A STUDY OF REMOVAL CHARACTERISTICS OF THE ROTATING BIOLOGICAL CONTACTOR

By

DEE ANN SANDERS GARRETT

Bachelor of Science

University of Missouri--Rolla

Rolla, Missouri

1971

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1973

A STUDY OF REMOVAL CHARACTERISTICS

OF THE ROTATING BIOLOGICAL

CONTACTOR

Thesis Approved:

Don F Kincannon
Thesis Adviser

Richard N. DeVries

A. F. Gaudy Jr.

D Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

I cannot adequately express my appreciation to my adviser, Dr. Don F. Kincannon, using only words. He has been a constant source of help and encouragement and infinite patience. I also wish to thank Dr. A. F. Gaudy, Jr., and Dr. R. N. DeVries for their help in my education and for their careful reading of this manuscript.

Very special thanks are due Enos Stover for his help, suggestions, and initial work with the lab unit used in this study.

A sincere thanks is due Mrs. Carol Patterson for her accurate typing of this manuscript.

My husband, Jack, has been the greatest single source of encouragement to me in preparing this manuscript. My parents cannot be thanked sufficiently, either. My mother, especially, is responsible for a love of learning which has encouraged me to continue my education. Nor can I thank Don Herbert, "Mr. Wizard," enough for kindling my interest in the sciences.

This investigation was made possible through the financial support provided by the Environmental Protection Agency graduate training grant (1T1-WP-238-03).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

CHAPTER I

INTRODUCTION

In the natural environment, all living things are interrelated in a cycle of growth and decay. Nothing that dies is wasted; it becomes food for other living things. Nature has a way to clean things, clearing away the dead to make room for the living.

Wastes that enter water become food for microorganisms in the water, and the water is purified. But with the fast pace of living today, Nature cannot take care of all the wastes in the streams and rivers; and the waters become polluted. Science has found that for many wastewaters, the natural method of purification is still the best; therefore, biological processes are used widely in the treatment of polluted waters. The process is speeded up and takes place outside the streams and rivers, and the wastewater returned is sufficiently purified for Nature to finish the job.

One of the oldest biological treatment methods still used today is the trickling filter. The name is misleading, because the reactor does not act as a filter. It is more correctly called a fixed-bed reactor, and usually consists of an artificial bed of broken stone or various types of plastic media. The sewage is applied by moving arms as droplets or spray. It then trickles down through the porous fixed bed on which a biological slime growth has accumulated. The organic constituents in the waste are oxidized and used for growth and metabolism by the organisms attached to the filter media.

Another biological treatment process is activated sludge, more properly called a fluidized-bed reactor. The reactor is usually a large rectangular basin in which the mixed liquor, consisting of water, wastes and microorganisms, is agitated and aerated. After settling, some of the sludge is returned to maintain a high level of biological solids in the reactor. The organics in the waste are removed biologically to be used as food for microorganisms.

One of the newest methods of biological waste treatment is the rotating disc biological contactor. The system consists of a series of closely spaced discs which are mounted on a horizontal shaft and rotated while partially immersed in wastewater. The microorganisms which feed on the waste become attached to the discs. In this way, the rotating disc process resembles a fixed-bed reactor. When excess growth builds up, shearing forces strip some of the bio-mass from the discs. These biologically active solids are kept in suspension, and the rotating biological contactor takes on some of the characteristics of an activated sludge unit.

The rotating disc process has been studied by several researchers and has been found to be effective in waste treatment. It is the purpose of this study to correlate the rotating disc performance with that of other treatment processes, notably trickling filters.

CHAPTER II

LITERATURE REVIEW

The rotating disc process is a recent development. It had its beginnings in research done in West Germany in 1958 by Hartmann and Popel (1). The process gained acceptance readily and has been used in Europe for over ten years (2). At the present time, over 1,000 commercial plants are in operation, primarily in West Germany, France, and Switzerland. These plants treat a variety of domestic and industrial wastes and range in size from 12 to 100,000 population equivalent. The process was brought under study in the United States in 1965, and now there are ten commercial installations here with six more due to be completed by the end of 1972 (1).

The rotating biological contactor process consists of a series of closely spaced discs mounted on a horizontal shaft and rotated while partially immersed in wastewater (3). The discs are generally made of polystyrene and are contained in a prefabricated or site-cast trough of a size such that approximately 40 percent of the disc area is submerged (4). The rotation of the discs serves to alternately contact the discs with wastewater and the air. This provides dissolved oxygen through thin film transfer and the mixing action of the water in the trough, so that a plentiful supply of oxygen is available for aerobic microbial activity (3). The plentiful oxygen supply also serves to promote high oxidation rates (4).

The discs provide a large surface area for the growth of micro-organisms. The growth occurring on the discs is generally of a filamentous nature, giving an even larger microbially-active surface area (3). It has been proven that surface area plays an important role in the removal efficiency of a fixed-bed reactor (5).

The rotating disc process primarily resembles a fixed-bed reactor, but it also has some characteristics of a fluidized-bed reactor. Figure 1 shows an efficiency curve comparing a rotating disc to activated sludge and trickling filter processes (4).

Several types of wastes have been treated using the rotating disc process. The first commercial installation in the United States was for a cheese waste, and the process has been widely tested on dairy wastes. Other types of waste treated, either on a pilot scale or a full scale, are domestic waste, poultry waste, bakery waste, winery waste, yeast waste, digestor supernatant, thermally conditioned sludge liquor, and slaughterhouse waste (1).

A study was conducted in 1967 to test a pilot plant rotating disc unit on dairy waste. Previous tests had shown the process to be effective at removal of a synthetic dairy waste, so the first field application of the rotating disc process was on a dairy waste. Using a two-stage unit with 3-foot diameter discs, an average COD reduction of approximately 70 percent was achieved (6). Birks and Hynek (7) report that a BOD reduction of 90 percent was achieved with a rotating disc unit used on a cheese processing waste. This waste had been previously treated anaerobically in septic tanks to reduce the initial BOD by 50 percent. The unit used had four stages, ten-foot discs, and an integral clarifier. The average residence time per stage was 1.5 to 2.0 hours. In studies

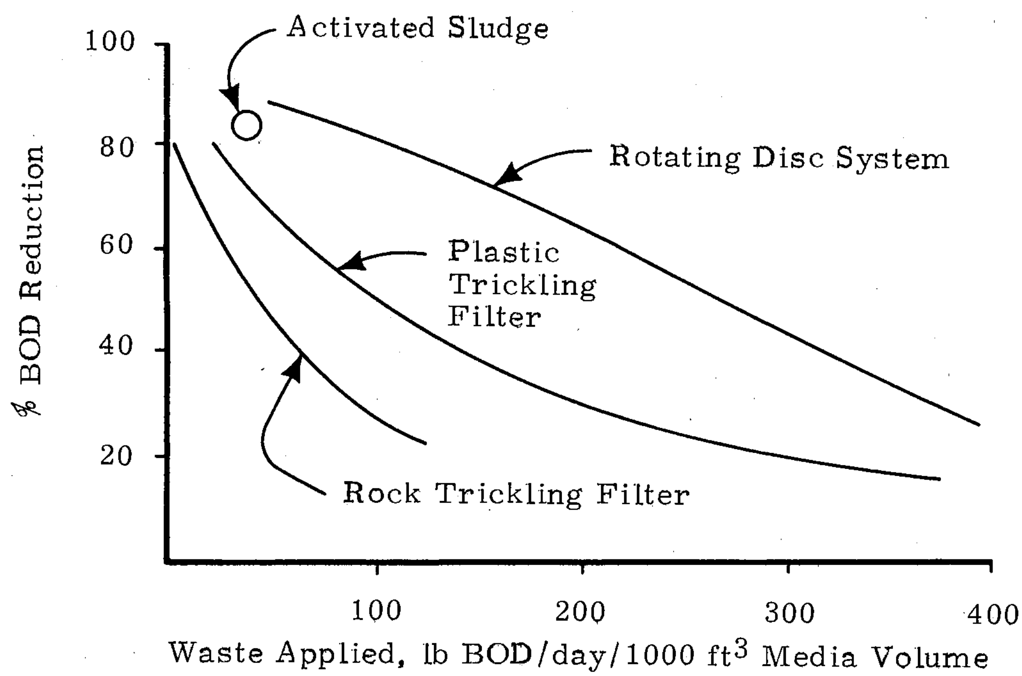

Figure 1. Rotating Disc System Performance Compared to Activated Sludge and Trickling Filters

reported by Antonie (3), a fresh dairy waste with an initial BOD of one thousand milligrams per liter (1000 mg/l) was reduced to 300 mg/l BOD with a detention time of 0. 3 hours for roughing treatment, and to a polished effluent of 30 mg/l BOD in 2. 5 hours. A septic dairy waste was treated with 98 percent efficiency using a 2. 9 hour detention time.

The rotating disc process has been successfully used for domestic wastewater treatment in the United States. A study of domestic wastes was begun in late 1969 which showed that a 90 percent BOD reduction could be achieved with a residence time of 80 to 90 minutes, using a two-stage system. If a 90 percent overall removal efficience is required, a 40- to 60-minute residence time is all that is necessary, assuming good primary clarification is available (8). Torpey, Heukelekian, Keplovsky, and Epstein (9) conducted a study on a total system for reclamation of wastewater. The rotating disc unit used was 10-stage with 3-foot aluminum discs. With a residence time of 5 to 6 minutes per stage, the BOD was reduced by 93 percent, and the COD was reduced by 78 percent. Antonie and Van Aacken (2) report a plant being built to treat the domestic waste from a medium-sized municipality. The plant will have a capacity of 4, 000 persons and will provide 90 percent BOD reduction.

From a study using the rotating disc process to treat anaerobic lagoon effluent, Chittendon and Wells (10) report a BOD reduction of 83. 2 percent. The pilot plant used was a 3-stage unit with 4-foot discs. The residence time per stage was 25 minutes. The waste entered with a DO level of zero, and the effluent from the first stage had a DO concentration of 0. 9 to 1. 5 mg/l.

The removal of nitrogen has become an important consideration in waste treatment. Using a 2-stage unit and a residence time of 90 minutes, 95 percent ammonia nitrogen and 90 percent Kjeldahl nitrogen removals were achieved on domestic wastewater (8). Torpey, et al., followed a conventional disc unit for secondary treatment with a series of illuminated aluminum discs on which algae were attached. This unit effectively reduced both nitrogen and phosphorus (9).

Stover (11) studied the removal efficiency of the rotating disc process on a meat packing waste. The unit used was a miniature, 6-stage unit with 2-foot discs. With an average residence time of 2. 5 hours, the COD of the waste was reduced approximately 50 percent by the first stage. Removal throughout the rest of the unit depended upon the COD of the influent.

Any industrial treatment will be subject to shock loads at times. The rotating disc process has been shown to be affected less by shock loads than other biological treatment processes. A synthetic dairy waste was fed to a rotating disc unit with the hydraulic flow rate varying to approximate a regular 8-hour work day. The two-stage unit produced an effluent with a COD reduction averaging 66 percent. Other fluctuating flow patterns were used, with 70 to 80 percent average COD reduction. The biological growth adjusted quickly to flow changes and did not slough even at detention times as low as 3 minutes (12). Stover (11) also reported that a shock load of washwater does not reduce the removal capacity of the unit. A shock load even serves to enhance the removal capabilities once normal flow is resumed.

CHAPTER III

MATERIALS AND METHODS

Rotating Disc System

The rotating disc unit employed in this study was a 4-foot, 10-gallon pilot plant model built by Autotrol Corporation. It consisted of six stages or compartments separated by baffles to allow flow from one stage to the next, while the baffles served to foster a predominance of different organisms in each stage. There were 5 discs per stage, for a total of 30 discs in the entire unit. A 1/10 horsepower, 110 volt a. c. electric motor was used to rotate the discs at 11 rpm. The disc diameter was 23. 25 in., giving a surface area of 2. 96 sq. ft. on each side of the disc. The total surface area of the media available for microbial growth was therefore 177. 5 sq. ft. The volume of the unit taken as a cylinder was 11. 8 cu. ft.

Waste

The waste used in this investigation was a synthetic substrate using sucrose as a carbon source. The composition of the waste (See Table 1) was such that the carbon source was the limiting growth factor. A sucrose waste was chosen because of the purity and low cost of sucrose when purchased in technical grade. The waste can be made up in a concentrated form, also, and the COD of the feed to the unit can be easily changed by altering the amount of concentrated feed used.

