

THE TREATMENT OF ALCOHOL WASTEWATER BY ROTATING  
BIOLOGICAL CONTACTORS (RBC)

By

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Dedicated to my parents,  
Bill and Marie Qualls

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## CHAPTER I

### INTRODUCTION

Since the oil embargo of the early 1970's, the United States has become more aware of the energy shortage. Alternative energy sources are being explored in more detail and more money from both private and public sources are being invested in these ideas. The alcohol fuel industry is now being considered as a partial solution to the energy shortage and as a potential new agricultural industry. The United States is rich in grains used for feedstock for the ethanol production industry. Corn, milo, and wheat are the major grains used in the alcohol production industry (1, 2).

There are three broad types of ethanol plants. The first type produces anhydrous ethanol primarily used for commercial blending of gasoline. The second type of plant produces 180 to 190 proof ethanol. This alcohol is dried to 200 proof and mixed with gasoline to upgrade the octane level in gasoline. The third type includes the small farm units that produce ethanol of 160 to 190 proof. This is primarily used for direct fuel use.

The wastewaters from the alcohol production process are high strength and require characterization and treatability data so that the best and most economical means of treatment can be employed. Present treatment of this wastewater consists of screening-dewatering of the grain solids

and evaporation of the liquid fraction. This evaporation process is very energy intensive and time consuming.

A schematic representation of a flow diagram for the larger fuel alcohol production facilities is shown in Figure 1. The grain is ground, mixed with water and enzymes, and then cooked for the preparation of the starch for its conversion to sugar. During saccharification, the next step, different enzymes act on the exposed starch molecules to convert them to fermentable sugars. Ethanol is produced from the sugars by yeast. The product of fermentation, beer, contains about 10 to 12 percent ethanol. The ethanol is then separated prior to distillation if packed distillation columns are used (3).

For each bushel of grain used, 30 to 35 gallons of water are required. The products of fermentation include 17 pounds of carbon dioxide, 2.5 gallons of anhydrous ethanol, and 25 to 30 gallons of stillage containing the grain residue at 6 to 9 percent solids content (3).

The biological treatment option investigated during these studies was the rotating biological contactor (RBC). This treatment process provides a treated effluent that can be recycled back to the plant, used for irrigation or discharged. This process is relatively easy to operate and produces a good quality effluent.

After analysis of the data and the determination of the biokinetic constants, the Kincannon-Stover model for RBC scale-up and design was evaluated (4). The Kincannon-Stover model is based on the concept of concentration coupled with the hydraulic surface loading rate to get the total loading rate applied to a system. This model was based upon trickling-filter work introduced in the early 1970's by Cook and Kincannon

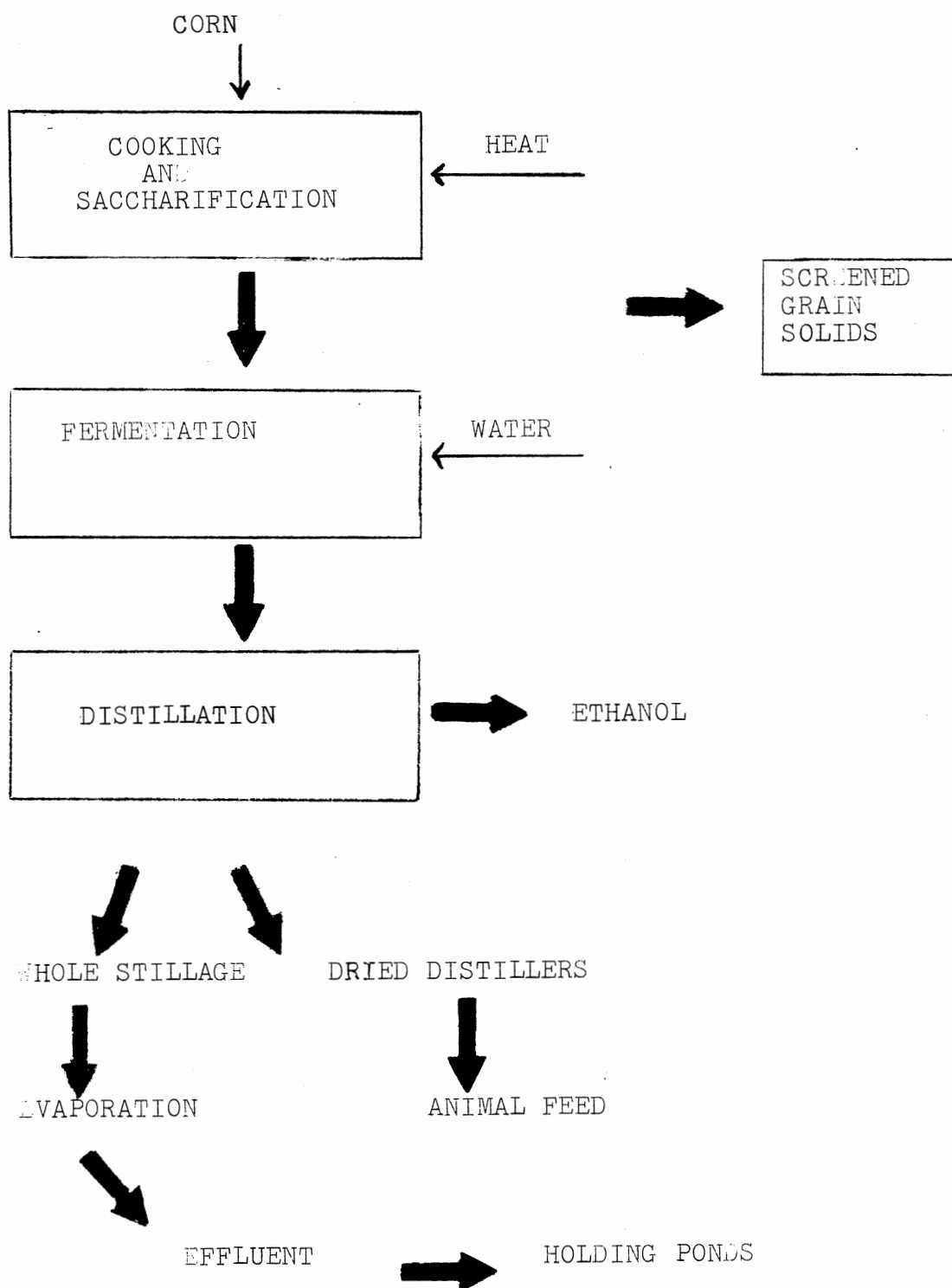


Figure 1. Process Flow Diagram (Larger Alcohol Plants)

(5). This work was used and applied to the RBC process by Stover and Kincannon (4).

## CHAPTER II

### LITERATURE REVIEW

#### History of RBC Process

The RBC is a relatively new process in the United States. The "rotating drum" goes back to the 1920's. Investigators in both the United States and Germany experimented with using rotating wood surfaces (6). The RBC systems as presently used evolved from the research work of Hartman and Popel in West Germany in 1958 (6).

The RBC system was manufactured in 1959 by J. Conrad Stengelin. These systems were two to three meters in diameter and made of polystyrene (6). The first commercial installation went on a stream in West Germany in 1960 (6).

After 1960, further development of the RBC stopped in Europe. But between 1960 and 1965, in the United States, Allis-Chalmers did much for the development of rotating discs. In 1967, Allis-Chalmers began their first field testing of the RBC at a dairy plant. Wastes from the dairy process was fed to the unit to determine its capabilities under actual field conditions. The test unit succeeded in achieving 80 percent COD reduction of loadings as high as 400 pounds COD/day/1000 ft<sup>3</sup> (6).

Until 1972, the polystyrene discs were not compact and the overall process was simply too expensive. Then came an important breakthrough: the development of a more compact disc, one with much more surface area for a given volume. Autotrol now came out with an arrangement of 1/16

inch-thick polyethylene sheets with a 1/2 inch space separating them filled with a honeycombed polyethylene configuration.

In addition to the previously mentioned work with municipal wastewater, there has been much work on the RBC as an industrial wastewater treatment possibility. Some of the commercial wastes studied included cheese, bakery, winery, yeast, and slaughterhouse waste. The effectiveness of the RBC in treating slaughterhouse wastes have been reported by Stover, Chittenden and Wells, and Stover and Kincannon (7, 8, 9). Stover observed a two-phase removal rate corresponding to the high removal in the first stage compared with lesser removal in the latter stages. Stover and Kincannon (9) used a synthetic waste and a slaughterhouse waste (organic and hydraulic loadings) to determine their influence on removal characteristics. Their conclusions, found in this study, were that the RBC performance is a function of the total organic loading. They also found that much higher removal efficiencies could be found using synthetic wastewater instead of the slaughterhouse wastewater. Refinery wastes have been treated with the RBC with removal efficiencies as great as 60 to 75 percent BOD removal (10).

The RBC has been used in tertiary treatment by several researchers. Noss and Miller (11) described the use of the RBC for secondary treatment and recarbonation following low level lime addition for phosphorous removal. Cheung and Krauth (12) investigated the effects of nitrate concentration in RBC's.

The industrial wastewater field is relatively new with the use of the RBC. In addition to fields previously mentioned, there have been other researchers such as Chesler and Eskelund (13) who evaluated RBC's for the treatment of explosives manufacturing wastes. Acid mine

drainage wastes were treated in pilot scale studies by Olem and Unz (14). O'Shaughnessy et al. (15) applied RBC's to oil shale retort wastewater. Borghei (16) described treatment of the effluent of a glucose-production plant using a RBC packed bed.

### Process Description

The RBC process is an aerobic, continuous flow, wastewater treatment system designed for municipal and many industrial wastewaters. The RBC converts the influent feed that contains soluble biodegradable organics into biomass and carbon dioxide. The excess biomass generated by these units is separated by a secondary clarifier.

Wastewater from the primary clarifier is introduced into the tank containing a series of disks mounted on a horizontal shaft. These discs (media) are mounted in such a way that 40 percent of the media are submerged in the wastewater at all times. As the discs rotate through the wastewater, a thin film of biomass begins to grow on the disks.

The film of biomass is responsible for the removal of the biodegradable organic wastewater constituents. The media are continually rotated so that the biomass film is alternatively exposed to fresh wastewater and air. If the rotating stops, the film will dry out and form a hard layer on the discs. Upon rewetting of the film, sloughing can occur.

The discs are separated by baffles to avoid short circuiting. The heaviest growth and greatest substrate removal occurs on the first stage and lessens with each succeeding stage.

The inner film becomes anaerobic and turns black. Shearing forces along with these anaerobic conditions result in the sloughing of the

biomass. These sloughed solids are removed from the RBC tank and passed on to the final clarifier.

Sack et al. (17) found that in a four-stage RBC system, the overall appearance of the sludge ranged from a black stringy stage to a greenish-brown slime on the latter stages.

According to several sources (Torpey (18), Prescod (19), Sack (20), and Antonie (21)), the development of the types of microbes on the media is dependent on the type of wastewater entering each stage and the amount of nutrients the microbes see. The basic microbial makeup of the RBC system is reported to be as follows:

The predominant organisms including Sphaerotilus and zoogloeal bacteria are present on all disks. Besides these two important kinds, the diversity and abundance of free swimming protozoa (Paramecium, Cyclidium, Ocomonas, Oxytrichia, and Euglena) are present in the first few stages is much thicker than the bacterial slime produced on the later disks ([10], p. 8).

The attachment of the microbes onto the disks is very important to the RBC process. The mechanism of attachment is primarily due to filamentous organisms such as Sphaerotilus. These microorganisms serve as a skeletal system to which other microorganisms can attach (17). The thickness of the biofilm is due to the amount of filamentous organisms present. As the amount of energy source is reduced in each stage, the population of the filamentous organisms decreases. This leads to a thinner biofilm on the disks (21).

### Design Factors

The major dependent design variables are: rotational speed, temperature, organic loading, and hydraulic loading. Each of these will affect the design and operation of the unit.

At residual times less than 100 minutes, the removal of BOD and  $\text{NH}_3\text{-N}$  always decreases as the flow rate increases or the residence time decreases (22). The surface hydraulic rate is usually expressed in gallons per day per square foot ( $\text{gpd/ft}^2$ ). The question of whether the efficiency of a RBC is dependent upon the organic concentration of a waste or the hydraulic flow rate has been debated for many years. In 1971, Cook and Kincannon (5) showed exclusively that the organic concentration of a waste was the deciding factor as to how a trickling filter would perform. Stover and Kincannon (4) presented the same type of conclusions for the RBC. From these papers and conclusions drawn from them, a model for the scale-up of RBC's was presented. This model will be explained further in the preceding sections.

Another important factor affecting treatment efficiency is temperature. The increasing temperature of the wastewater increases the rate of substrate utilization. From a previous study (22), the percentage of BOD removal does not increase much at  $55^\circ\text{F}$  or above.

Nitrification exhibits a greater sensitivity to temperature and hydraulic loading rate. If the hydraulic loading rate is controlled at less than  $1.0 \text{ gpd/ft}^2$ , for municipal wastewaters, the percentage of  $\text{NH}_3\text{-N}$  removed is not greatly influenced by the temperature of the wastewater unless it reaches below  $55^\circ\text{F}$  (22). The temperature of the wastewater affects the amount of dissolved oxygen in the wastewater.

There are several operational problems that can occur with the RBC system. The RBC system performs better in the winter than in the summer at some plants. Low DO levels in the first stages and low pH levels in later stages affected bio-activity.

The rotation of the media through the wastewater not only allows for aeration and mixing, but also provides shearing forces that cause sloughing of excess microbial growth.

The function of the first stage is to remove organic material. Subsequent stages are used to remove ammonia if it is necessary to meet  $\text{NH}_3\text{-N}$  standards.

Wastewater DO levels of one to two mg/l are considered to be minimal to avoid DO limiting conditions. Anaerobic conditions can occur if inadequate  $\text{O}_2$  transfer and mixing occur. The sludge floating and settling in the corners turns black and a distinctive odor begins to be emitted.

The amount of  $\text{O}_2$  that a wastewater requires is dependent on the strength and type of wastewater. The total amount of  $\text{O}_2$  necessary to stabilize a waste is referred to as the ultimate oxygen demand. The ultimate  $\text{O}_2$  demand includes not only the amount of  $\text{O}_2$  required to stabilize the carbonaceous fraction, but also that required to transform microbially  $\text{NH}_3\text{-N}$  to  $\text{NO}_3\text{-N}$ . For untreated domestic wastewater there is little  $\text{O}_2$  demand by the nitrifiers within the first eight days of stabilization.

The  $\text{BOD}_5$  test is indicative of the  $\text{O}_2$  demand by the carbonaceous organisms only. If significant populations of nitrifiers are present, the total  $\text{BOD}_5$  is a poor indicator of the treatment of the system.

Nitrification is the oxidation of  $\text{NH}_3\text{-N}$  to nitrate, and denitrification is the reduction of nitrate to nitrogen gas. Nitrification is used to control wastewater effluent levels of ammonia, but both nitrification and denitrification are used to control total nitrogen levels in the effluent. Usually 5 percent of the oxygen demand is the amount of nitrogen assimilated during oxidation of carbonaceous material (23).

The importance of nitrogen control in wastewater effluents is its impact on receiving streams. As ammonia is oxidized to nitrate, the DO levels are decreased. Nitrate is readily available for assimilation by plant life, causing algal blooms when present in significant quantities. As pH decreases, the rate of nitrification declines. Temperature also affects nitrification by decreasing by 50 percent for every 10°C drop in wastewater temperature below 30°C (3). This value differs from one engineer to another. These values are from average municipal wastewater studies. For example, the nitrification rate at 10°C would be about half that at 20°C. Organic removal rates for the RBC process should decrease 25 percent for every 10°C drop in wastewater temperature below about 30°C (3).

