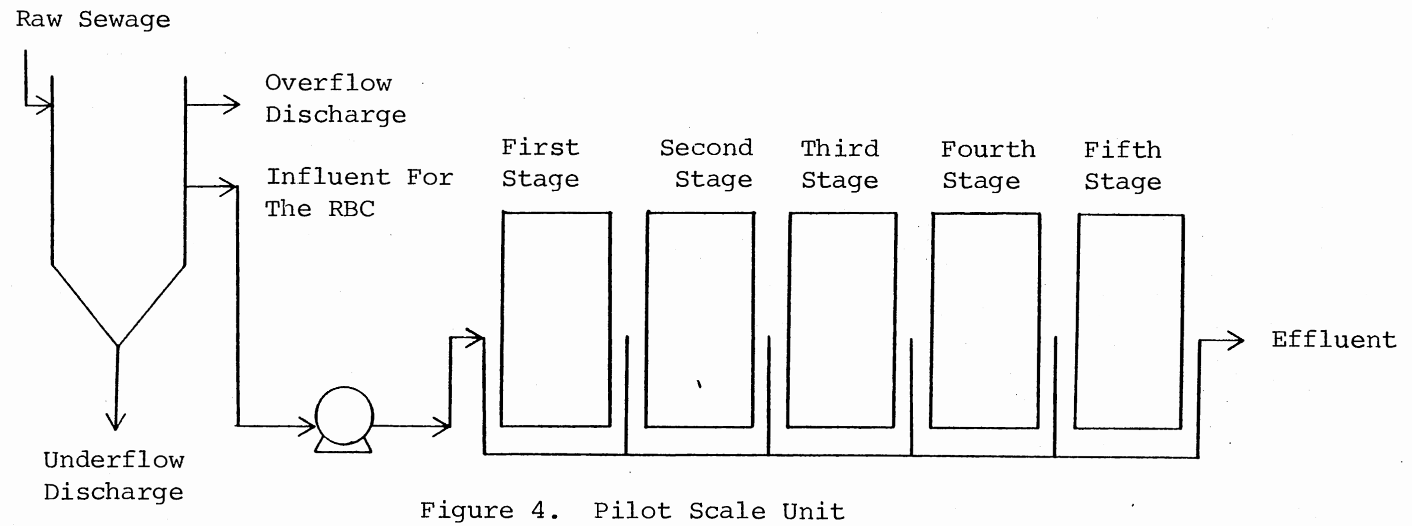

Figure 4. Pilot Scale Unit

soluble total organic carbon (TOC), biological solids, ammonia-nitrogen (NH_3-N), and nitrate-nitrogen (NO_3-N) were determined.

Analytical Procedures

The methods adopted to measure D.O., pH, TBOD, BOD, COD, TOC, total suspended solid (TSS), volatile suspended solid (VSS), total solid (TS), volatile solid (VS), NH_3-N, NO_3-N and temperature during this investigation are given below.

Dissolved Oxygen

The dissolved oxygen was measured by an Orion D.O. probe and YSI meter.

pH and Temperature

pH was determined by a Beckman expandomatic SS-2 pH meter, and was standarized at pH 7.0 and pH 4.0 before use. Temperature was measured with a Sargent Welch thermometer.

Total and Soluble Biological Oxygen Demand (TBOD & SBOD)

Samples for TBOD were nonfiltered influent wastewater and the effluent supernatant, which was settled for half an hour. Filtrate was used for SBOD determination. Both TBOD and SBOD were detemined in accordance with the procedure outlined in Standard Methods, except that the titration method was substituted by using a D.O. probe to obtain the initial D.O. and the D.O. after five days. Nitrapyrin (99%) was used as an inhibitor.

Chemical Oxygen Demand (COD)

Filtered COD was determined by using the method developed by the Hack Chemical (Hack Chemical Co., Ames Iowa).

Total Organic Carbon (TOC)

The Oceangraphic Total Carbon Analyzer was used to determine the TOC concentration of the filtered samples.

Biological Suspended Solids

The suspended solids concentration (total suspended solids and volatile suspended solids) was determined using glass microfiber filters (Whatman).

Bio-film Solids

The bio-film solids concentration was determined by removing 1 sq. in of biomass from the disc and placing it in a tare dish. The biomass was weighed and then placed in the drying oven at 103°C for two hours. It was cooled in a desiccator and weighed to determine the total solid concentration. The tare dish was then placed in the furnace for 15 minutes at 550°C, cooled in the desiccator, and weighed to determine the volatile solids concentration.

Ammonia-Nitrogen (NH_3-N), Nitrate-Nitrogen (NO_3-N)

The filterd ammonia-nitrogen and nitrate-nitrogen were determined by using the Hach Chemicals Procedures. (Hach Chemical Co., Ames, Iowa).

CHAPTER IV

RESULTS AND DISCUSSION

Carbon Removal

The study plan called for each system to be operated at varies organic loadings. Since the BOD would be controlled by the raw sewage, the organic loading was controlled by varying the hydraulic flow to the system.

The RBC was studied at three separate hydraulic flow rate. These were 1.131, 2.314, 3.806 Gpd/ft^2. Due to the decrease in the BOD of the wastewater during each phase of the study, all three loadings were very close. Figure 5 shows the average BOD for each study period. It is seen that the initial BOD's averaged 75 mg/l for the first period, 49 mg/l for the second period, and 30 mg/l for the third period. These were all reduced to approximately 3 mg/l at the fifth stage. It indicated that when RBC treating municipal wastewater with varies hydraulic flow rate and concentrations, it also achieved the same effluent quality. The removal efficiency accomplished by this pilot unit ranged from 90 to 96 percent. It should be noted that the majority of the removal was accomplished in the first stage. Also, the curves for these three BOD concentrations indicate that something other than zero order kinetics was occurring. A plot of the data on semi-log paper is presented in Figure 6. If first order kinetic were valid a straight line would result for each loading. However, Figure 6 shows that

