RESPONSE OF THE BIO-DISC PROCESS TO SLAUGHTER-

HOUSE WASTEWATER TREATMENT

By

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CHAPTER I

INTRODUCTION

In man's exploration and exhaustion of natural resources, water has not been overlooked. Man has considered the water domain to be an endless one, and as a result he has polluted it to no end. In order to survive, man must reduce the amount of pollution applied to this essential part of his environment.

One of the largest problems is the pollution of natural waters from industrial wastewaters. Man's technology has advanced to the degree that it will exterminate him if he is not careful. Man's technology and education have brought him into this state of being; now they have to get him out of it.

Streams, lakes, rivers, etc. are biological reactors in themselves. Biological engineering must become an integral part of the environment if man is to survive. Either new methods and processes, a better understanding of existing ones, or a combination of both must come about.

This research was conducted in order to study the feasibility of applying the rotating biological contactor for the treatment of slaughterhouse wastewater. The organic strength of the wastewater was varied by dilution with tap water, and then applied to the system for examination.

CHAPTER II

LITERATURE REVIEW

A. Slaughterhouse Wastewater

Slaughterhouse and meat packinghouse waste is mainly organic in character. It is similar to domestic sewage, but is greater in strength by four to five times, or more. Contents of the mixed waste depend on plant recovery practices, good housekeeping within the plant, and plant operations (1). The first step in an industrial waste survey should be an evaluation of waste handling within the plant. The organic content of the wastewater can be reduced tremendously by good housekeeping and recovery practices.

Removal of blood, grease, and paunch manure constitute the major problem encountered in the treatment of slaughterhouse waste. Recovery of these three products greatly reduces undesirable contents of the wastewater. Recovery practices can be profitable in large slaughterhouses. For example, dried blood can be used for livestock feed, plywood adhesive, fertilizer ingredients, or as a protective colloid. In most small slaughterhouses, recovery practices are not incorporated because they would be too expensive. Therefore, wastewater from small slaughterhouses consists of a mixed combination of blood, grease, paunch manure, and washwater.

In this case, grease recovery is the important first step in the treatment process. Grease recovery can be a profitable process when properly controlled. The solids problem can be overcome by screening or sedimentation. Next comes the secondary treatment process for the wastewater. Since slaughterhouse wastewater is similar to domestic sewage, methods similar to those used for its treatment are also applicable to slaughterhouse waste. Trickling filters, sand filters, activated sludge, anaerobic digestion, and chemical coagulation have been shown to produce satisfactory treatment. These methods have been discussed by Gold (1), and Steffen (2), in summaries on treatment methods for packinghouse and slaughterhouse wastes. Wastes from small slaughterhouses and packinghouses have been treated in settling tanks or septic tanks, followed by sub-surface disposal fields, leaching pits, cesspools in series, filter beds, filter trenches, and dry wells.

Trickling filter plants are not a new concept in the slaughterhouse waste treatment area. Wymore (3) described the installation of a crushed limestone medium trickling filter plant installed and put in operation in June, 1948. Operation of the trickling filters at the Sioux Falls, South Dakota, plant were described by Bradney, Nelson, and Bragstad (4).

Activated sludge in the treatment of slaughterhouse wastewater has been used mostly where slaughterhouse waste and domestic sewage are combined for treatment. Studies have been made by Poppe (5) on the combined treatment of domestic sewage and slaughterhouse waste with and without the addition of biocatalysts. Hopkins and Dutterer (6) described an activated sludge system with alum treatment preceding, for the treatment of slaughterhouse waste alone.

Studies by Rudolfs and del Quercio (7) have shown that slaughterhouse waste can be digested to any desired degree in upflow digesters by controlling the rate of feeding. BOD reduction of 95 to 98 percent can be obtained with relatively low loadings. Packinghouse wastes seem to be peculiarly adapted to anaerobic digestion, because thermal and mineral requirements are intrinsically present (8).

Where land space is available, anaerobic lagoons seem to be the most used form of biological treatment. A study by Wymore and White (9) shows a total lagoon system, anaerobic lagoons followed by aerobic lagoons, to achieve better than 90 percent removal of BOD. A study by Enders, Hammer, and Weber (10) shows anaerobic lagoons to be feasible for the first stage treatment. They can adequately handle shock loads and intermittent loadings. The bacterial activity is similar to that of conventional digestion.

Attempts have been made to find alternatives to the biological treatment of slaughterhouse wastes. Chemical precipitation has been used successfully by the Kerber Packing Company. The Bartlow Packing Company plant has obtained an overall BOD reduction of 94.6 percent with chemical coagulation, settling, and the settled effluent applied to an aero-filter.

Attempts have been made to remove the protein from slaughterhouse wastewater. Studies by Tønseth and Berridge (11) show reduction of BOD from 70 to 90 percent by protein precipitation. Lignin sulphonic acid molecules of high molecular weight have the ability to precipitate proteins.

B. <u>The Bio-Disc Process</u>

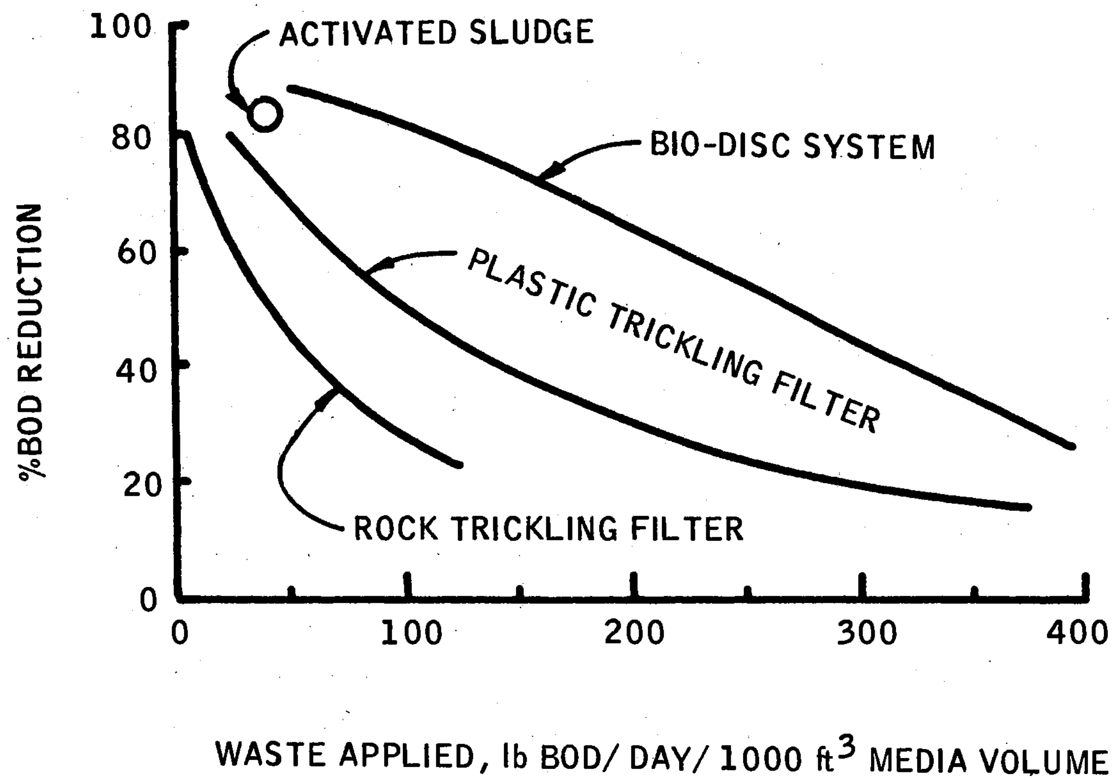
Secondary biological waste treatment may be coming into a new age in the United States. Rotating discs that provide aerobic biological action have been proven commercially successful in three European countries (12). This waste treatment process has been developed, tested, and proven in over 600 different installations. At the end of 1972, there will be sixteen bio-disc plants in operation in the United States (13). There are presently ten in operation, and six under construction.

The bio-disc system consists of closely spaced discs supported by a rod passing perpendicularly through the discs. This process is noiseless, easy to operate, and requires a minimum of maintenance and power (14). The rotating discs are partially submerged in the wastewater. The microbial population is alternately passed through the air and the wastewater. The rotating discs serve three primary purposes (14):

1. They provide media for the support of a fixed microbial growth.
2. They contact the growth with the wastewater.
3. They aerate the wastewater to provide the dissolved oxygen necessary to maintain aerobic biological activity.

This process seems to operate similar to both the trickling filter process and the activated sludge process. Trickling filters are artificial beds of stone or porous medium over which an organic waste is applied. Microorganisms accumulate on the filter medium and remove the organic matter contained in the wastewater for use as nutrients for biological metabolism (15). Activated sludge is defined as "sludge floc produced in a raw or settled sewage by the growth of zoogleal bacteria and other organisms in the presence of dissolved oxygen, and accumulated in sufficient concentration by returning floc previously formed" (16). The bio-disc process seems to operate as a combination of these two processes with important benefits and advantages of each. Figure 1 shows a comparison of the efficiency obtainable by a bio-disc from that

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


100
80
60
40
20
0
%BOD REDUCTION
ACTIVATED SLUDGE
BIO-DISC SYSTEM
PLASTIC TRICKLING FILTER
ROCK TRICKLING FILTER
0
100
200
300
400
WASTE APPLIED, lb BOD/ DAY/ 1000 ft3 MEDIA VOLUME

obtained by trickling filters and activated sludge (17).

Antonie (18) has reported the effectiveness of the bio-disc process in the treatment of domestic wastewater. A package plant following the primary clarifier has achieved effective removal of BOD and suspended solids for a residence time of twenty minutes in the disc system and thirty minutes in a secondary clarifier. Removal of 95 percent ammonia nitrogen and 90 percent Kjeldahl nitrogen were obtained by a residence time of ninety minutes. The process has the capability of oxidizing both carbonaceous and nitrogenous BOD in very short retention times.

This process has been shown by Birks and Hynek (19) to sustain high performance levels under high hydraulic and organic loads while treating cheese-processing wastes. From performance data, it was indicated that the unit could compensate for an acid waste feed and still provide efficient reduction. Antonie (20) has shown by field tests that the bio-disc process is capable of treating the combined wastes and whey wastes of a dairy plant under field conditions as effectively as synthetic dairy waste under controlled conditions.