## CHAPTER III

### METHODS AND MATERIALS

#### Test Unit

The small scale rotating biological contactor unit used during this study consisted of a tank constructed of plexiglass which was divided by five baffles to form six stages. Later in the study the first baffle was removed to facilitate better mixing and prevent dead spaces. The baffles had openings at their bases to allow flow throughout the unit. Mounted on the shaft that ran down the center of the unit were polyethylene discs. There were four of these discs in each stage (Figure 2). Each disc was approximately 1/8 inch thick and 6 inches in diameter. This resulted in a total disc surface area of 9.43 square feet for the entire unit. Small plexiglass paddles were inserted between the discs to insure complete mixing and keep the solids in suspension. The final stage contained an overflow weir which directed the effluent into a sample bottle. The volume of the unit was 7.6 liters. Hydraulic flow rates of 0.12 gpd/ft<sup>2</sup>, 0.18 gpd/ft<sup>2</sup>, and 1.20 gpd/ft<sup>2</sup> were used in this study. The alcohol wastewater was pumped up from the floor from a feed bottle and directly added into the front of the first stage. Several types of pumps were employed to achieve the diversity of flow into the unit. A Sigma finger pump and a Cole-Palmer Masterflex tubing pump were used with the most success. The Cole-Palmer pump had a small head on it, and at a high flow rate it wore out the tubing about every two days. The

FLOW (GPD/FT<sup>2</sup>)

0.12

0.18

1.22

ROTATIONAL SPEED (RPM)

8.0

30.0

18.0

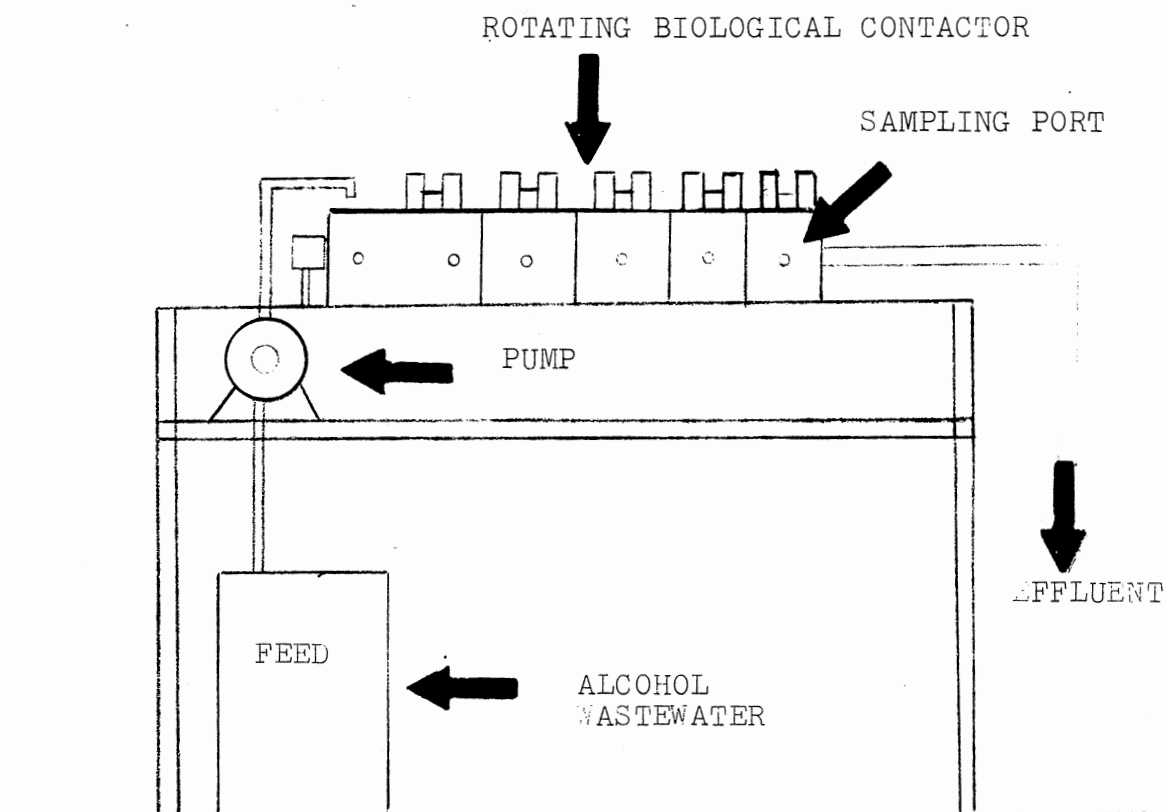


Figure 2. Experimental Apparatus and Operating Conditions

rotational speed of the discs was changed because of a change in motors to drive the unit. The first motor was a Barcol that turned the discs at 8 rpm. It lasted for one month. The next motor tried was a variable speed Cole-Palmer stirring motor in which the worm gear eventually wore out. It turned the discs at 30 rpm. The last motor that was used in this study was a variable DC motor made by the Cole-Palmer Company and it could turn the shaft at 18 rpm without any binding. The shaft had to be replaced after six months due to failure of the metal. The bearings had to be replaced after a few months of constant turning. A center support bearing was placed on the middle baffle for extra support.

#### Alcohol Wastewater

The stillage or wastewater used for these studies was collected from the Oklahoma State University Agricultural Engineers' 200,000 gallons per year capacity fuel alcohol research facility.

Raw wastewater from the alcohol production facility was devoid of essential elements. Nitrogen and phosphorous were added to the feed before it was added to the unit. The amount of nutrients added to the mixture was calculated by the ratio of BOD:N:P  $\rightarrow$  100:5:1. Nitrogen was added to the mixture in the form of ammonium chloride. Phosphate was added to the feed solution in the form of phosphoric acid. For example, a solution of wastewater feed was needed with a  $SBOD_5$  of approximately 500 mg/l. After diluting the raw feedstock until the appropriate  $SBOD_5$  was obtained, 2.4 grams of  $NH_3Cl$  were added to a 25-liter bottle. To obtain this amount of  $NH_4Cl$  to add, the following formula was used:

$$\frac{\text{Grams/Mole Nitrogen}}{\text{Grams/Mole } NH_4Cl} = (\text{Grams to be added}) \times * = 25 \text{ mg/l}$$

(X\*) 25 liters = Grams to be added/25 liters

To obtain the amount of phosphate to be added in the form of phosphoric acid, a stock solution of 50 ml of concentrated phosphoric acid was added to a 1-liter container of distilled water. Then 6.5 ml of this stock solution was added to the feedstock. The 6.5 ml of this stock solution was determined based on the molecular weight of both phosphorous and phosphoric acid, as well as the density of phosphoric acid. These wastewaters were characterized and subjected to pretreatment studies. The results are listed in Table I.

A summary of the raw wastewater characteristics from the ethanol production facility from both corn and milo feedstocks at the Oklahoma State University fuel and alcohol research facility are presented in Table I (3). These results characterize the wastewater (raw feedstock) that was used in this RBC study.

The supernatant was diluted to provide the influent feed for the RBC studies. Tap water was used to dilute the raw wastewater. A magnetic stirrer was employed to mix the nutrients with the wastewater.

The test unit was seeded with sludge from an aerobic activated sludge unit that used alcohol wastewater as its primary feedback. Since the sludge was already acclimated, it readily started to metabolize the feed. This sludge was fed as a batch process for one week. Raw undiluted wastewater was fed directly to the sludge during this time. After this initial week, the unit was converted into a continuous flow unit. The unit was operated under continuous flow conditions until sufficient growth appeared on the discs. Suspended solids data were collected every other day to determine if steady state conditions had been met. After steady state conditions were met, samples were collected at six locations.

TABLE I  
RELATIVE RAW WASTEWATER (THIN STILLAGE) CHARACTERISTICS

Parameter*	Corn Feedstock		Milo Feedstock	
	Mean	Standard Deviation	Mean	Standard Deviation
TS	32,200	9,300	42,800	2,150
TDS	18,600	7,100	20,400	6,800
SS	11,800	3,700	22,500	5,100
VSS	11,300	3,500	19,500	2,600
Total COD	64,500	12,600	75,700	12,100
Soluble COD	30,800	6,200	40,700	9,100
Total BOD <sub>5</sub>	26,900	800	34,900	2,000
Soluble BOD <sub>5</sub>	19,000	2,100	21,700	1,360
Soluble TOC	9,850	2,200	14,900	2,500
Total P	1,170	100	1,280	100
Soluble P	1,065	75	1,075	150
Total TKN	755	115	---	---
Soluble NH <sub>3</sub> -N	130	60	---	---
Total Carbohydrate	8,250	750	---	---
Soluble Carbohydrate	2,250	780	---	---
Soluble Glucose	750	---	---	---
pH (Range)	3.3-4.0	---	3.4-4.0	---

\*All units in mg/l except pH.

These locations were: the influent, end of the first stage, and end of the remaining four stages. The end of the fifth represented the effluent. Samples were obtained with a flat ended 25 ml pipette. The flat ended pipette allowed solids to be collected without clogging the end of the pipette. During certain test periods, the solids were very slimy and would clog the end of the pipette. When these samples were filtered, they would completely clog the filter pores at very small volumes. To remedy this situation, 100 ml of the samples were allowed to settle in a 250 ml flask for about one minute. From these samples, SBOD, STOC, and SCOD data were obtained.

The flow rate was measured each day with a small 50 ml graduate cylinder. The tests that were performed were biochemical oxygen demand, chemical oxygen demand, total organic carbon, and suspended solids.

## CHAPTER IV

### ANALYTICAL PROCEDURES

#### Suspended Solids

The suspended solids concentration was measured gravimetrically by filtering the sample through 0.45 micron milapore filters. The following procedure was used for analysis. Filter papers were placed in aluminum pans and placed in a drying oven at 103°C until all the moisture on them had evaporated. After removal from the oven, the filters and pans were placed in a desiccator to cool to a constant weight. The dry weights were then recorded. Twenty-five milliliters of sample were filtered through the filter papers with the use of a vacuum pump. If the solids would not dewater well, 10 milliliters of sample were filtered. After filtering, the filter papers were placed in the pans and dried for about two hours. A homogeneous mixture of solids was difficult to obtain due to the clumping of the solid material. Duplicates of each sample were treated in the same manner as the originals.

#### Chemical Oxygen Demand

The chemical oxygen demand of the filtrate was measured using the Hach procedure. The procedure is basically the same one as the procedure outlined in Standard Methods. The refluxing time is the same but there are smaller quantities of chemicals used and a smaller quantity of sample is needed for analysis. Standards are made for high and low

range data. A curve is plotted from the standards concentration against adsorbence. The samples are read on a spectrometer and matched with their respective curves. The standard solutions were made of Glucose.

#### Biochemical Oxygen Demand

The biochemical oxygen demand of the filtrate was determined using procedures outlined in Standard Methods, except that a dissolved oxygen (DO) probe was used instead of the titration method. The DO probe was used to read the initial DO in the BOD bottle as well as the DO after five days.

#### Total Organic Carbon

The total organic carbon of the filtrate was measured using the Oceanographic Total Carbon Analyzer. Standards for both total and inorganic carbon were prepared. The total organic carbon concentration was calculated by subtracting the total inorganic carbon concentration from the total carbon concentration.

## CHAPTER V

### RESULTS

#### SBOD, SCOD, and STOC Removal

SBOD, SCOD, and STOC removal characteristics at various hydraulic loadings as a function of stage are shown in Figures 3 through 8. These figures are typical for the study. Figure 3 describes the behavior of the unit at  $0.18 \text{ gpd/ft}^2$ . As can be seen from this plot, the initial SBOD concentration was  $270.0 \text{ mg/l}$ , and this was reduced to approximately  $5.0 \text{ mg/l}$  by the time it left the five-stage unit. The removal efficiency accomplished by this unit is approximately equal to 98 percent. It should be noted that more than 94 percent of the removal was accomplished in the first stage.

Figure 4 represents the typical removal of SCOD at a hydraulic loading of  $0.18 \text{ gpd/ft}^2$ . The initial SCOD concentration at one of the organic loadings was  $270.0 \text{ mg/l}$ , and this was reduced to approximately  $20.0 \text{ mg/l}$  by the time it exited the unit. The removal efficiency accomplished by this unit is approximately equal to 93 percent. The removal efficiency of the first stage, calculated by a reduction of  $270.0 \text{ mg/l}$  to  $65.0 \text{ mg/l}$  SCOD, was equal to 80 percent, thereby showing that most of the removal occurred in the first stage of the unit. At a higher organic loading, the SCOD initial concentration was reduced from  $315.0 \text{ mg/l}$  to  $25.0 \text{ mg/l}$ . This reduction resulted in removal rate efficiencies of 92 percent. The SCOD concentration was reduced from  $315.0 \text{ mg/l}$  to  $85.0$

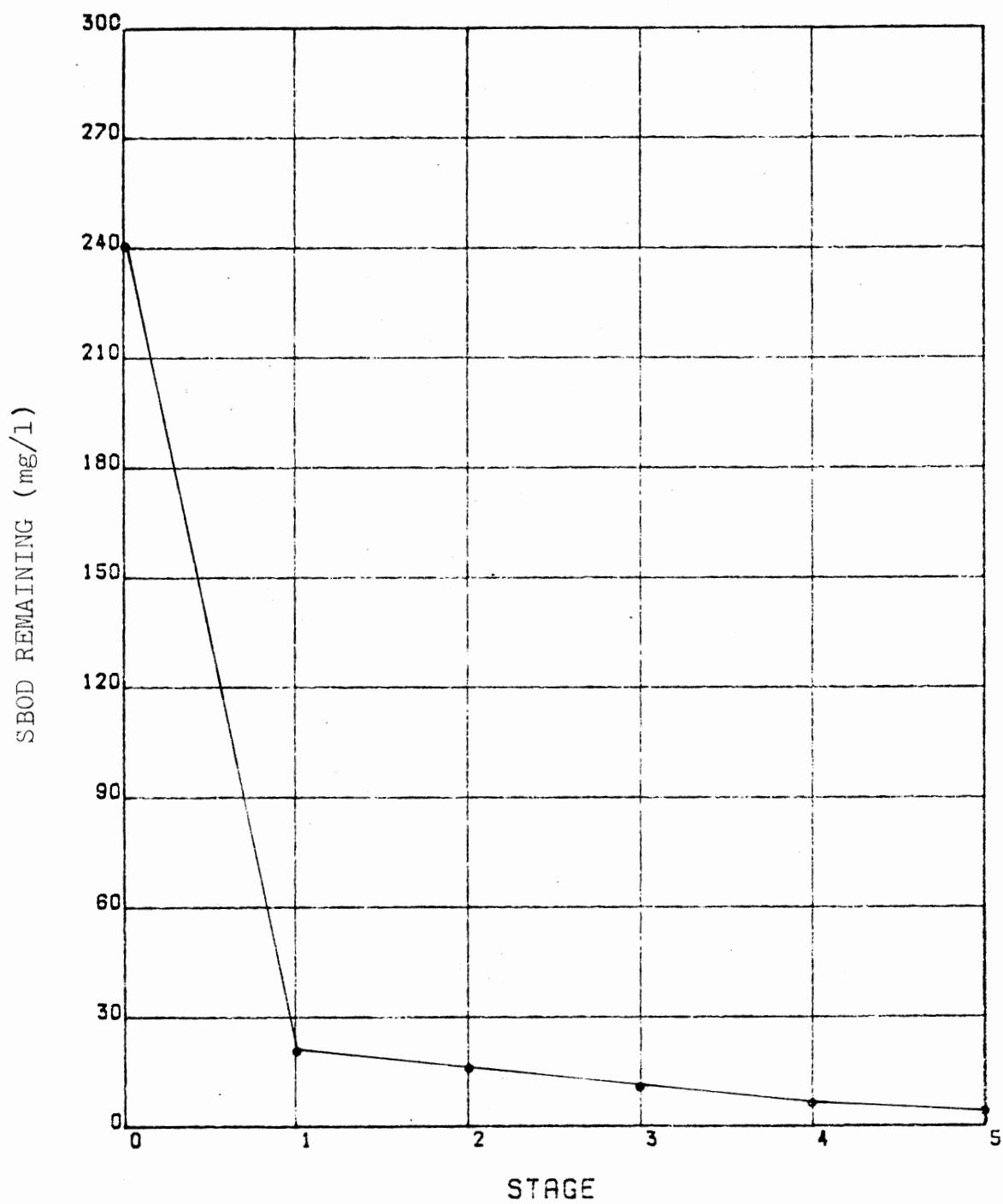


Figure 3. SBOD Remaining Versus Stage for Hydraulic Loading of  $0.18 \text{ gpd/ft}^2$