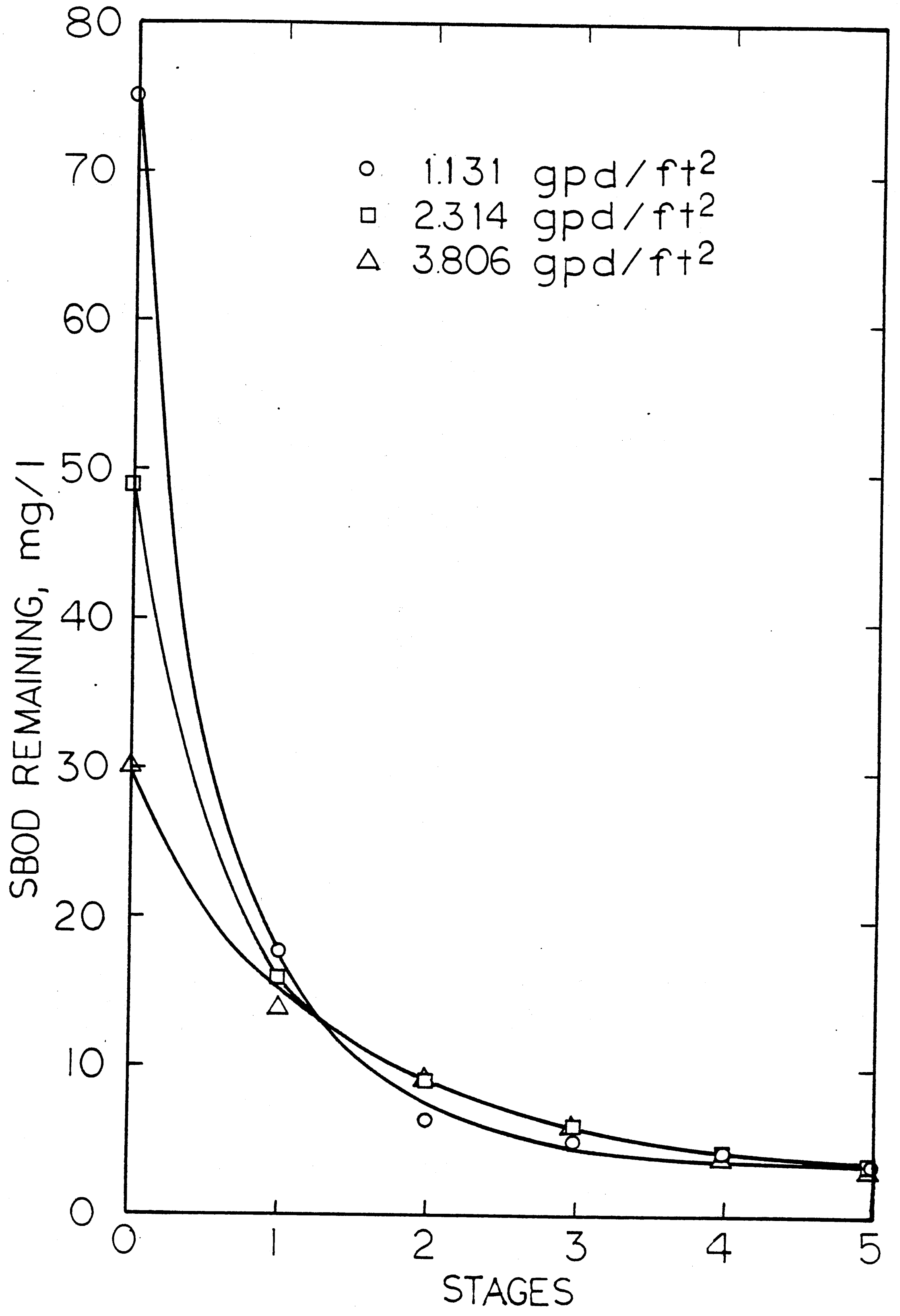

Figure 5. Soluble SBOD remaining per stage

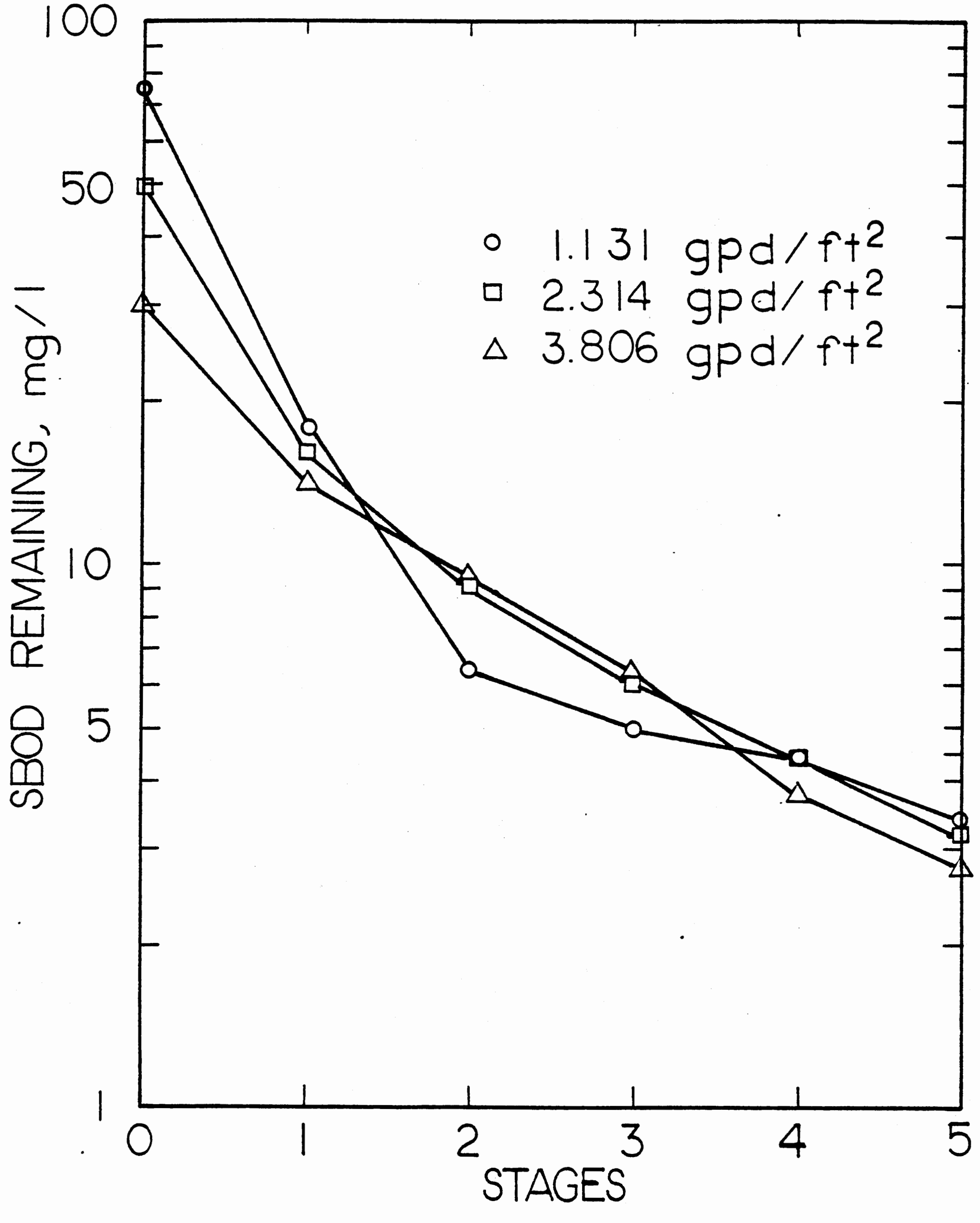

Figure 6. Semi-log plot of soluble BOD remaining per stage.

the BOD removal kinetics, by stages, can be approximated by two separate first order rates. Thus, in order to use a first order kinetic design approach, one kinetic constant must be applied to the first stage and a second kinetic constant applied to the remaining stage.

By using the second order kinetic design approach, Figure 7 shows the reciprocal of the BOD concentration plotted against detention time. It appears that the first-condition plots as a straight line but the second and third conditions do not. If the second order kinetic design approach is correct, all conditions should form straight lines. Thus, the second order kinetic design approach is not suitable for the RBC process.

Kornegay and Andrews, Schroeder, Friedman, and Eckenfelder's expressions are based upon the removal rate as a function of substrate concentration. This relationship is shown in Figure 8. The data is very scattered and the correlation coefficient (R) is low (R = 0.621).

Figure 9 shows the same data used in Figure 8 except that the specific substrate utilization rate is shown as a function of specific loading (FS_i/A). It is based upon Kincannon and Stover (K/S) model. It is seen that much less scatter occurs. Actually, very little scatter occurs below a loading of 1.5 lbs SBOD 5/day/1000 ft^2.

To calculate the specific loadings and specific substrate utilization rates, the influent substrate concentration S_i, was taken as the influent SBOD for the entire RBC. However, the effluent substrate concentration, S_e, was taken as the effluent from any stage under consideration. The area, A, is the 1000 ft^2 of surface area under consideration (6).

The concept of total organic loading is the combination of

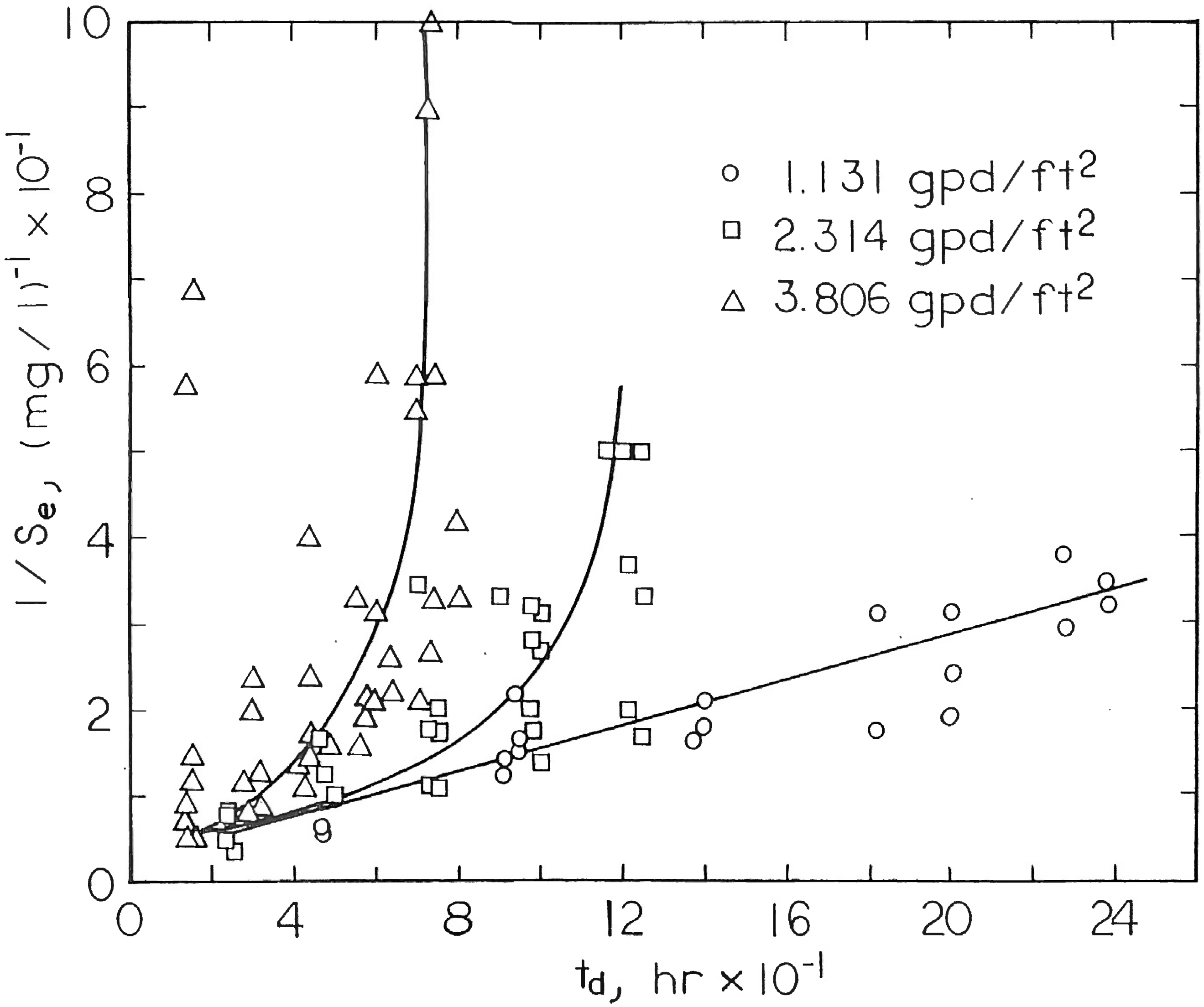

Figure 7. Reciprocal soluble BOD remaining versus detention time.

