RESPONSE OF A FIXED-BED REACTOR TO QUANTITATIVE AND HYDRAULIC SHOCK LOADS

By

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Bachelor of Science

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Fort Collins, Colorado

1972

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
December, 1975

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AND HYDRAULIC SHOCK LOADS

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ACKNOWLEDGEMENTS

I would like to thank Dr. Don F. Kincannon, my principal adviser for his assistance and patience during this study. He has provided inspiration through his dedication to our science and his dedication to providing a good education for his students.

I would also like to thank Dr. A. F. Gaudy, Dr. R. N. DeVries, and Dr. Marcia Headstream.

The other students of the department were of great help, by being friends as well as giving technical assistance. Antone, Azar, Bartel, Bradley, Chen, Hapke, Manickam, Esfandi, Pirote, Lowe, Reddy, Saleh, and Weaver were there in many memorable times.

My parents, Merle and Charlene Kepler, who helped me throughout my life.

This study was funded in part by an EPA training grant number T-900078-01.

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CHAPTER I

INTRODUCTION

Trickling filters have been in use for sewage treatment since before 1900. The term "trickling filter" is actually a misnomer, as they are not filters at all, but rather a medium on which biological growth may occur. The use of a misnomer for so many years is symbolic of the lack of understanding of the actual workings of the system. The awakening of the people to the need for a clean environment and the resultant state and federal requirements have spurred research in all methods of wastewater treatment, including trickling filters.

With the research into sewage treatment has come a new type of trickling filter, with the media for biological growth made of that space age material, plastic. The old "rose bowl" is gone. Aromas and following visions of concrete structures filled with rocks and topped by an irrigation sprinkler will hopefully not be with us for long. The new trickling filter uses plastic medium, has no concrete walls, and stands tall in the air, thanks to the lost weight. The increased void space allowed by the plastic media allows more air to circulate, greatly reducing the chances of anaerobic activity and the resultant stink.

Design methods have found new ideas, also. At one time design was based solely of population served. Current designs are based upon pilot plant results, and chemical analysis of the wastewater.

Until recent years, published literature on trickling filters was the result of operational plants. Pilot plants allow control of input conditions, affording a better view of the effect of input upon output.

Trickling filter plants have been unpopular for the past fifteen years. During this time the activated sludge method of sewage treatment has predominated. The activated sludge process offers several advantages, and the kinetics of the biological processes are understood. In a completely mixed activated sludge system, the substrate is of the same concentration throughout. In the trickling filter, the substrate concentration varies throughout. Herbert (1) states that he considers fixed film reactors inefficient, and that they should be replaced by other types of reactors.

The activated sludge system offers operational controls of the micro-organism population which can be used to deal with shock loads if they are anticipated. Activated sludge units are easily set up in the laboratory, the result being a wealth of design and operational information about them.

Trickling filters have several distinct advantages, however. Plastic media has reduced the cost, allowed greater depth due to lessening of structural requirements, and greater airflow due to increased void ratios. Kincannon and Sherrard (2) state that the biological tower (plastic media trickling filter) requires less power than activated sludge and produce less solids. The biological tower is also less sensitive to poor operation than activated sludge, in regard to shock loads and bulking sludge. They indicate that a high rate trickling filter may be more stable under shock loads than a high rate activated sludge system. Successful treatment of shock loads in high rate activated sludge systems requires the operator to be aware of the incoming shock and that he knows what to do with it. Failing one of these can result in very poor treatment. In trickling filters response is governed by the micro-organisms, and the operator has very little control over the process.

Shock loads are everyday occurrences in domestic and industrial treatment plants. In domestic plants, the first shock of the day occurs in the morning, when everybody gets up and uses the toilet and shower. Later in the day, industrial users may dump large quantities of organic matter, or a great deal of relatively clean water, causing quantitative and hydraulic shocks, respectively. Hopefully the treatment plant will be able to handle these shocks.