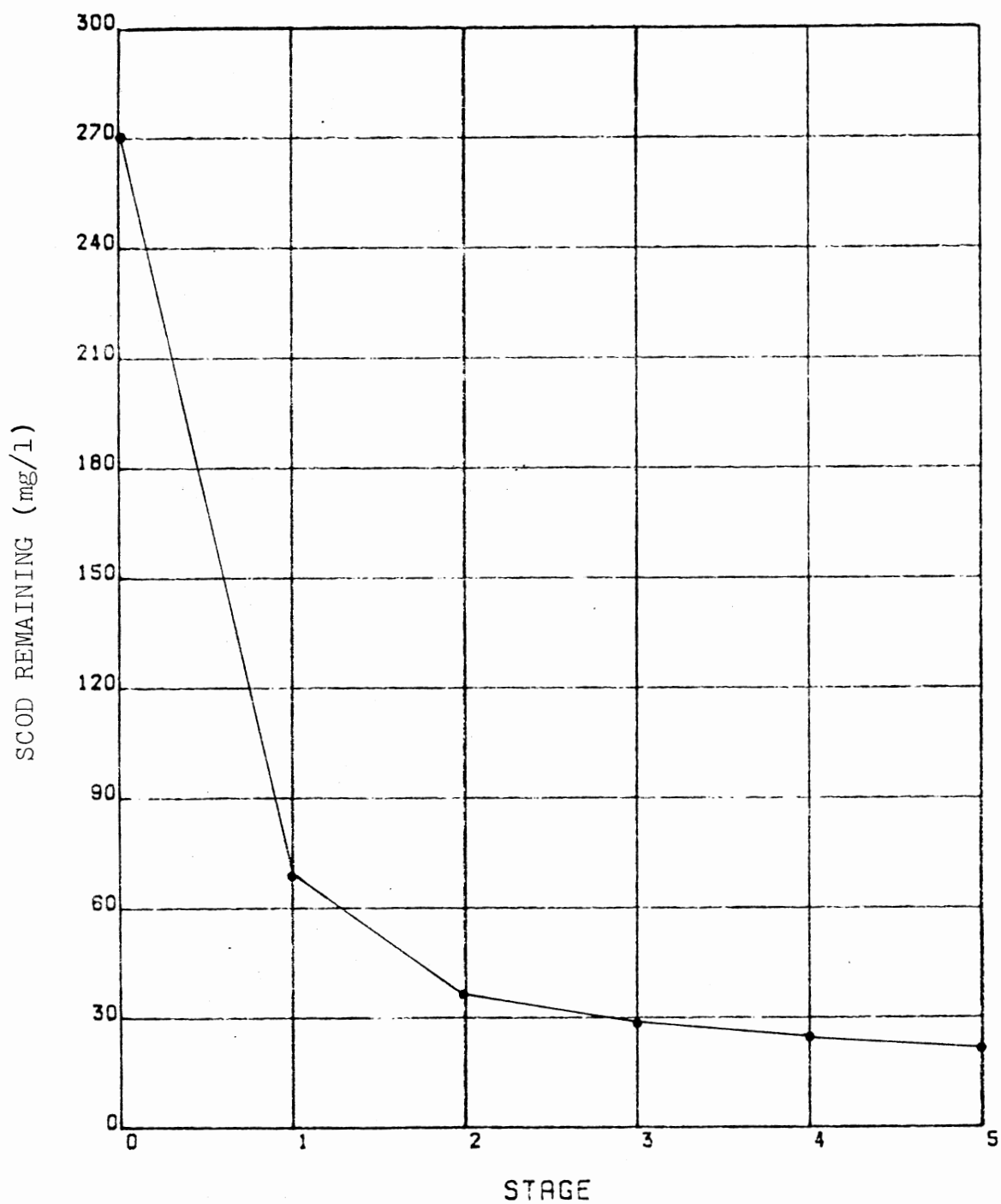


Figure 4. SCOD Remaining Versus Stage for Hydraulic Loading of 0.18 gpd/ft<sup>2</sup>

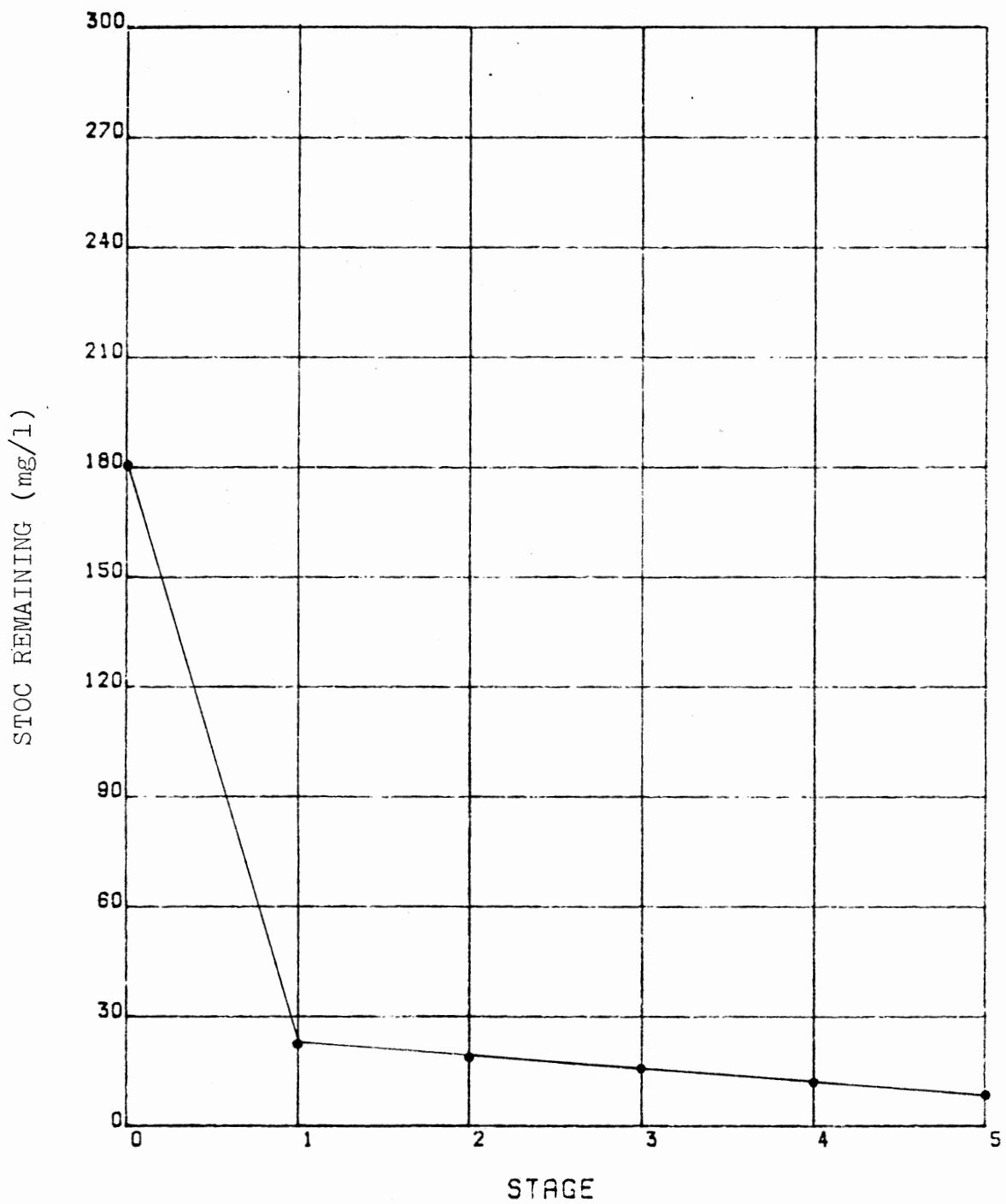


Figure 5. STOC Remaining Versus Stage for Hydraulic Loading of 0.18 gpd/ft<sup>2</sup>

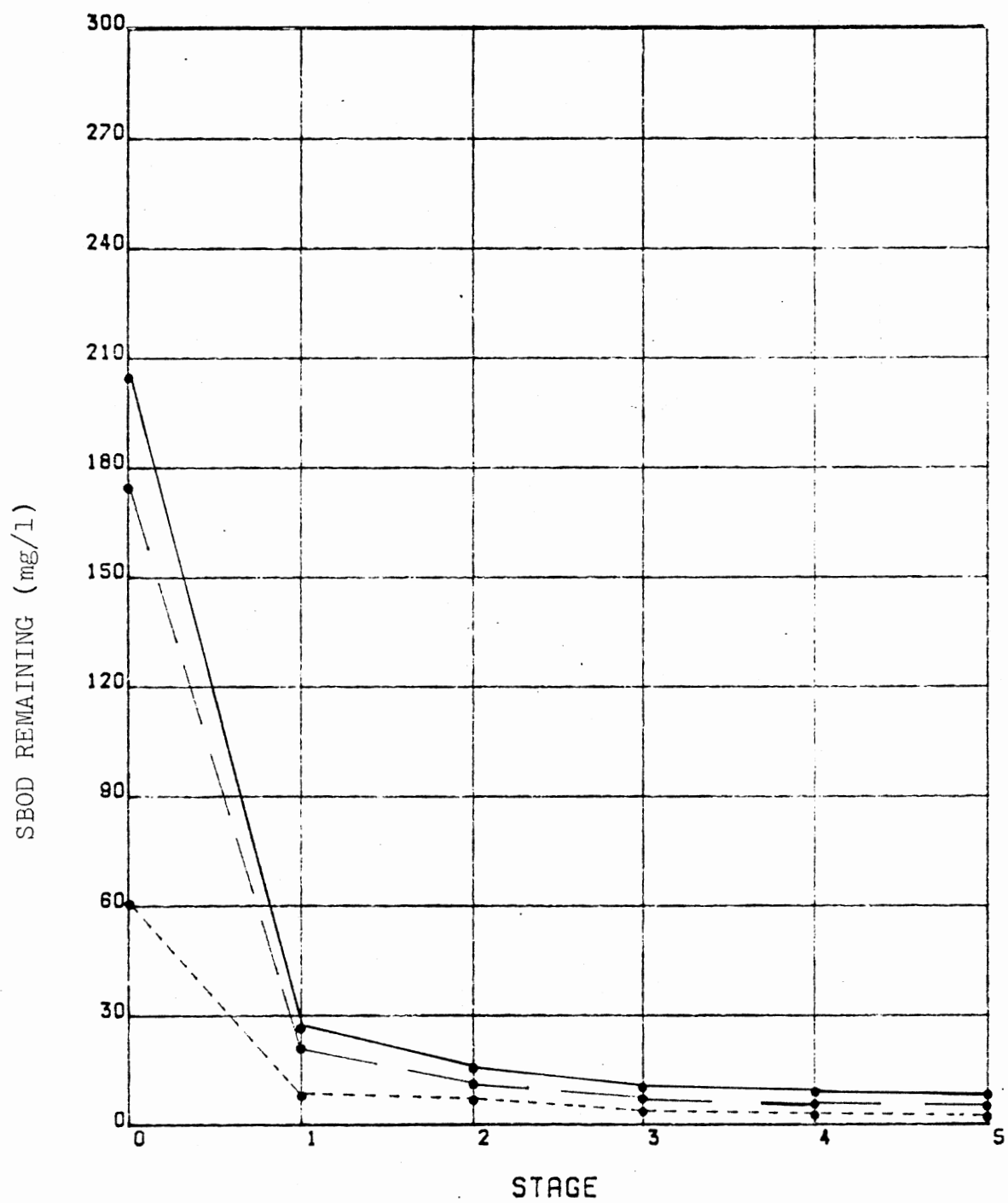


Figure 6. SBOD Remaining Versus Stage for Hydraulic Loading of 1.22 gpd/ft<sup>2</sup>

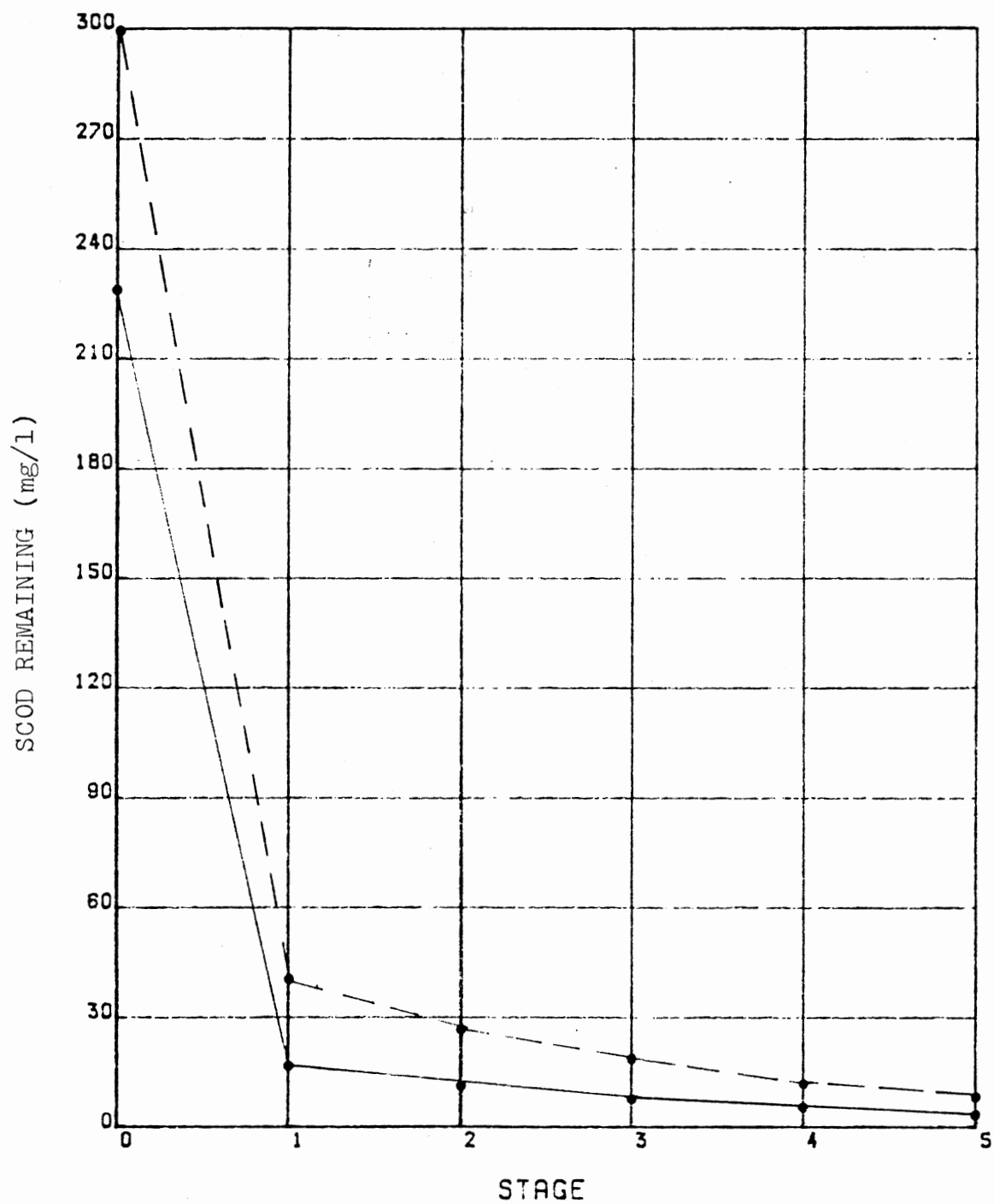


Figure 7. SCOD Remaining Versus Stage for Hydraulic Loading of 1.22 gpd/ft<sup>2</sup>