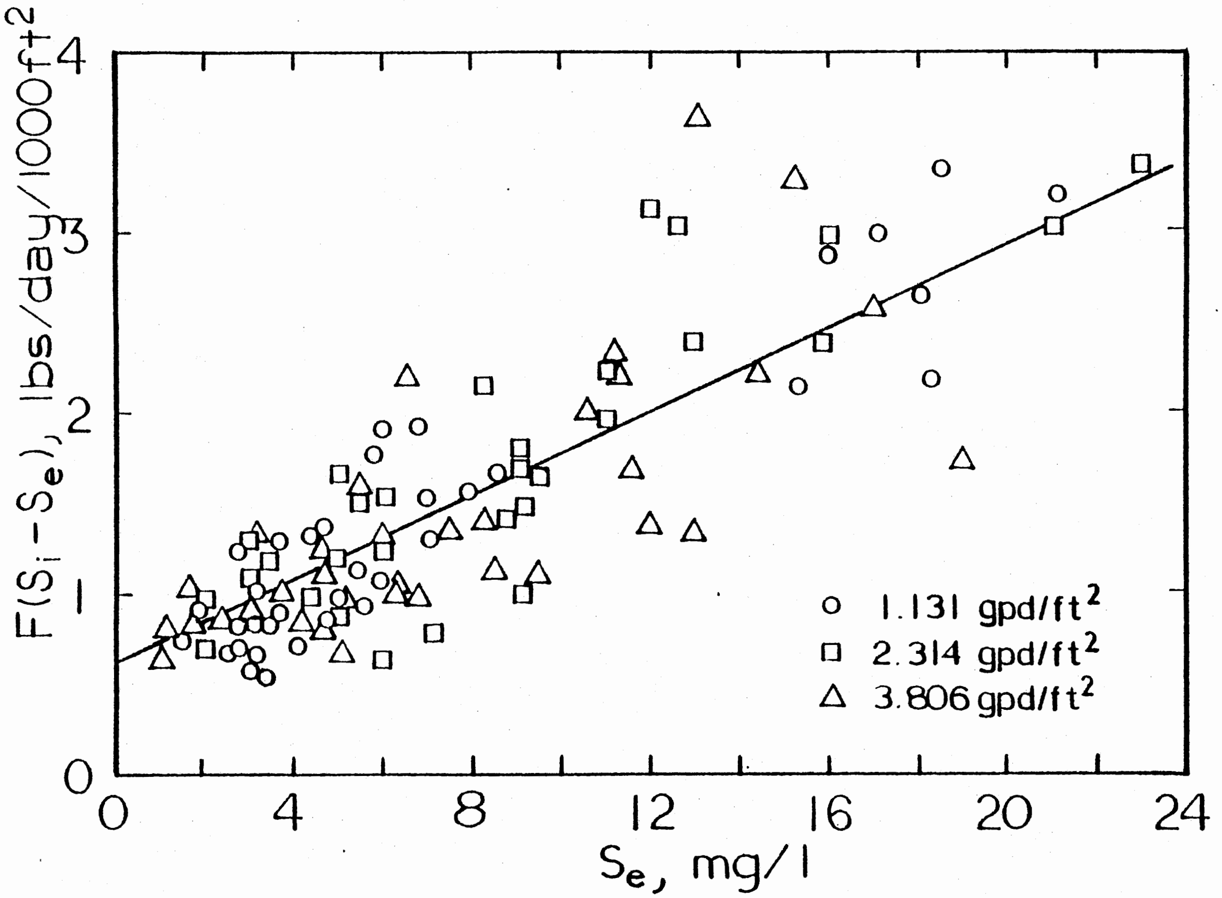

Figure 8. Specific utilizational rate versus substrate concentration

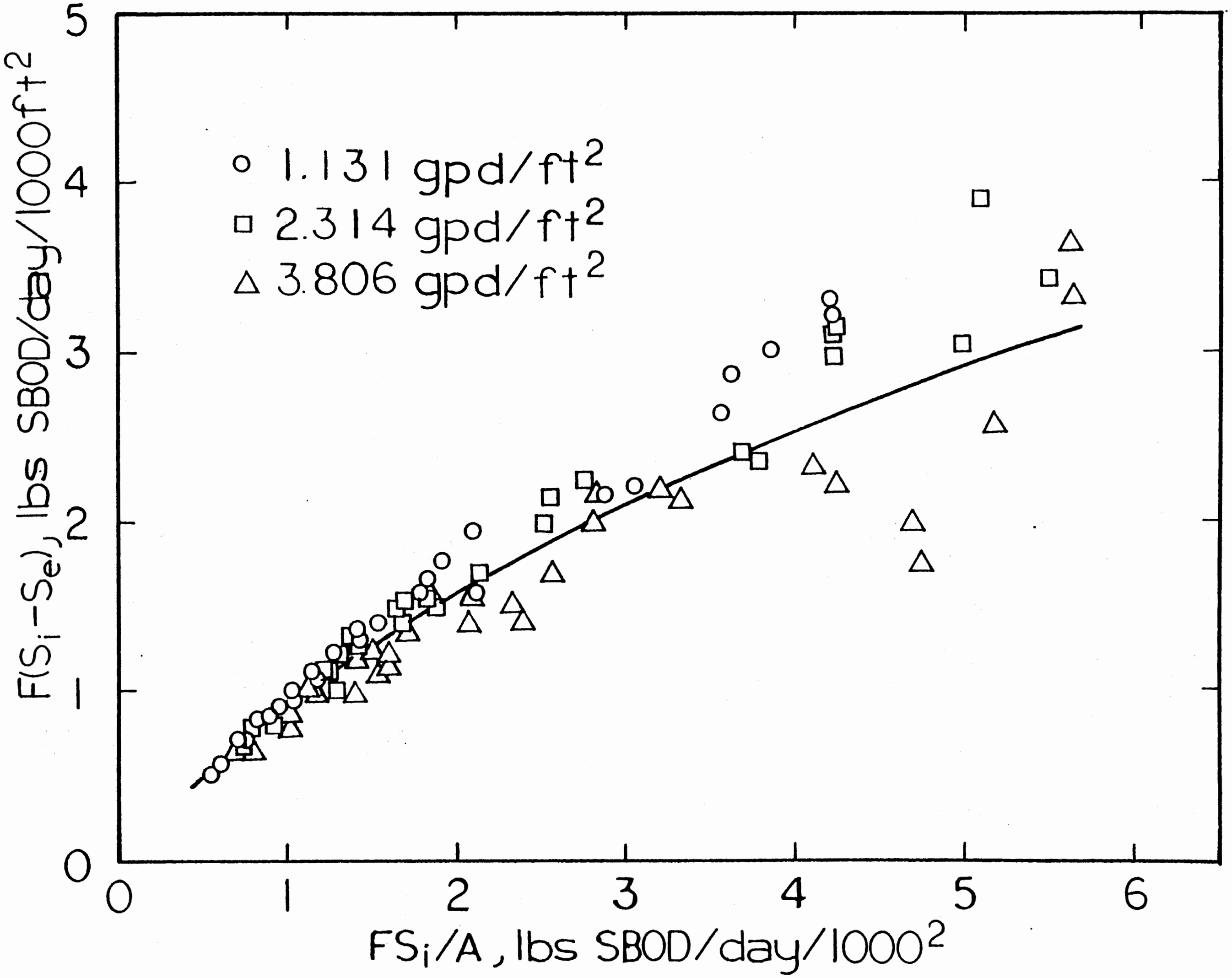

Figure 9. Specific substrate utilization rate as a function of loading

hydraulic flow rate and organic concentration. One advantage of the organic loading concept is the capability to obtain a better prediction of the substrate removal and treatment efficiency at any loading condition.

Figure 10 shows a semi-log plot of the same relationship in Figure 9. Again, this figure indicates that very little scatter occurs below a loading of 1.5 lb SBODs/day/1000 ft^3. The amount of BOD removed per lb of BOD applied begins to significantly decrease at a breaking point of 1.5 to 2.0 lbs BOD/day/1000 ft^2. It shows more readily in Figure 11 than in Figure 10 and, beyond these loading conditions, the removal capabilities decrease. Also, it indicates that first order kinetic is not suitable for RBC process.

The information shown in Figure 9 and 11 can be translated into a relationship of treatment efficiency as a function of a given RBC treating municipal wastewater at any particular loading rate desired, irrespective of the reaction kinetics (zero, first or second order).

Figure 12 shows the reciprocal plot and the determination of the K/S constants. The linearity of the data points indicates that it is Monod kinetics. The kinetic constants were found to be

$$U_{max} = 6.2$$

$$K_B = 5.9$$

By using the FMC data with loadings less than 2 lbs. BOD/day/1000 ft^2 on any one stage, the K/S kinetics constants are determined to be $U_{max} = 5.5$, and $k_B = 5.7$. Also Process Application have found that the Govalla data gives a $U_{max} = 6.0$ and $k_B = 6.1$ (19). The slight variation could be

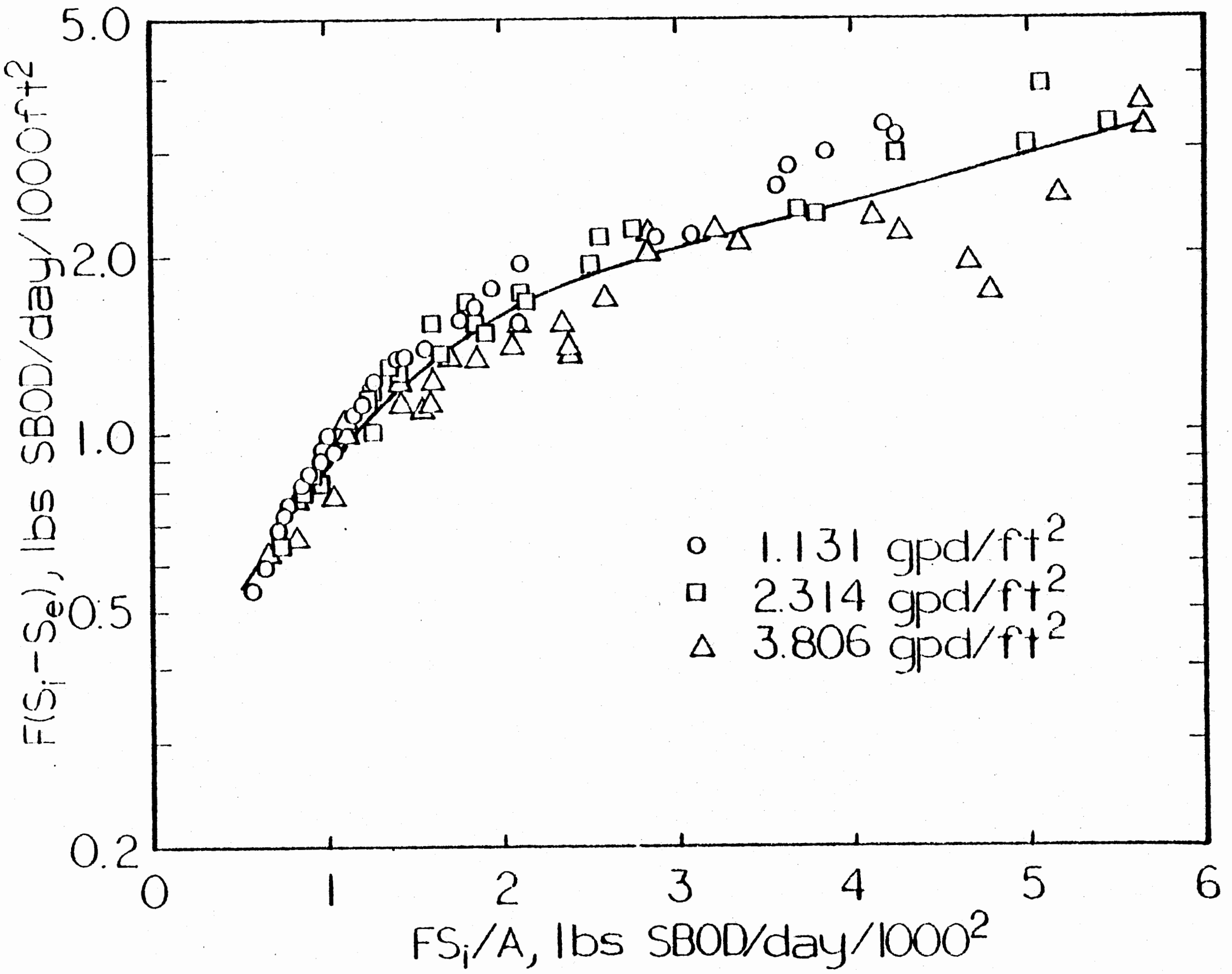

Figure 10. Semi-log relationship of soluble BOD removal (lbs/day/1000/ft^2) as a function of soluble BOD applied.