TABLE I

COMPOSITION OF CONCENTRATED SYNTHETIC FEED FOR 100 mg/l SUCROSE

Constituent	Concentration
Sucrose	100 mg/l
$Na_2HPO_4 \cdot 12\ H_2O$	12 mg/l
$MgSO_4 \cdot 7H_2O$	10 mg/l
$FeCl_3 \cdot 6H_2O$	0.05 mg/l
$CaCl_2 \cdot 2H_2O$	0.75 mg/l
$MnSO_4 \cdot H_2O$	1.00 mg/l
$(NH_4)_2\ SO_4$	25 mg/l
Tap water to volume	

Another reason for choosing a sucrose synthetic waste was for purposes of comparison. Several studies have been done on trickling filters using this formula of waste.

The wastewater was placed in two holding tanks, each having a capacity of 240 liters. Next, the waste was pumped into the holding basin at the head of the rotating disc unit, where it was dipped into the first stage by four rotating bucket feeders. Here, in the first stage, the biological treatment began. The waste flowed through each of the next five stages and out the effluent line into the sanitary sewer.

The pumps used in this study had flow control valves to maintain steady flow rates. Three different flow rates were used in this study: 0.25 gpd/ft^2, 0.50 gpd/ft^2, and 0.75 gpd/ft^2. The detention times at these flow rates were 80 minutes, 160 minutes, and 240 minutes, respectively.

Experimental and Analytical Procedures

An initial seed of effluent from the primary clarifier at the Stillwater sewage treatment plant was added to the feed to aid in the start-up of the microbial population. The unit was operated for three weeks prior to testing to allow sufficient time for the acclimation and growth of the microorganisms. After this period, tests showed that an equilibrium had been reached. A minimum of three days was allowed thereafter for acclimation at each particular feed concentration and flow rate. To assure that the unit had reached equilibrium, samples were taken until the results of two runs were comparable. The COD's, pH values, and solids were then averaged.

Seven samples were collected each sampling period. The first sample was collected directly at the influent line. The samples from the ends of stages 1 through 6 were collected with the aid of a glass tube connected to a rubber hose. Approximately 150 ml of wastewater was collected into a glass beaker at each stage.

pH

Following collection, the pH of the mixed liquor was immediately determined using a Beckman pH meter. The meter had been previously adjusted by the use of a buffer compound of pH 6.8.

Biological Solids

The weight of the biological solids was determined gravimetrically by filtration of the mixed liquor samples through membrane filters (0.45μ size, Millipore Corporation). The following procedure was employed in the measurement of suspended biological solids: Filters were placed in aluminum pans weighing approximately 1.5 grams each. The pans were placed in a drying oven for one hour at a temperature of 103° C., then cooled in a desiccator to constant weight. The weights of the tares were then recorded. Twenty-five ml of each sample was then centrifuged (Sorvall Superspeed Centrifuge, type SS-1A, Ivan Sorvall, Inc.) to reduce the time of filtration. The samples were filtered with the aid of a vacuum pump. First the supernatant was filtered, then the pellet of solids formed by centrifugation was removed with a metal spatula and placed on the filter. After complete filtration, the filters were returned to the aluminum pans and placed in a drying oven at 103° C. The filters were dryed to constant weight, which required several hours for samples containing particularly high levels of solids. The samples were cooled in a desiccator, then weighed, and the biological solids concentrations calculated.

Chemical Oxygen Demand

The COD of the membrane filtrate was determined in accordance with Standard Methods (13). Mercuric sulfate and silver sulfate were used in all determinations.

CHAPTER IV

RESULTS

Removal Capabilities of the Rotating Biological Contactor

Low Hydraulic Loading

COD removal characteristics at a hydraulic loading of 0.25 gpd/ft^2 of the rotating disc unit utilizing a synthetic sucrose waste are shown in Figure 2. The influent COD, COD of the wastewater leaving each stage, and the effluent COD are shown. It can be seen that a majority of the COD is removed in the first stage, Thereafter, only minor amounts of COD are removed per stage. It can also be seen that the COD of the effluent is always slightly higher than the COD of the waste leaving the fifth stage. This occurrence is due to a build-up of solids at the outlet of the unit and will be discussed in greater detail in the following chapter.

Figure 3 shows the percent COD remaining at each sampling point. This more clearly shows the rapid removal achieved by the first stage, and shows the COD approaching a limiting lower value in the later stages. The removal efficiency increased with an increase in organic loading for the first three experiments, then decreased for the last two. The slime accumulated on the discs increased in thickness as organic loading increased, and growth on the discs of the last stages noticeably increased. At lower loadings, most of the growth was concentrated on

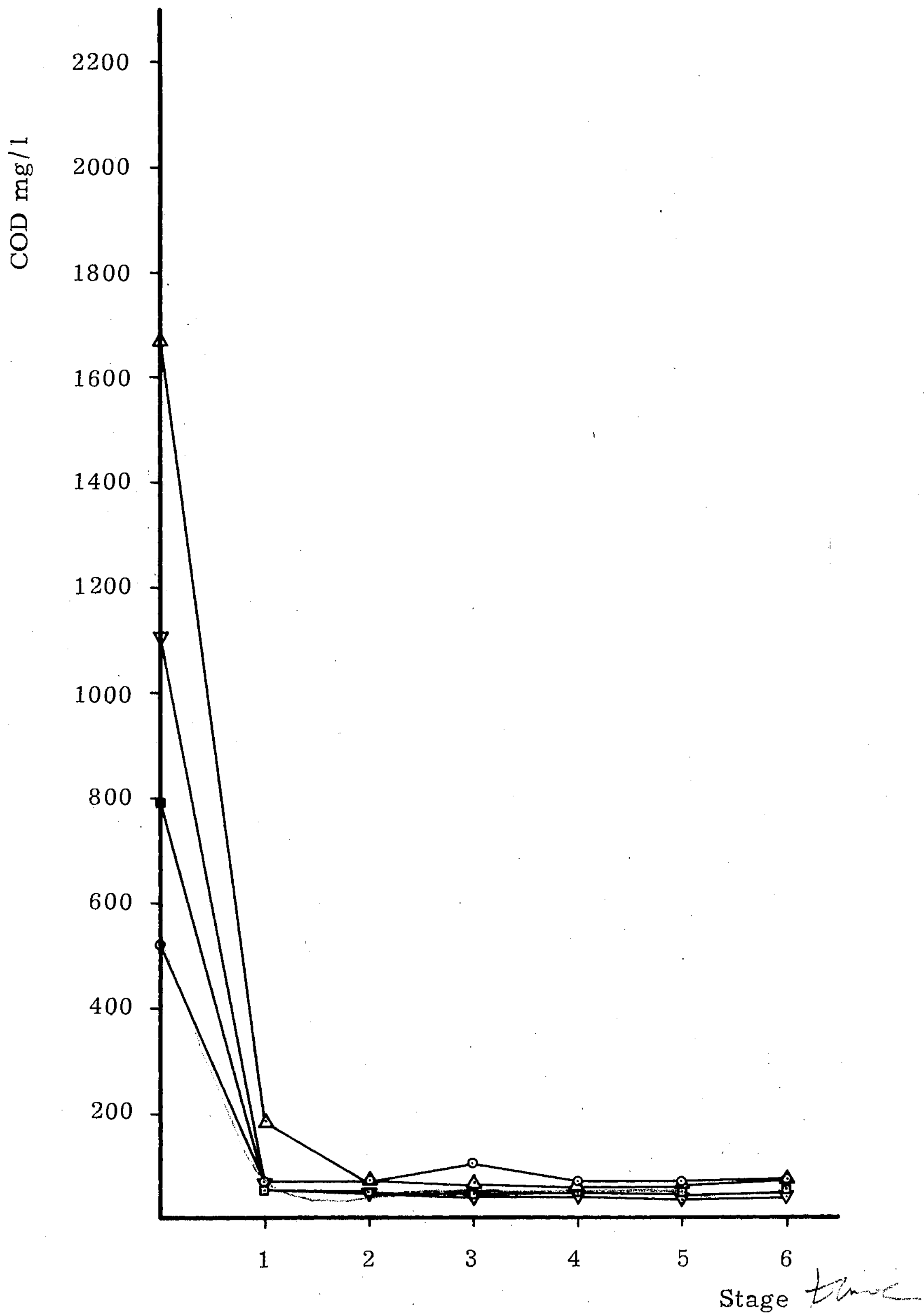

Figure 2. Chemical Oxygen Demand Removal for Low Hydraulic Loading

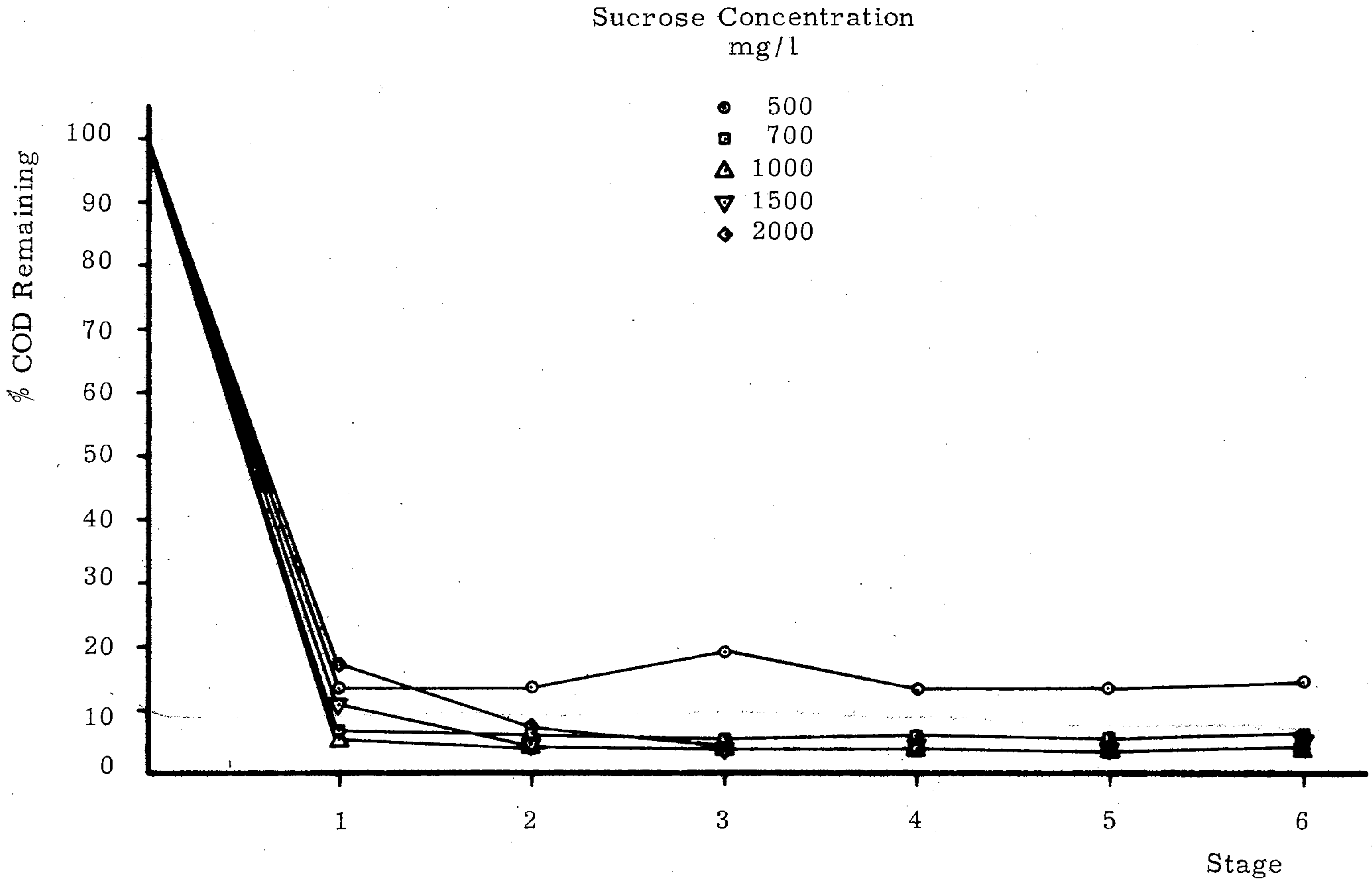

Figure 3. Percent COD Remaining vs Stage for Low Hydraulic Loading

the first two stages with very little and spotty growth on the last four stages. This build-up of microbial growth on the discs could account for an increased efficiency up to a loading at which growth was not sufficient to oxidize all the available organics. A peak in the COD at the third stage at the lowest organic loading was due to a large accumulation of solids in that stage.

The plot of logarithmic percent COD versus stage is shown in Figure 4. The removal rate (slope of the line) through the first stage is always greater than the removal rate in the rest of the unit. This is due to a majority of the waste being removed in the first stage.