Chittenden and Wells (21) discussed the ability of rotating discs to treat the effluent from anaerobic lagoons treating slaughterhouse wastewater. Up to 93 percent BOD reduction of the effluent from the lagoon was reached by applying different flow rates and disc rotation speeds.

Torpey, Heukelekian, Kaplovsky, and Epstein (22) have done research on the removal of nitrogen and phosphorus on illuminated rotating discs. The effluent from a previous unit serves as the influent to the illuminated disc unit. The growth of filamentous algae on these discs is readily harvestable, as compared to those grown in oxidation ponds. Research is presently going on in regard to this application of the bio-disc.

One of the largest problems encountered in the treatment of industrial wastewaters is fluctuation in flow patterns. Antonie (23) studied the performance of the bio-disc process under fluctuating wastewater flows utilizing a synthetic wastewater. This process demonstrates very stable operation under such conditions, and thus further enhances its applicability to the treatment of industrial wastewaters.

CHAPTER III

MATERIALS AND METHODS

A. General

This study was first attempted at the location of the slaughterhouse itself. Problems with solids were encountered, due to an attempt to pump directly from the grease trap. Because of these pumping problems and freezing of the unit, the decision was made to move the unit to the laboratory. This move eliminated most of the former problems, but created new ones. Problems like collecting and hauling the wastewater to the laboratory were now encountered. These were solved by using 5-gallon containers and a university truck. The wastewater was collected from the sewer line following the grease trap at the slaughterhouse and transported to the laboratory. Solids presented no problem since the wastewater was collected after the grease trap. In the laboratory, the wastewater was either used directly or diluted with tap water to the desired concentration before use. Cattle and hog blood were the major constituents of the wastewater.

To eliminate excessive hauling, the unit was operated as a batch unit during the start-up period. An initial seed of sewage obtained from the Stillwater municipal sewage treatment plant was added to the first feed to aid in the start-up of the microbial populations. To allow for sufficient acclimation and growth of the microorganisms, a three-week waiting period was maintained before experiments were started. After the first three weeks, the microbial growth was stabilized and showed little tendency to sloughing. The unit was operated as a continuous flow system during experiments, and was again operated as a batch system between experiments. This was done in order to eliminate excessive hauling. Operating the system as a batch unit seemed to cause no noticeable effect on the microorganisms so long as a sufficient amount of liquid was present to keep the discs wet.

B. Bio-Disc System

The bio-disc unit employed in this study was a four ft. long, ten gallon capacity, miniature unit built by the Autotral Corporation, specifically for experimental purposes. It consisted of six compartments or stages separated by partitions with holes in the bottom of each partititon to allow flow from one stage to the next. Each stage consisted of five rotating polystyrene discs 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 eleven revolutions/min. A disc diameter of 23.25 inches gave a surface area of 2.96 sq. ft. for each side of the disc. The total surface area of polystyrene medium available for microbial growth was therefore 177.5 sq. ft. The volume of the unit taken as a cylinder was 11.8 cu. ft.

The wastewater was placed in a holding tank with a capacity of approximately seventy gallons. Next, the wastewater was pumped into the first section of the unit, where it was dipped into the first stage by four rotating dippers. Here, in the first stage, was where the actual biological treatment began. From here the waste flowed through each of the next five stages and out the effluent line, where it was collected and discharged to a sanitary sewer.

Two different pumps were employed for this study, due to pumping problems and the low flow rates that were required. For the first two experiments, a positive displacement screw type pump driven by a 1/6 horsepower, 110 volt a.c. electric motor, was used. A bypass system was placed around the pump so that the flow rate could be easily adjusted. The bypass served as a recirculation line so that part of the discharge could be recirculated, the amount of which could be controlled by a valve. Flow rates of two GPD/ft^2 and one GPD/ft^2, respectively, were used in these experiments. A lower flow rate than could be attained by this pump was necessary, due to the type of wastewater and the small capacity of the unit. Therefore, the decision was made to go to a centrifugal pump with a control valve on the discharge side of the pump. This control valve served the same purpose as the bypass system on the first pump. It could be adjusted to let only the desired amount of flow pass, and recirculate the rest inside the pump. This second pump was driven by a 1/3 horsepower, 110 volt a.c. electric motor. For the remaining experiments, a flow rate of 0.5 GPD/ft^2 was used. This corresponded to a detention time of approximately two hours and forty minutes. The major portion of the study was run at this flow rate.

C. <u>Experimental and Analytical Procedures</u>

After the start-up of each continuous flow experiment, sufficient time--at least one detention time--was allowed for the unit to be flushed out and reach equilibrium operating conditions before samples were collected. Once the unit had reached equilibrium, samples were collected every hour for the first two experiments, and every two hours for the remaining experiments.

Seven samples were collected each sampling period. The first sample was collected directly at the influent line. Samples were then collected at the end of stages one though six, respectively; the sample after stage six was the effluent. The samples were collected with the aid of a glass tube connected to a rubber hose. The wastewater was siphoned into plastic sampling bottles. In order to obtain a representative sample, the flow was allowed to run through the tubing for a short period of time before being collected.

Following collection, the pH of the sample was immediately determined, using a Beckman pH meter, and recorded. The pH meter had been previously adjusted by using buffer compounds of pH four and seven. The dissolved oxygen at the influent and the effluent of the unit was measured at random times during an experiment to make sure that the process was not oxygen-limiting. This was accomplished with the aid of an oxygen analyzer manufactured by the Precision Scientific Company. Also at random times during several experiments, the influent and effluent temperatures were measured in order to determine the temperature drop of the wastewater as it passed through the unit.

A chemical oxygen demand was determined for each sample by the procedure outlined in Standard Methods (24). From this data, a plot of COD measured in mg/l remaining after each stage versus sampling time was made. An average of the influent COD and those at each stage along the unit were calculated. From this data, the percent COD remaining per stage was calculated and plotted versus stage on arithmetic graph paper and then on one cycle semi-logarithmic graph paper. From this semi-logarithmic plot, the substrate removal rate "K" was determined, "K" simply being the slope of the line. The substrate removal rate was then plotted against the applied organic load in lbs COD/day/ft^2. Along with these plots, the COD removal efficiency versus applied organic loading in lbs COD/day/ft^2 were also plotted on arithmetic graph paper. Some of the effluent samples were filtered through HA 0.45 μ Millipore filters, and the COD of the filtrate was determined for comparison with the unfiltered COD.

The procedure outlined in the paragraph above was carried out for each experiment, including a shock load experiment. In this shock load experiment, a regular type experiment was carried out; then washwater from the slaughterhouse was introduced to the unit. Washwater was pumped into the unit for a time longer than the detention time to allow for a thorough flushing. This washwater remained in the unit for a period of fifteen hours. Wastewater was again applied to the unit the next morning. This experiment was intended to simulate actual operating conditions that would be encountered in the treatment of slaughterhouse wastewater.

A gram staining procedure was applied to microorganisms from the front, the middle, and the end portions of the unit, in order to determine the predominant type of organisms present during the final portion of the study. The technique listed below was employed (25).

1. Separate smears of the microorganisms were prepared.
2. These were air-dried and heat fixed.
3. Each smear was covered with crystal violet, and the excess stain rinsed off with a gentle stream of tap water after one minute.
4. Iodine was applied for one minute and rinsed off.

5. The slide was tilted, and alcohol was added until the drippings were faintly colored. The slide was then immediately rinsed with tap water.
6. Next, the smears were counterstained with safranin for thirty seconds, rinsed, and blotted dry with bibulous paper.

These slides were then observed with the aid of a microscope, using the oil immersion objective and full even illumination.