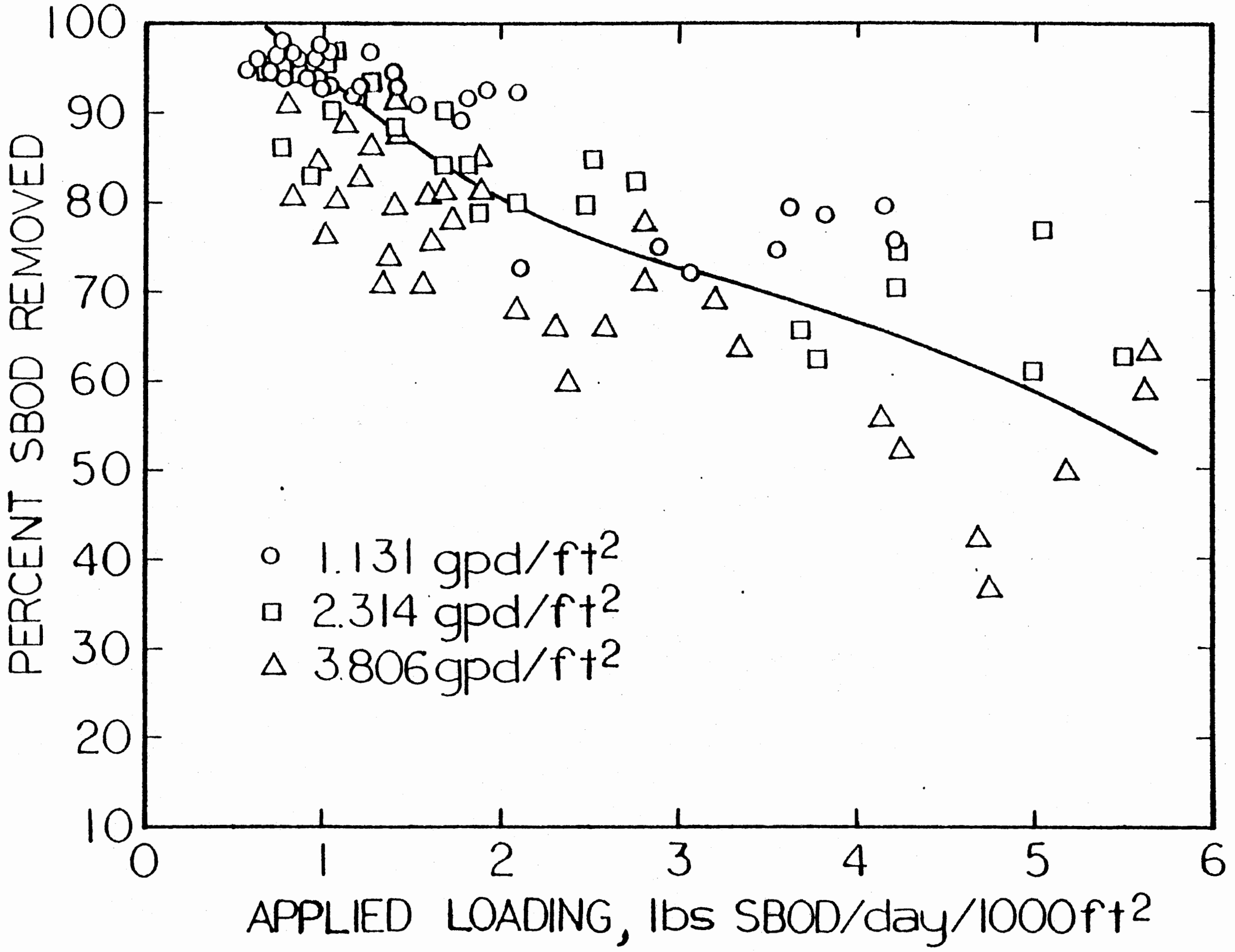

Figure 11. Percent soluble BOD removed as a function of applied loading in lbs/day/1000 ft^2.

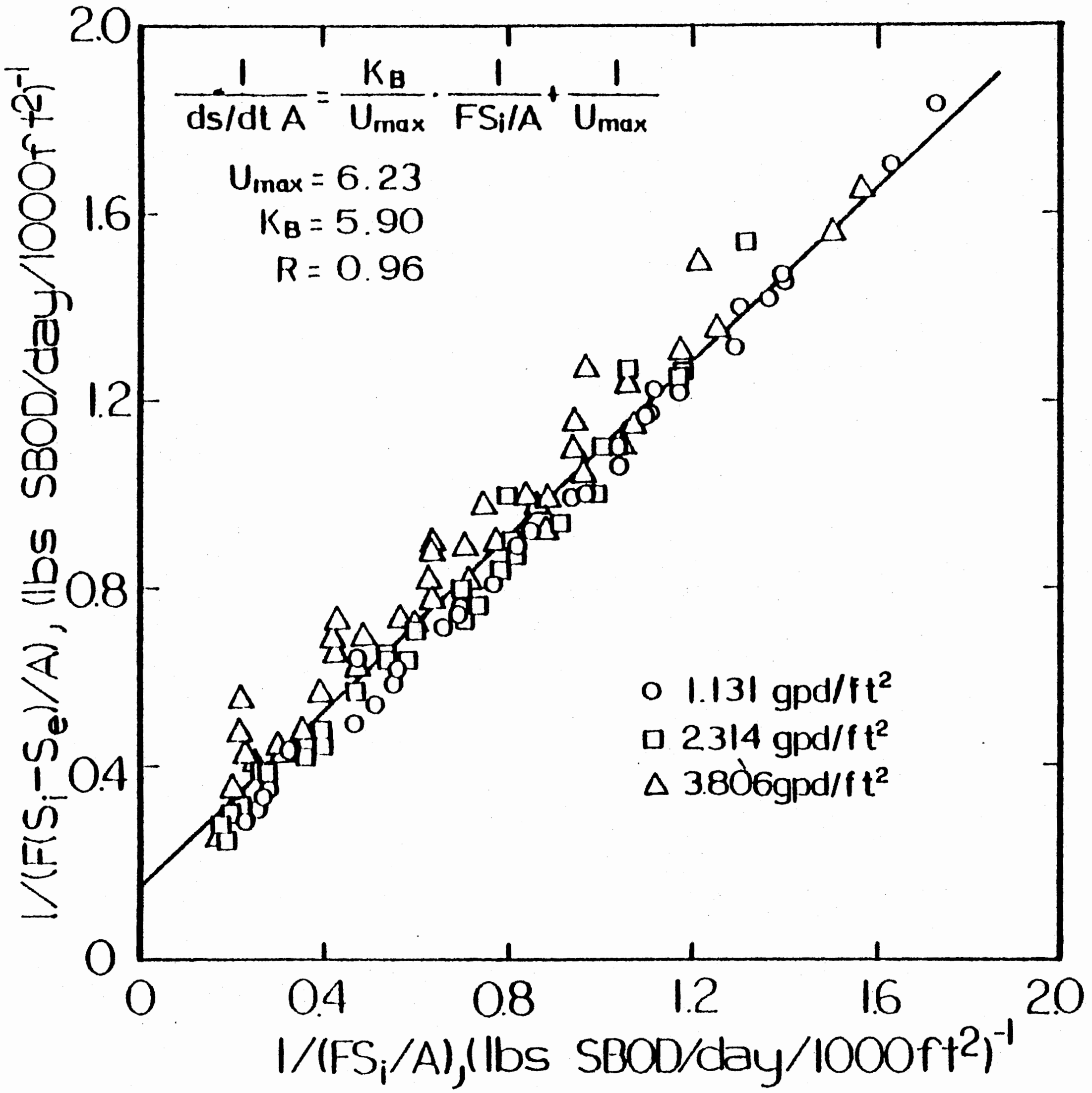

Figure 12. Reciprocal plot of soluble BOD removed verse soluble BOD applied.

due to the differences in the conditions in which data was obtained or due to the variations in the wastewater. The above data indicate that K/S model will be a more conservative design model for the RBC scale-up process. It was found that the 1.0 meter pilot unit has the same biokinetic constants as a full scale RBC if loadings below 2 lbs. BOD/day/1000 ft^2 are applied to the RBC (19). This important finding shows that the 1.0 meter pilot unit can be used for treatability studies without worrying about scale-up.

Figure 13 is a plot of SCOD removal as a function of respective stages on semi-log paper. The removal efficiency ranged from 87 to 68 percent. Figure 14 is a plot of the same relationship as Figure 13, but is in terms of TOC removal. The removal efficiency ranged from 63 to 42 percent. Since the linearity of the data points obtained from the Kincannon and Stover model was more consistent for the SBOD values than for either the SCOD or TOC values, the SBOD is a better RBC design parameter for treating municipal wastewater.

Figure 15 and Figure 16 show the reciprocal plot and determination of the K/S constants in terms of SCOD and TOC, respectively.

$U_{max_{SCOD}} = 8.8$, $K_{B_{SCOD}} = 9.6$

$U_{max_{TOC}} = 0.7$, $K_{B_{TOC}} = 0.8$

By plotting the lbs of solids produced as a function of lbs BOD removed in Figure 17, the biokinetic constants, true yield (Y_t) and decay constant (k'_d) were determined.