Medium Hydraulic Loading

COD removal characteristics at a hydraulic loading of 0.50 gpd/ft^2 are shown in Figure 5. A majority of the waste is oxidized in the first stage, and the COD tends to approach a limiting value in the later stages. Again, the COD generally increases from the fifth to the sixth stages, except at higher organic loadings. The plot of percent COD remaining vs stage (Figure 6) shows the decreasing efficiency as organic loading increases. The exception is again in the lower range. Figures 5 and 6 also show that as organic loading increases, the removal efficiency of the first stage decreases. This results in the later stages coming into use.

Figure 7 shows the logarithmic percent COD removed vs the stage. It is seen from this plot that as the organic loading increases, the initial removal rate extends to later stages, giving a higher efficiency in the end stages. As organic loading increases, the percentage of organics available to later stages increases. As with the lowest hydraulic

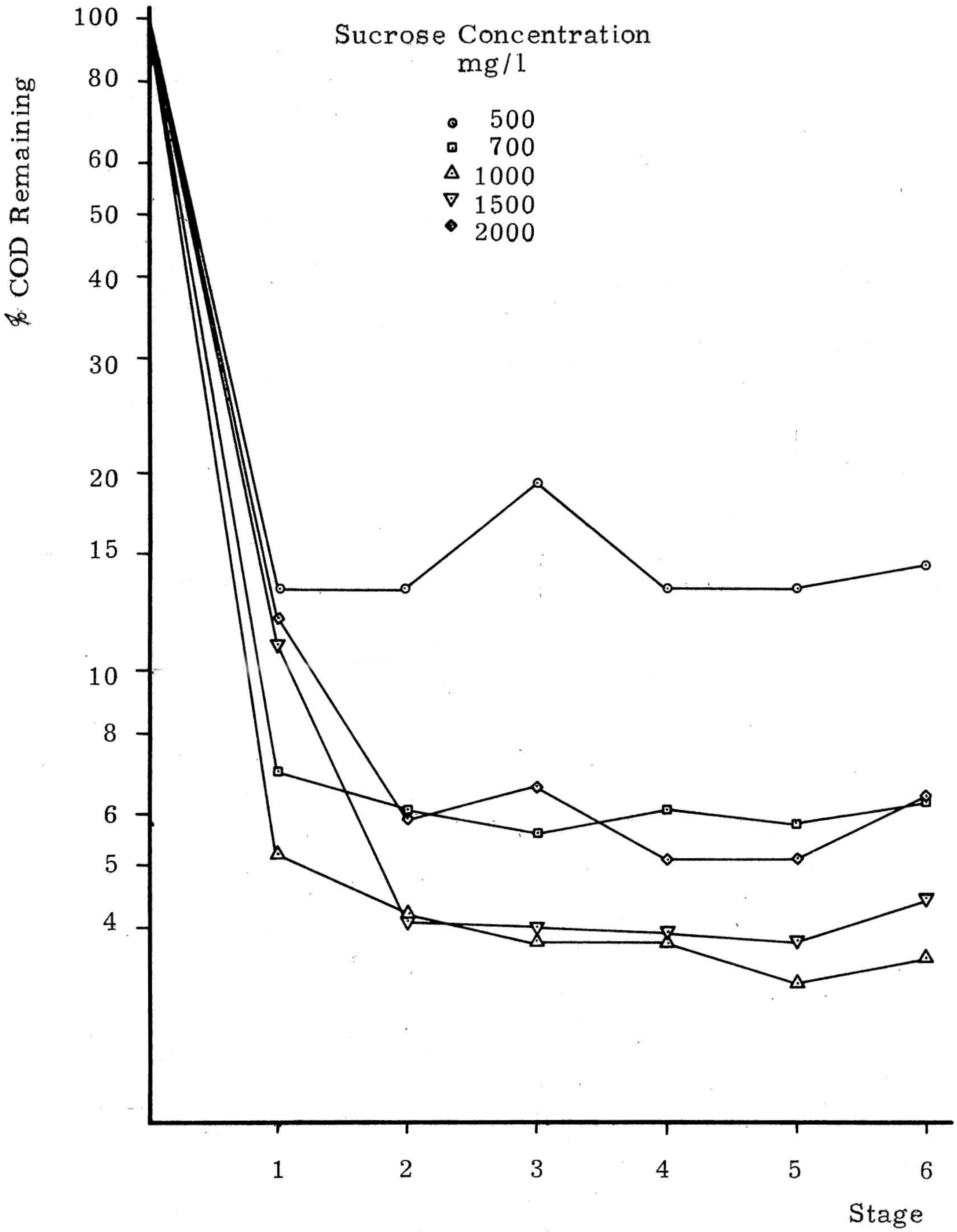

Figure 4. Logarithmic Percent COD Removed Per Stage at Low Hydraulic Loading

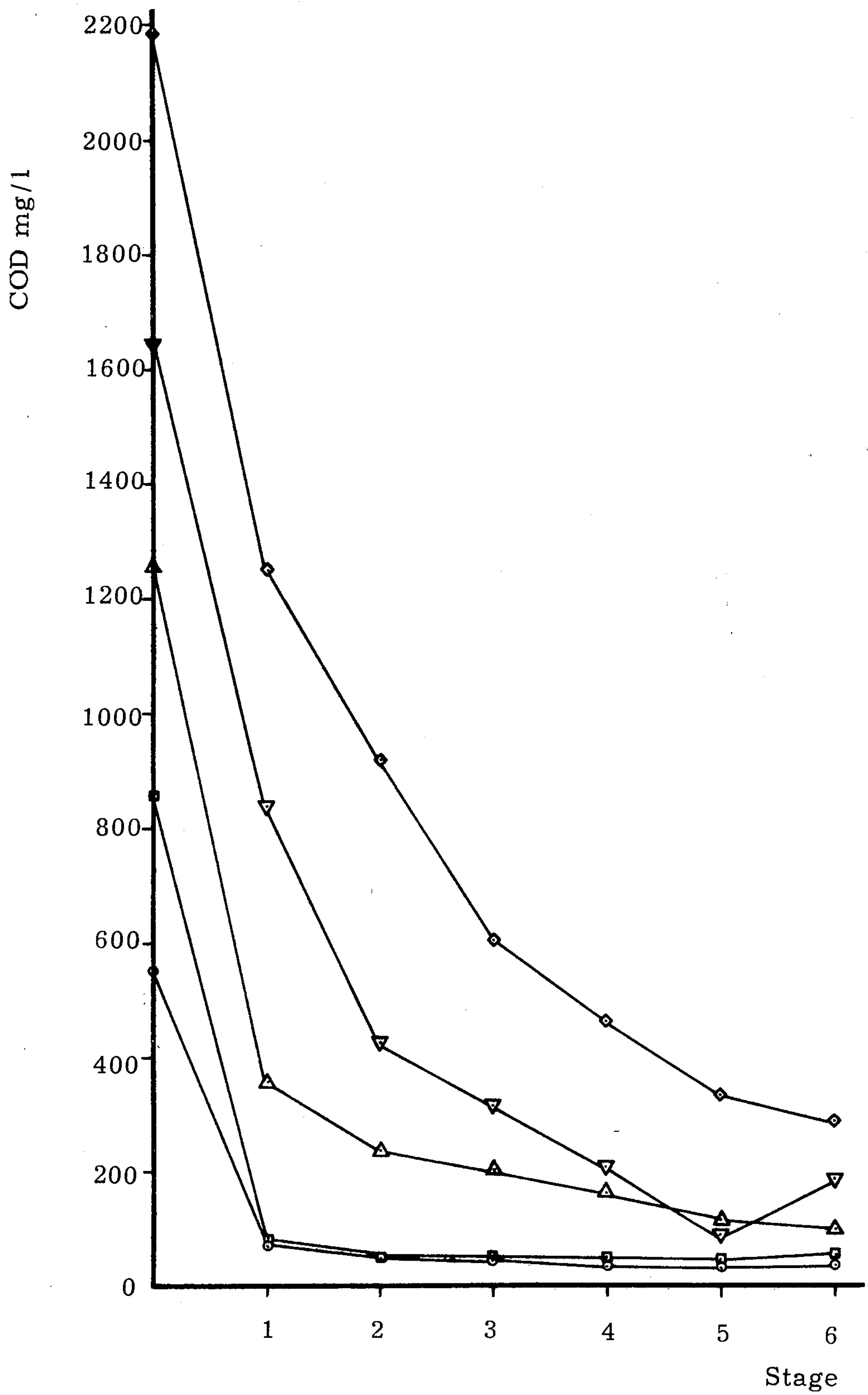

Figure 5. Chemical Oxygen Demand Removal for Medium Hydraulic Loading

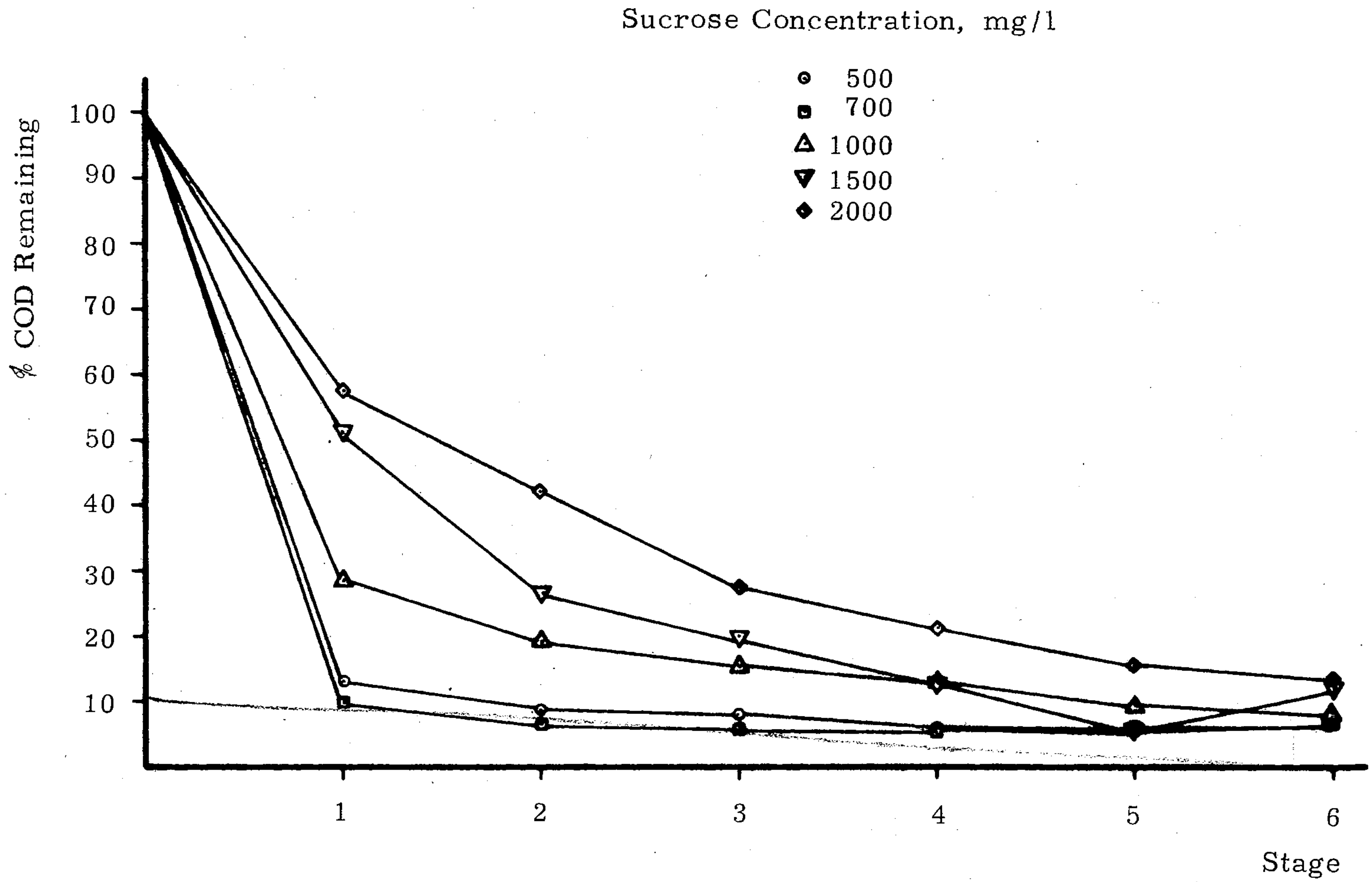

Figure 6. Percent COD Remaining vs Stage for ~~Medium~~ Hydraulic Loading

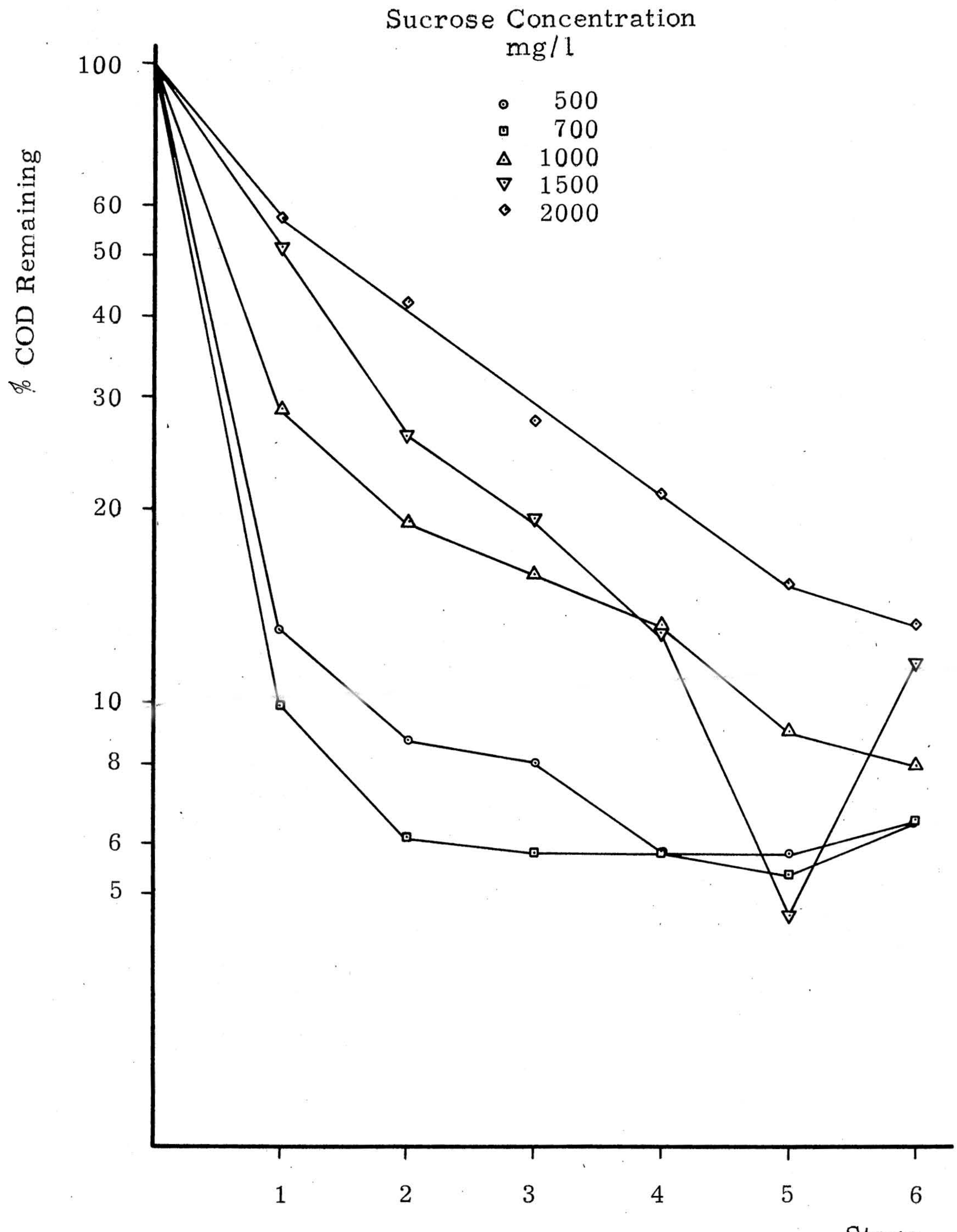

Figure 7. Logarithmic Percent COD Removed Per Stage at Medium Hydraulic Loading