To the authors knowledge, this the first research to be done on the effects of shock loads on trickling filters under controlled conditions. This study considers the response of trickling filters to both changes in substrate concentration and hydraulic flow rate. Substrate was shocked at 2 times, 3 times, and 4 times the original concentration. The hydraulic load was shocked at 2 times and 2.6 times the original load.

CHAPTER II

LITERATURE REVIEW

A. Introduction

The literature contains no articles dealing with the effect of shock loading on trickling filters. A great deal of work has been done on the response of activated sludge systems to shock loads, however. This work is of interest because both systems follow the growth kinetics according to Monod (3). Bentley (4) has shown that the activated sludge parameters of mean cell residence time, cell yield, and substrate utilization may be used for fixed-bed reactors, making the systems comparable in some ways.

The literature does contain some recent work on the kinetics of substrate removal and flow in fixed-film reactors under steady state conditions.

B. Shock Loads

A shock load is any input to a biological system which causes an abrupt change in the environment. In this study, quantitative and hydraulic shock loads were administered. Other types of shock loads are qualitative, toxic, pH, and temperature. Definitions follow:

Quantitative shock. A quantitative shock load is one in which the concentration of the waste increases rapidly. The flow rate should not vary significantly, and the nature of the waste remains the same.

Hydraulic shock. A hydraulic shock is one in which the flow of the waste water increases rapidly, while the concentration and nature of the organic material in the waste remain relatively constant.

Qualitative shock. A qualitative shock load is one in which the chemical nature of the waste suddenly changes.

C. Response of Activated Sludge Systems to Shock Loads

Komolrit (5) studied the effect of quantitative and qualitative shock loads upon an activated sludge system with various detention times and sludge ages. He found that detention time was an important factor in the ability of the system to deal with a quantitative shock load. He also found that young cells responded more rapidly to both quantitative and qualitative shock loads. Release of metabolic intermediates was more prevalent in young cell systems, also. The major facet of this study concerned substrate preference, adaptability and enzyme production disturbance in qualitative shock loads.

Krishman and Gaudy (6) conducted experiments with qualitative shock loads. In response to a shock of the six carbon sugar glucose on a system acclimated to three carbon glycerol alcohol, the intermediate production was again observed. The authors concluded that the effect of the new substrate upon enzyme production controls response to the qualitative shock, in concurrence with the work of Komolrit.

Gaudy and Englebrecht (7) found that the quantitative shock load may show a successful response even in nitrogen deficient systems. The carbonhydrates may be stored and subsequently oxidized. They found that the amount of substrate channeled into sludge synthesis and substrate utilization is not constant, but shifts at a decelerating rate from synthesis to respiration. They found significant intermediate production in a qualitative shock load.

Ragthaidee (8) treated quantitative shock loads in an activated sludge system with a 24-hour detention time. He found that with this long detention time he was able to treat a five-fold increase in substrate concentration with 95% removal. He claimed that the success was not dependent upon sludge age. Carbohydrate content of the sludge remained the same throughout the shock.

Schaezler, McHarg, and Busch (9) used a completely mixed reactor and batch systems. Mathematical models of these systems were made, and the data from the systems was used to varify the predictive capability of the model. They found that slow growing cultures with long detention times could respond to increases in substrate concentration better than fast growing cultures with short detention times. They conclude that the growth rate is independent of substrate concentration above low levels of substrate in the reactor. The model proposed is dependent upon the rate of substrate change in the reactor, and the phase of the growth curve. Other mathematical models of activated sludge are given by Eckhoff and Jenkins (10) and Popel (11).