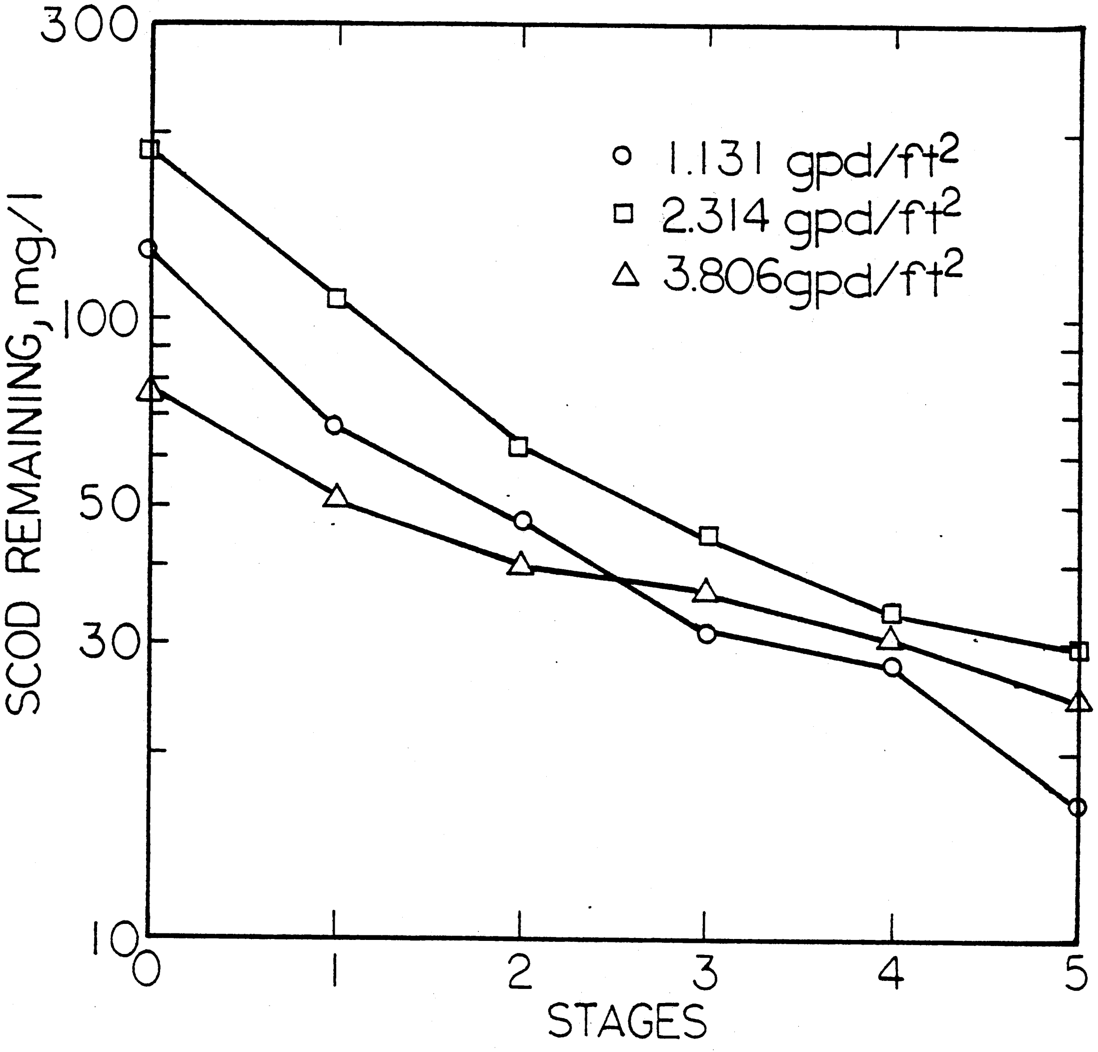

Figure 13. Semi-log plot of SCOD remaining per stages.

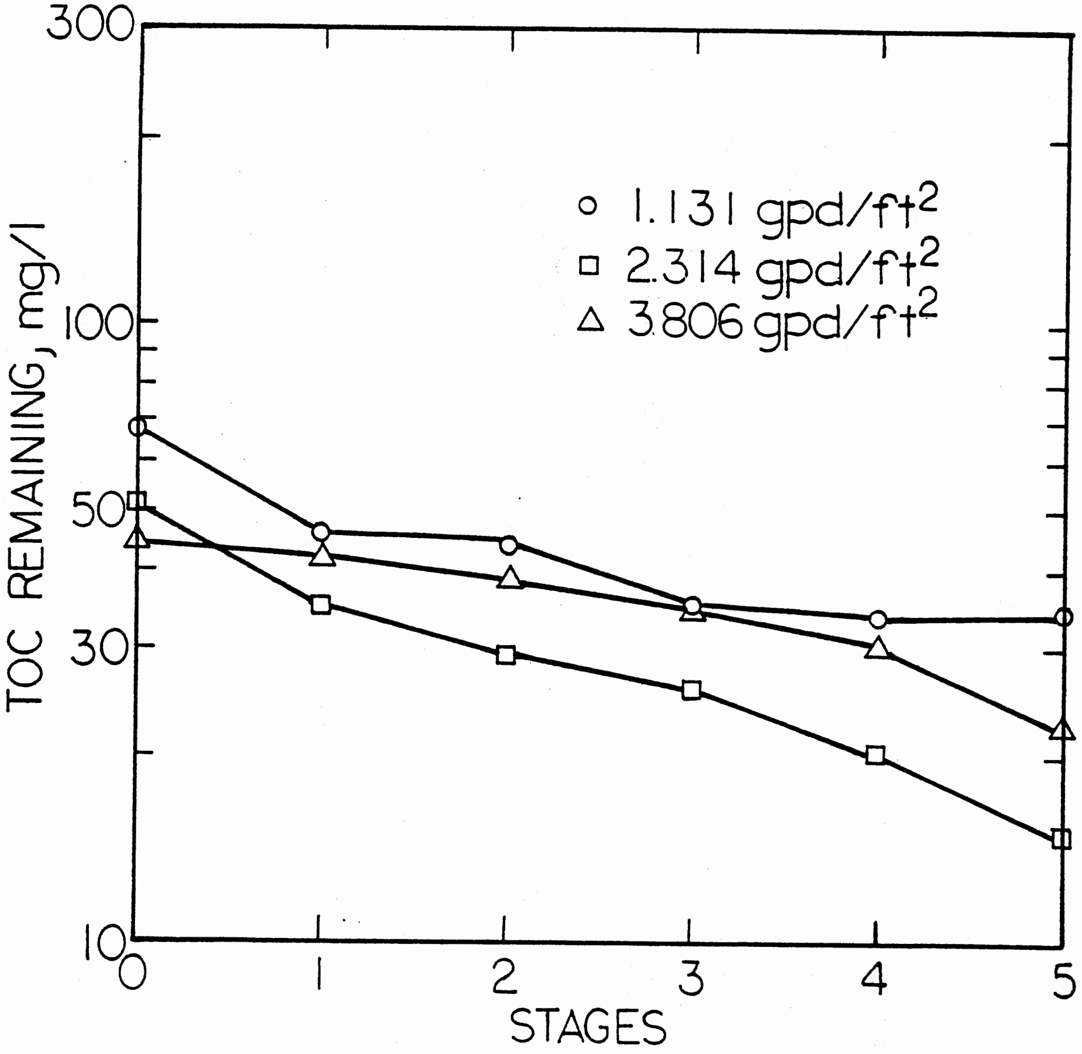

Figure 14. Semi-log plot of TOC remaining per stages.

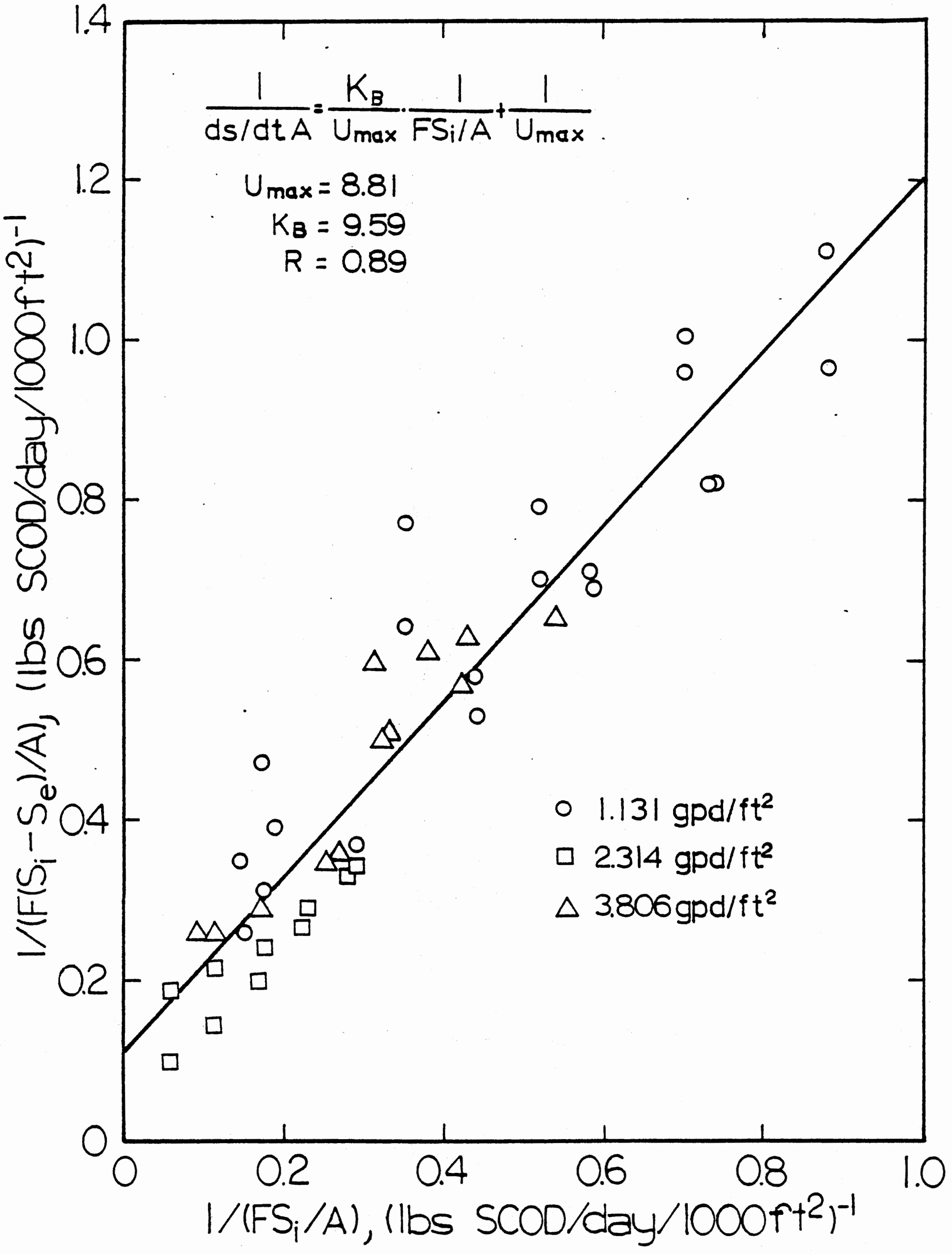

Figure 15. Reciprocal plot of soluble COD removed versus soluble COD applied.