CHAPTER IV

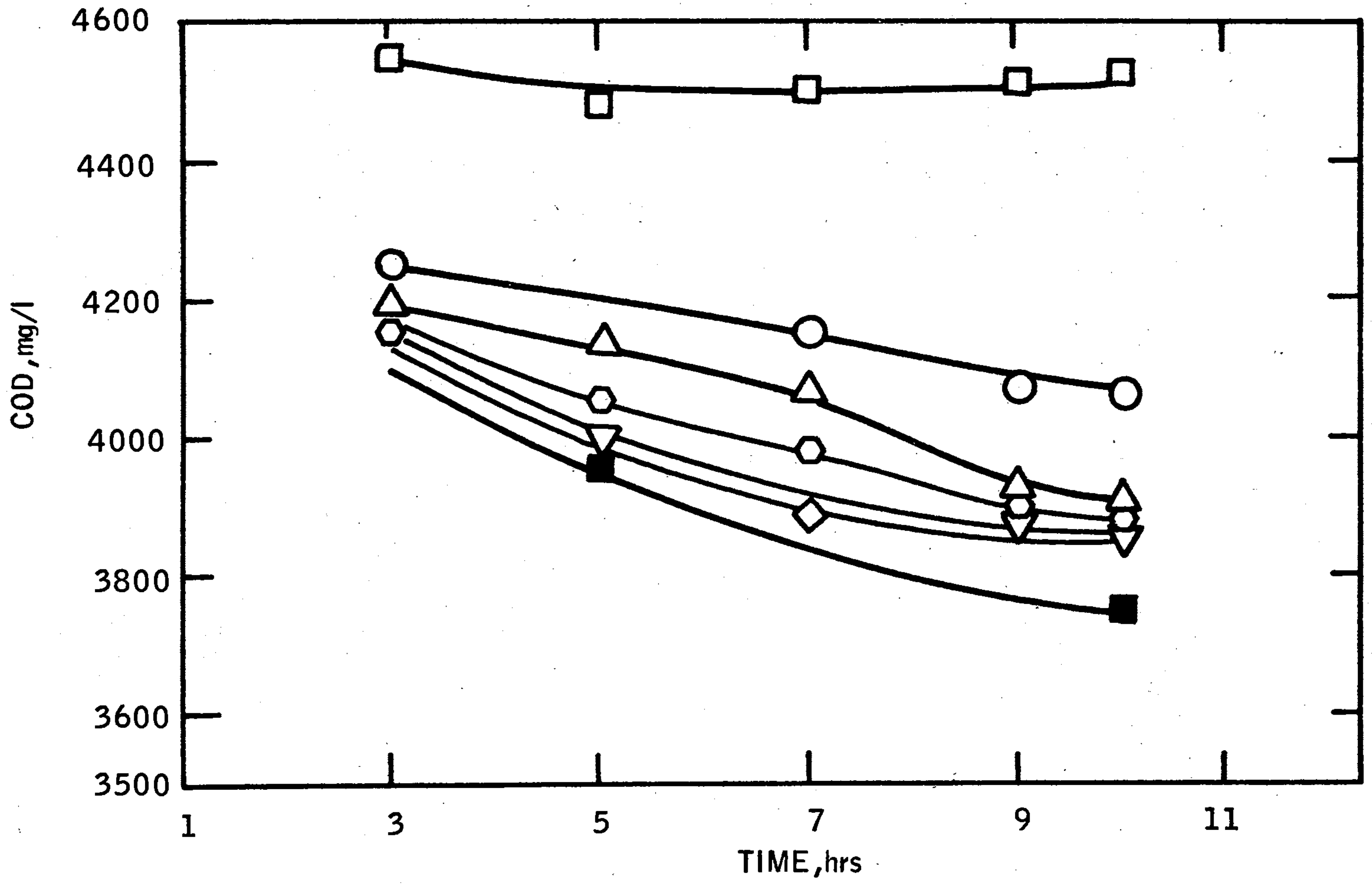
RESULTS

A. Removal Capabilities of the Bio-Disc

COD removal capabilities of the bio-disc unit utilizing slaughterhouse wastewater are shown in Figures 2, 3, and 4. The influent COD, COD of the wastewater leaving each stage, and the effluent COD are shown. These represent three of the eleven experiments, including the shock load experiment (discussed later), that were carried out during this study. It was not deemed necessary to represent all experiments, since all experiments showed similar removal characteristics. These three figures are presented here because they show the COD removal obtained by the unit at a high, a medium, and a low organic loading.

Since the unit was operated as a batch system between experiments, a three-hour period was waited after the start-up of each experiment before samples were collected. At the flow rate used, the retention time of the liquid in the unit was between 2.5 and three hours. In some experiments (Figure 3) this was a sufficient time period, but in others (Figures 2 and 4), the process had not reached equilibrium operating conditions at this time. However, equilibrium operating conditions had been reached by the second sampling period. The largest difference in COD removal between the first and second sampling periods always occurred at the lowest organic loadings (Figure 4). The only reasonable

Figure 2. Chemical Oxygen Demand Removal by the Six Stage Unit Process for a High Organic Loading



4600
4400
4200
4000
3800
3600
3500
COD, mg/l
1
3
5
7
9
11
TIME, hrs

Figure 3. Chemical Oxygen Demand Removal by the Six Stage Unit Process for a Medium Organic Loading

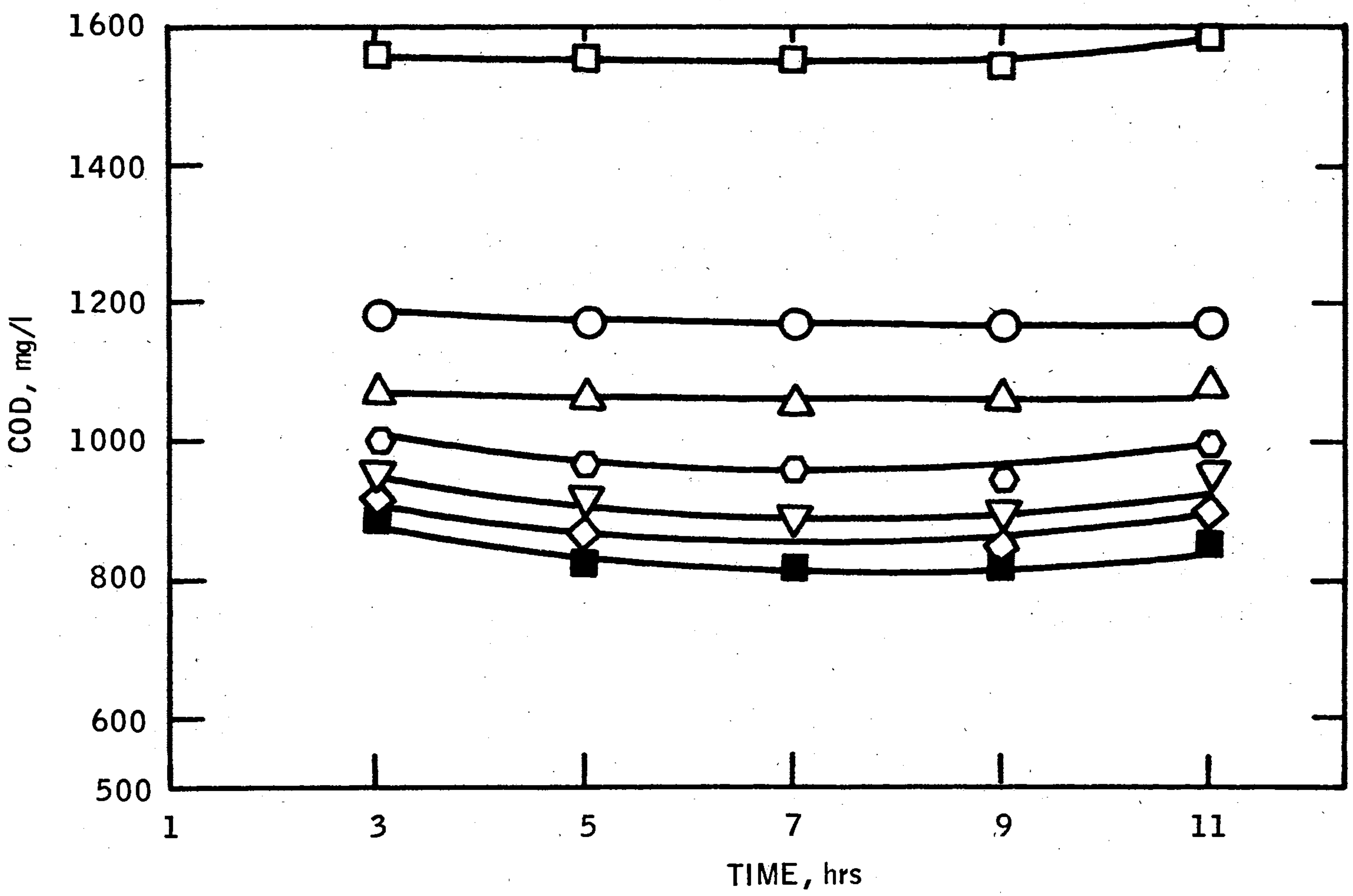
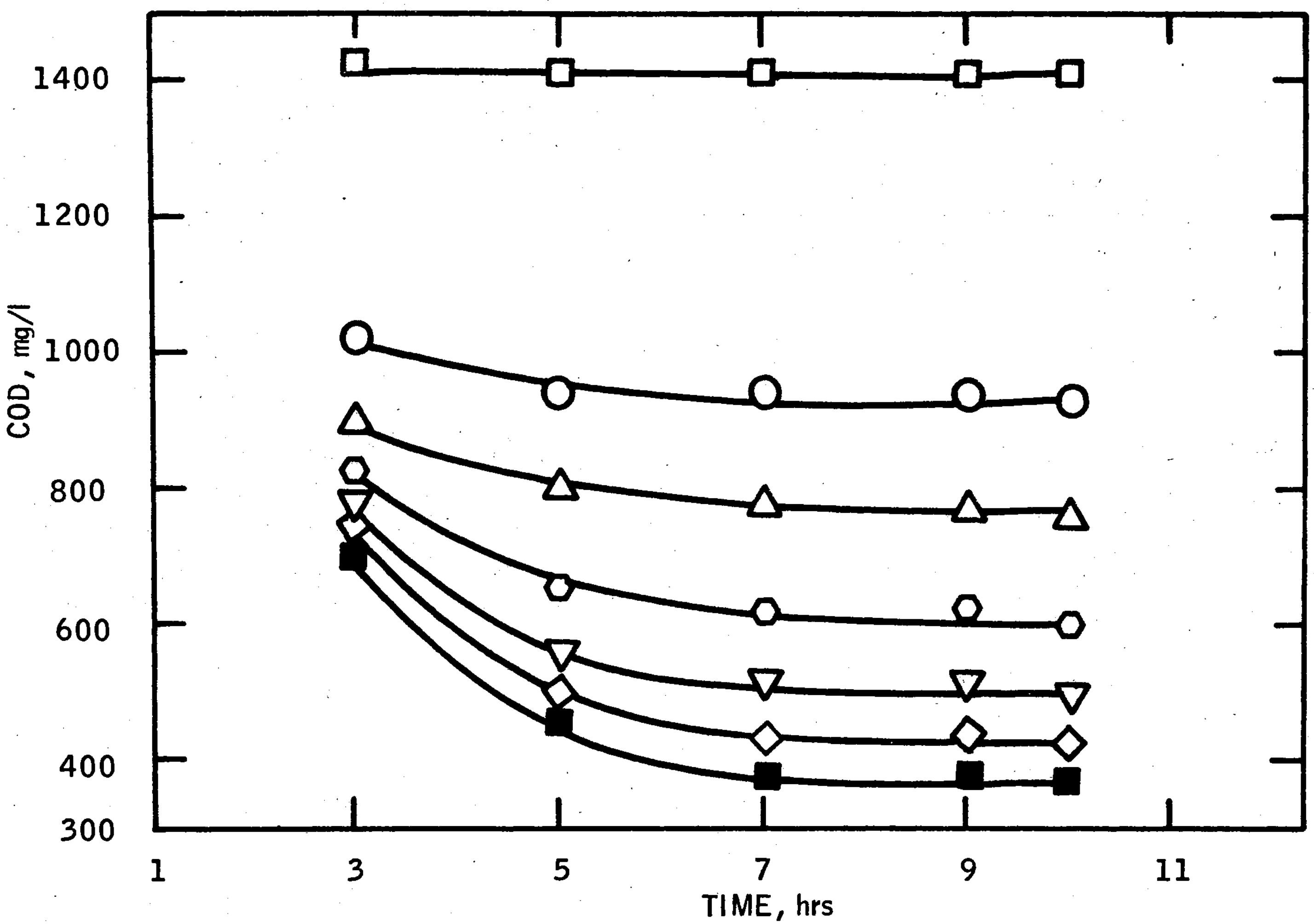

1600
1400
1200
1000
800
600
500
COD, mg/l
1
3
5
7
9
11
TIME, hrs

Figure 4. Chemical Oxygen Demand Removal by the Six Stage Unit Process for a Low Organic Loading



COD, mg/l
1400
1200
1000
800
600
400
300
1
3
5
7
9
11
TIME, hrs

explanation for this occurrence is that the unit was always fed with waste of extremely high organic strength during batch operation in order to eliminate excessive hauling of wastewater.