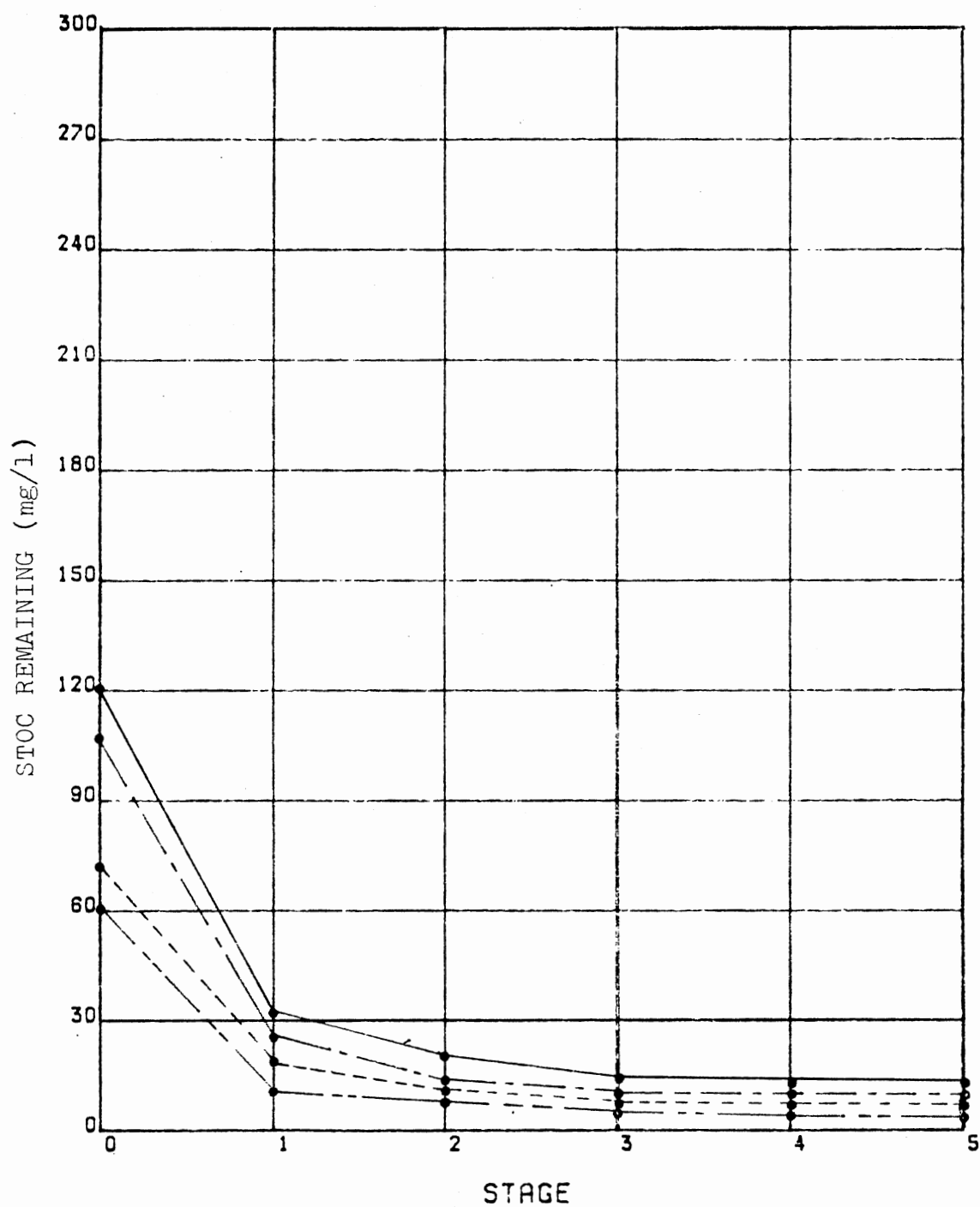


Figure 8. STOC Remaining Versus Stage for Hydraulic Loading of 1.22 gpd/ft<sup>2</sup>

mg/l in the first stage of the unit. The removal rate efficiency of the first stage was equal to a 73 percent reduction of the SCOD in the wastewater.

Figure 5 represents the removal of STOC at  $0.18 \text{ gpd/ft}^2$ . This figure represents a typical curve that was seen throughout the study. The initial STOC concentration of 180.0 mg/l was reduced to 10.0 mg/l by the time the wastewater exited the unit. The removal efficiency throughout the entire unit equalled 94 percent. The first stage removal rate efficiency was 81 percent. This was calculated by a reduction of 180.0 mg/l to 35.0 mg/l.

Figure 6 represents the removal of SBOD at  $1.22 \text{ gpd/ft}^2$ . The initial SBOD concentrations for three different organic loadings were 60.0 mg/l, 170.0 mg/l, and 200.0 mg/l. The respective effluent concentrations were 1.0 mg/l, 3.0 mg/l, and 8.0 mg/l. The resulting percentage reductions for these three conditions are 99, 98, and 96 percent, respectively. The increased influent concentrations yields increased effluent concentrations. The first stage SBOD reductions for the three loadings were 95, 91, and 90 percent, respectively.

Figure 7 represents the removal of SCOD at a hydraulic loading rate of  $1.22 \text{ gpd/ft}^2$ . The initial SCOD concentration was 225.0 mg/l, and the effluent concentration was approximately 1.0 mg/l. This resulted in a net reduction of SCOD by 99.5 percent. The second organic loading had an initial SCOD concentration of 300.0 mg/l and a final effluent value of 6.0 mg/l. This resulted in a reduction of the SCOD by 98 percent. Most of the SCOD removed occurred in the first stage at both conditions. At the lower of the two conditions, the initial concentration of 225.0 mg/l SCOD was reduced to 15.0 mg/l SCOD. This resulted in a net

reduction of SCOD by 93 percent. The higher organic loading condition had an initial concentration of 325.0 mg/l SCOD and was reduced to 40.0 mg/l. This resulted in a net reduction of 88 percent of the SCOD in the first stage.

Figure 8 represents the removal of STOC at a hydraulic loading of 1.22 gpd/ft<sup>2</sup>. Several different loadings were tried and the initial concentrations of these loadings were: 60.0, 70.0, 110.0, and 120.0 mg/l. The effluent SCOD concentrations for these loadings are: 5.0, 10.0, 15.0, and 20.0 mg/l. The resulting reduction percentages for these loadings were: 92, 86, 86, and 85 percent. An increase in the influent concentration resulted in an increase in the effluent concentration and a decrease in percentage of reduction.

The first stage STOC concentrations were 10.0, 20.0, 25.0, and 32.0 mg/l, respectively. This resulted in first stage reduction percentages of 83, 72, 77, and 73 percent, respectively.

At the hydraulic loading of 1.22 gpd/ft<sup>2</sup>, the average SBOD concentration decreased by 98 percent, the SCOD concentration by 98 percent, and the STOC concentration by 87 percent. These averages were based on data collected over the entire unit. The average first stage reduction percentages varied from 92 percent for SBOD, 91 percent for SCOD, and 76 percent for STOC.

Tables II through VII list applied loadings versus removed loadings for SBOD, STOC, and SCOD. The efficiency of the units under different conditions are listed in the following pages.

TABLE II

BOD REMOVAL BY ROTATING BIOLOGICAL CONTACTOR (RBC)  
TREATMENT OF ALCOHOL WASTEWATER AT AN ORGANIC  
LOADING LESS THAN 1 LB/DAY/1000 FEET<sup>2</sup>  
THROUGHOUT ENTIRE UNIT

Applied, Lb/Day/1000 Ft <sup>2</sup>	Removed, Lb/Day/1000 Ft <sup>2</sup>	Efficiency, Percent
0.23	0.23	100.0
0.27	0.26	96.3
0.43	0.43	100.0
0.50	0.50	99.4
0.57	0.57	100.0
0.78	0.76	97.4

TABLE III

BOD REMOVAL BY THE RBC AT LOADINGS GREATER THAN  
1 LB/DAY/1000 FEET<sup>2</sup> THROUGHOUT ENTIRE UNIT

Applied, Lb/Day/1000 Ft <sup>2</sup>	Removed, Lb/Day/1000 Ft <sup>2</sup>	Efficiency, Percent
1.22	1.22	100.0
1.67	1.67	100.0
2.52	2.51	99.6
3.35	3.23	96.4
5.03	4.76	94.6

TABLE IV

COD REMOVAL BY ROTATING BIOLOGICAL CONTACTOR (RBC)  
TREATMENT OF ALCOHOL WASTEWATER AT AN ORGANIC  
LOADING LESS THAN 1 LB/DAY/1000 FEET<sup>2</sup>  
THROUGHOUT ENTIRE UNIT

Applied, Lb/Day/1000 Ft <sup>2</sup>	Removed, Lb/Day/1000 Ft <sup>2</sup>	Efficiency, Percent
0.41	0.39	95.1
0.51	0.48	94.1
0.61	0.58	95.1
0.71	0.67	95.2

TABLE V

COD REMOVAL BY THE RBC AT LOADINGS GREATER THAN  
1 LB/DAY/1000 FEET<sup>2</sup> THROUGHOUT ENTIRE UNIT

Applied, Lb/Day/1000 Ft <sup>2</sup>	Removed, Lb/Day/1000 Ft <sup>2</sup>	Efficiency, Percent
2.32	2.32	100.0
4.23	4.20	99.3
5.29	5.18	97.9
7.05	6.61	93.7
10.58	9.48	89.6

TABLE VI

TOC REMOVAL BY ROTATING BIOLOGICAL CONTACTOR (RBC)  
TREATMENT OF ALCOHOL WASTEWATER AT AN ORGANIC  
LOADING LESS THAN 1 LB/DAY/1000 FEET<sup>2</sup>  
THROUGHOUT ENTIRE UNIT

Applied, Lb/Day/1000 Ft <sup>2</sup>	Removed, Lb/Day/1000 Ft <sup>2</sup>	Efficiency, Percent
0.21	0.21	100.0
0.33	0.33	100.0
0.55	0.55	100.0
0.64	0.64	100.0
0.95	0.95	100.0

TABLE VII

TOC REMOVAL BY THE RBC AT LOADINGS GREATER THAN  
1 LB/DAY/1000 FEET<sup>2</sup> THROUGHOUT ENTIRE UNIT

Applied, Lb/Day/1000 Ft <sup>2</sup>	Removed Lb/Day/1000 Ft <sup>2</sup>	Efficiency, Percent
1.33	1.33	100.0
1.80	1.80	100.0
2.40	2.40	100.0
4.39	4.23	96.4
4.51	4.30	95.3

## CHAPTER VI

### DETERMINATION OF BIOKINETIC CONSTANTS

#### FOR SBOD, SCOD, AND STOC

The concept of total organic loading was employed to evaluate the data. Total organic loading is the combination of hydraulic flow rate and organic concentration. One advantage of the total organic loading concept is the capability to predict substrate removal and treatment efficiency at any loading condition. The smaller the diameter of the RBC, the higher the treatment efficiency with the same wastewater. Therefore, direct scale-up from a small-scale system because of oxygen transfer limitation and the biodegradability of the wastewater is obtained. Full-scale systems data of  $\text{lbs/day/1000 ft}^2$  applied versus  $\text{lbs/day/1000 ft}^2$  removed yield a curve that cannot be defined solely with zero, first, or second-order kinetics. The curves tend to follow different orders of reaction kinetics as the organic loadings are increased. It has been seen that as the BOD applied approaches higher and higher values, the BOD removed approaches a maximum value where further increases in BOD applied cause no further increase in BOD removed. This relationship can best be described mathematically by the Monod equation and monomolecular kinetics.

Monod kinetics also predict the maximum BOD removal rate observed in RBC's. At a certain loading condition, the RBC becomes saturated with BOD, apparently due to  $\text{O}_2$  limitations, and the removal rate does

not increase with increasing BOD loadings. The system becomes  $p_2$  limited at these conditions and seems to be zero order kinetics. Smaller diameter units transfer more  $O_2$  into the system so that the maximum substrate utilization rate ( $U_{\max}$ ) will be greater than the full-scale system.

Figure 9 represents the specific substrate utilization rate as a function of total organic loading for all the SBOD loading rates. SBOD applied is plotted against SBOD removed to obtain the maximum substrate utilization rate. If the curve has flattened out, then the maximum substrate removal has been achieved.

Figure 10 represents the SBOD curve at a low loading rate. The curve does not flatten out because the maximum substrate utilization has not been obtained. A comparison of the two curves is presented here. With these curves, one can determine how well a system will perform at these conditions with this particular wastewater.

Figure 11 represents the reciprocal of the SBOD applied ( $1/\frac{FS_i}{A}$ ) versus the reciprocal SBOD removed ( $1/\frac{F(S_i - S_e)}{A}$ ) to determine  $U_{\max}$  and  $K_b$ . In Figure 11, only loading rates less than 1 lb/day/1000 ft<sup>2</sup> will be considered. The method of data analysis is based upon the Kincannon and Stover model for RBC design. This method eliminates or reduces the amount of data scatter found with most of the other models. The curve is now in a linear form.

Figure 12 represents the reciprocal SBOD applied versus the reciprocal SBOD removed for all of the data. The biokinetic constants change from those of the low loading because of the change in the total organic loading. The slope was determined to be 0.9955 and the Y-intercept