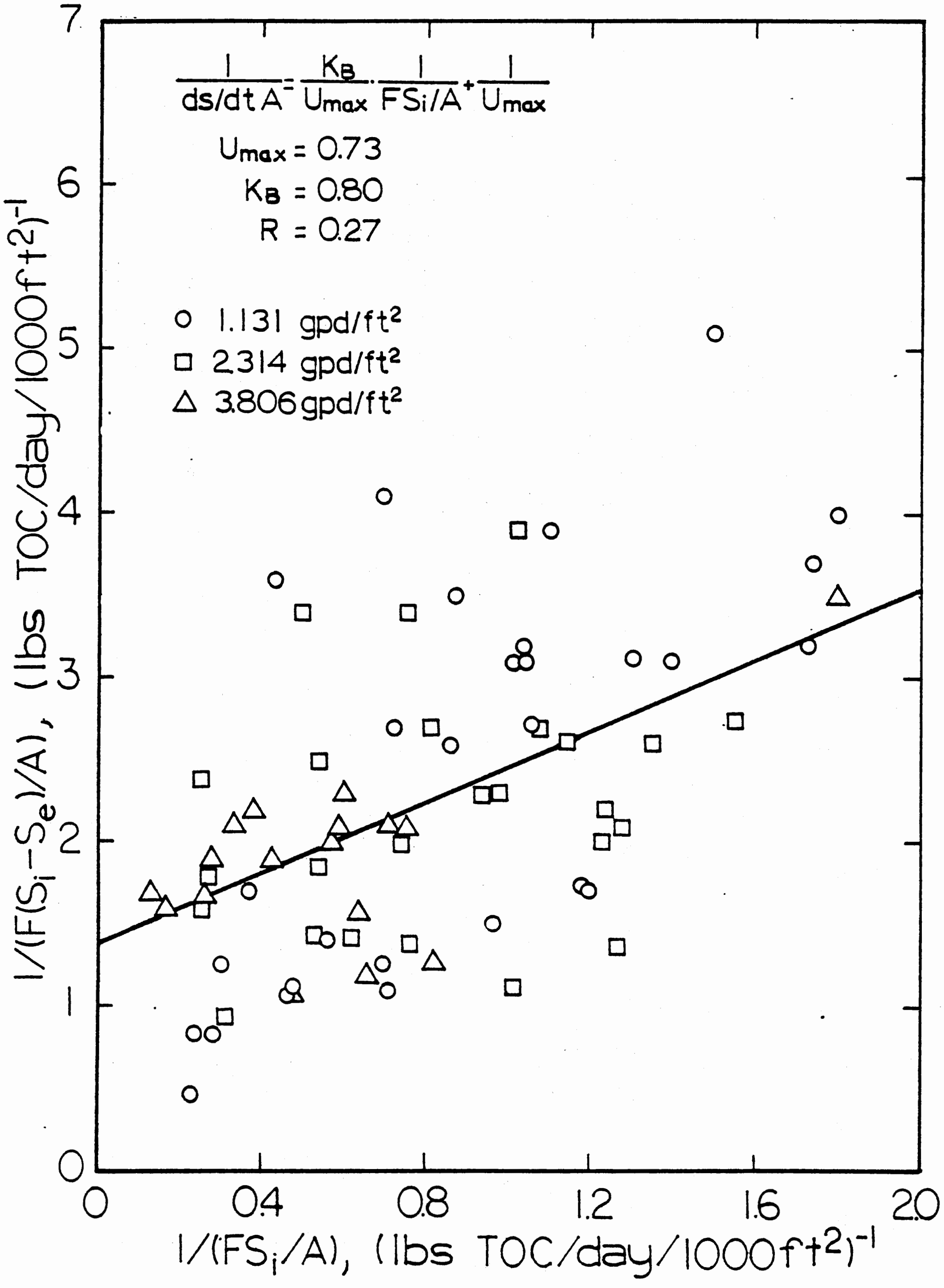

Figure 16. Reciprocal plot of TOC removed versus applied TOC loading

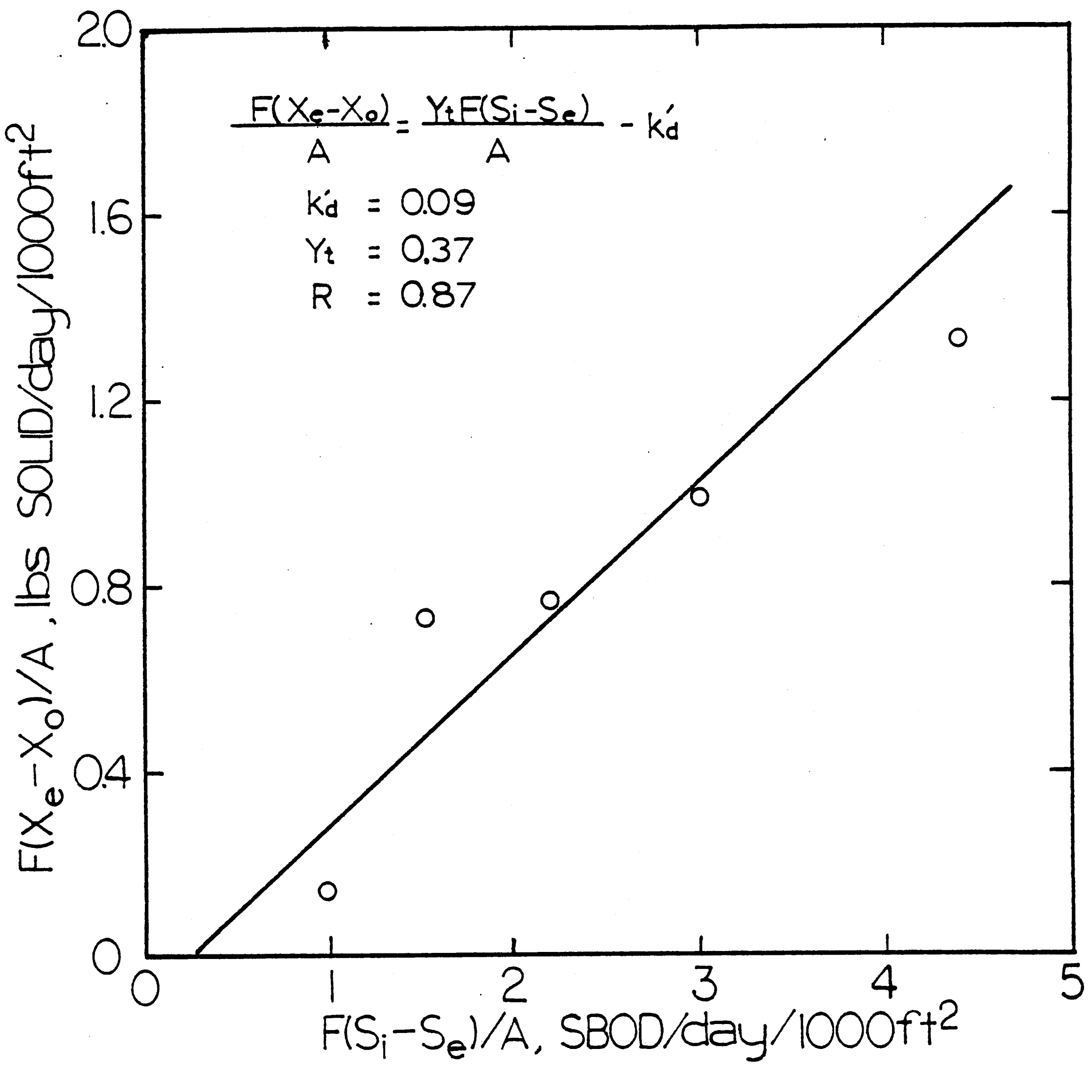

Figure 17. Determination of Y_t and k'_d for RBC.

Y_t = 0.37 lbs solids/lb SBOD removal

k'_d = 0.09 lbs solids/day/1000 ft^2

Y_t and k'_d must be determined to calculate the amount of the sludge that will be produced.

Nitrification

Figure 18 shows a plot of ammonia-nitrogen remaining versus stages, and Figure 19 shows a semi-log plot of the same relationship. The removal efficiency ranged from 39 to 98 percent. Figure 20 shows the nitrite-nitrogen produced against stages and a plot of the same data is on semi-log paper in Figure 21. Figures 18, 19, 20 and 21 provide nitrification data for the three hydraulic flow rates studied. It is shown that nitrification occured at all three flow rates, and it began at different stages for each flow rate. In order to determine the organic loading at which nitrification began, a plot of SBOD remaining against stages is also shown on Figures 18, 19, 20, 21. It was found when nitrification occured, the organic loading on a single stage was reduced to 0.85 lbs. BOD/day/1000 ft^2. This is shown at all three hydraulic flow rates. Also, from the obtained nitrification data, the nitrate-nitrogen production rate was found to be 0.15 lbs./day/1000 ft^2.

Figure 22 shows the specific NH_3-N utilization rate as function of specific NH_3-N loading. However, the data used for this analysis was only for when nitrification occured. The NH_3-N removal decreases as NH_3-N loading rate increases and, when the applied NH_3-N applied approaches higher and higher values, the NH_3-N removed approaches a maximum value where further increase in NH_3-N applied caused no further