loading, the kinetics appear complex, not clearly first order. The highest organic loading curve appears to exhibit two-phase, first order removal, however, breaking at the first stage.

High Hydraulic Loading

The removal exhibited by the unit at the highest hydraulic loading, 0.75 gpd/ft^2, was extremely good. A change in predominance began during the acclimation period at the lowest organic loading, and the new type or types of organisms continued to replace the growth that was characteristic of the pervious series of experiments. As can be seen from Figure 8, the COD of the waste was rapidly reduced at all organic loadings, much more so than 0.5 gpd/ft^2 but not as much as 0.25 gpd/ft^2. In Figure 9, it can be seen that the first stage removed greater than 70 percent of the initial COD in all cases, and a limiting value of COD was rapidly approached. After stage 2, the percent COD remaining was nearly the same for all organic concentrations.

The removal rates for this series of experiments can be seen as the slopes of the lines in Figure 10. As organic loading increases, there is a definite increase in the number of stages through which the initial substrate removal rate continued. However, in no case can first order kinetics be seen. In all experiments, the removal rate became negative from the fifth to the sixth stage.

pH Characteristics

Low Hydraulic Loading

The change in pH with stage at a hydraulic loading of 0.25 gpd/ft^2 is shown in Figure 11. The pH initially is around 7.0 in all cases and