Grady (12) uses an analog computer to model the response of an activated sludge system to transient loading. Monod's (3) and Herbert's (1) kinetics from the basis of Grady's model. The basic equations of this model are:

$$\frac{dS}{dT} = \frac{Q}{V} (S_i - S) - X \left(k_d + \frac{\mu_m}{Y}\right) \left(\frac{S}{K_s + S}\right) \qquad (1)$$

and

$$\frac{dX}{dT} = \frac{X(\mu_m S - k_d Y K_s)}{(K_s + S)} \tag{2}$$

where

S_i = inflow substrate concentration

S = substrate concentration in reactor

Q = flowrate

V = volume of reactor

X = concentration of micro-organisms in reactor

μ_m = maximum growth rate of micro-organisms

k_d = maintenance coefficient

Y = yield (wt. of micro-organisms produced/wt. of substrate treated)

T = time

K_s = Monod's constant = S when $u = u_m/2$

Grady uses the analog computer to solve this equation. He concludes that the biochemical response to a quantitative shock load is strongly dependent upon the steady state growth rate constant prior to the shock. The lower the growth rate, the better the response. For a constant growth rate, response is relatively independent of hydraulic detention time.

Storer and Gaudy (13) used similar equations, and found that the Monod equation could not accurately predict the shape of the substrate and micro-organism concentration curves following a 3-fold quantitative shock load. The Monod equation did, however, come close to predicting the peak of the substrate removal curve. They blamed the failure of the

Monod equation on a hysteresis effect. That is, the cell concentration is dependent not only upon the substrate concentration, but also whether the concentration is on the increase or decrease.

While the models described may predict the response of activated sludge systems to quantitative shock loads, the problem of predicting trickling filter response is much more difficult, since the substrate concentration is different at every point in the reactor.

D. Substrate Removal Kinetics of Fixed Media Systems

Bentley (4) compared the design and operational control parameters of activated sludge systems, with experimental results from the Oklahoma State University trickling filter. He found that the ideas of food to micro-organism ratio, observed yield, and specific utilization were valid for fixed media systems. Solids production was shown to be a function of total organic loading.

Deen (14) found that removal of substrate was a function of the total organic loading applied and that neither substrate concentration nor hydraulic flow could be considered independently. The filter removed substrate throughout its depth according to first order kinetics. Equal total organic loadings produced equal removal.

Kornegay and Andrews (15, 16) have conducted the most significant research on fixed film media. They used completely mixed annular reactors in their experiments, but have analyzed trickling filters as well. By conducting a mass balance upon a differential element in a trickling filter, they have arrived at the equations:

$$Q(S_i - S) = \frac{\mu_m}{Y} (A) \ (X) \ (d) \ (\frac{S}{K_s + S}) \tag{3}$$

where

S_i = inflow substrate concentration

S = outflow substrate concentration

Q = flow

μ_m = maximum growth rate

Y = yield

A = surface area available for growth

d = effective depth of biological growth

X = specific weight of micro-organisms

K_s = Monod's constant, = S where $u = u_m/2$

and integrated with respect to depth:

$$K_s \ln (\frac{S_i}{S}) + (S_i - S) = \frac{\mu_m \ adHX}{QY} Z \tag{4}$$

where

H = cross sectional area

a = surface area per unit volume

Z = depth in filter

Kornegay and Andrews found the effective depth of the micro-organisms to become a constant after a certain organic loading. They found the maximum effective depth to be 70 μ. While increased loading may increase the total depth of slime on the media, this increased slime depth had no effect on substrate removal.

Kornegay and Andrews also conducted a type of shock loading. They made small decreases in the influent concentration. They concluded that fixed film media response to shock loads was sufficiently fast that steady state equations were acceptable for design.

Cook (17) utilized the same mass balance equation as Kornegay and Andrews. He found that data obtained on the OSU Laboratory trickling filter confirmed the equation. He operated the trickling filter and retained the effluent for solids analysis. He could thus find μ_m, Y, and K_s; the constants relating cell growth to substrate load. He found that the equation was not highly sensitive to variations in μ_m and K_s. Cook substituted his values back into the equation and found that micro-organism surface area was a major factor in removal. Most of Cook's studies were run with light loadings, insufficient to produce full growth on the media. In the study presented here, all loadings should produce full effective growth on the media. Cook concluded that first order kinetics were followed, and were a result of micro-organism concentration varying with depth.