The removal characteristics per stage of the unit for these three experiments are shown in Tables I, II, and III. All of the values shown represent average values obtained from the data collected during each sampling period. All three experiments were carried out at a flow rate of 0.5 GPD/ft^2.

The influent and effluent CODs at each stage in mg/l, along with the percent COD removal per stage are shown. In every experiment conducted with slaughterhouse wastewater, approximately 50 percent of the total COD removed throughout the entire length of the unit was removed in the first stage. This aspect of COD removal can be seen in column 3 of the tables. The experiment depicted in Figure 4 and Table III was the only experiment throughout the entire study in which the unit removed less than 50 percent of the total COD in the first stage. At this organic loading (the lowest loading studied), 46 percent of the total COD was removed by the first stage.

The substrate removal rates "K_1" and "K_2" achieved by the unit and the pH of the wastewater at each stage are shown in the tables. Both of these parameters will be discussed in more detail in later sections.

The percent of the total COD removed per stage of the unit is shown in Figure 5. Each curve represents a different experiment at a different organic load. The family of curves depicted in Figure 5 represents the three experiments shown in Figures 2, 3, and 4, plus two curves obtained from the shock load experiment (Figure 10).

Effluent COD removals achieved by the unit are represented in

TABLE I

SUMMARY OF RESULTS OF EXPERIMENT AT HIGH ORGANIC LOADING

Stage	Organic Load COD (mg/l)	% COD Removed	pH	Substrate Removal Rate (K)
Influent	4510		8.0	
1	4080	9.5	8.5	$K_1 = 0.040$
2	3980	12.0	8.6	
3	3910	13.0	8.7	$K_2 = 0.008$
4	3880	14.0	8.7	
5	3840	15.0	8.8	
(Eff) 6	3760	17.0	8.8	

TABLE II

SUMMARY OF RESULTS OF EXPERIMENT AT MEDIUM ORGANIC LOADING

Stage	Organic Load COD (mg/l)	% COD Removed	pH	Substrate Removal Rate (K)
Influent	1550		8.1	
1	1170	25	8.5	$K_1 = 0.15$
2	1060	32	8.6	
3	950	39	8.7	$K_2 = 0.03$
4	890	42	8.7	
5	850	45	8.8	
(Eff) 6	820	47	8.8	

TABLE III

SUMMARY OF RESULTS OF EXPERIMENT AT LOW ORGANIC LOADING

Stage	Organic Load COD (mg/l)	% COD Removed	Substrate Removal Rate (K)
Influent	1410		
1	935	34	$K_1 = 0.180$
2	770	54	
3	610	57	$K_2 = 0.073$
4	505	64	
5	420	70	
(Eff) 6	370	74	

Figure 5. Percent Chemical Oxygen Demand Removed per Unit Length in Stages

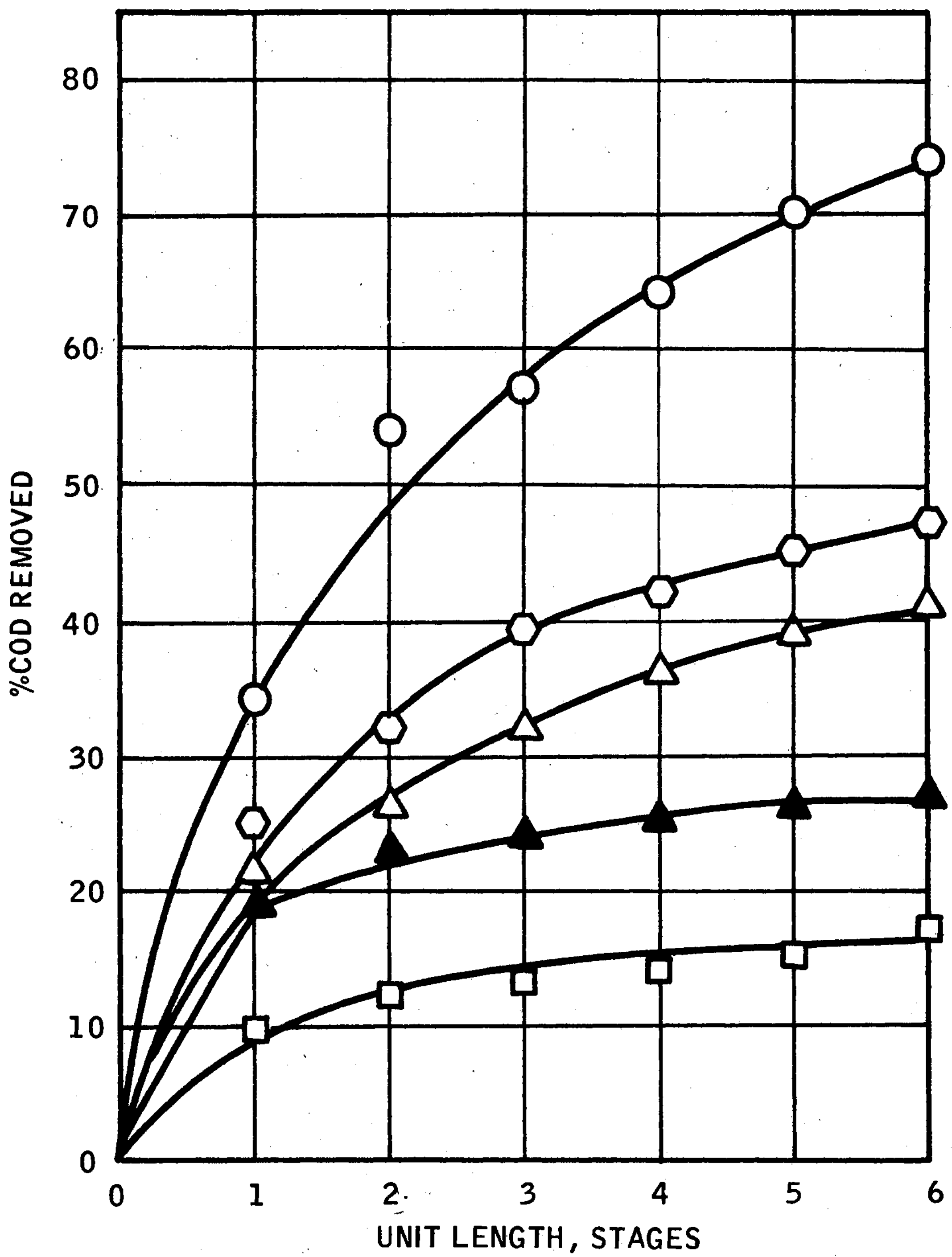

%COD REMOVED
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
UNIT LENGTH, STAGES

Figure 6. The total percentage of COD removed by the unit is shown for various organic loadings. Each point represents a different experiment, all of which were carried out at flow rates of 0.5 GPD/ft^2. At this hydraulic loading rate, the bio-disc unit achieved a removal efficiency of 80 percent when the organic loading was 1000 mg/l COD. As can be seen in Figure 6, the removal efficiency decreased as the organic concentration (COD) was increased.

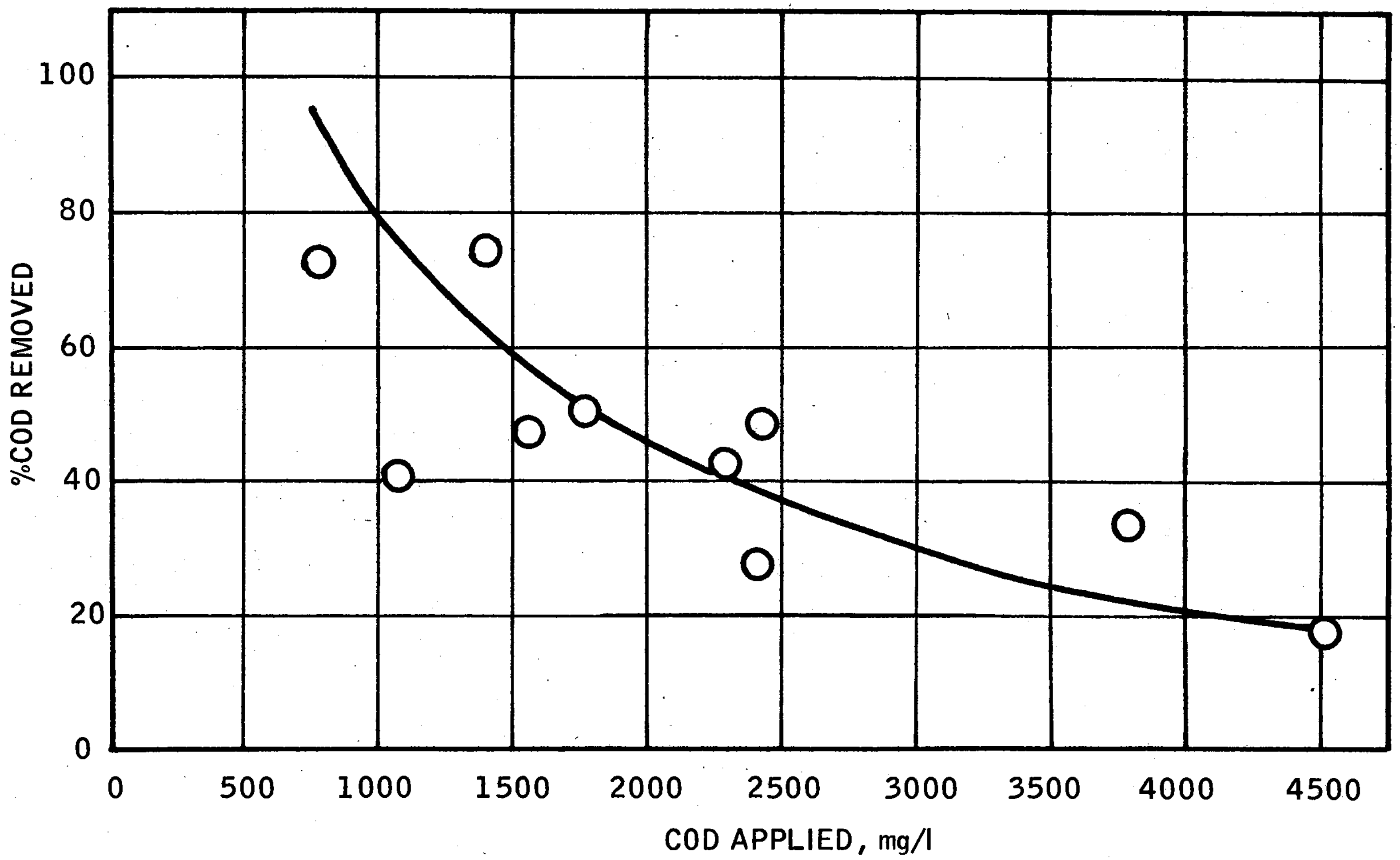
B. <u>Substrate Removal Rate Characteristics</u>

The COD remaining in mg/l per stage of the unit for the experiments represented in Figures 2, 3, 4, and 10 are shown in Figure 7. Each curve again represents a different experiment of a different organic load. Identically shaped curves were recognized by Torpey, Heukelekian, Kaplovsky, and Epstein (22) in rotating disc pilot plant studies on domestic wastewater at the Jamaica water pollution control plant in New York City.