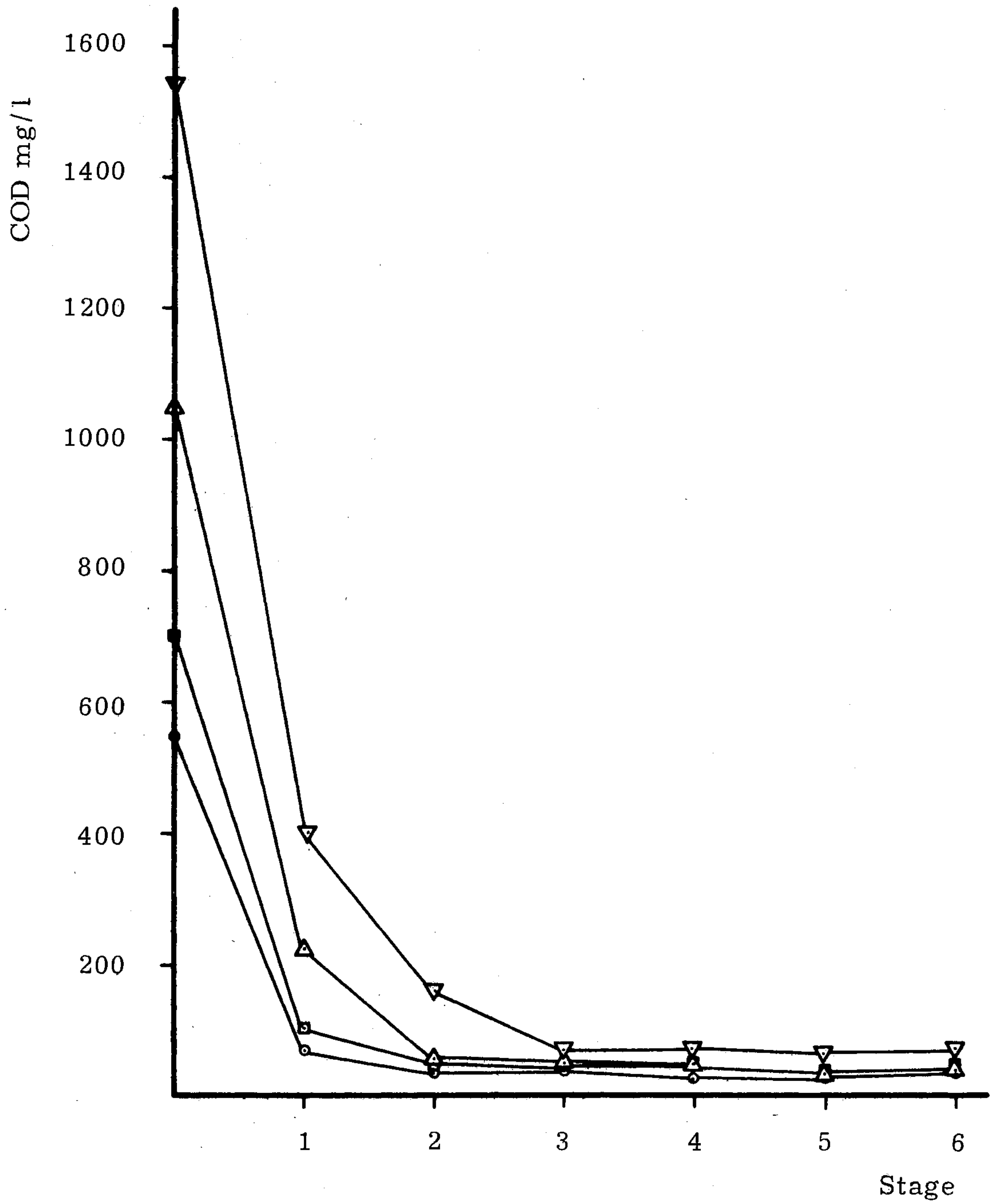

Figure 8. Chemical Oxygen Demand Removal for High Hydraulic Loading

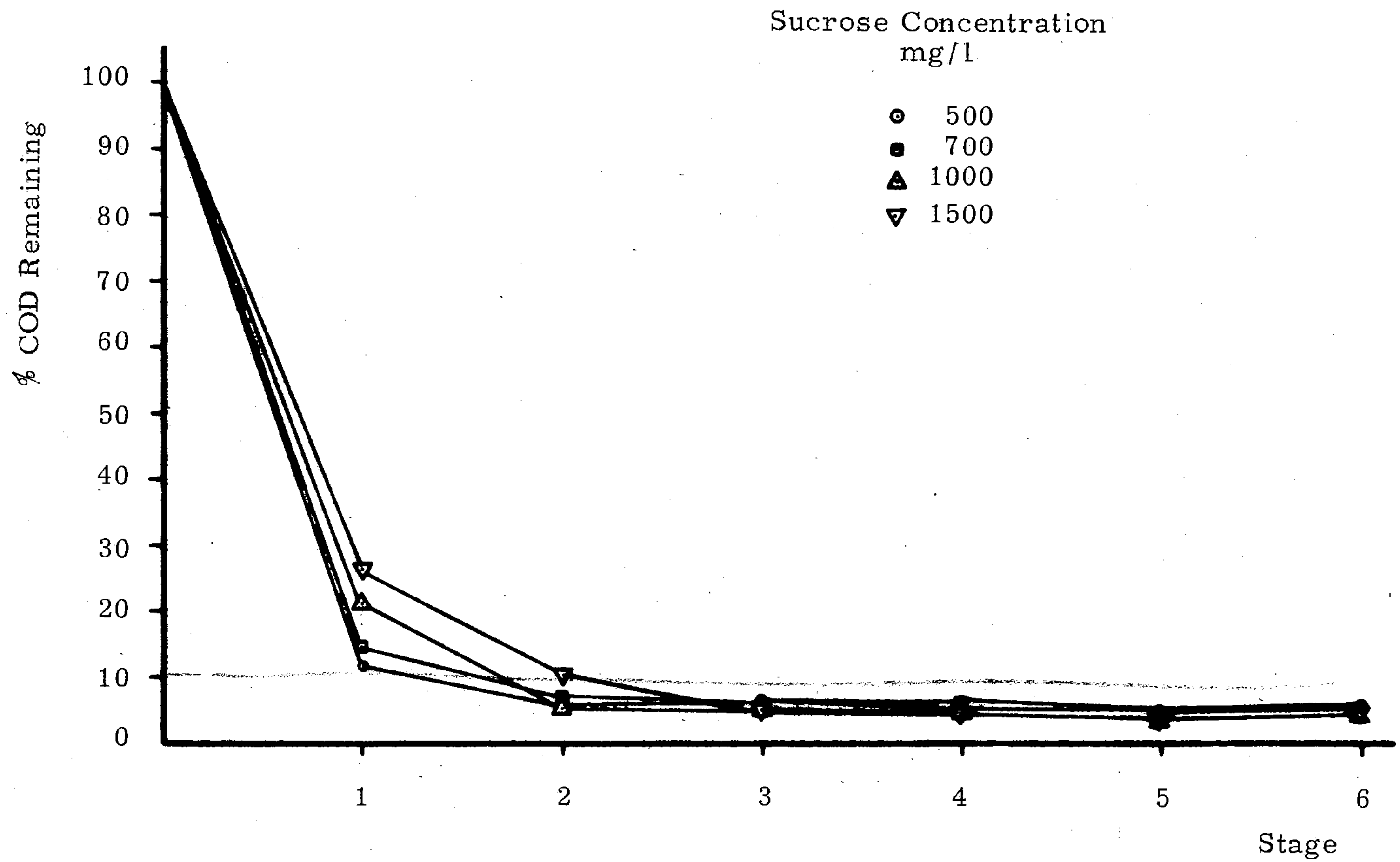

Figure 9. Percent COD Remaining vs Stage for High Hydraulic Loading

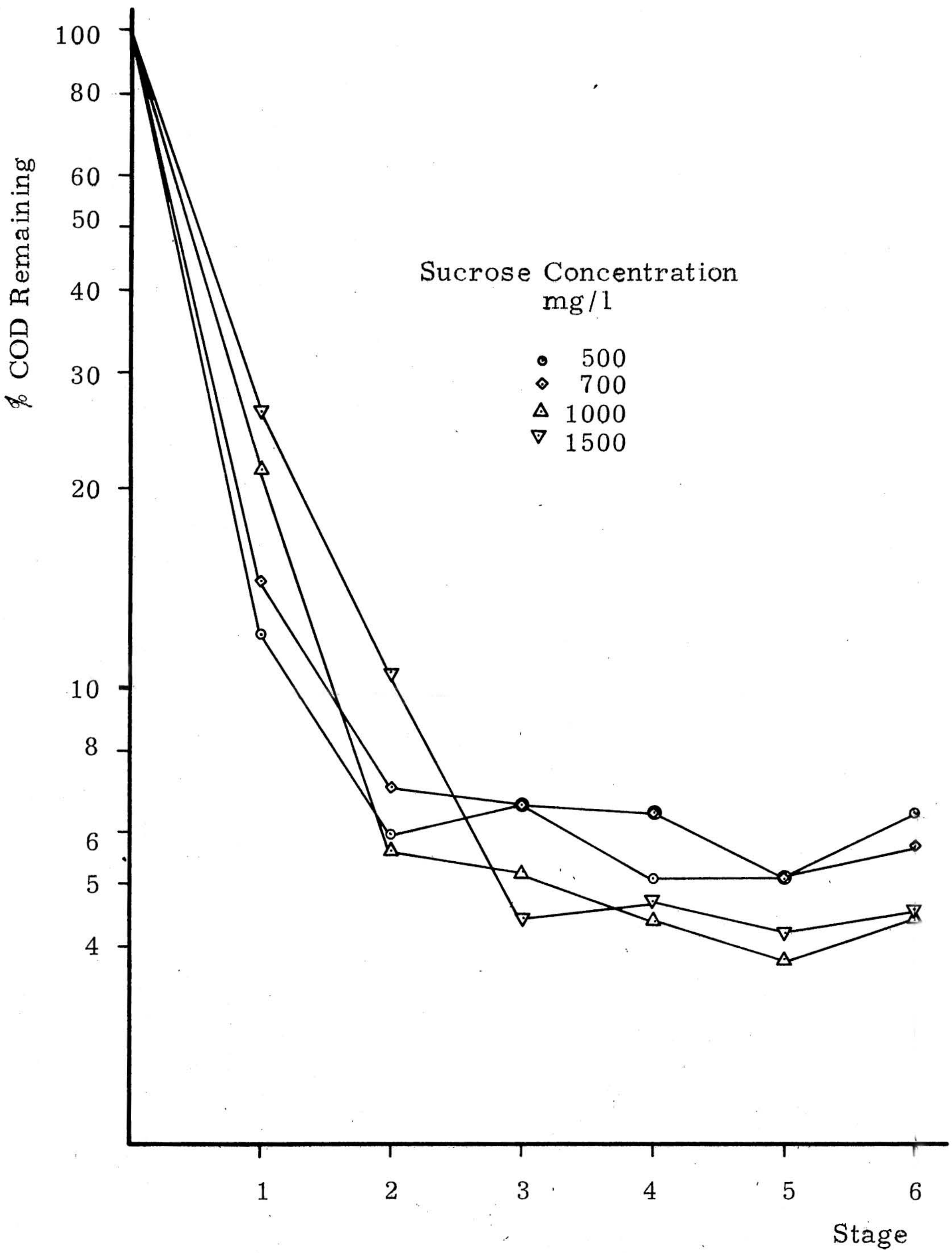

Figure 10. Logarithmic Percent COD Removed Per Stage at High Hydraulic Loading

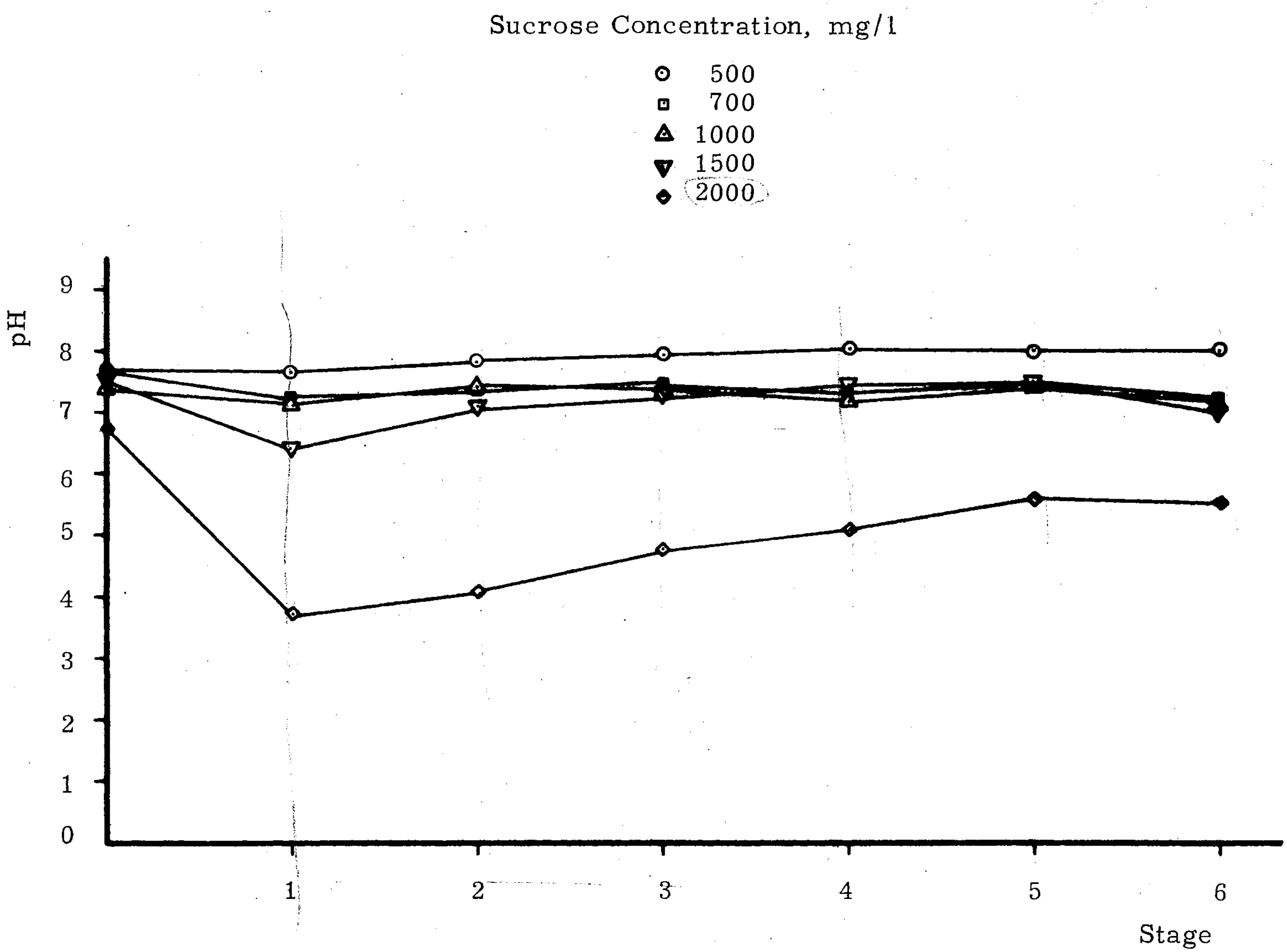

Figure 11. pH vs Stage for Low Hydraulic Loading

is lower at the end of the first stage in all but one experiment. At a feed concentration of 500 mg/l, the pH does not drop. After the first stage, the pH begins to rise generally throughout the rest of the unit. At some points, notably the sixth stage, the pH of the waste drops. This corresponds to a high solids level in all but one instance. As the organic loading increases, the drop in pH through the first stage is magnified, and the pH does not return to the initial value.

Medium Hydraulic Loading

The tendencies in pH levels seen at the lower hydraulic loading were evident here. In Figure 12, the pH is plotted vs the stage for a hydraulic loading of 0.50 gpd/ft^2. In all experiments, the pH dropped at the end of the first stage, then rose throughout the rest of the unit. At the highest organic loading, the pH continued to drop through the second stage; but this was the only experiment in which the pH recovery did not begin after the first stage. Again, in all but the highest organic loading, the pH was lower at the sixth stage than at the fifth.

High Hydraulic Loading

The unusual characteristics of the highest hydraulic loading included the pH values. As seen in Figure 13, the pH never dropped more than 0.3 from the influent to the first stage, and the values rose from the first stage to the fifth. All experiments showed a decrease in pH through the final stage.