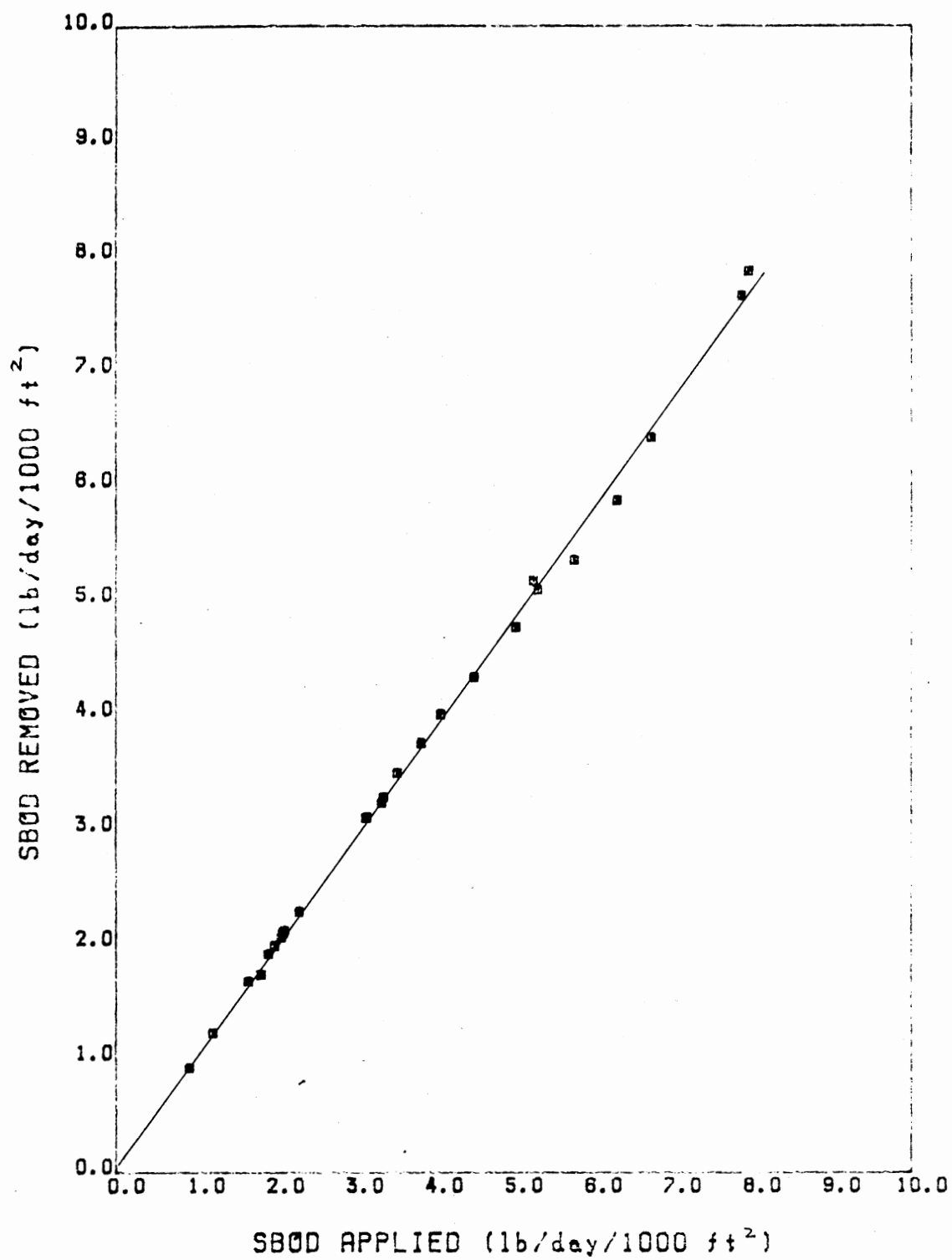


Figure 9. SBOD Applied Versus SBOD Removed at All Loading Rates

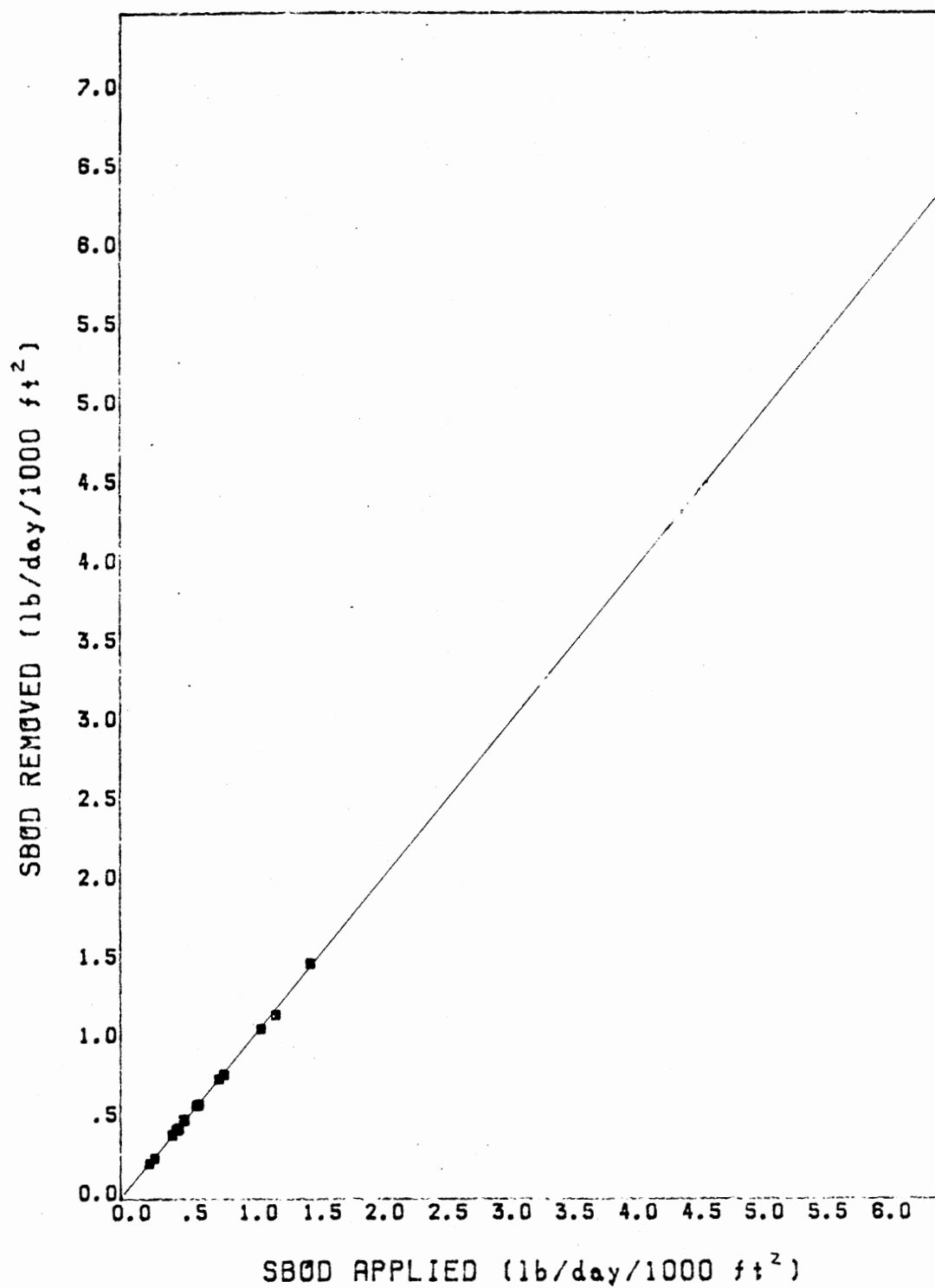


Figure 10. SBOD Applied Versus SBOD Removed at Low Loading Rates

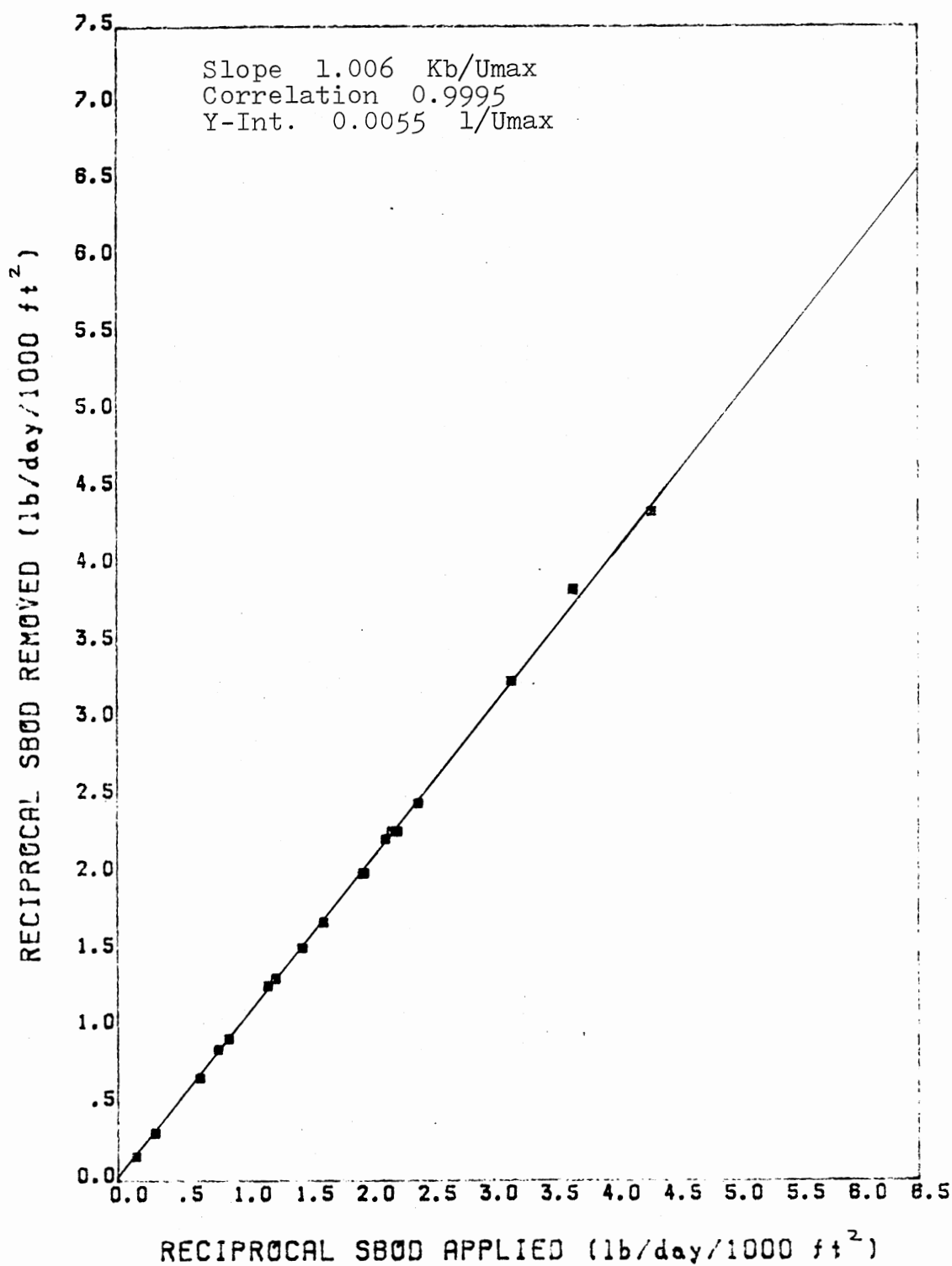


Figure 11. Determination of  $U_{max}$  and  $K_b$  at Low Loading Rates  
Less Than 1 Lb/Day/1000 Ft<sup>2</sup>

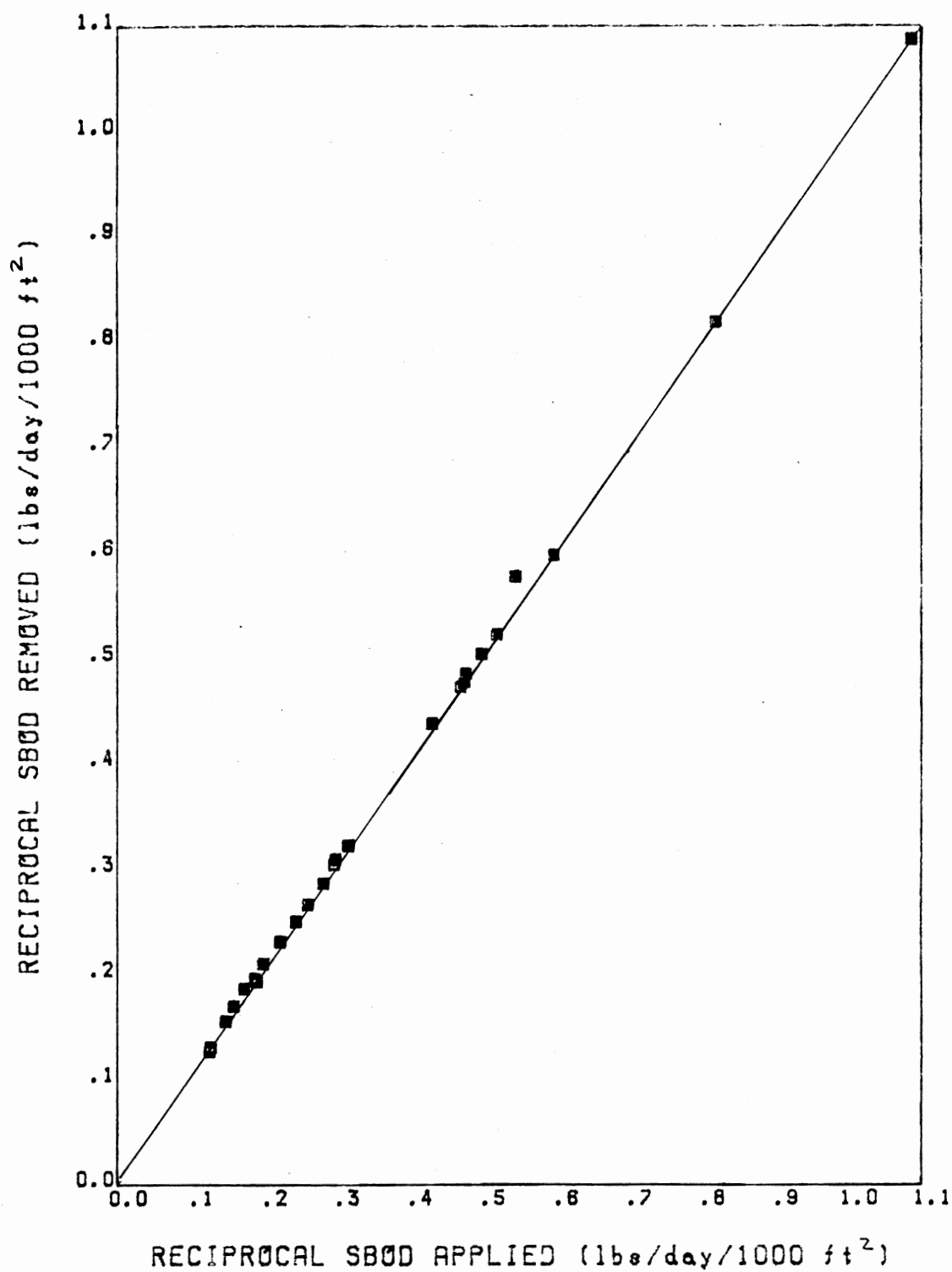


Figure 12. Determination of  $U_{\max}$  and  $K_b$  at All Loading Rates

equal to 0.007. From the equation

$$A = \frac{\frac{FS_i}{U_{\max} S_i}}{S_i - S_e} - K_b$$

$U_{\max}$  was calculated to be 142.85 and  $K_b$  is equal to 143.50.

Figure 13 represents the plotting of SCOD applied versus SCOD removed for all the data. The representative curve starts to flatten out at the upper range.

Figure 14 represents the SCOD applied versus the SCOD removed at loadings less than 1 lb/day/1000 ft<sup>2</sup>. At this low loading rate, the curve looks linear but in reality is not. All of the SCOD data points were linearized by the Kincannon-Stover model. Scatter was reduced drastically with this method as can be seen by this graph.

All of the high and low loadings were plotted in Figure 15 for the reciprocal kinetic constants for SCOD. This figure represents the reciprocal SCOD removed for all the data. All of the high and low loadings were plotted in Figure 15 to determine the  $U_{\max}$  and  $K_b$ . The slope of the line was equal to 1.019 and the Y-intercept was equal to 0.016. Therefore,  $U_{\max}$  equals 62.5 and  $K_b$  equals 60.40.

The low loadings were plotted for the reciprocal SCOD applied versus reciprocal SCOD removed in Figure 16. The biokinetic constants were determined from the slope of 0.9937 and the Y-intercept of 0.0006.  $U_{\max}$  was calculated to be 166.67 and  $K_b$  was equal to 165.62.

Figure 17 represents the specific substrate utilization rate as a function of total organic loading. This particular figure represents the STOC applied versus STOC removed at all of the loading rates. The