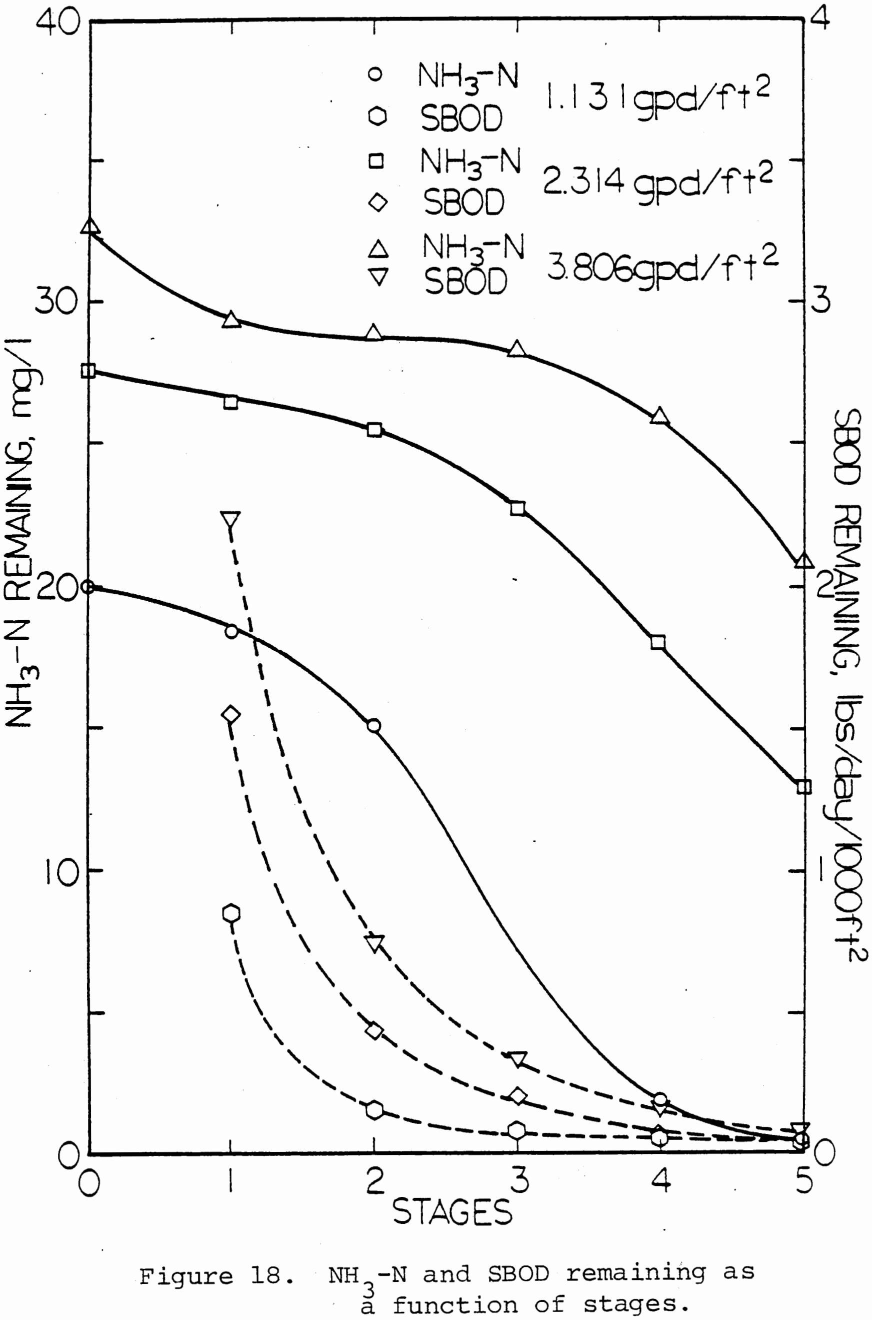

Figure 18. NH_3-N and SBOD remaining as a function of stages.

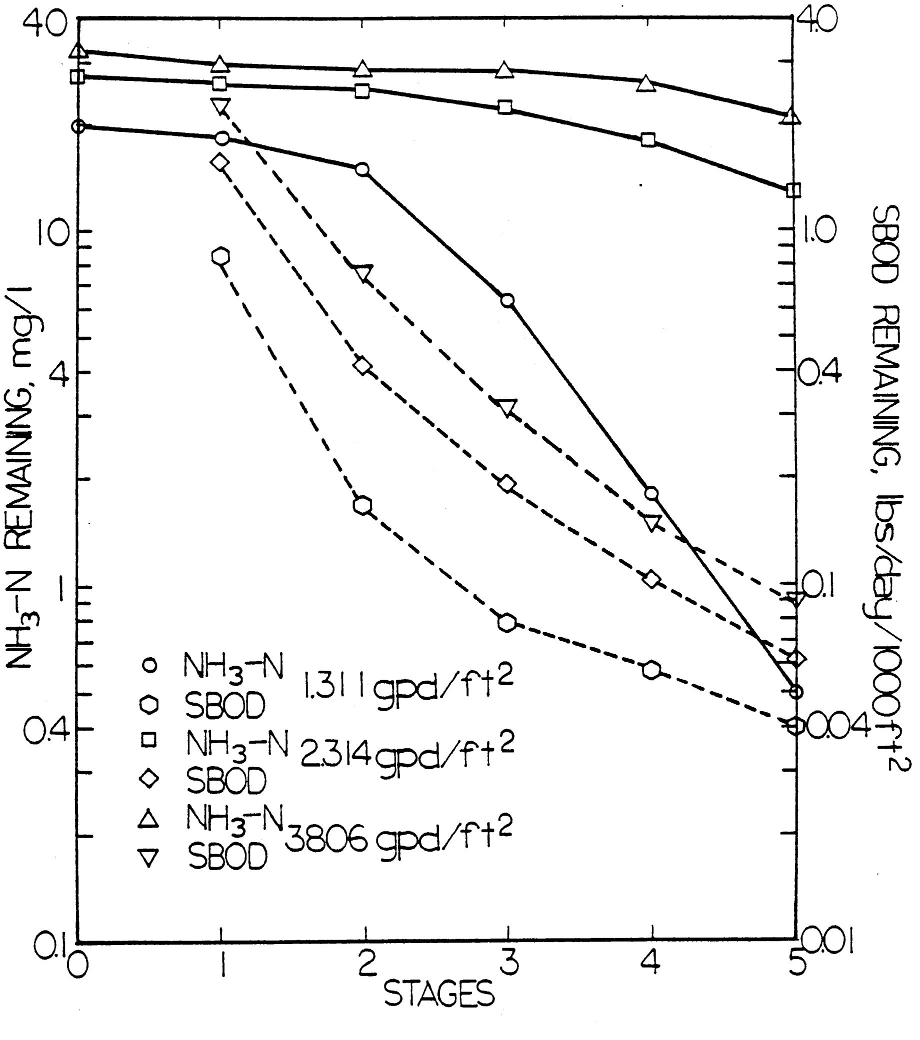

Figure 19. Semi-log plot of NH_3-N and SBOD remaining as a function of stages.

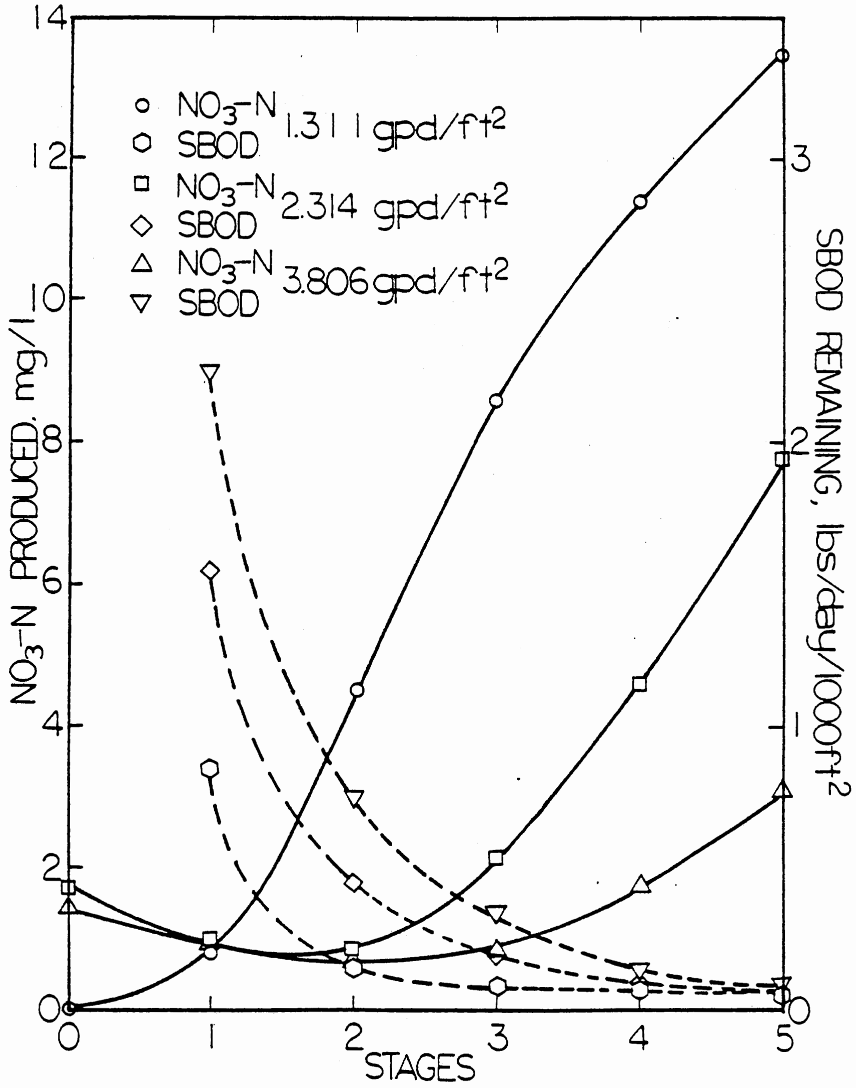

Figure 20. NO_3-N produced and SBOD remaining as a function of stages.

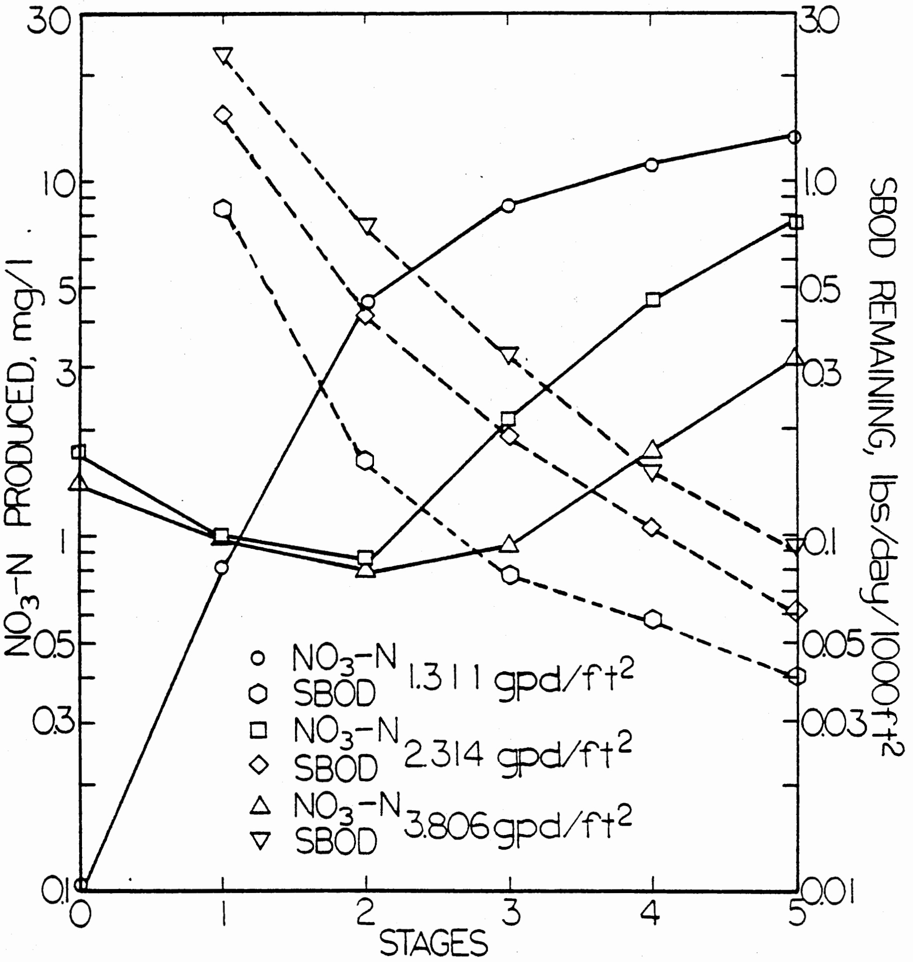

Figure 21. Semi-log plot of NO_3-N produced and SBOD remaining as a function of stages.