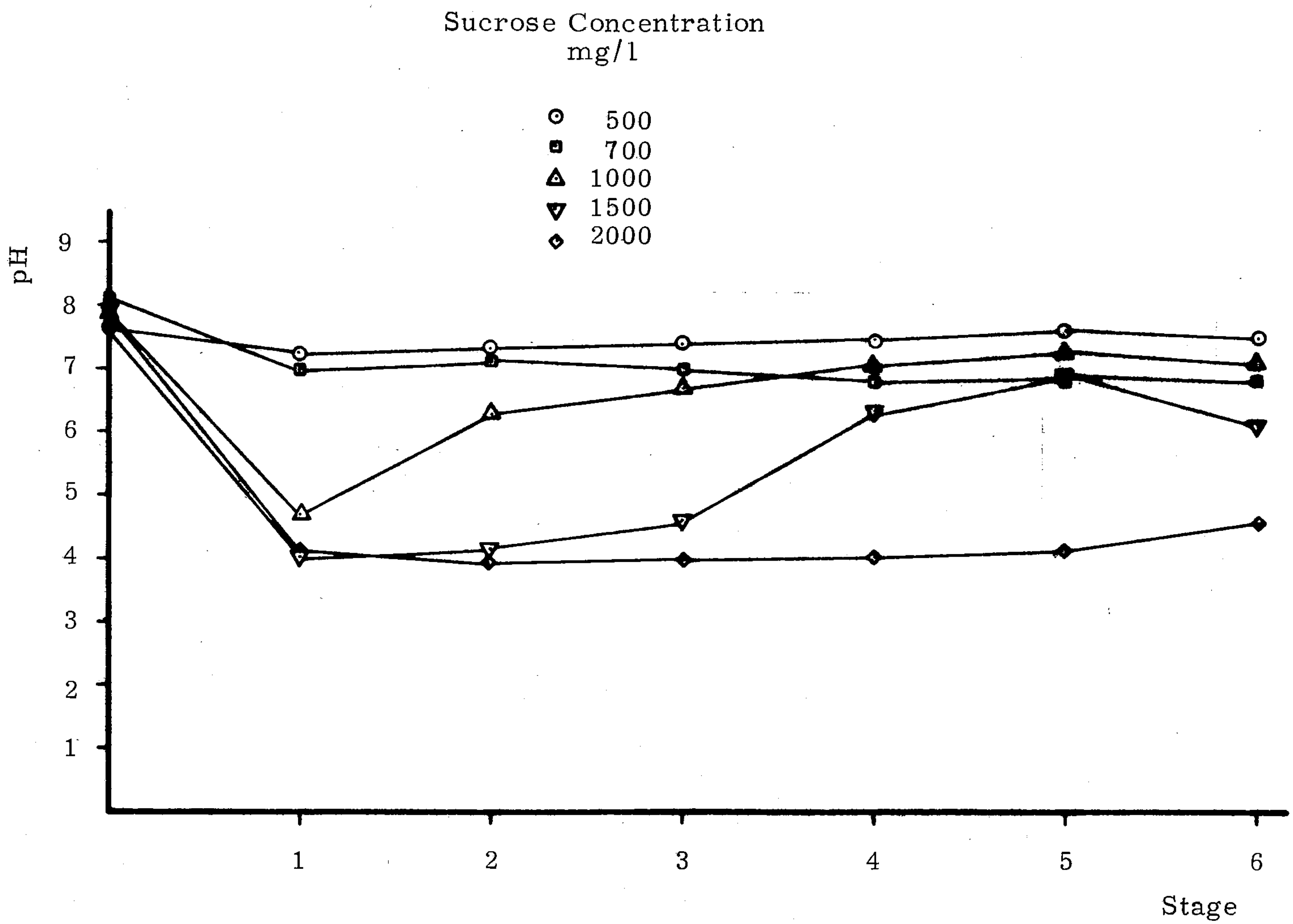

Figure 12. pH vs Stage for Medium Hydraulic Loading

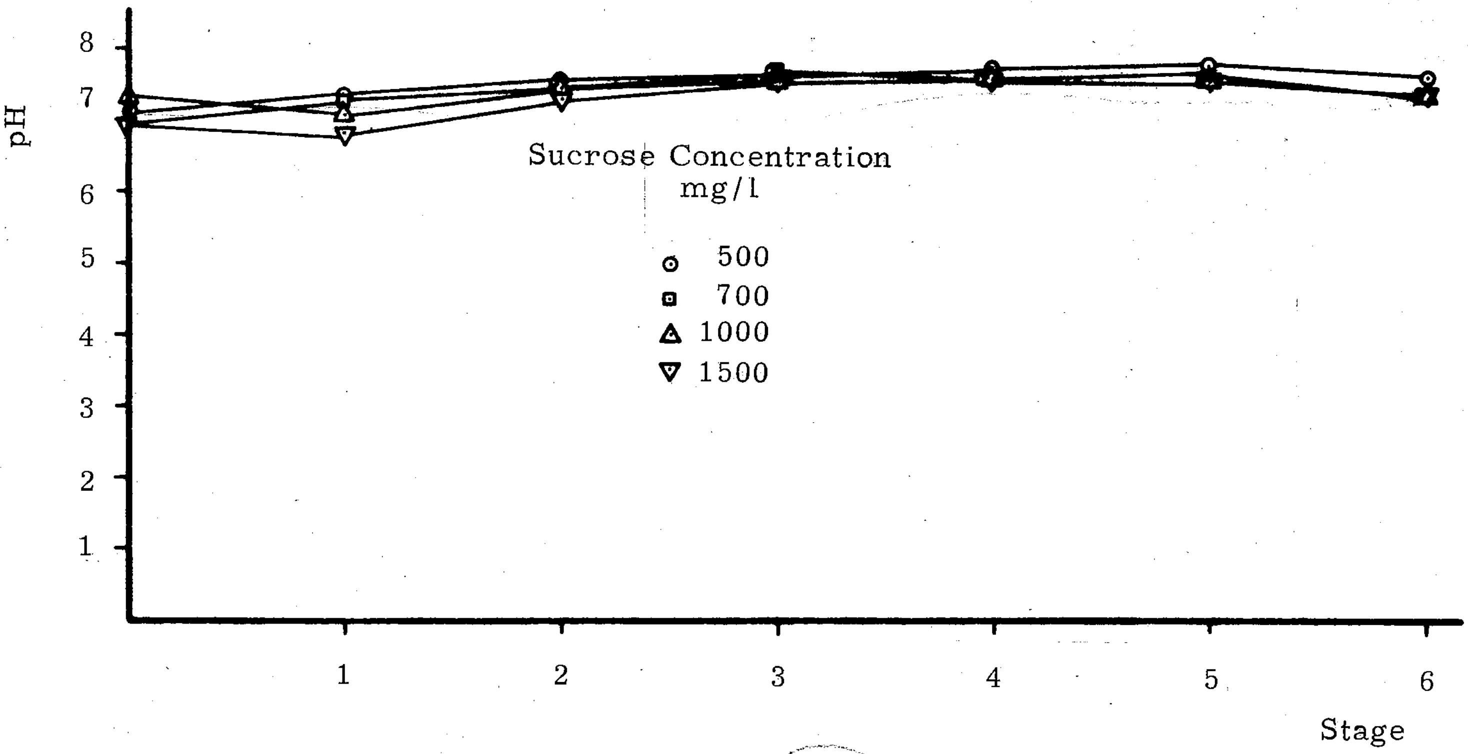

Figure 13. pH vs Stage for High Hydraulic Loading

Biological Solids Characteristics

No definite trend can be seen in the biological solids levels as the hydraulic or organic loadings increase. The values obtained are reported in the summaries of the experiments at each hydraulic loading in Tables II, III, and IV. These values are only approximate because of the problems encountered in sampling. Only 25 ml of mixed liquor could be filtered without clogging the millipore filter. However, the solids in the unit, while thoroughly mixed by the disc rotation, were in such large masses that it was impossible to obtain a representative sample of 25 ml size.

Substrate Removal Rate Characteristics

The percent COD remaining per stage of the unit are shown in Figures 4, 7, and 10. It can be seen that there is a distinct change in slope after the first or second stage. As organic load increases, the slope change occurs after the second stage. This is the reverse of the trend noted by Stover (11) in studies of the rotating disc unit using a slaughterhouse waste.

The initial substrate removal rate, K_1, was determined for each particular hydraulic and organic loading. Since the majority of the waste is removed in the first stage, the removal rate was calculated for that stage only. Shown below is the derivation of the kinetic equation, as reported by Stover (11):

$$\frac{dS}{d\,(\text{Stage})} = -KS$$

$$\frac{dS}{S} = (-K)\, d\,(\text{Stage})$$

TABLE II

SUMMARY OF ROTATING DISC PERFORMANCE AT HYDRAULIC LOADING OF 0.25 GPD/FT^2

	Stage	COD Remaining mg/l	Percent Remaining	pH	Solids mg/l
500 mg/l	0	528	100.0	7.70	0
	1	70	13.3	7.65	1590
	2	70	13.3	7.85	1130
	3	101	19.1	7.95	1470
	4	70	13.3	8.05	900
	5	70	13.3	8.00	680
	6	76	14.4	8.00	890
700 mg/l	0	790	100.0	7.70	0
	1	55	7.0	7.25	850
	2	48	6.1	7.35	570
	3	44	5.6	7.45	930
	4	48	6.1	7.30	3890
	5	46	5.8	7.50	610
	6	50	6.3	7.25	3350
1000 mg/l	0	1105	100.0	7.35	0
	1	58	5.2	7.15	1770
	2	46	4.2	7.40	350
	3	42	3.8	7.40	580
	4	42	3.8	7.20	2780
	5	36	3.3	7.40	420
	6	40	3.6	7.15	5980
1500 mg/l	0	1670	100.0	7.50	0
	1	182	10.9	7.40	1170
	2	69	4.1	7.05	510
	3	66	4.0	7.25	330
	4	65	3.9	7.45	210
	5	64	3.8	7.50	330
	6	74	4.4	7.00	7170
2000 mg/l	0	2355	100.0	6.75	0
	1	400	17.0	3.70	1130
	2	176	7.5	4.05	3160
	3	106	4.5	4.75	520
	4	97	4.1	5.10	1170
	5	93	3.9	5.60	330
	6	104	4.4	5.50	3380

TABLE III

SUMMARY OF ROTATING DISC PERFORMANCE AT HYDRAULIC LOADING OF 0.50 GPD/FT^2

	Stage	COD Remaining mg/l	Percent Remaining	pH	Solids mg/l
500 mg/l	0	552	100.0	7.65	0
	1	72	13.0	7.25	1430
	2	48	8.7	7.35	470
	3	44	8.0	7.40	690
	4	32	5.8	7.45	380
	5	32	5.8	7.65	240
	6	36	6.5	7.50	720
700 mg/l	0	858	100.0	8.10	0
	1	85	9.9	7.00	1040
	2	52	6.1	7.10	320
	3	50	5.8	7.00	840
	4	50	5.8	6.80	1020
	5	46	5.4	6.85	690
	6	56	6.5	6.70	1450
1000 mg/l	0	1255	100.0	7.90	0
	1	358	28.5	4.70	590
	2	238	19.0	6.30	450
	3	200	15.9	6.70	580
	4	164	13.1	7.05	510
	5	113	9.0	7.30	350
	6	100	8.0	7.10	3090
1500 mg/l	0	1640	100.0	7.90	0
	1	836	51.0	4.00	610
	2	428	26.1	4.15	410
	3	314	19.1	4.60	580
	4	207	12.6	6.30	350
	5	84	5.1	6.85	280
	6	188	11.5	6.10	9870
2000 mg/l	0	2185	100.0	7.60	0
	1	1250	57.2	4.10	630
	2	918	42.0	3.95	450
	3	602	27.6	4.00	330
	4	462	21.1	4.05	550
	5	332	15.2	4.15	510
	6	288	13.2	4.60	6240

TABLE IV

SUMMARY OF ROTATING DISC PERFORMANCE AT HYDRAULIC LOADING OF 0.75 GPD/FT^2

	Stage	COD Remaining mg/l	Percent Remaining	pH	Solids mg/l
500 mg/l	0	545	100.0	7.10	0
	1	65	11.9	7.40	570
	2	32	5.9	7.60	470
	3	36	6.6	7.60	3440
	4	28	5.1	7.60	360
	5	28	5.1	7.70	450
	6	25	6.4	7.80	3860
700 mg/l	0	700	100.0	6.95	0
	1	100	14.3	7.30	3470
	2	49	7.0	7.50	1610
	3	46	6.6	7.70	800
	4	45	6.4	7.60	1700
	5	36	5.1	7.70	580
	6	40	5.7	7.30	4380
1000 mg/l	0	1050	100.0	7.35	0
	1	223	21.2	7.10	350
	2	59	5.6	7.45	4940
	3	55	5.2	7.55	1570
	4	46	4.4	7.55	1050
	5	40	3.8	7.55	860
	6	46	4.4	7.35	9560
1500 mg/l	0	1540	100.0	6.95	0
	1	400	26.0	6.80	1250
	2	160	10.4	7.30	1780
	3	68	4.4	7.55	670
	4	72	4.7	7.60	1270
	5	64	4.2	7.60	310
	6	70	4.5	7.30	5260

$$\ln \frac{S}{S_o} = -K\,(\text{Stage}-\text{Stage}_o)$$

$$-K = \frac{(\ln \frac{S}{S_o})}{(\text{Stage}-\text{Stage}_o)}$$

where

S = substrate

K = substrate removal rate (Stage^{-1})

$\frac{dS}{d\,(\text{Stage})}$ = change in substrate concentration with respect to stage.

For the K_1 values determined, only one stage was used, reducing the equation to:

$$-K = \ln \frac{S}{S_o} \; .$$

The values obtained are shown in Table V and plotted vs total organic loading in Figure 14. A decreasing-rate curve can be drawn through the points obtained from the low and medium hydraulic loadings in the medium to high total organic range. However, the very high removal rates at the highest hydraulic loading results in the points from that set of experiments lying above the curve formed by values from the lower loadings. This effect is more noticeable at the higher total organic levels. Both curves appear to be approaching lower limiting values.

Unit Operation Characteristics

It has been suggested by Deen (14) and Cook and Kincannon (15) that the removal efficiency of a fixed-bed reactor does not depend solely upon either the organic loading or the hydraulic loading. The efficiency

TABLE V

SUBSTRATE REMOVAL RATES FOR APPLIED ORGANIC LOADINGS

	S_o mg/l	Loading lbs COD/day/1000 ft^3	K_1
0.25 gpd/ft^2	528	97.3	2.02
	790	145	2.66
	1105	204	2.96
	1670	308	2.22
	2355	433	1.77
0.50 gpd/ft^2	552	204	2.04
	858	316	2.32
	1255	462	1.26
	1640	604	0.68
	2185	806	0.56
0.75 gpd/ft^2	545	300	2.13
	700	385	1.95
	1050	577	1.55
	1540	846	1.35