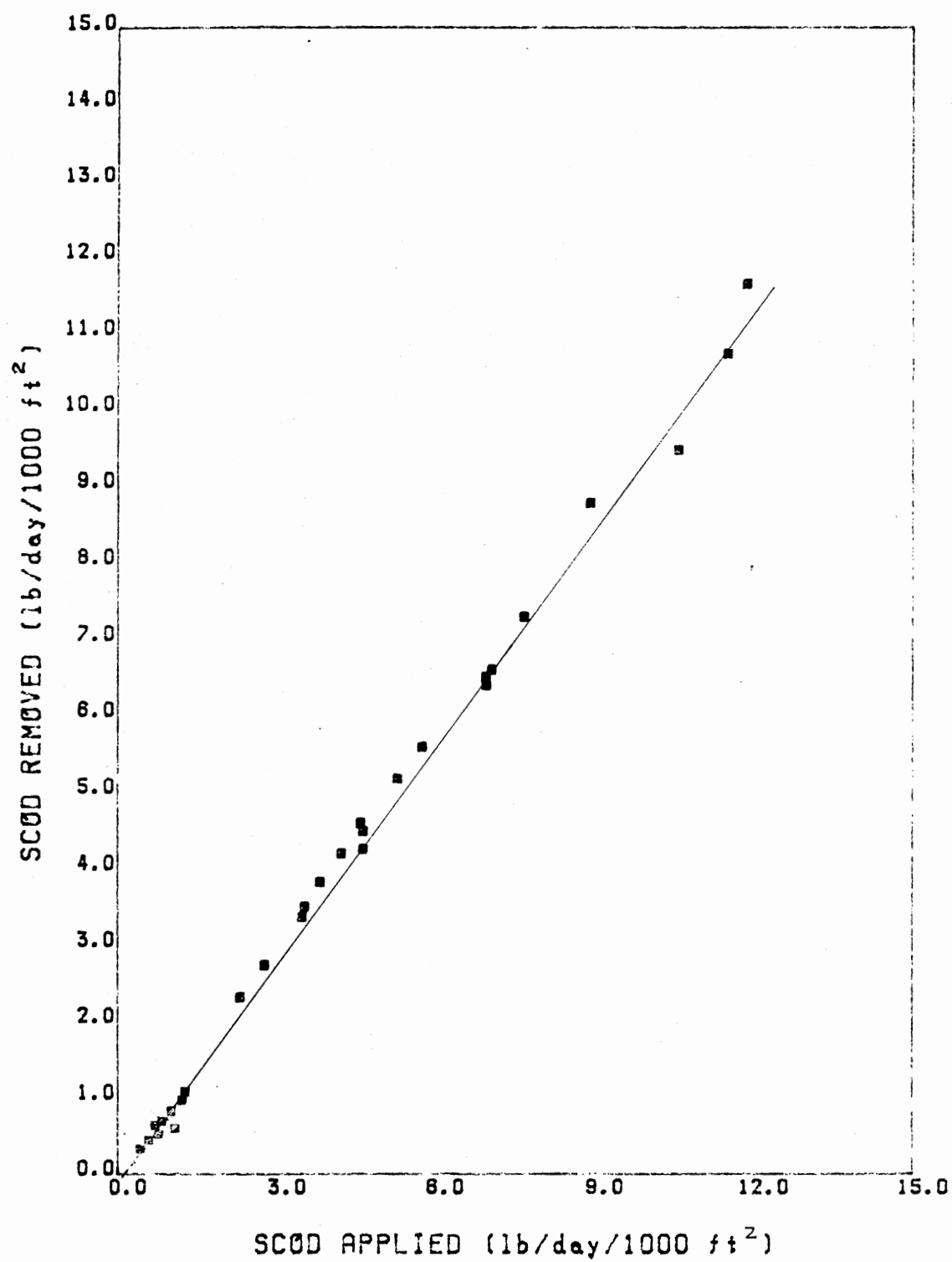


Figure 13. SCOD Applied Versus SCOD Removed at All Loading Rates

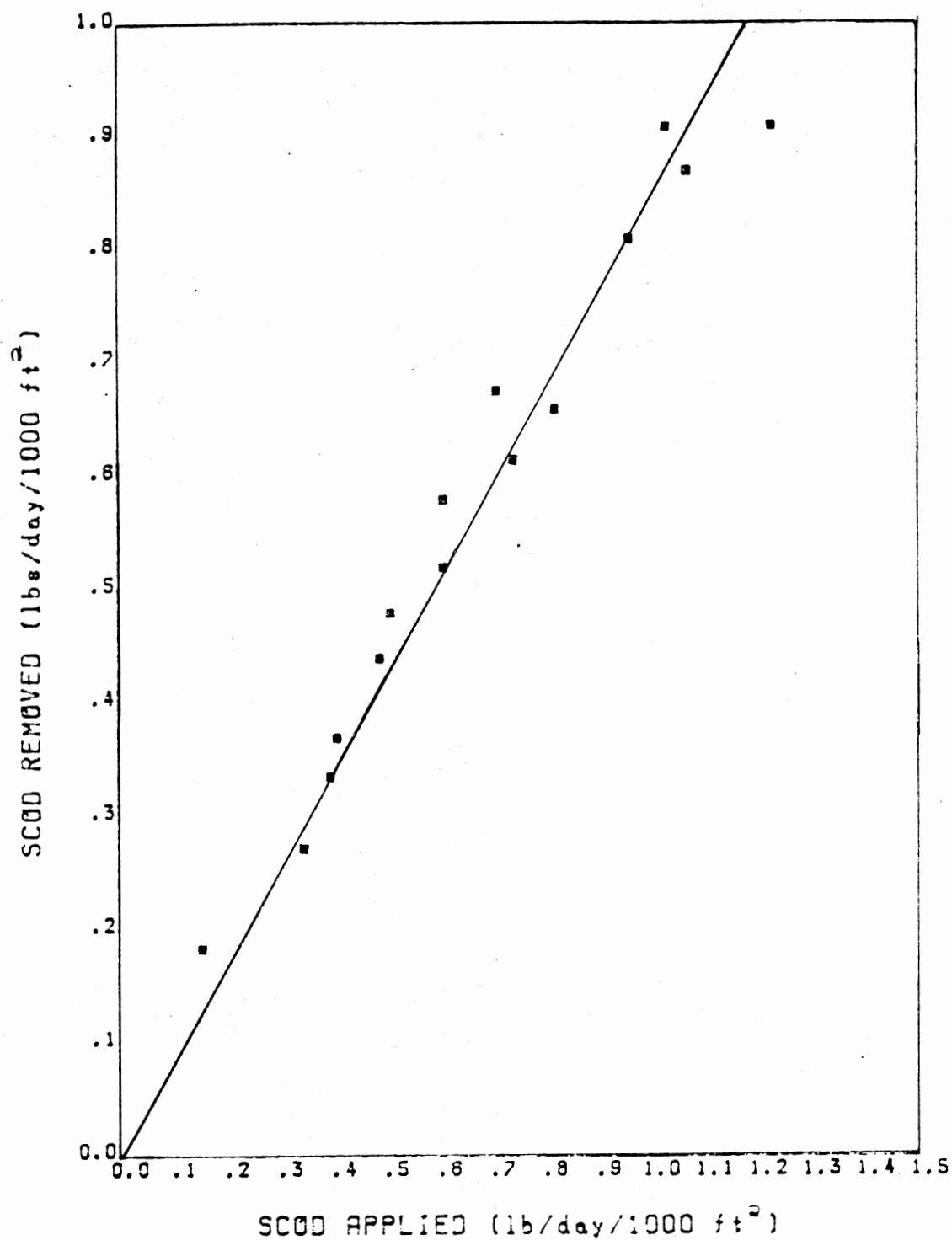


Figure 14. SCOD Applied Versus SCOD Removed at Loadings Less Than 1 Lb/Day/1000 Ft<sup>2</sup>

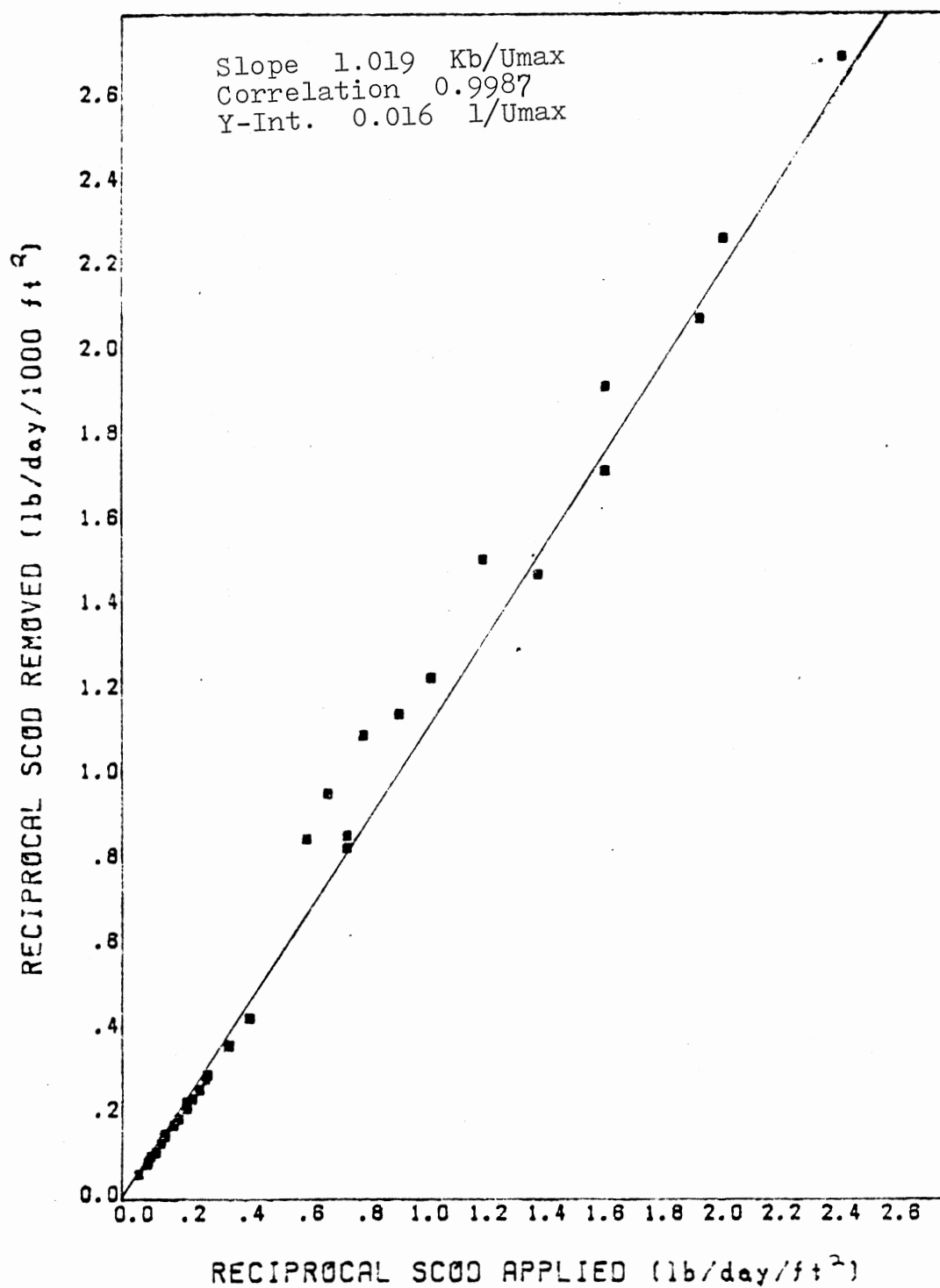


Figure 15. Determination of  $U_{max}$  and  $K_b$  at All Loading Rates

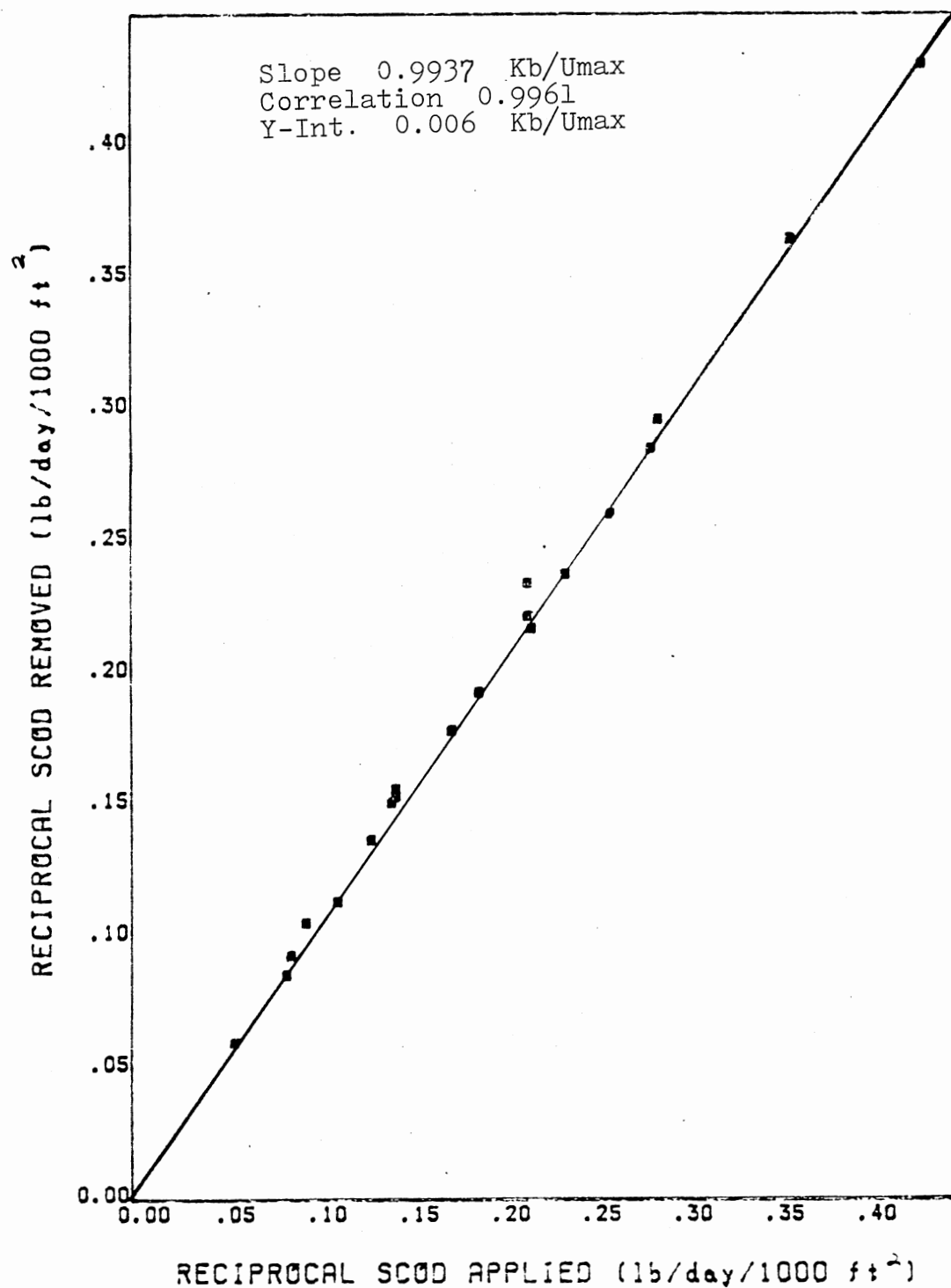


Figure 16. Determination of  $U_{\max}$  and  $K_b$  at Low Loading Rates Less Than 0.5 Lb/Day/1000 Ft<sup>2</sup>

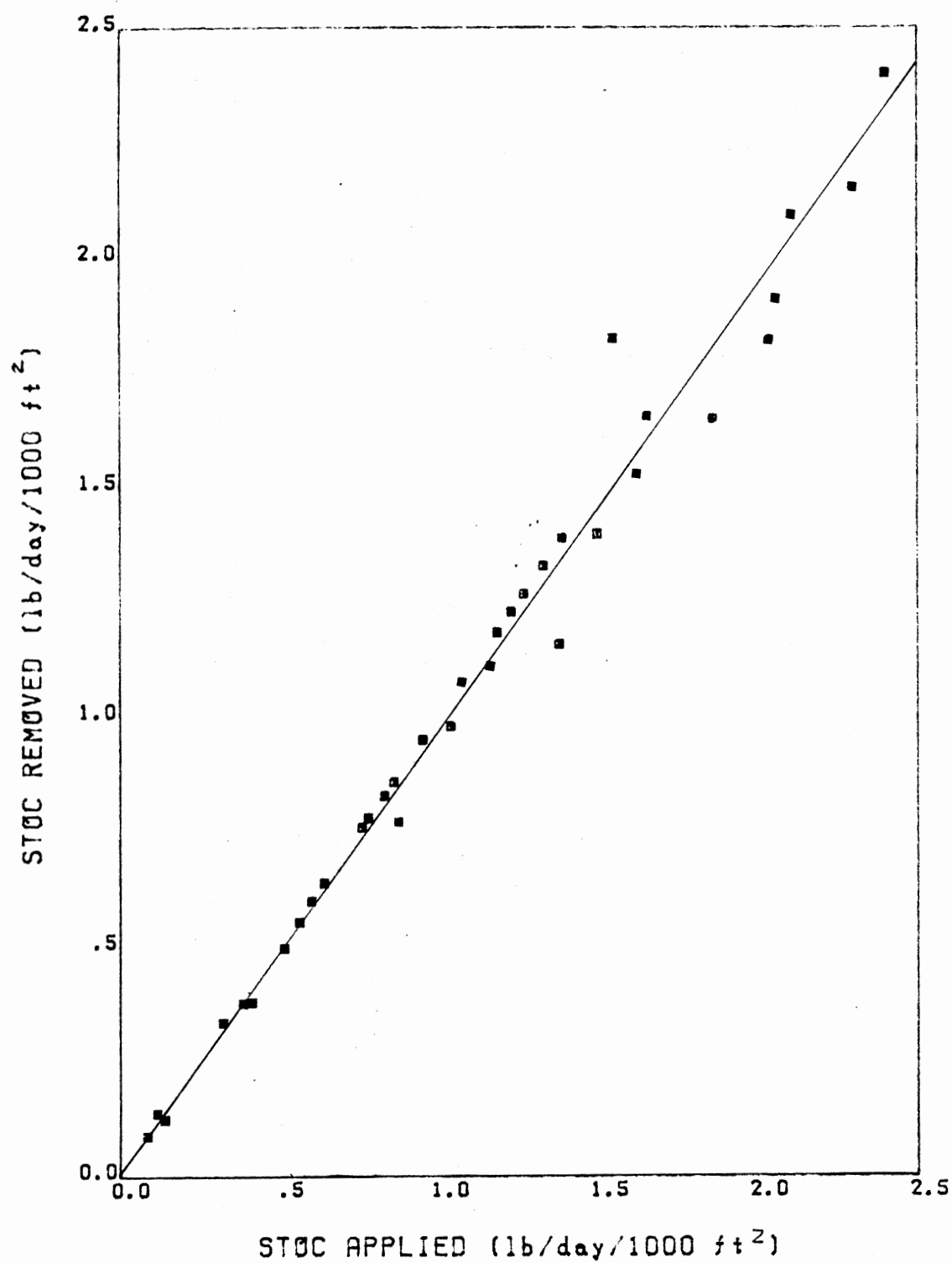


Figure 17. STOC Applied Versus STOC Removed  
at All Loading Rates

curve remains linear throughout the range of 0.0 to 4.5 lb/day/1000 ft<sup>2</sup>. The maximum removal rate has not been achieved.

The low end of the STOC curve is plotted in Figure 18. The curve follows a linear relationship.

The reciprocal STOC applied versus TOC removed is plotted in Figure 19 for the determination of  $U_{\max}$  and  $K_b$  for the low data. The slope of the line is equal to 0.9960, and the Y-intercept is equal to 0.014. Therefore,  $U_{\max}$  is equal to 71.43 and  $K_b$  is equal to 71.14.