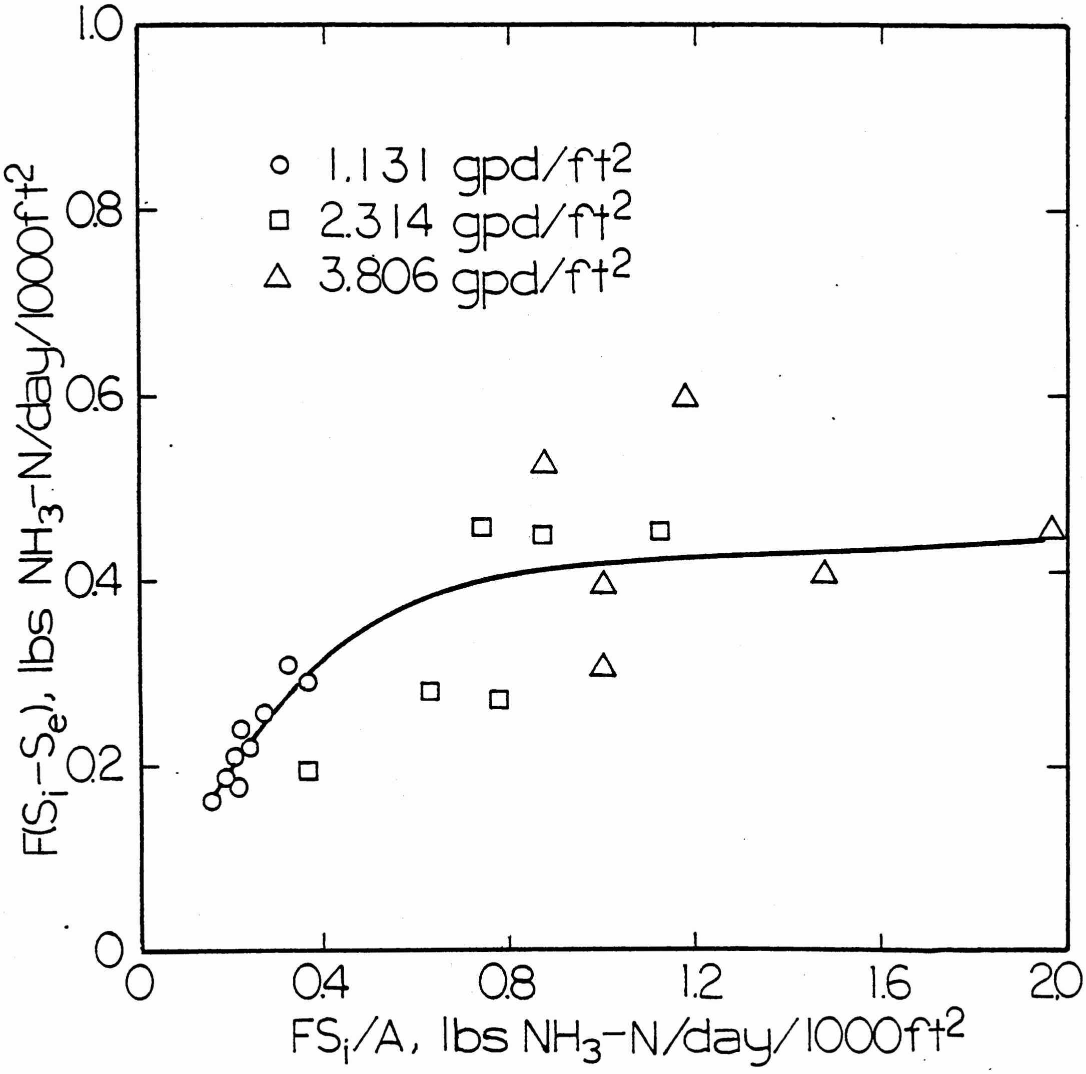

Figure 22. Specific substrate removal as a function of applied loading.

increase in NH_3-N removed. The RBC will then no longer be considered as a desirable process for the ammonia-nitrogen removal. The data shows little scattering. When loading is below 0.35 lbs/day/1000 ft^2, and it shows the capability to obtain 98 percent removal efficiency.

The relationships shown in Figure 22 can be fitted with a hyperbolic function similar to the "Monod equation" as follows:

$$N_R = \frac{N_{R(max)} N_o}{k_S + N_o}$$

where

N_o = Applied NH_3-N loading in lbs NH_3-N/day/1000 ft^2

N_R = NH_3-N removed in lbs NH_3-N/day/1000 ft^2

$N_{R(max)}$ = Maximum NH_3-N removed in lbs NH_3-N/day/1000 ft^2

k_S = saturation constant.

This equation can be rearranged to make a linear plot as follows:

$$\frac{1}{N_R} = \frac{k_S}{N_{R(max)}} \cdot \frac{1}{N_o} + \frac{1}{N_{R(max)}}$$

$N_{R(max)}$ and k_S can be determined from the slope intercept. Figure 23 shows the reciprocal plot and the biokinetic constant for NH_3-N removal were found to be

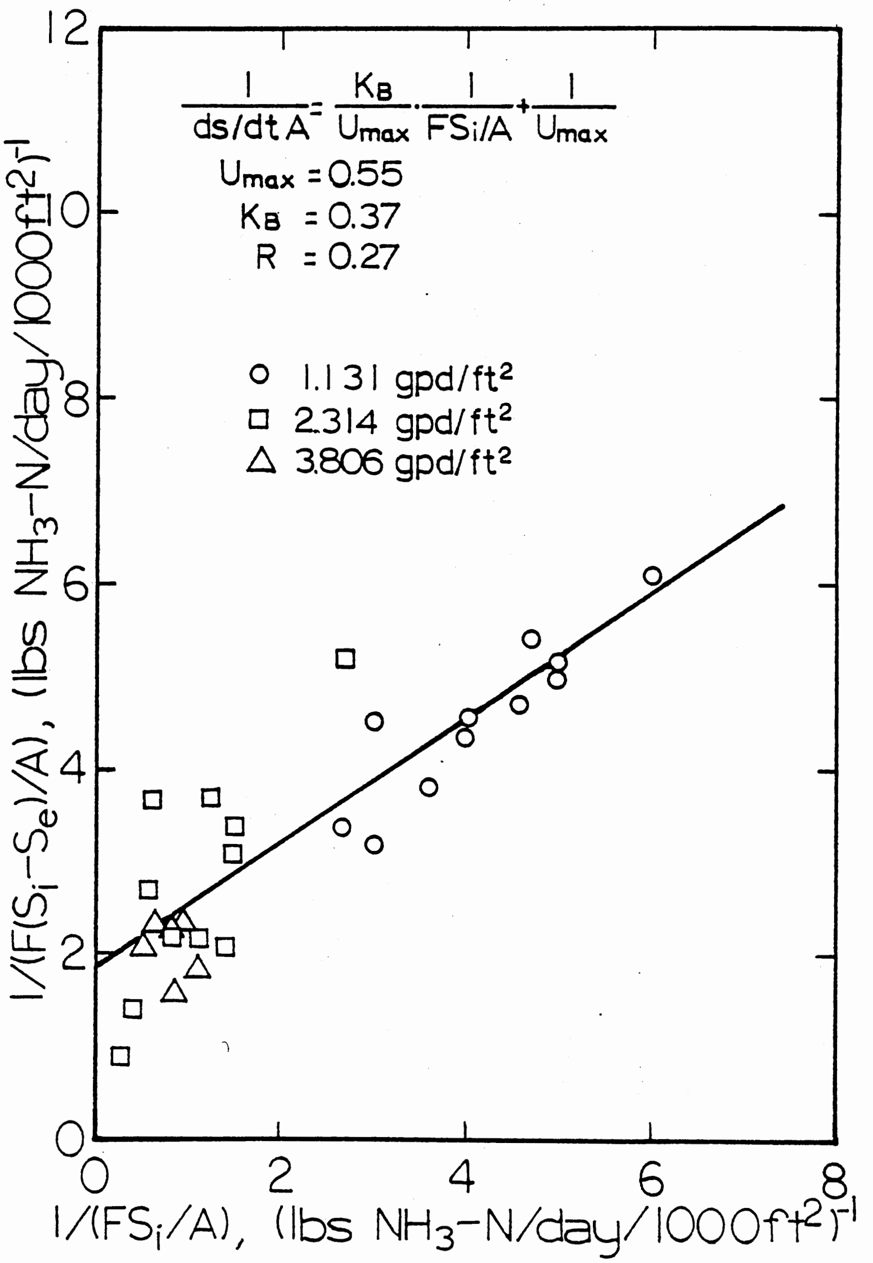

Figure 23. Reciprocal plot of NH_3-N removed as a function of applied NH_3-N loading.

$N_{R(max)} = 0.55$

$k_S = 0.37$

Nitrification needs to be studied in more detail. However, these findings provide a means to predict when and at what rate nitrification will occur and the limitations for RBC scale-up design.

CHAPTER V

CONCLUSION

Based on the RBC pilot study, the following conclusions may be drawn:

1. The Kincannon and Stover (K/S) model provides a more conservative design approach for the RBC process treating municipal wastewater.

2. The RBC process achieves high carbonaceous removed at a loading below 2 lbs. SBOD/day/1000 ft^2, and, above this loading rate, the removal rate will decrease.

3. When municipal wastewater is loaded at a rate of 2 lbs SBOD/day/1000 ft^2 or less, the 1.0 meter diameter pilot unit can be used directly for scale-up design without oxygen limitation.

4. SBOD has shown to be a better design parameter over SCOD and TOC for the scale-up design treating municipal wastewater.

5. Nitrification occurs when the organic loading on a single stage was reduced to 0.85 lbs. SBOD/day/1000 ft^2.

6. The RBC process achieves high performance on nitrification at a loading rate below 0.35 lbs NH_3-N/day/1000 ft^2.

7. Nitrate-nitrogen production rate was found to be 0.15 lbs/day/1000 ft^2.

8. The RBC process can either be used as a biological secondary wastewater treatment process or to up grade an existing plant for carbonaceous removal and to achieve nitrification.

CHAPTER VI

SUGGESTIONS FOR FUTURE STUDY

Based on the findings of this study, the following recommendations are made for future studies involving the RBC and municiple wastewater.

(1) Compare treatment efficiencies with the same wastewater at different rotational speeds

(2) Conduct a more detailed study on nitrification.

(3) Compare the different temperature effects on carbanaceous removal and nitrification.

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