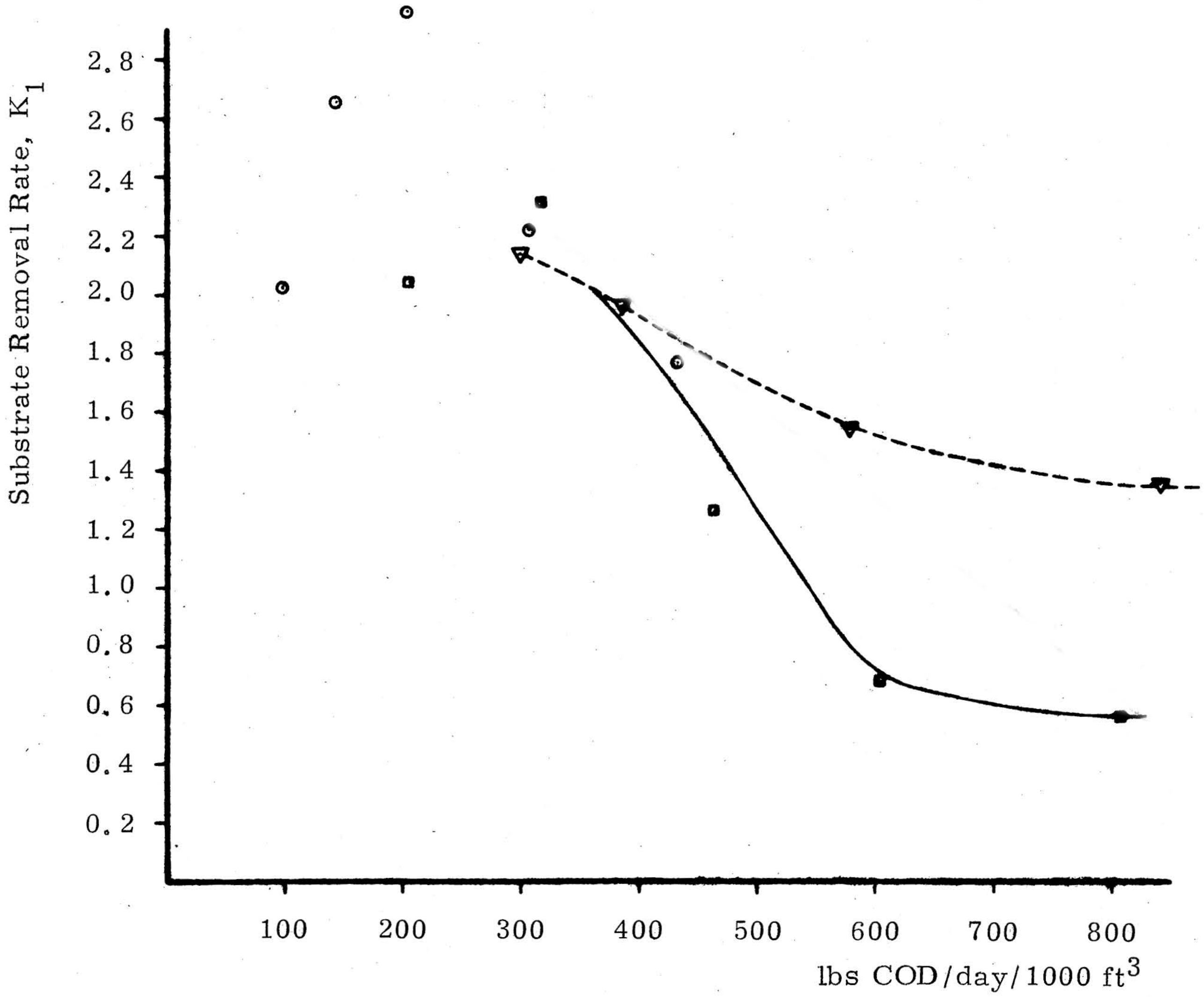

Figure 14. Substrate Removal Rates vs Applied Organic Loading

seems to be dependent upon both factors and has been shown to be a function of the total organic loading applied to the unit, as pounds of COD/day/1000 ft^3 of filter media. Similar organic loadings, each approximately 300 pounds of COD/day/1000 ft^3 of reactor volume, were compared to ascertain if this method is applicable to the rotating disc process. The values of COD remaining and the percent COD remaining at each stage for similar organic loadings are found in Table VI. A close correlation can be seen. The results of these experiments are plotted in Figure 15. A plot of total organics applied vs the efficiency of the unit for all the experiments is shown in Figure 16. The points plotted are calculated from data obtained at stages preceding the breakpoint in the removal rate curves. It is seen that the points cluster around one curve at the lower total organic loadings, but two curves are formed at the higher organic levels. This is due to very high removals at a hydraulic loading of 0.75 gpd/ft^2.

TABLE VI

COMPARISON OF SIMILAR TOTAL ORGANIC LOADING REMOVAL

COD REMAINING

		Stage						
gpd/ft^2	mg/l	0	1	2	3	4	5	6
0.25	1670	1670	182	69	66	65	64	74
0.50	858	858	85	52	50	50	46	56
0.75	545	545	65	32	36	28	28	35

PERCENT COD REMAINING

		Stage						
gpd/ft^2	mg/l	0	1	2	3	4	5	6
0.25	1670	100	10.9	4.1	4.0	3.9	3.8	4.4
0.50	858	100	9.9	6.1	5.8	5.8	5.4	6.5
0.75	545	100	11.9	5.9	6.6	5.1	5.1	6.4

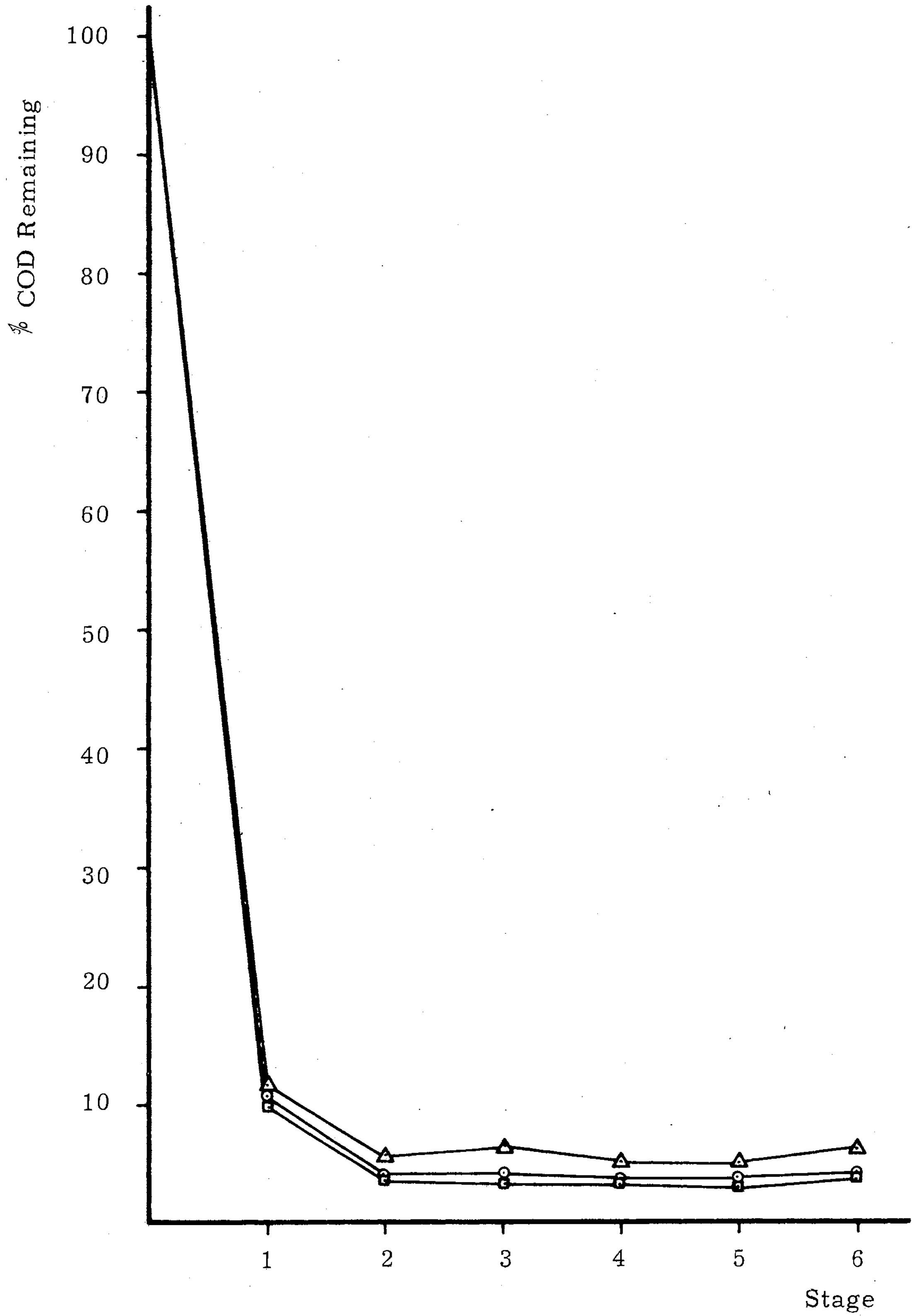

Figure 15. Comparison of Removal at Similar Total Organic Loadings

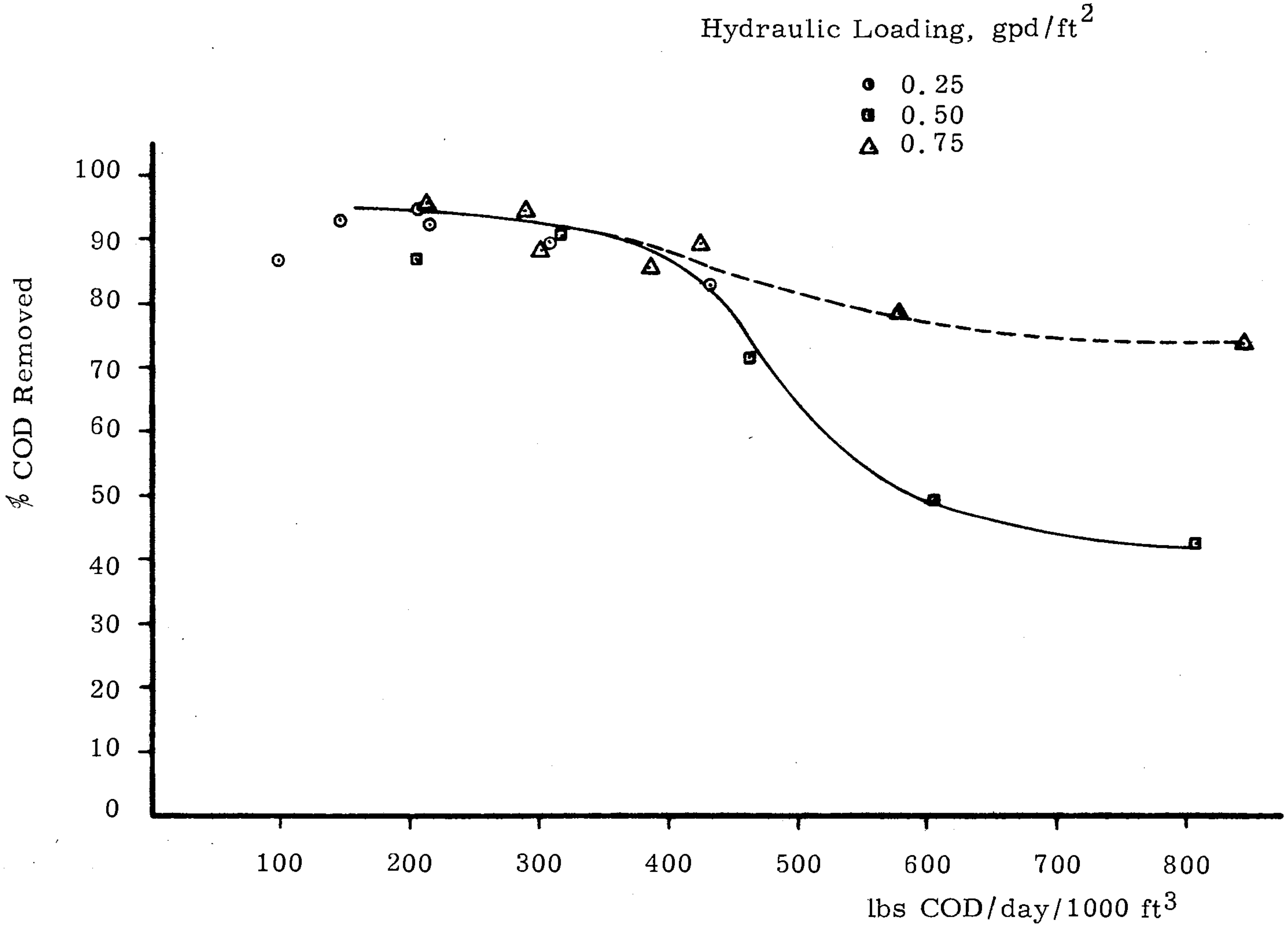

Figure 16. Percent COD Removed vs Applied Organic Loading

CHAPTER V

DISCUSSION

The purpose of this study was to investigate the removal characteristics of the rotating disc process and to correlate these findings with data obtained from similar studies performed on trickling filters. The process has been shown to be effective in treating dairy waste (3, 6, 7), municipal waste (2, 8, 9), anaerobic lagoon effluent (10), and slaughterhouse waste (11).

The use of a sucrose synthetic waste provided direct correlation with studies done on trickling filters and provided a carbon source of standard quality. Hydraulic flow rate was regulated carefully, and the temperature of the waste and laboratory remained fairly constant. From these factors, it can be concluded that a controlled environment was maintained for these experiments.

COD Removal Characteristics

The majority of the COD removal in all experiments occurred in the first stage of the unit. This accounted for the high K_1 values calculated and is partially a result of the ease with which a sucrose waste is oxidized. The plot of K_1 values vs total organics applied shows that at low loadings not all the first stage might be needed. The K_1 values are lower at an organic loading of 100 lbs COD/day/1000 ft^3 than at 300 lbs COD/day/100 ft^3. If the length differential used in the equation

$$- K_1 = \frac{\ln \frac{S}{S_o}}{(\text{Stage-Stage}_o)}$$

were less than one stage, the resultant K_1 values would be higher. In addition to the ease with which sucrose is oxidized, the amounts of microbial growth on the stages could contribute to the high removal rates. The layer of growth on the first stage was always thicker than the growth on later stages. Kornegay and Andrews (16) concluded in a study using a submerged rotating drum inside a reactor that active film thickness has a direct relationship on removal.