The percent COD remaining per stage of the unit for the same experiments depicted in Figure 7 are shown in Figure 8. It can be seen in these semi-logarithmic plots that a first-order decreasing rate of removal is characteristic of the unit for slaughterhouse wastewater. Note that in every case there is a distinct slope change following either the first stage or the second stage. In every experiment during this study, two distinct slopes were observed.

As can be seen in Figure 8, there exists a definite slope change following the first stage for the higher organic loads. When lower organic loads were applied, the slope change occurred in the second stage. These slope changes correspond to a change in the rate of substrate utilization by the microorganisms.

Figure 6. Percent Chemical Oxygen Demand Removed vs. Applied Organic Loading



100
80
60
40
20
0
%COD REMOVED
0
500
1000
1500
2000
2500
3000
3500
4000
4500
COD APPLIED, mg/l

Figure 7. Chemical Oxygen Demand Remaining per Unit Length in Stages

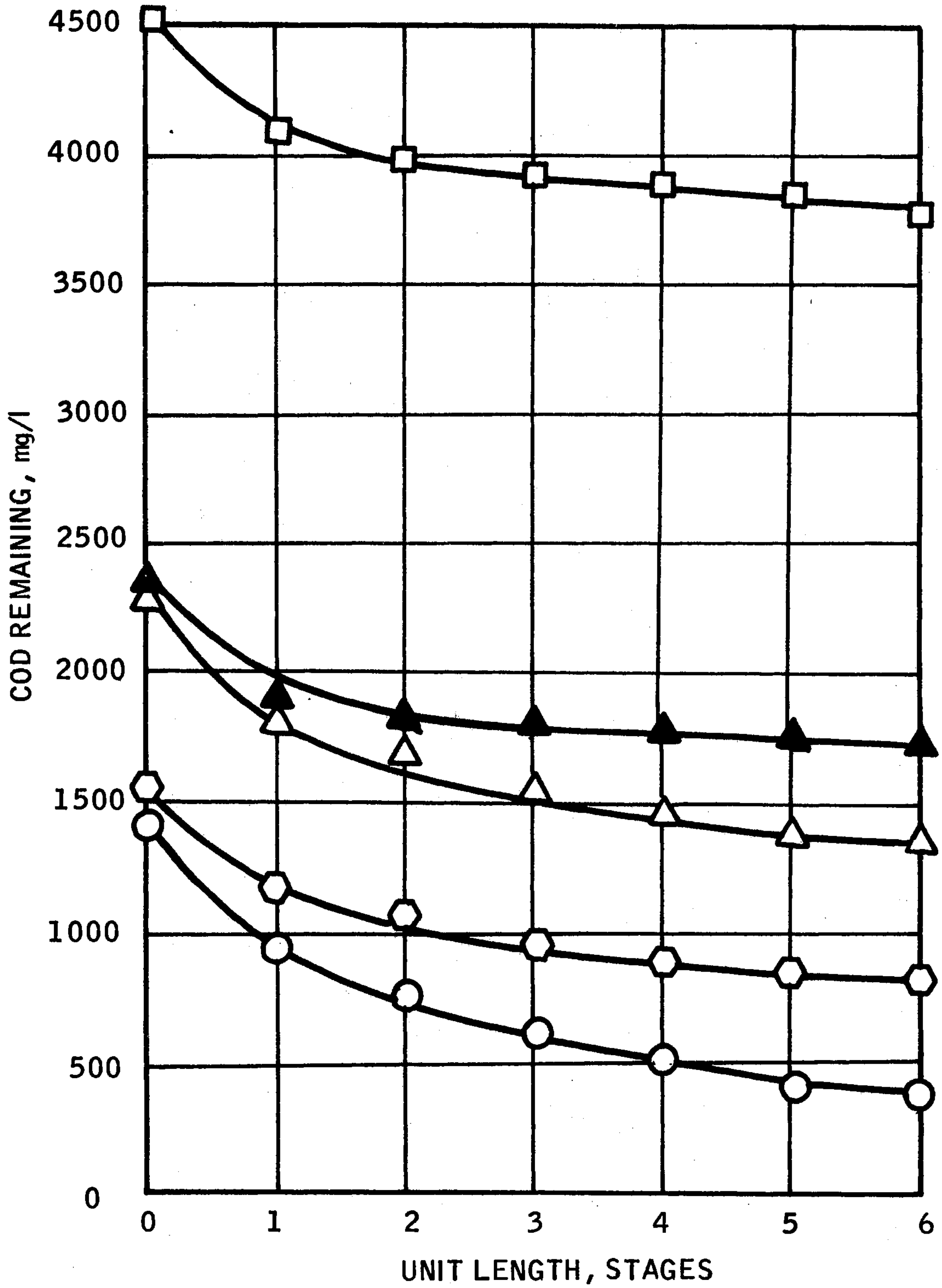
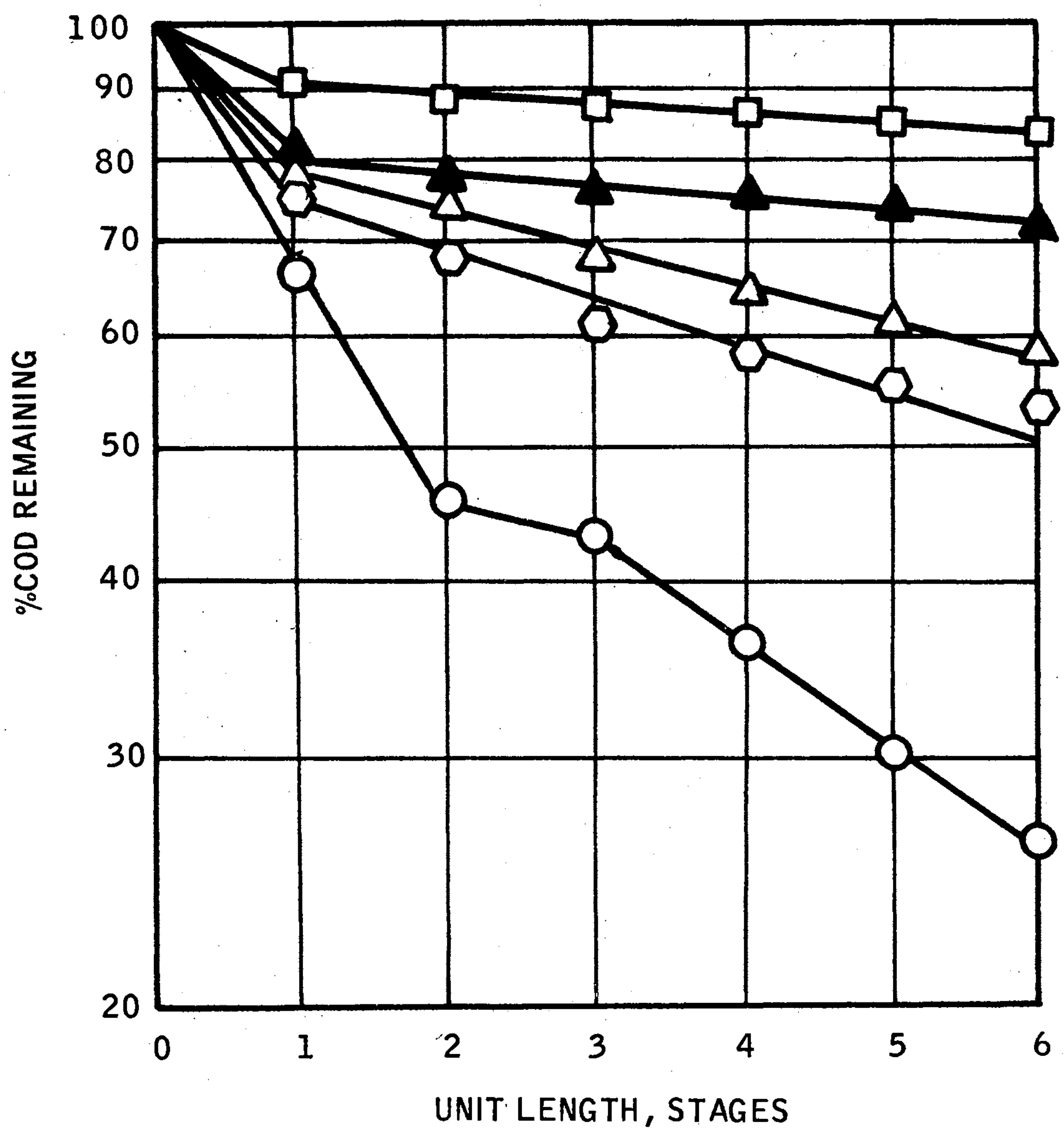

4500
4000
3500
3000
2500
2000
1500
1000
500
0
COD REMAINING, mg/l
0
1
2
3
4
5
6
UNIT LENGTH, STAGES

Figure 8. Logarithmic Chemical Oxygen Demand vs. Unit Length in Stages


100
90
80
70
60
50
40
30
20
%COD REMAINING
0
1
2
3
4
5
6
UNIT LENGTH, STAGES

These substrate removal rates, "K_1" and "K_2," were determined for each of the applied organic loadings. "K_1" represents the first phase removal rate, and "K_2" represents the second phase removal rate.