Cook also found evidence of non-carbohydrate intermediates. Cook claims that a saturation phenomenom is a result of substrate removal approaching a limiting value.

Jank and Drynan (18) conducted experiments on an inclined plane. Their data confirmed the mass balance analysis of Kornegay and Andrews.

CHAPTER III

MATERIALS AND METHODS

A. Experimental Approach

The Oklahoma State University Bioengineering laboratories contain a 9-foot deep plastic media trickling filter. Shock loads were administered to this trickling filter by proper control and mixing of a concentrated feed and Stillwater tap water. The unit was operated at a steady state prior to the shock load, and would be operated at the increased loading until a new steady state was achieved. Samples were taken at regular intervals and at various depths in order to determine the response.

B. Experimental Apparatus

The trickling filter consisted of two plexiglass towers. These towers were connected in series so that the effluent from the first tower fed through a pump to the top of the second tower. Both of the towers had a cross-sectional area of one (1) square foot. The first tower had four one cubic foot modules of Flocor plastic media stacked vertically. The second tower had five one cubic foot modules stacked vertically. Between each module of plastic media was a gap of approximately four inches, with holes bored in the side of the plexiglass enclosure for taking samples. These holes were plugged when samples were not being taken. A collection trough was at the bottom of

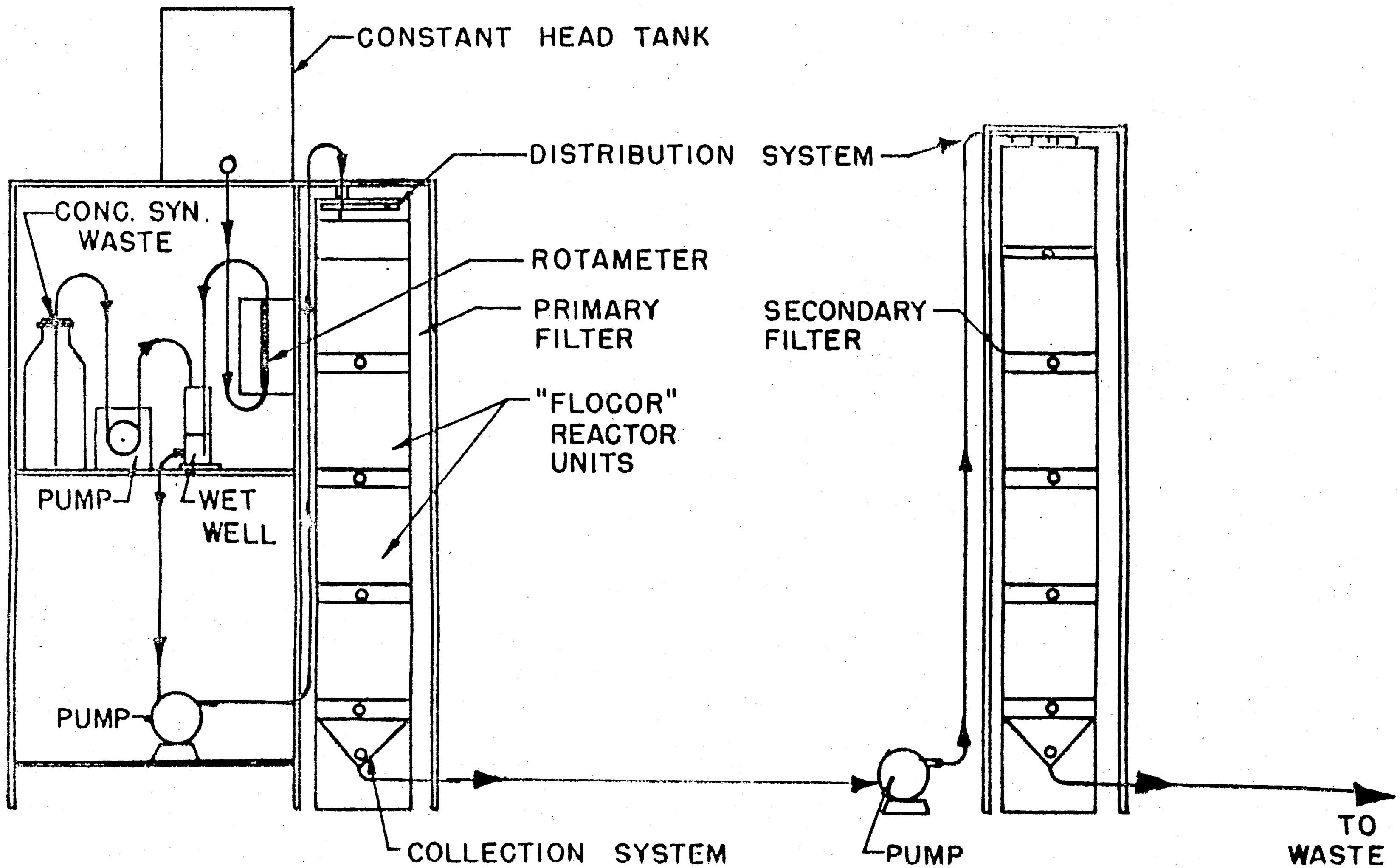

Figure 1. Experimental Apparatus

each tower. Water in the first collection trough was pumped to the top of the second tower, while water in the second collection trough was wasted into the local sewer.

The Flocor media is made of rigid PVC plastic. It was developed by the Imperial Chemical Industries, Ltd., London, England, and has previously been licensed in the United States by the Ethyl Corporation. Flocor has 2 1/4 inch triangular openings, and each cubic foot provides a maximum of 27 square feet of surface area on which biological growth may occur. The void ratio of 97% allows sufficient air flow for oxygen reaction with the micro-organisms