Occasional midpoint peaks and frequent endpoint rises in COD were usually correlated with a high solids level in the mixed liquor. Some of the cells in the wastewater had probably lysed, releasing soluble organics into the water, causing the COD to rise.

The phenomenal removal at the highest organic loading was the result of an unexpected and almost complete change in predominance. While the growth on the discs initially contained basically light-colored filamentous organisms similar to those reported by Antonie (3), the new growth was dense, somewhat thinner, and a metallic gray color.

pH Characteristics

The pH values from these experiments are similar to values obtained by others. Fleming (5) and Cook (17) noted that pH generally drops in the first foot of a trickling filter and rises after that. Both studies were conducted on a synthetic sucrose waste. At a high total organic loading, Cook (17) noted that the pH continued to drop after the first foot of filter depth. This effect was seen in the experiment run at a hydraulic loading of 0.50 gpd/ft^2 and an organic loading of 2000 mg/l of sucrose. The stable pH values obtained from experiments at the highest hydraulic loading would seem atypical of this process and cannot normally be expected.

Solids Characteristics

As reported earlier, the values of biological solids determined in this study were only approximate. The pilot plant model rotating disc unit used in this study had no clarification and an outlet which was not designed to allow solids to leave the unit in the effluent. These factors, combined with heavy and constant sloughing, led to large masses of solids accumulating in the unit. The result of this build-up was a lowering of pH, probably due to organic acids produced by the suspended biological solids, and a lowering of COD removal efficiency.

It was occasionally necessary to wash excess solids from the discs due to the development of nuisance conditions, mainly odors. This washing was always done at least three days prior to the next sampling period. Torpey, et al., (9) reported that the unit used by his group had to be washed down occasionally to prevent bridging between the discs and that removal efficiency was not impaired.

Unit Operation Characteristics

The total organic loading method has been shown to be reliable for trickling filters (14, 15, 17). From the data presented in Table VI, it would appear that the method is also reliable for the rotating disc process, when the first stage of the unit is used in the volume calculations.

The total organic loading vs efficiency curve (Figure 16) should be a usable indicator of removal characteristics of the rotating disc process if only the lower curve is used. The removal at the highest organic loading is too high to be relied upon since microbial predominance is not predictable.

Figure 17 shows a comparison of the removal efficiency of the rotating disc reactor with two types of trickling filters. The loading parameter used is total organics applied, in lbs COD/day/1000 ft^3. The curves for the trickling filters were obtained from studies by Deen (14) and Cook (17) on sucrose synthetic waste. The efficiency of the rotating disc process is noticeably higher at all organic loadings. A plateau on the rotating disc curve indicates an almost constant removal efficiency of 93 percent at loadings up to 300 lbs COD/day/1000 ft^3. This plateau is not typical of a trickling filter, as can be seen from the figure. The effect could be due to the activated sludge characteristics of the rotating disc process. The removal carried out by the suspended solids in the reactor would contribute to the removal by the microorganisms on the discs, maintaining a high efficiency through a wide range of total organic loadings.

From Figure 17 it can be seen that the rotating biological contactor is unexcelled by conventional biological treatment methods. It has better removal and has the additional advantages of being quiet, reliable, requiring very little power, and creating fewer odors.

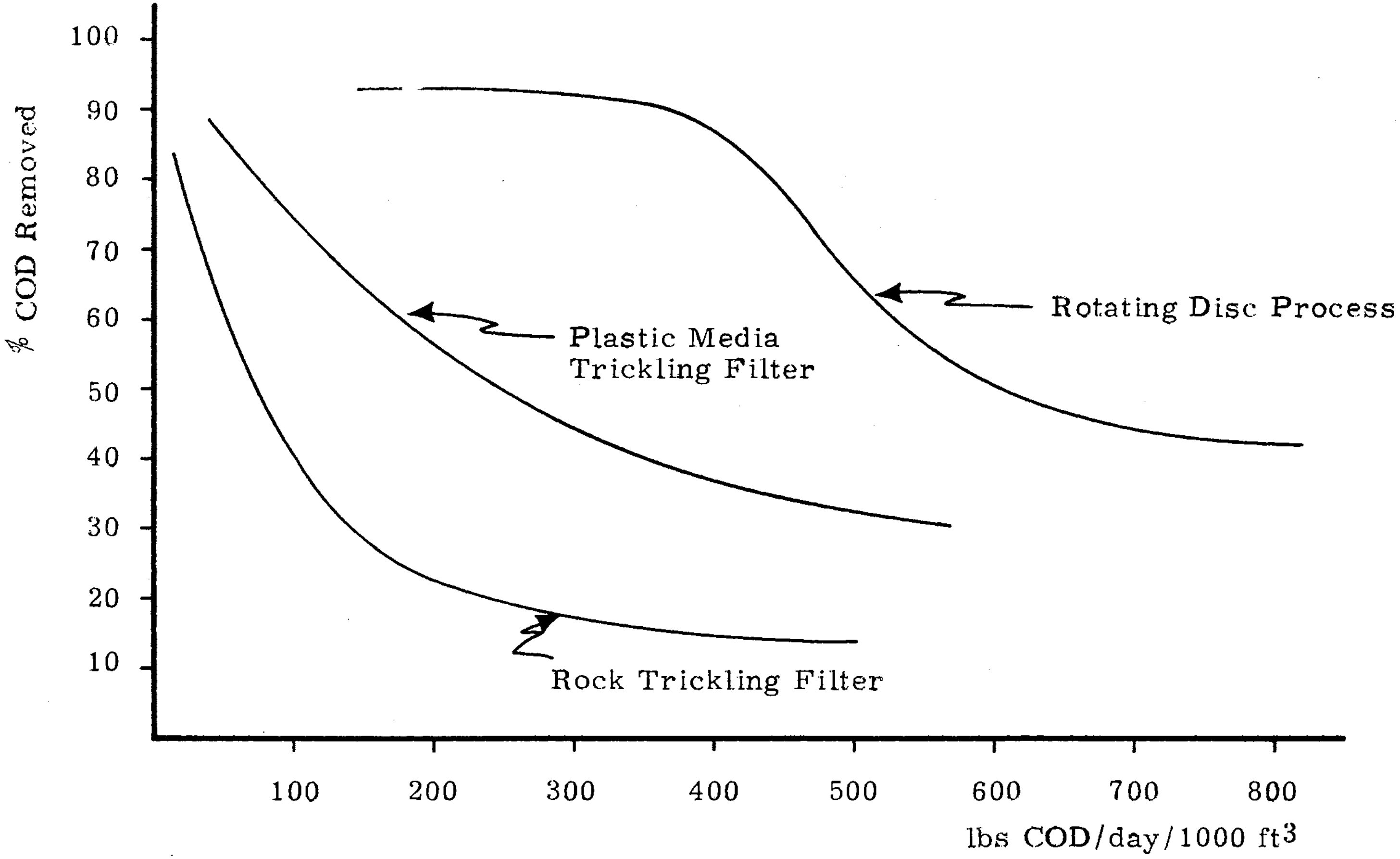

Figure 17. Comparison of Performance of Rotating Biological Contactor with Trickling Filters

CHAPTER VI

CONCLUSIONS

The results of this study support the following conclusions:

(1) The rotating biological contactor is an effective method of secondary waste treatment. It exhibits better removal than rock trickling filter or plastic trickling filter, when removal is measured in terms of lb COD/day/1000 ft^3 of reactor volume.

(2) The total organic loading method of determining efficiency is applicable to the rotating disc process.

CHAPTER VII

SUGGESTIONS FOR FURTHER STUDY

Study the removal efficiency of a one-stage unit followed by a clarifier. The effluent can then be recycled or treated by more discs in series.

Try to separate the removal due to the suspended solids from that caused by the growth on the discs. Start a bench-scale activated sludge unit from a seed obtained from the rotating disc mixed liquor and investigate the removal capabilities.

Run chemical analyses to determine the types of wastes existing after the initial removal phase to determine why this waste does not degrade in the disc.

A SELECTED BIBLIOGRAPHY

(1) Birks, Carl W. "Industrial Applications of the Bio-Disc Process." 23rd Oklahoma State University Industrial Waste and Advanced Water Conference, 1972.

(2) Antonie, Ronald and Karen Van Aacken. "Rotating Discs Fulfill Dual Wastewater Role." Reprint from Water and Wastes Engineering (January, 1971).

(3) Antonie, Ronald. "The Bio-Disc Process: New Technology for the Treatment of Biodegradable Industrial Wastewater." Chemical Engineering Symposium Series, Water, 67, (1970), 585-588.

(4) ------. Bio-Disc: Advanced Rotating Disc Process for Water Pollution Abatement. Pamphlet published by Autotrol Corporation, Bio-Systems Division, Milwaukee, Wisconsin.

(5) Fleming, Murry L. "The Effect of Surface Area on the Performance of a Fixed-Bed Reactor." (Unpublished Masters Thesis, Oklahoma State University, Stillwater, Oklahoma, 1970).

(6) Antonie, Ronald. "Preliminary Results of a Novel Biological Process for Treating Dairy Wastes." Paper presented at the 24th Purdue Industrial Waste Conference (May, 1969).

(7) Birks, Carl W and Robert H. Hynek. "Treatment of Cheese Processing Wastes by the Bio-Disc Process." Paper presented at the 26th Purdue Industrial Waste Conference (May, 1971).

(8) Antonie, Ronald. "Application of the Bio-Disc Process to Treatment of Domestic Wastewater." Paper presented at the 43rd Annual Conference of the Water Pollution Control Federation (October, 1970).

(9) Torpey, Wilbur N., H. Heukelekian, A. Joel Kaplovsky, and R. Epstein. "Rotating Disks with Biological Growths Prepare Wastewater for Disposal or Reuse." Journal Water Pollution Control Federation, 43, (1971), 2181-2188.

(10) Chittenden, Jimmie A. and James W. Wells, Jr. "Rotating Biological Contactors Following Anaerobic Lagoons." Journal Water Pollution Control Federation, 43, (1971), 746-754.

(11) Stover, Enos L. "Response of the Bio-Disc Process to Slaughterhouse Wastewater Treatment." (Unpublished Masters Thesis, Oklahoma State University, Stillwater, Oklahoma, 1972).

(12) Antonie, Ronald. "Response of the Bio-Disc Process to Fluctuating Wastewater Flows." Paper presented at the 25th Purdue Industrial Waste Conference (May, 1970).

(13) Standard Methods for the Examination of Water and Wastewater. 13th Edition. Published by the American Public Health Association. (New York, 1971).

(14) Deen, Terry R. "Some Effects of Organic and Hydraulic Loadings on a Fixed-Bed Reactor." (Unpublished Masters Thesis, Oklahoma State University, Stillwater, Oklahoma, 1969).

(15) Cook, E. E. and D. Kincannon. "An Evaluation of Trickling Filter Performance." Paper presented at the 25th Purdue Industrial Waste Conference, (May, 1970); also in Water and Sewage Works Journal, 1971.

(16) Kornegay, Billy H. and John F. Andrews. "Kinetics of Fixed-Film Biological Reactors." Journal Water Pollution Control Federation, R460-468, (1968).

(17) Cook, E. E, "Kinetics and Mechanisms of Fixed-Bed Reactors." (Ph.D. Thesis, Oklahoma State University, Stillwater, Oklahoma, 1970).

VITA

Dee Ann Sanders Garrett

Candidate for the Degree of

Master of Science

Thesis: A STUDY OF REMOVAL CHARACTERISTICS OF THE ROTATING BIOLOGICAL CONTACTOR

Major Field: Bioenvironmental Engineering

Biographical:

Personal Data: Born April 8, 1949, in Miami, Oklahoma, the daughter of Mr. and Mrs. Robert H. Sanders. Married Jack Taylor Garrett, Jr., on May 18, 1972.

Education: Graduated from Wyandotte High School, Wyandotte, Oklahoma, in May, 1967; received the degree of Bachelor of Science in Civil Engineering from the University of Missouri--Rolla, Rolla, Missouri, in May, 1971; completed requirements for the Master of Science degree at Oklahoma State University, Stillwater, Oklahoma, in May, 1973.

Professional Experience: Undergraduate Research Participant, University of Missouri--Rolla, May, 1969, through August, 1969, and May, 1970, through August, 1970; engineering aide for Continental Pipe Line Company, May, 1971, through August, 1971; bioenvironmental trainee, September, 1971, through July, 1972, at Oklahoma State University.

Membership in Professional Societies: Member, Water Pollution Control Federation; Associate Member, American Society of Civil Engineers; Member, Chi Epsilon, Tau Beta Pi, and Phi Kappa Phi.