The diphasic removal characteristics existed for every organic load applied. Both phases of removal were of the first-order decreasing rate (Figure 8). Shown below is the derivation of the kinetic equation for substrate removal:

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

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

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

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

where S = substrate

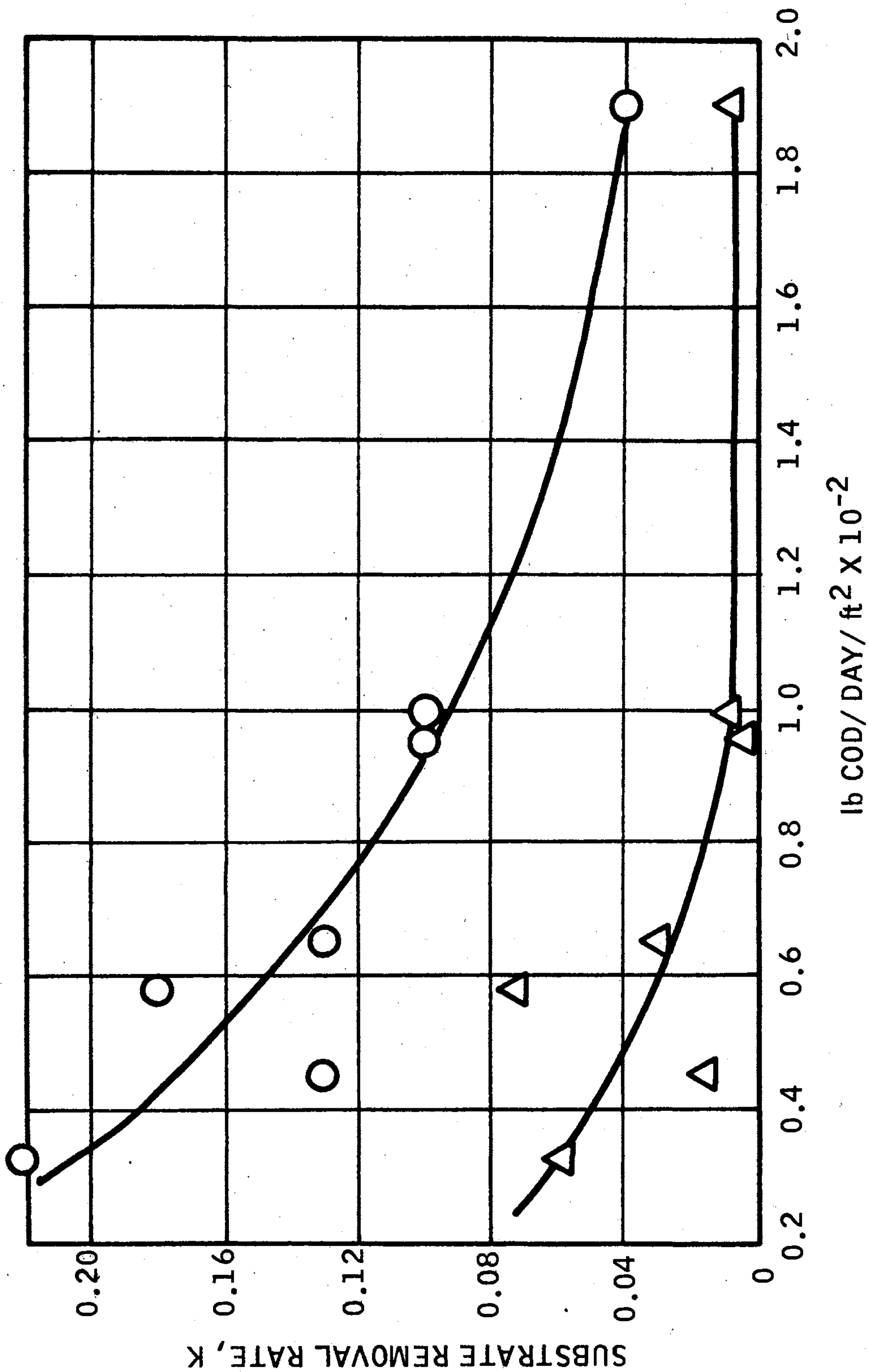
K = substrate removal rate (Stage^{-1})

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

These removal rates were shown to decrease and "K_2" to approach a constant minimum value as the applied organic load was increased (Figure 9).

At the lower organic loads, the first phase removal rate "K_1" continued into the second stage before the slower second phase removal rate "K_2" became effective. When the first phase removal continued into the second stage, there corresponded a leveling off period of removal in the third stage before the second phase removal started. Similar observations were also noted for other experiments of low organic loadings.

Figure 9. Substrate Removal Rates vs. Applied Organic Loading


SUBSTRATE REMOVAL RATE, K
0
0.04
0.08
0.12
0.16
0.20
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
lb COD/ DAY/ ft^2 X 10^{-2}

The relationships between the substrate removal rates "K_1" and "K_2" and applied organic loading in lbs/COD/day/ft^2 are shown in Figure 9. The second phase removal rate is much less than the first phase removal rate. Both removal rates decreased as the applied organic loading increased. The second phase removal "K_2" approached a constant minimum value for the range of loadings utilized in this study. At this point, a higher organic load did not affect the removal rate. The first phase removal rate "K_1" was approaching a constant minimum value also, but "K_1" values for higher organic loads would have to be determined to make a definite statement.

C. Shock Load Results

The operational characteristics of the unit both before and after the shock load of washwater are shown in Figure 10. The influent COD was rapidly dropped from 2360 mg/l to 300 mg/l. The COD removals obtained by each stage of the unit during this experiment are shown in Table IV. As mentioned earlier, these values are average values taken from the various sampling periods.

The influent COD before and after the shock load differed by less than 100 mg/l; yet there existed a significant difference between the two COD removal values obtained. A 27 percent removal corresponding to a loading of 2360 mg/l COD was observed before the shock load, where a 42 percent COD removal corresponding to a 2280 mg/l COD loading was observed after the shock load. The variance in substrate removal rates before and after the shock load can be seen in Table IV. The value for "K_1" was equal to 0.100 both before and after the shock load; whereas "K_2" was equal to 0.009 before, and 0.028 after the shock load. This tremendous increase in the second phase removal rate explains the

Figure 10. Chemical Oxygen Demand Removal by the Unit Process Before and After a Shock Load

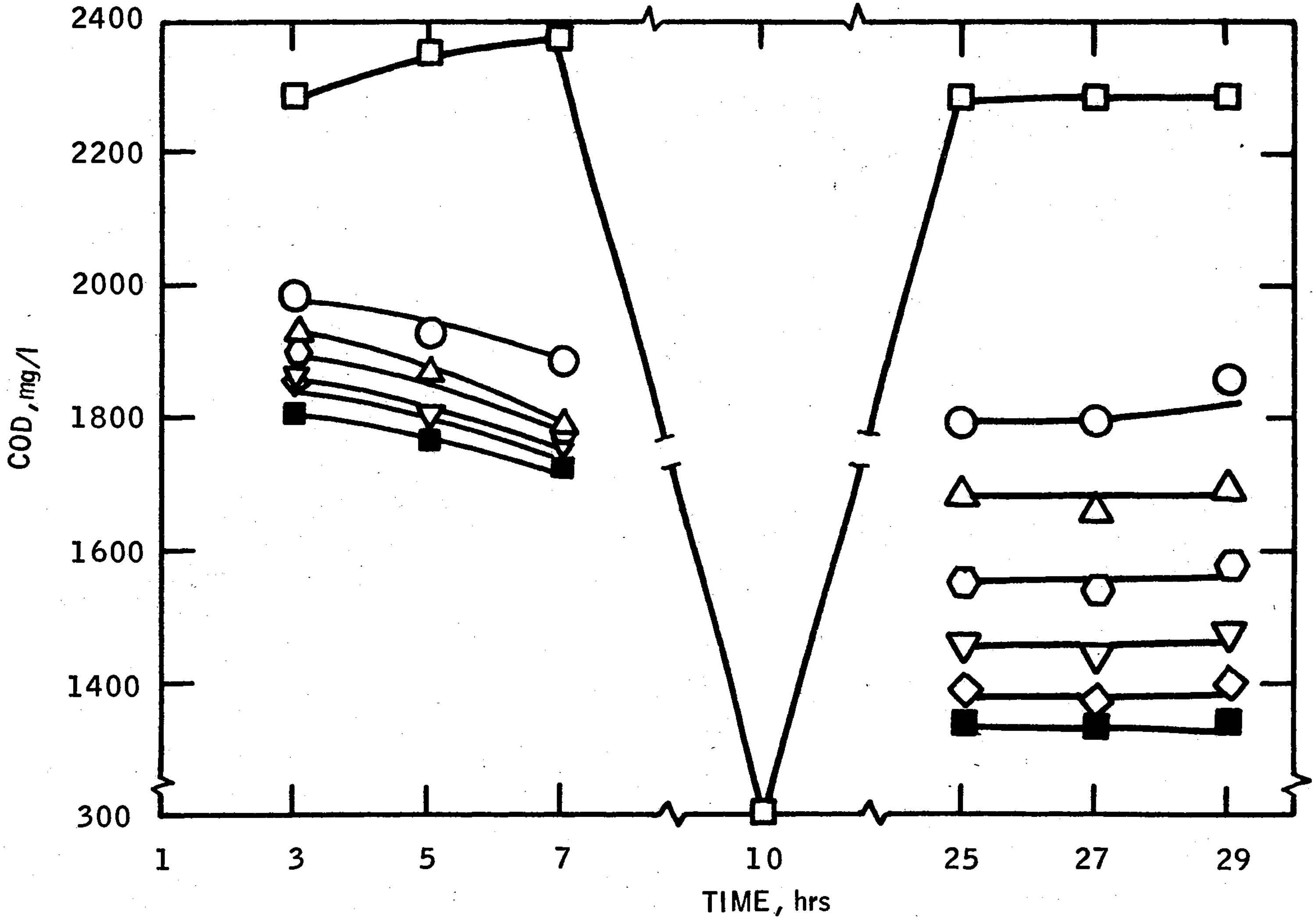

2400
2200
2000
1800
1600
1400
300
COD, mg/l
1
3
5
7
10
25
27
29
TIME, hrs

TABLE IV

SUMMARY OF RESULTS OF SHOCK LOAD EXPERIMENT

Stage	Organic Load COD (mg/l)		% COD Removed		Substrate Removal Rate (K)	
	Before	After	Before	After	Before	After
Influent	2360	2280				
1	1900	1800	19	21	$K_1 = 0.100$	$K_1 = 0.100$
2	1820	1680	23	26		
3	1800	1540	24	32		
4	1780	1450	25	36	$K_2 = 0.009$	$K_2 = 0.028$
5	1750	1380	26	39		
(Eff) 6	1730	1330	27	42		
Filtered	1650	1240				

increase in COD removal after the shock load of washwater. Again, after the shock load, 50 percent of the total COD that was removed occurred in the first stage of the unit.