Hydraulic flow to the system was maintained by means of a constant head tank which received a constant flow of tap water from the Stillwater distribution system. As the experiments were conducted in the summer months, it was decided that the water temperature should be sufficiently constant and warm. From the constant head tank the water flowed through a rotameter, by which flow rate could be adjusted. From the rotameter, the flow passed into a wet well where it would be mixed with concentrated feed, and pumped to the top of the first tower.

Sucrose ($C_{12}H_{22}O_{11}$) was employed as the carbon source for the synthetic waste used in this experiment. Ammonium-nitrate fertilizer was employed as the nitrogen source. Commercial grade lawn fertilizer with an analysis of 33% nitrogen was readily obtainable. Of the 33% nitrogen, 16% was in the form of nitrates and 16% was in an ammonium compound. The fertilizer was soluble, but since the concentration was quite strong, the solution was continuously stirred to keep it well mixed. Approximately 50 ml. of concentrated H_2SO_4 was added to 40 liters of concentrated feed to increase solubility and prevent microbial growth. The concentrated feed was pumped to the wet well by a Cole-Parmer Masterflex Tubing Pump. Desired organic concentrations could be achieved by varying the pumping rate. Composition of the synthetic waste is presented in Table I.

TABLE I

COMPOSITION OF SYNTHETIC WASTE RELATIVE TO A SUCROSE CONCENTRATION OF 100 mg/l

Constituent	Concentration
$C_{12}H_{22}O_{11}$ (sucrose)	100 mg/l
Ammonium-Nitrate fertilizer	64
$MgSO_4 \cdot 7H_2O$	10
K_2HPO_4	6
$MnSO_4 \cdot H_2O$	1
$CaCl_2$	0.75
$FeCl_3 \cdot 6H_2O$	0.05

The concentrated feed was mixed with the diluting water in the wet well by a magnetic stirrer. From there it was pumped to the top of the first tower by a Teel Rotary-Screw Pump (Model Ip610). The pump was driven by a Dayton single speed motor (Model KS55JXBJB - 913). All feed lines were chlorinated as necessary to prevent biological blockage.