Determination of biokinetic constants for all of the data is shown in Figure 20.  $U_{\max}$  and  $K_b$  were calculated for all the STOC data shown. The slope of the line was determined to be 0.9936, and the Y-intercept to be 0.020. With these numbers  $U_{\max}$  was calculated to be 50.0 and  $K_b$  was equal to 49.68. All of the data points were plotted on the graph to compare these kinetic constants to those of the separate loadings.

The kinetic constants vary somewhat, but the major criteria for comparison are between  $U_{\max}$  and  $K_b$ . In the Kincannon-Stover model explained earlier, a slight difference between  $U_{\max}$  and  $K_b$  will cause a great difference in the required area for treatment. All of the constants should be carried out to three places. A summary of the constants is listed in Table VIII.

The true yield and decay constant must be determined to calculate the amount of sludge that will be produced. Figures 21 and 22 represent the SBOD removed versus the solids produced. Figure 21 represents the  $Y_t$  and  $K_d$  at all loading rates. There was much scatter in these data due to the solids fluctuation in the RBC. The slope of the line is equal to  $Y_t$ . The Y-intercept is equal to  $K_d$ .  $Y_t$  was determined to be 0.80 and  $K_d$  was equal to 0.07.

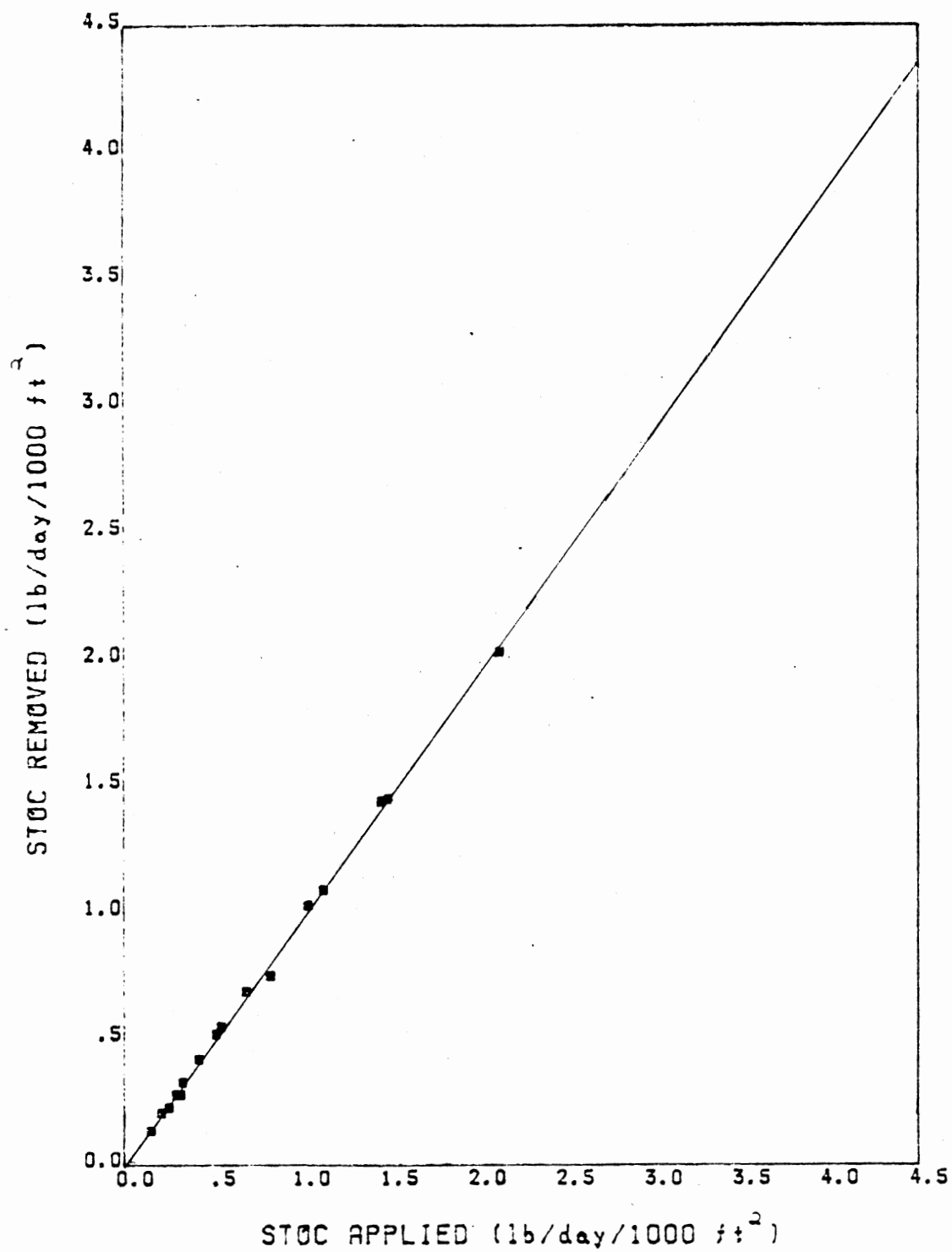


Figure 18. STOC Applied Versus STOC Removed at Low Loading Rates Less Than 2.0 Lb/Day/1000 Ft<sup>2</sup>

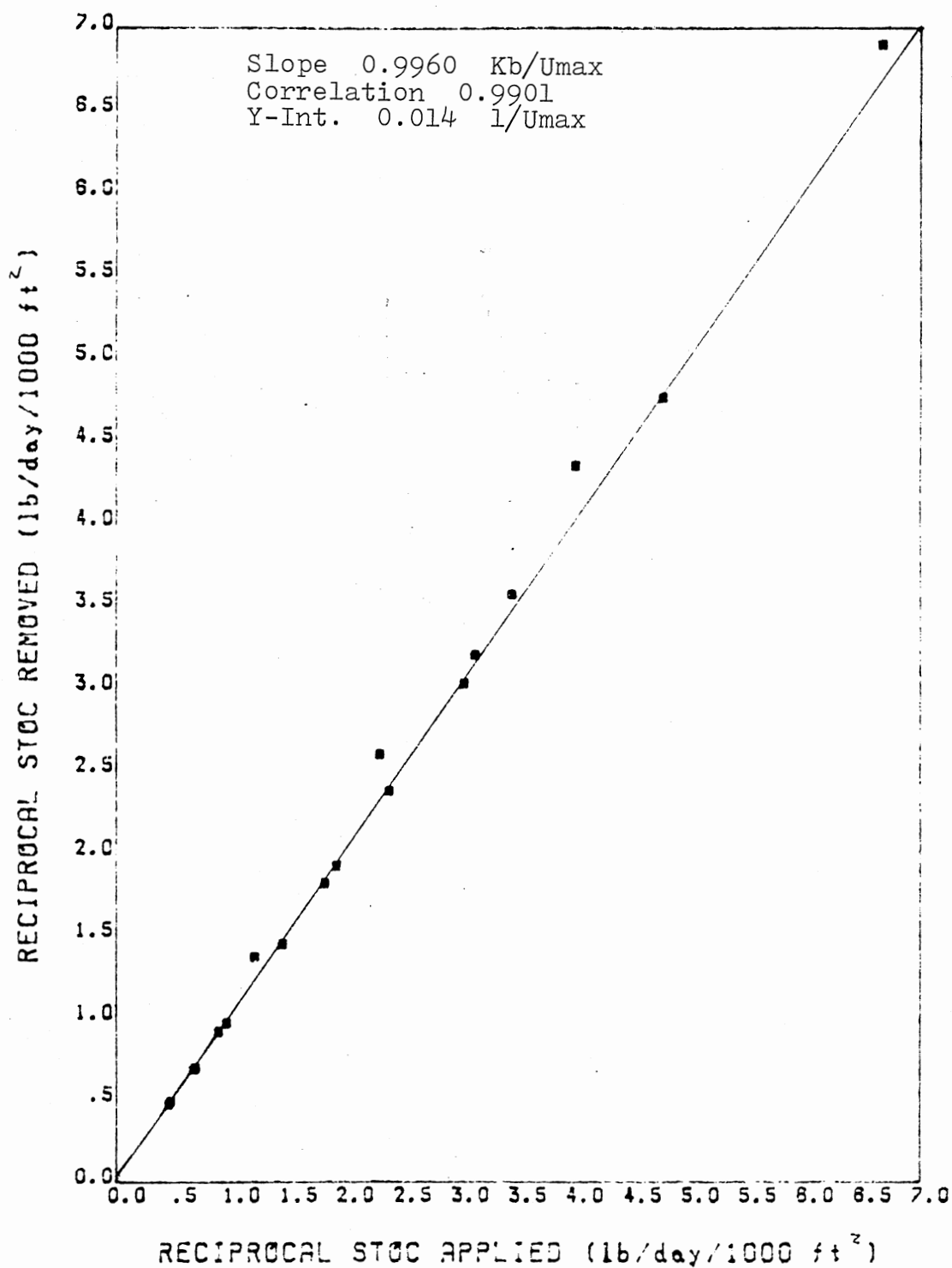


Figure 19. Determination of  $U_{max}$  and  $K_b$  at Low Loading Rates Less Than 2.0 Lb/Day/1000 Ft<sup>2</sup>

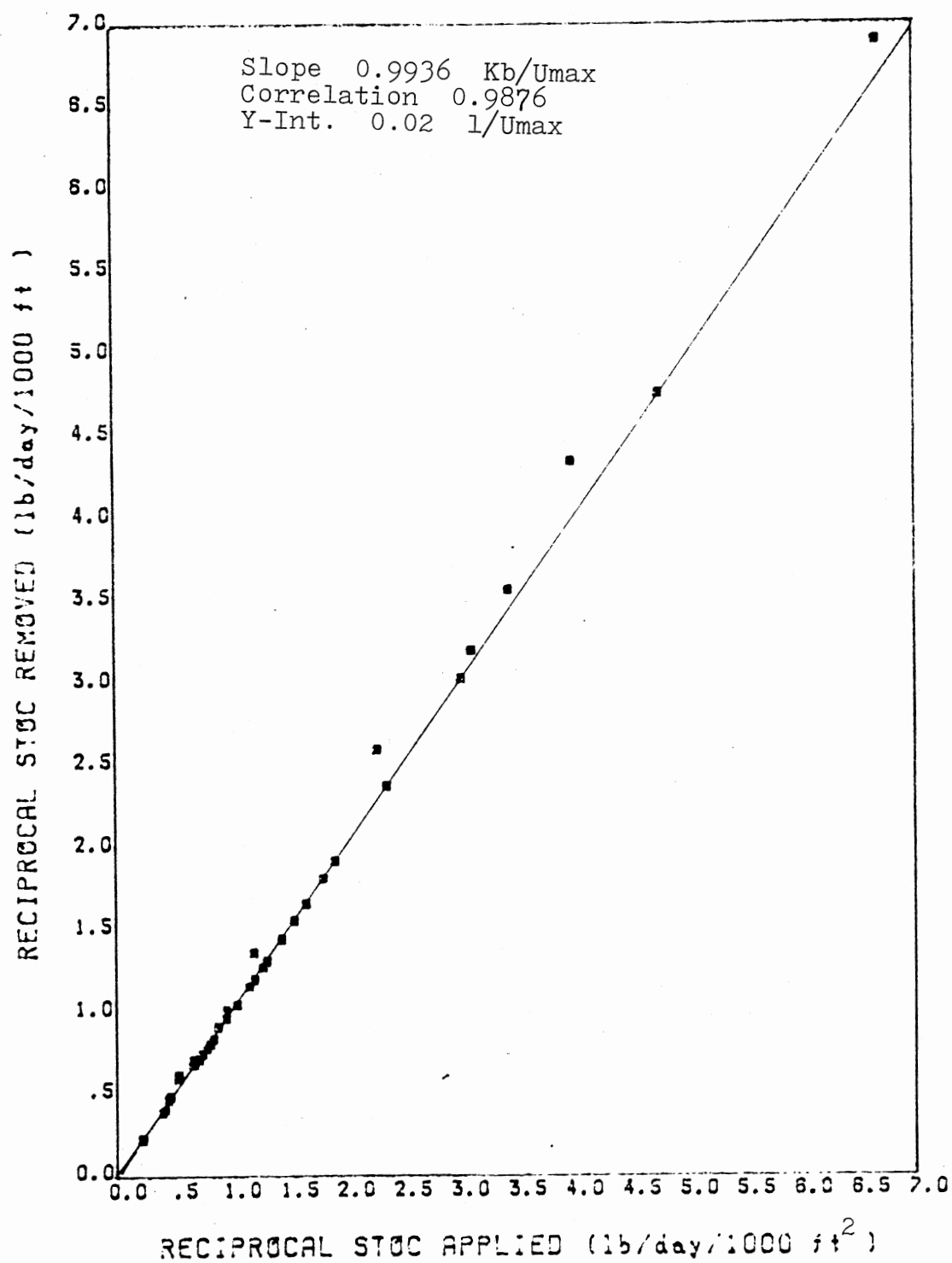


Figure 20. Determination of  $U_{max}$  and  $K_b$  at All Loading Rates

TABLE VIII  
BIOKINETIC CONSTANTS DETERMINED FROM  
SBOD, SCOD, AND STOC DATA

Parameter	$U_{\max}$	$K_b$	$Y_t$	$K_d$
<u>SBOD</u>				
All	142.85	143.50	0.08	0.07
Low	181.82	182.91		
<u>SCOD</u>				
All	62.50	63.75	0.61	0.40
Low	165.62	166.67		
<u>STOC</u>				
All	50.00	49.68	1.47	0.20
Low	71.43	71.14		