D. Unit Operation Characteristics

The COD removal capacity, measured in the effluent, of the unit for slaughterhouse wastewater is shown in Figure 11. Each point corresponds to a separate experiment. In each experiment, the applied organic loading was of different concentrations. A COD removal efficiency of 80 percent was achieved at a loading of 0.004 lbs COD/day/ft^2. As the organic loading was increased, the removal efficiency decreased and seemed to approach a constant minimum value. At loadings of 0.039 lbs COD/day/ft^2 and greater, only 10 percent COD removal was obtained by the unit.

A curve of this type shows the reaction of the unit over a wide range of organic loadings. One continuous relationship can be observed for the unit rather than developing a family of curves. This curve has great significance, since it can be used for design purposes.

pH determinations were made during several experiments in order to establish any significant change in pH of the wastewater as it flowed through the unit. Average values of pH change for the different sampling times are shown in Tables I and II. The increase in pH of the wastewater as it passed through the unit is shown in Figure 12. The initial wastewater pH was in the alkaline range (8.1). As it passed through the unit, the pH jumped considerably in the first stage to a pH of 8.5. Following the first stage, the pH increase tapered off and reached a final pH of 8.8 in the effluent. These values are averages obtained from all of the experiments in which pH was determined.

Figure 11. Percent Chemical Oxygen Demand Removed vs. Applied Organic Loading

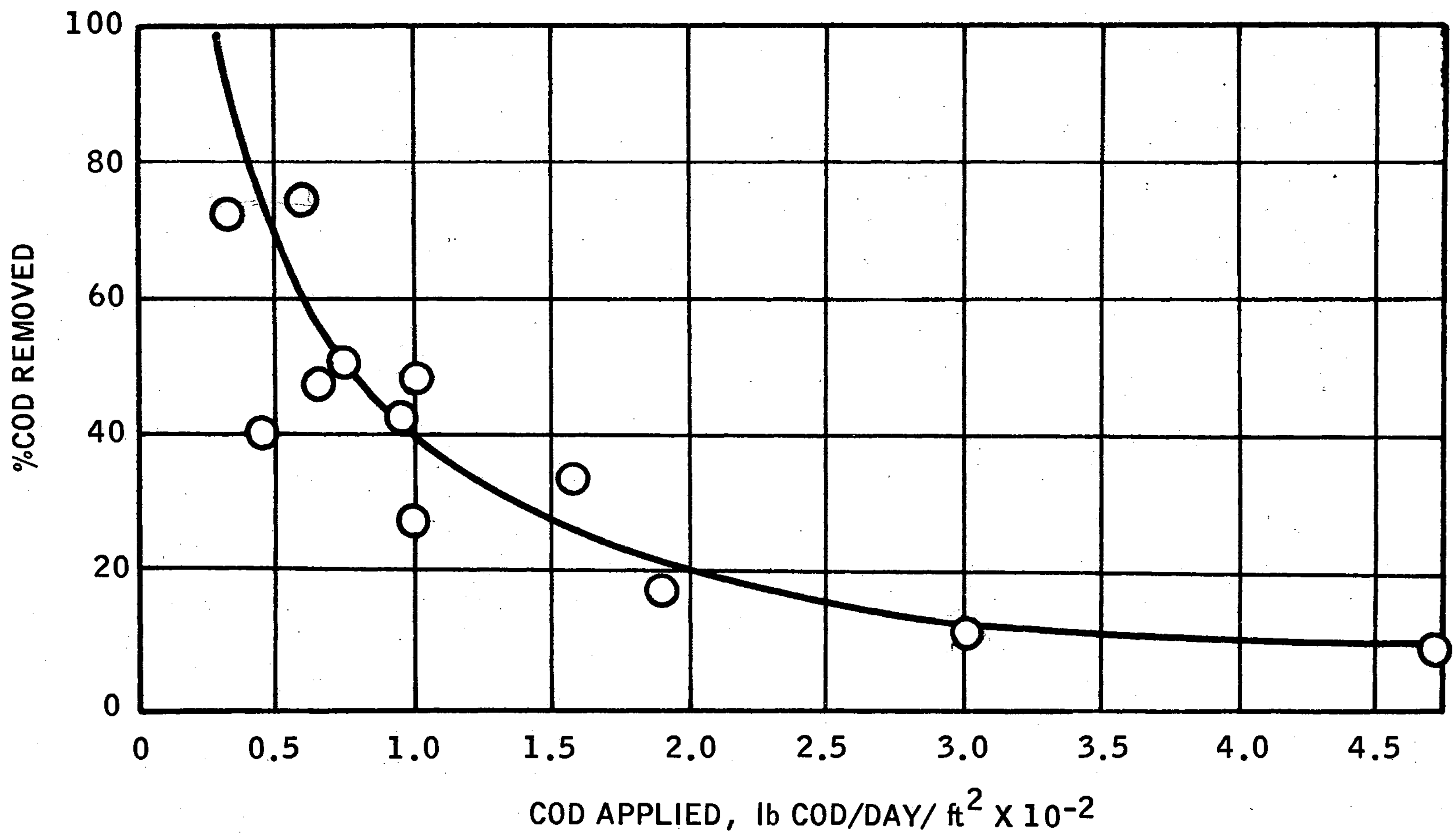
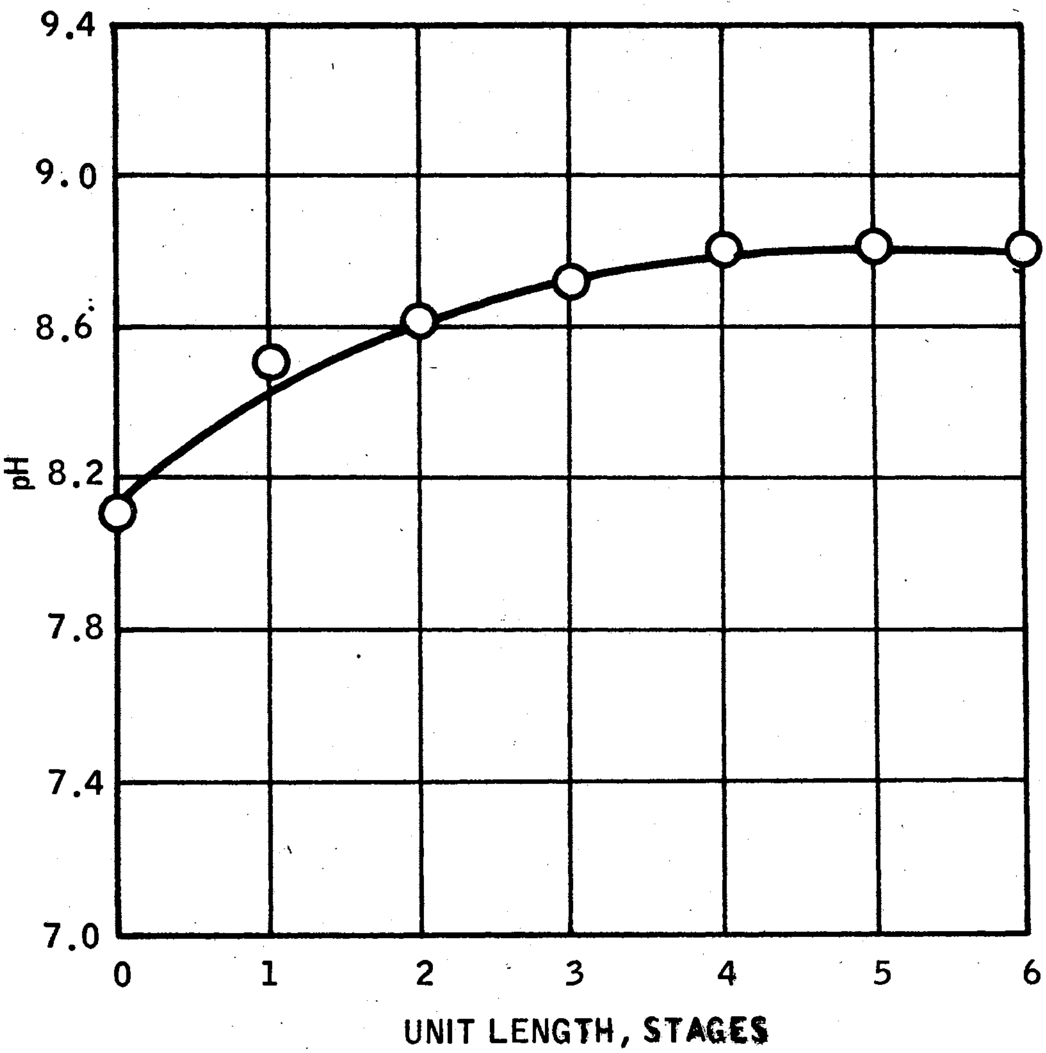

100
80
60
40
20
0
%COD REMOVED
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
COD APPLIED, lb COD/DAY/ ft^2 X 10^{-2}

Figure 12. pH Increase per Unit Length in Stages.



9.4
9.0
8.6
8.2
7.8
7.4
7.0
pH
0
1
2
3
4
5
6
UNIT LENGTH, STAGES

This is in agreement with a study by Birks and Hynek (19) on cheese processing waste, where they showed that the bio-disc process increased the waste pH into the alkaline range.

A temperature drop of 25^{o}F was noted between the influent and effluent on all experiments in which temperature was observed. The influent temperature was around 80^{o}F, with the effluent being around 55^{o}F. This temperature drop was due to the tremendous evaporation rate of the liquid as it passed through the unit. The wastewater in the unit would evaporate to dryness in a 48-hour time period without the addition of more wastewater.