Distribution at the top of each tower was accomplished by a perforated circular section of tubing. A plexiglass baffel was between the sprinkler and the media to aid in achieving a more uniform distribution.

Effluent from the first tower was passed to a wet well, then pumped to the top of the second tower. Pump and distribution system were similar to those described earlier.

C. Experimental and Analytical Procedures

The unit was operated at a steady state of 300 mg/l in order to obtain initial growth. Seeding was done by passing biological solids wasted from the other units in the laboratory into the filter. Steady state conditions were verified by consecutive day COD samples. After each shock load, the unit was returned to this state and operated for at least one week before another shock load was administered.

The unit was shocked by varying the flow rate of the rotameter or feed pump, as required. Samples were taken of the feed, and after 2 ft., 4 ft., 6 ft., and 9 ft. of the media had been encountered. Samples were taken at short time intervals immediately after the shock and at more distant intervals later on. Samples were taken of the steady state conditions immediately before a shock.

Samples were taken with the aid of a sampling wand. This consisted of a piece of PVC tubing which had been halved along the longitudinal axis. It was placed between the layers of media and moved back and forth so as to obtain a representative sample.

Five samples were then filtered through Millipore membrane filters (0.45 μ). The filtrate of each was distributed to the COD flasks in

20 ml. samples. When anthrone tests were run, the filtrate was diluted as necessary and distributed into capped test tubes for later analysis. Chemical Oxygen Demand (COD) tests were run according to Standard Methods (19). Anthrone tests were conducted according to Ramanathan, Gaudy, and Cook (20).

CHAPTER IV

RESULTS

Five shock loads were administered to the plastic media biological tower. Quantitative shocks were at 2 times, 3 times, and 4 times the normal 300 mg/l substrate concentration. Hydraulic shocks were at 2 times and 2.6 times the normal 500 gal/day flow. In each case the higher loading was continued until a new steady state was achieved.

A. Response to Quantitative Shock Loads

The shock load of 2 times the original substrate concentration was dealt with very successfully by the system. Feed was shocked from 300 to 600 mg/l at a constant 500 gal/day/ft^2. Data from Table II is presented in Figures 2 and 3. Figure 2 indicates that a new steady state COD value was arrived at almost immediately. No upset to the system is apparent. Figure 3 shows the percent remaining COD as a function of time. While the upper stages of the filter required a short time to achieve a new removal efficiency, the upset and time lag are insignificant. The tower dealt with the shock load very effectively.

The response of the biological tower to a shock load of 3 times the original substrate concentration is shown in Table III and Figures 4 and 5. This shock was from 350 to 1050 mg/l at a constant 500 gal/day/ft^2. The two figures show a considerable upset for approximately 6 hours following the shock. At first the tower achieved good removal, close to

TABLE II

RESPONSE TO A SHOCK LOAD OF 2 TIMES THE ORIGINAL SUBSTRATE CONCENTRATION

Time	Flow	Feed COD	Depth in Filter							
			2 feet		4 feet		6 feet		9 feet	
hr:min	gal/day	mg/l	COD	% Remain	COD	% Remain	COD	% Remain	COD	% Remain
-24:00	500	255	167	65	155	61	54	21	29	11
-0:55	500	326	225	69	134	41	130	39	42	13
0:00	500									
0:10	500	631	485	77	280	44	201	31	109	17
0:50	500	671	489	73	315	47	206	31	117	17
2:25	500	658	408	62	279	42	186	28	121	18
4:35	500	634	436	69	279	44	166	26	121	19
8:05	500	760	483	63	328	43	185	24	110	14
17:35	500	647	445	68	373	58	252	39	181	28
24:25	500	622	576	93	399	64	227	36	134	21