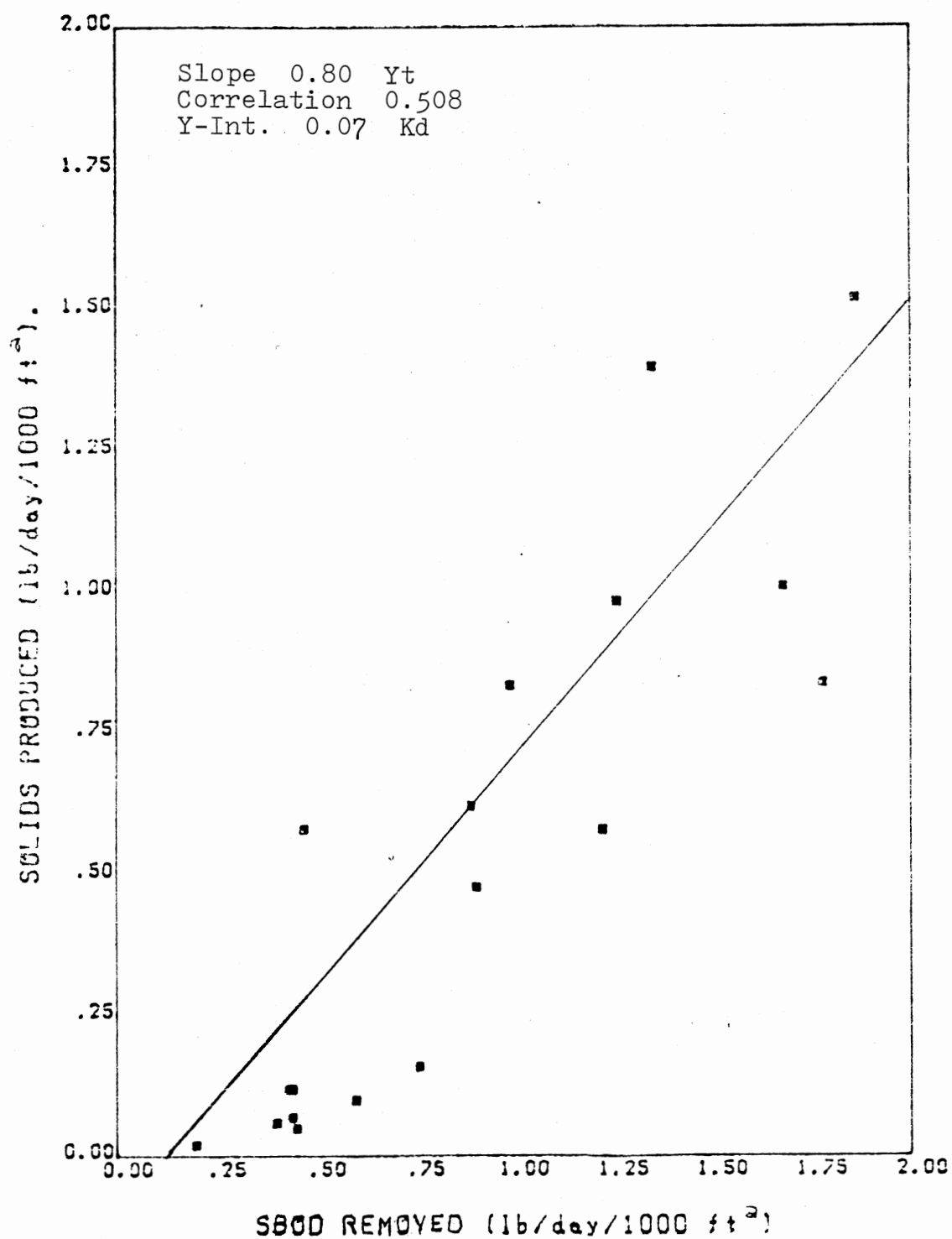


Figure 21. Determination of  $Y_t$  and  $K_b$  at All Loading Rates

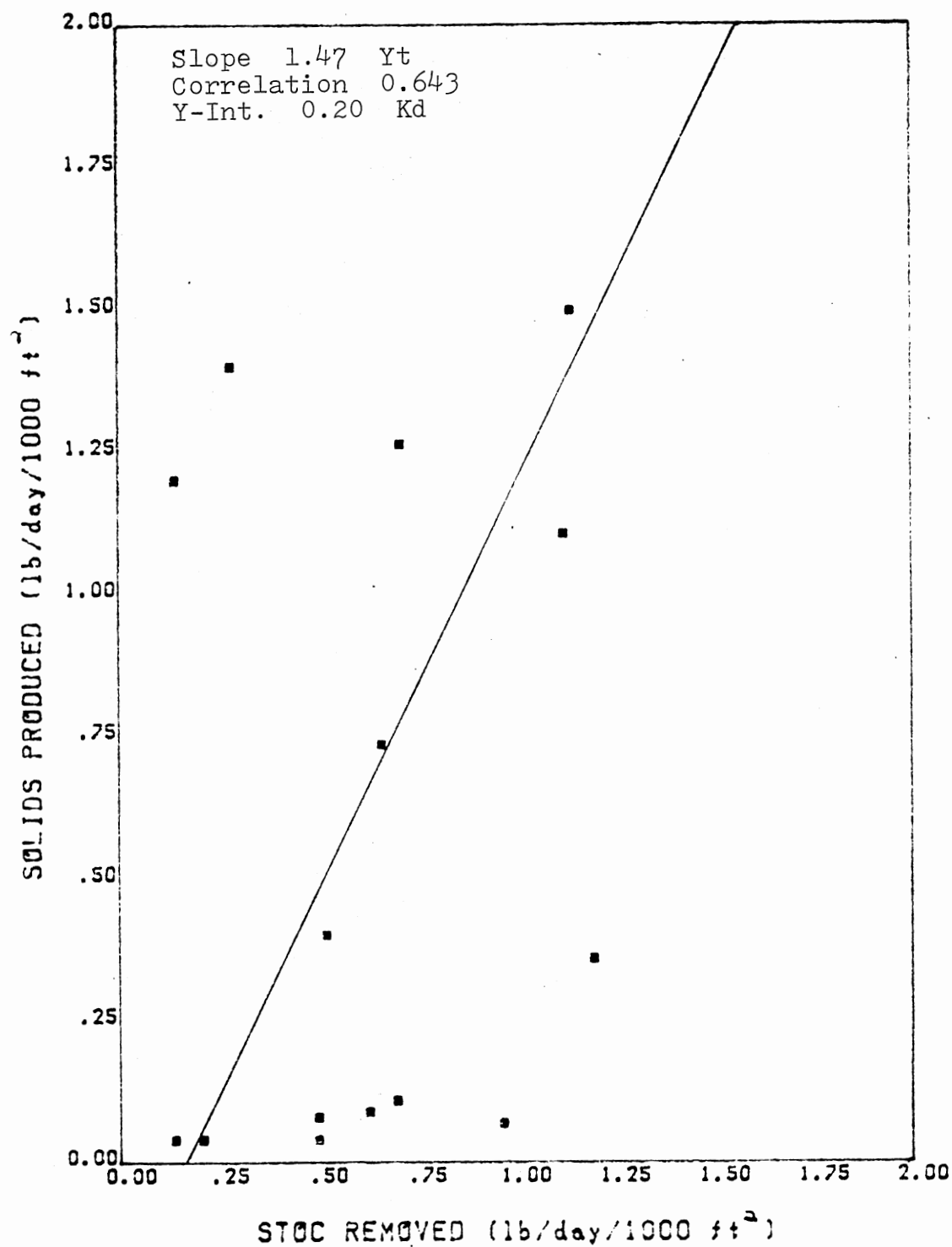


Figure 22. Determination of  $Y_t$  and  $K_b$  at All Loading Rates

Figure 22 represents the determination of  $Y_t$  and  $K_d$  at all loading rates for STOC. The slope was calculated to be 1.47, which was equal to  $Y_t$ . The Y-intercept was calculated to be 0.20, and this is equal to  $K_d$ .

Figure 23 represents the determination of  $Y_t$  and  $K_d$  at all loading rates for SCOD. The slope was determined to be 0.61, which was equal to  $Y_t$ . The Y-intercept is equal to 0.04. This is equal to  $K_d$ .

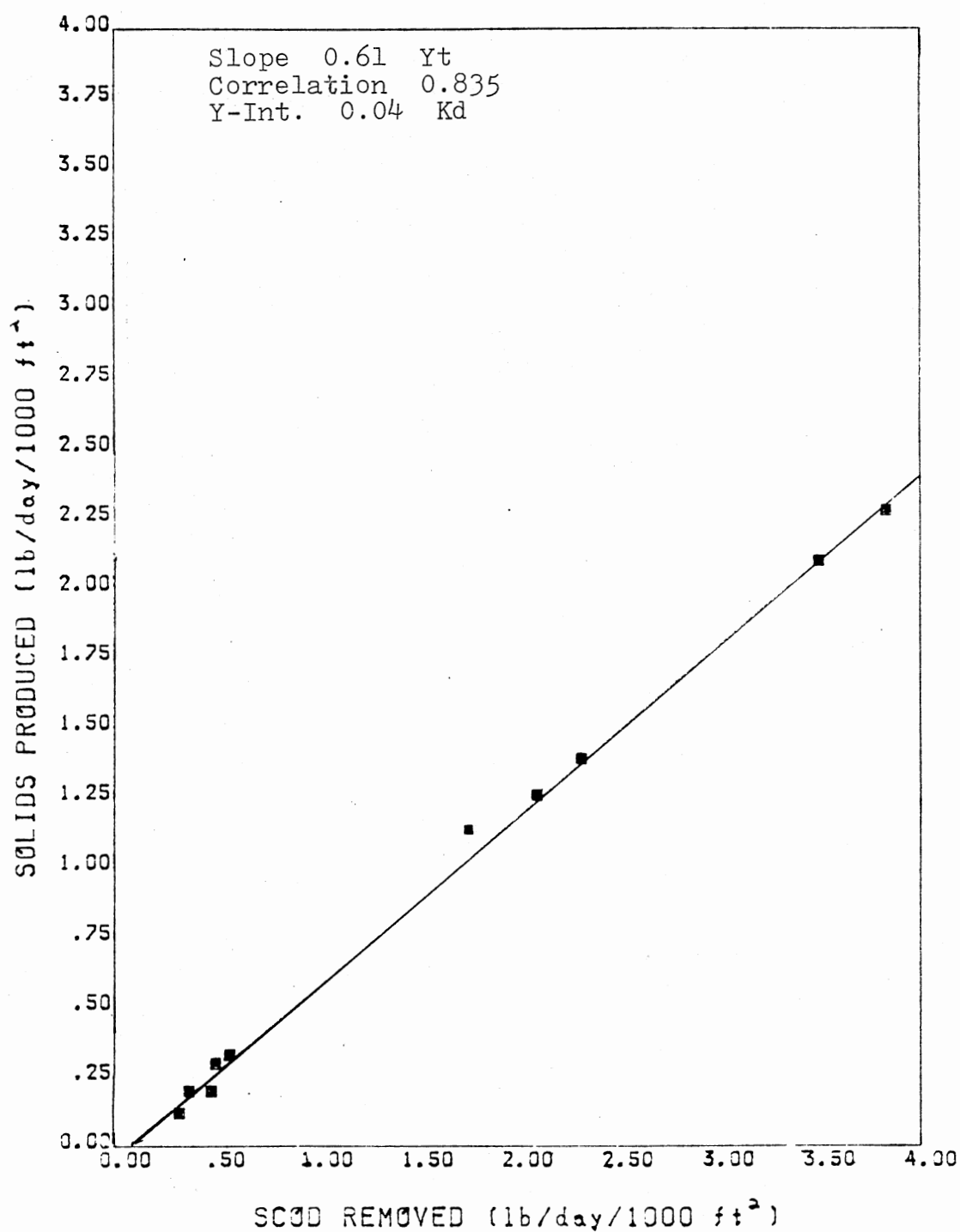


Figure 23. Determination of  $Y_t$  and  $K_b$  at All Loading Rates

## CHAPTER VII

### DISCUSSION

The purpose of this investigation was to determine the feasibility of using the rotating biological contactor to treat wastewater from a full-scale alcohol production plant. There has been considerable work done on fixed film kinetics, especially with the RBC. The rotating biological contactor may hold the key to the future of the wastewater treatment field. Rotating biological contactors have a number of characteristics which make them desirable for the design engineer. They can provide a very high degree of treatment. They require less area than most other comparable processes. They can be retrofitted easily to existing plants. RBC's show high efficiency in oxygen transfer.

They handle organic overloading well, due to the large biomass on the discs. Since they involve attached growth, they are much less likely to fail through washout when conditions adverse to biological growth occur. There is no bulking, foaming, or floating of sludge to interfere with the plant's overall efficiency.

The RBC uses up to 50 percent less energy than conventional activated sludge units. Over the lifetime of the plant, this can be a substantial savings.

Rotating biological contactors are simple to operate. There is no sludge or effluent recycle. The sloughed biomass settles well and can be more easily recovered than solids from an activated sludge tank.

Clarifier design is far less critical with the RBC unit than the activated sludge systems.

On the other hand, the RBC has several disadvantages. Structural problems tend to occur with several large-scale plants. Oil leaks from the drive units are common. Enclosures are necessary where very low air or water temperature occur in order to achieve acceptable performances. Suspended solids tend to accumulate in RBC reactors if removal in primary clarifier is inadequate.

Disc rotation affects wastewater treatment in several ways. It provides the contact between the biomass and the wastewater; it shears the biomass; it provides the needed oxygen to aerate the wastewater; and it provides the needed mixing velocity in each stage. There is an optimum velocity where above that point treatment efficiency will not increase.

For every RBC system, treating either municipal or industrial wastewater, there is a limit to the rate which the waste is applied for aerobic conditions to be maintained. Once pushed into this anaerobic region a number of problems can occur. Undesirable organisms will proliferate, and anaerobic and sulfur oxidizing bacteria microorganisms will be plentiful. The anaerobic bacteria normally coexist with aerobic microorganisms forming the underlayer of the biofilm. When overloading occurs, the tremendous growths which tend to develop are primarily anaerobic bacteria. This dead load decreases the life expectancy of the equipment.

#### Biological Solids Concentration

After the unit was stabilized, the solids concentration in the effluent decreased steadily and remained between 4 and 12 mg/l throughout the rest of the study. At first, at a SBOD concentration of 1000 mg/l,

the solids coming out of the system varied from 100 to 600 mg/l until the system stabilized. At a high loading on the first stage, black anaerobic sludge was produced. The film on the discs changed from a whitish-gray color to a black spotted film. As the hydraulic loading increased, the solids concentration in the mixed liquor became less dense. At higher flow rates, the solids concentration in the mixed liquor remained constant at 100 to 250 mg/l after the unit stabilized. The lower flow rates would not washout the solids, and the solids remained in the stages, causing the biomass to become denser. Anaerobic conditions were soon to follow. The biomass would turn black as previously mentioned. An offensive odor would be emitted with these conditions.

#### SBOD Removal Efficiency

As seen earlier in Tables II through VII, very good removal efficiency occurred with all loadings. The maximum substrate removal rate was never achieved with this system because of the low loadings on the system. As the total organic loading increases, the curve would become steeper and the efficiency lessen. If the maximum substrate utilization rate had been reached, the curve would start to follow zero order kinetics and flatten out.

#### SCOD Removal Efficiency

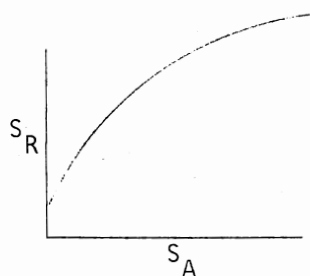
The removal efficiency for SCOD is outlined in Tables IV and V for loadings less than and greater than  $1 \text{ lb/day/1000 ft}^2$ . The maximum removal rate has not been reached at  $11.5 \text{ lb/day/1000 ft}^2$ . The best removal efficiencies occurred at the total organic loadings of 1 to  $5 \text{ lb/day/1000 ft}^2$ . At less than  $1 \text{ lb/day/1000 ft}^2$ , the system was underloaded

and the removal efficiencies indicate this point. The mixed liquor solids were metabolizing each other due to the lack of feedstock. The data collected during this period were very scattered. The wastewater was highly biodegradable and this could have led to a fluctuation in the data.

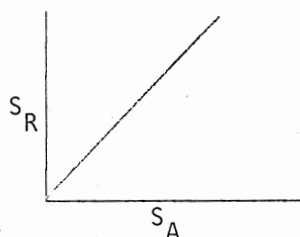
### STOC Removal Efficiency

The STOC removal efficiencies were very high throughout the study. At the levels observed, no maximum substrate removal was obtained. The curve does not flatten out and no maximum substrate removal was reached. Tables VI and VII list the efficiencies for STOC.

The small scale RBC unit performed well under differing conditions of concentration and hydraulic loading. The removal efficiencies were high for the SBOD, SCOD, and STOC data. The Kincannon-Stover model linearized the data points so that they could be evaluated. From the reciprocal plots, the kinetic constants of  $U_{\max}$ ,  $K_b$ ,  $Y_E$ , and  $K_d$  were determined. The area required for treatment as well as the concentration of the effluent ( $S_e$ ) could be determined from these kinetic constants. Basically, the Kincannon-Stover model plots pounds applied/day/1000 ft<sup>2</sup> ( $S_A$ ) versus pounds removed/day/1000 ft<sup>2</sup> ( $S_R$ ). The resulting curve is as follows:



The plot shows that the curve cannot be defined by either first, second, or zero order kinetics. The low end of the curve approaches first-order kinetics and the upper end of the curve approaches zero-order kinetics. This model eliminates the scatter in the data. Other models base their beliefs in that  $S_R$  versus  $S_A$  is the linear form as follows:



The equation of the line would be  $S_R = x S_A$ , whereas in the slope of the line and in the linear form it is constant;  $x$  is the treatment efficiency. This statement insinuates that no matter how many pounds are applied, the efficiency will be the same by the equation  $S_R = S_A (x)$  or  $x = S_R/S_A$ . This was proved incorrect by the evaluation of the data for SBOD, SCOD, and STOC.

## CHAPTER VIII

### CONCLUSIONS AND RECOMMENDATIONS

The results of the study support the following conclusions:

1. A conservative estimate design can be accomplished by using the Kincannon-Stover design method. It eliminates the scatter with other models.

2. Alcohol wastewater can be treated with the RBC with success, if one loads the stages correctly. It is not recommended to use this system because of the high strength of the wastewater. Overloading is likely to occur unless many units are employed and careful operational procedures are followed.

3. The RBC has great potential with low strength wastewaters such as municipal wastewater. The RBC unit can be used to upgrade an existing facility. The major cost of the system would be the capital cost of constructing the system. Municipalities employ this method because of low operational cost.

The recommendations for future study are:

1. Operate an RBC at different rotational speeds to compare treatment efficiencies with the same wastewater.

2. Explore large-scale unit treatment kinetics with the same wastewater.

3. Compare design cost of RBC, activated sludge, and biological towers for the same effluent requirements.

4. Experiment with different disc configurations and compare efficiencies for each other.
5. Operate RBC with different wastewaters and compare the data obtained with the data from alcohol wastewaters.
6. Compare sizes of RBC plants presently in use with their theoretical size calculated from the Kincannon-Stover model.
7. Experiment with different structural designs. For example, explore the possibilities of square, circular, and rectangular tanks.

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