Oxygen measurements were made several times with a dissolved oxygen probe during an experiment to make sure that the process was not oxygen limiting. The dissolved oxygen of the influent was 6.2 mg/l, while that of the effluent was 5.2 mg/l. From this it can be concluded that there is an oxygen utilization of only approximately one mg/l above that which is supplied by the unit. Therefore, oxygen utilization does not restrict the removal efficiency of the unit.

A microbiological technique, gram stain, was conducted on organisms from the front, the middle, and the end portions of the unit toward the end of the study period to determine the predominant type of organism present at this time. At the front of the unit, where most of the removal occurred, there were gram positive cocci and gram negative rods in what seemed to be equal predominance. In the middle portion, the predominant organisms were gram negative rods with scattered gram positive cocci. Gram negative rods dominated the end portion of the unit. No gram positive cocci were observed in this portion of the unit.

CHAPTER V

DISCUSSION

This investigation was conducted to study the feasibility of utilizing a rotating biological contactor for the treatment of slaughterhouse wastewater. The bio-disc has been shown to be effective in treating municipal sewage (18)(22), dairy waste (19)(20), and the effluent from anaerobic lagoons treating meat packing wastes (21). The results of this study provide definite data and observations about the performance of the bio-disc in treating slaughterhouse wastewater.

The utilization of a wastewater of this type provided a carbon source that would not vary much qualitatively from day to day. The influent temperature of the waste remained fairly constant at approximately 80^{o}F. The hydraulic flow rate was carefully controlled throughout each experiment. In considering these factors, it is concluded that a controlled experimental environment was maintained for this system.

A. COD Removal Characteristics

In all of the experiments except the one shown in Figure 4, over 50 percent of the total COD that was removed, occurred in the first stage of the unit. In this experiment, slightly less than 50 percent of the total removal occurred. As seen in Figure 8, this is the experiment where the first phase removal rate, "K_1," extended into the second stage of the unit. In other words, the maximum removal rate extended into the second stage; therefore, more removal was accomplished in the second stage than otherwise could have occurred at the "K_2" removal rate.

From these observations, it can be concluded that around 50 percent of the total COD that was removed occurred in the first stage. From Figure 5, it can be seen that most of the removal occurs in stage one, and the removal per stage tapers off for the rest of the unit. The pH (Figure 12) makes a considerable alkaline jump in the first stage, and then tapers off gradually like the COD removal. From these observations along with the fact that the microbial growth was more pronounced in the first two stages, it is seen that this is a significant change warranting further attention.

There exist many possibilities for the explanation of this phenomenon of two-phase substrate removal. Since this wastewater is a very complex substrate, the most reasonable explanation would be that of sequential substrate removal. That is, the more easily removable substrates are removed in the first stage or first two stages of the unit, leaving the organics which are more difficult to metabolize by the microorganisms to be removed in the rest of the unit. This could be due to different-sized molecules with the smaller micromolecules taken into the cells first, and then the larger macromolecules taken in by the cells in the latter portions of the unit. The removal of low molecular weight acids in the first phase would have to be considered, since this would allow for the noted increase in pH. The jump in pH in the first stage corresponds to the first phase removal rate, with the tapered increase in pH corresponding to the second phase removal rate. Consequently, the rate of substrate removal would decrease as the more easily assimilable substrates were removed leaving those which were difficult to metabolize to be removed during the second phase. One additional explanation would be a biochemical change in the wastewater with a release of intermediary metabolic byproducts given off by the microorganisms in the first phase removal state. These byproducts could inhibit the metabolic activities of microorganisms in later stages of the unit. The explanation of this phenomenon could be resolved only by a more detailed and more complete chemical analysis.

The other stages, especially following the second stage, do not add significantly to the total COD removal. A possible solution of this problem would be to follow stage number one with a clarifier, and then proceed to the rest of the unit. This would be a technique to investigate in future studies.

The diphasic removal rates existed for every organic loading applied to the unit. These diphasic removal rates are not due to a limited supply of biodegradable substrate. Supporting this statement is the fact that as the applied load to the unit was decreased, the first removal rate "K_1" extended into the second stage. If the second removal rate "K_2" came into being due to a limited supply of biodegradable substrate, then as the applied load was increased, the two removal rates would approach a single rate for the entire unit, or at least "K_1" would continue farther into the rest of the unit. As can be seen, this is definitely not the case (Figure 8). This type of diphasic removal rate has been commonly noted in trickling filters by Cook (15) and Fleming (26).

B. Response of the Bio-Disc to Shock Loads

The bio-disc has been shown by Antonie (23) to be effective in the processing of fluctuating wastewater flows. The purpose of the shock load experiment was to determine the effect, if any, on the removal capabilities of the unit after washwater remained in it for a certain period of time. A 15-hour time period was used to represent the time elapsed from quitting time one day to starting time the next day of slaughterhouse activity. Wastes of approximately the same COD concentrations were used before and after the shock of washwater.

The removal efficiency after the washwater set in the unit was better than it was before. The data representing this experiment can be seen in Figure 10 and Table IV. This statement is supported by the fact that the two different removals were measured so close to each other, and that the best removal was the second removal. Admittedly, different removals were noted for wastes close to the same COD concentration before, but these were at different time periods. The points on Figures 6 and 11 which differ considerably were from experiments run at the start of the study and those run at the last.

It is believed that the discrepancies in COD removal were due to increasing growth at first, and later to sloughing of the organisms. A considerable degree of sloughing was observed for the first couple of weeks after the start-up period. Then the growth seemed to become more stabilized and sloughed less often and to a lesser extent. From the considerations above and the fact that the washwater was so low in organic content, it was theorized that the microorganisms might have gone into an endogenous phase while the washwater was in the unit. Then, when the substrate was later supplied, the organisms returned to the substrate removal phase--perhaps at a more accelerated rate for a time.

C. Bio-Disc Characteristics Treating Slaughterhouse Wastewater

Neither suspended solids nor filtrate CODs were used as measurement parameters. The suspended biological solids were not of sufficient level in the unit to warrant measurement. The bio-disc system should operate as an activated sludge and as a trickling filter combination. Since the sampling technique mentioned earlier should have adequately represented the solids level, the unit seems to operate more like a trickling filter for this type of wastewater. Further recognition of this statement was noted by the succession of morphologically and biochemically specialized microorganisms that developed in the various stages of the unit. This is in contrast to the activated sludge process.

Some effluent samples were filtered, and the COD of the filtrate was determined for comparison with the unfiltered COD. A comparison of these values is shown in Table IV. As seen here and in other experiments, the difference was small enough to ignore filtration of the samples.

Figure 11 represents the relationship between COD removal and applied organic loading in lbs COD/day/ft^2. As would be expected, the removal efficiency decreases and approaches a constant minimum value as the organic load increases. Similar curves have been developed by Cook and Kincannon (27) from trickling filter data where a synthetic waste was utilized. This type curve would be a good approach to use in the design of bio-disc systems for waste treatment. By projecting the desired efficiency horizontally to the curve, and then dropping a vertical line, the allowed organic load in lbs COD/day/ft^2 can be read. This approach is used extensively in trickling filter design for secondary waste treatment.

The pH increase illustrated in Figure 12 is in agreement with other studies. The increased alkalinity of the waste as it progressed through the unit was observed in every experiment in which pH determinations were made. The pH jumps significantly after the first stage where 50 percent of the total COD removal occurred. In the remaining stages, the pH tapers off, as does the COD removal. This change in pH between the influent and the effluent can be taken as an indication of the bio-disc performance.

A significant temperature change of 25^{o}F was observed between the influent and the effluent wastewater. This temperature change was caused by the evaporation of wastewater as it passed through the unit. It was noted that if the unit, full at the start, was allowed to operate much over 48 hours without addition of liquid, it would become completely dry. This gives an indication of the tremendous evaporation rate.

As mentioned in the results, this process is not oxygen-limiting. The dissolved oxygen content of the wastewater as it leaves the unit is around 5 mg/l. This amount of oxygen is more than sufficient for aerobic microbial metabolism.

The gram staining technique gives the predominant type of organisms present at the time of staining only. The microbial predominance is subject to change. A change in microbial predominance could be another explanation for the disagreements in removal efficiencies noted in Figures 6 and 11.

This study indicates that the bio-disc can be a feasible solution to the treatment of slaughterhouse wastewater. The bio-disc system would have to be enclosed, if the climate was such that freezing occurred in the winter. Since the temperature of the waste drops considerably as it passes through the unit, this would be an important consideration. A method of solids removal or of pumping the solids would also be necessary.

Another very important consideration would be the organic content of the waste applied to the unit. Unless a large amount of water was used during the kill times, the COD of this waste would be exceptionally high. A solution to this problem would be a holding tank for equalization of the wastewater.

CHAPTER VI

CONCLUSIONS

The results of this investigation support the following conclusions:

(1) The rotating biological contactor can be a feasible solution for the treatment of slaughterhouse wastewater. It provides efficient treatment where freezing problems, solids problems, and organic equalization problems, if existing, are adequately solved.

(2) Approximately 50 percent of the total COD removal occurs in the first stage of the unit for this type of wastewater. This caused the noted diphasic removal rate in all organic loadings.

(3) The second phase removal rate "K_2" approaches a constant minimum value for the range of organic loadings utilized in this study. The removal efficiency also approaches a constant minimum value as the load increases.

(4) The shock load of washwater does not reduce the removal capacity of the unit.

(5) An indication of the bio-disc performance can be acquired by measuring the change in pH between the influent and the effluent wastewater.

(6) The bio-disc process is not oxygen limited in treating this type of wastewater.

(7) The COD removal characteristics per stage of the bio-disc unit treating slaughterhouse wastewater are remarkably similar to those obtained from trickling filters per foot of depth utilizing synthetic waste.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

Based on the findings of this study, the following suggestions are made for future studies involving the bio-disc and slaughterhouse wastewater:

(1) Study the effects on treatability of the waste by recirculation of effluent.

(2) Treatment of the wastewater by a large one-stage unit followed by a clarifier. From the clarifier go into another unit with more than one stage.

(3) Conduct a more detailed chemical analysis. Check the chemical components of the waste before and after the first stage treatment.

(4) Carry out a study for comparison of bio-disc performance with that obtained by trickling filters and activated sludge on slaughterhouse wastewaters.

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