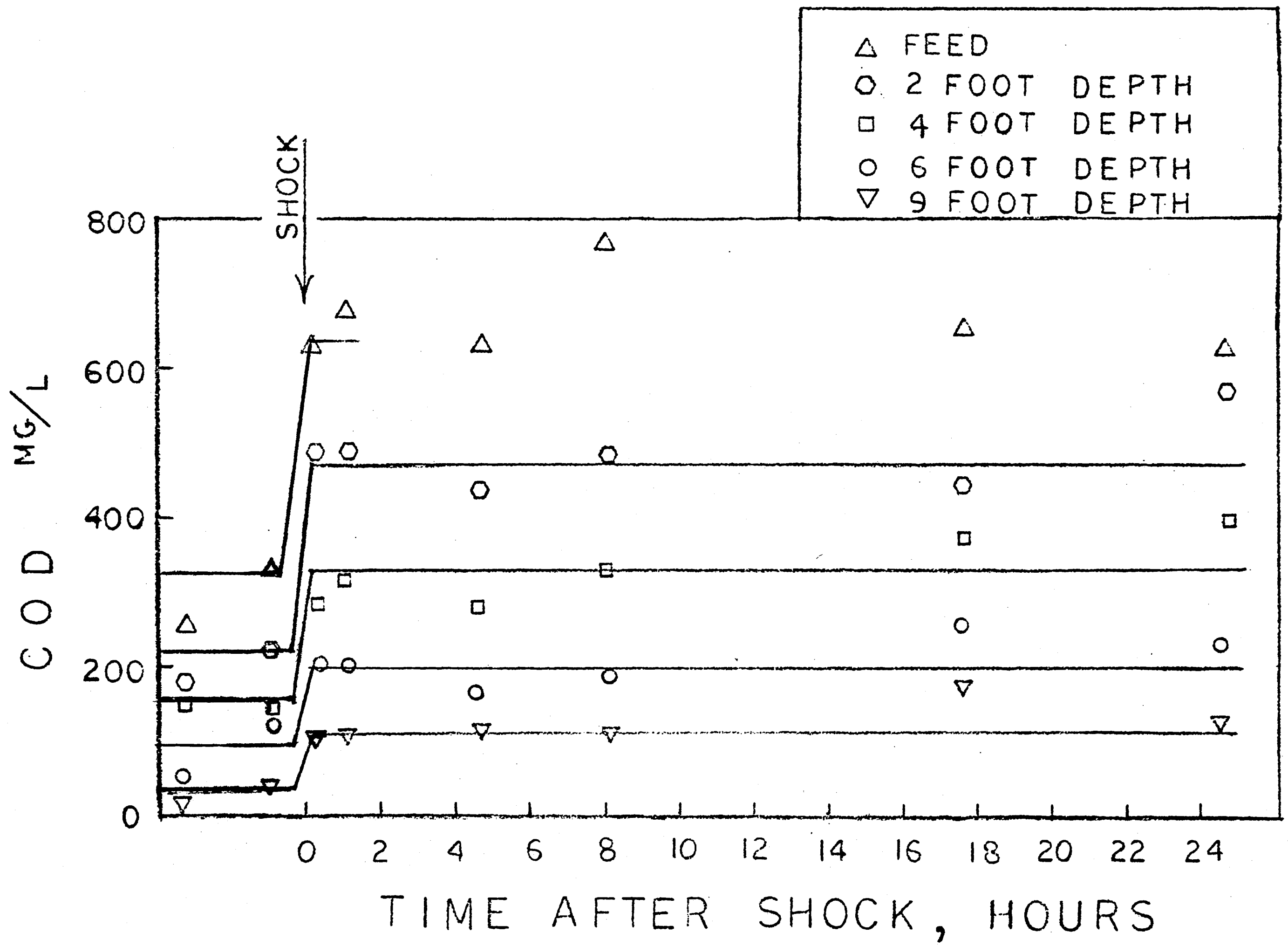

Figure 2. Response to a Shock Load From 350 mg/1 to 650 mg/1 at a Constant 500 gal/day/ft^2 as COD vs. Time

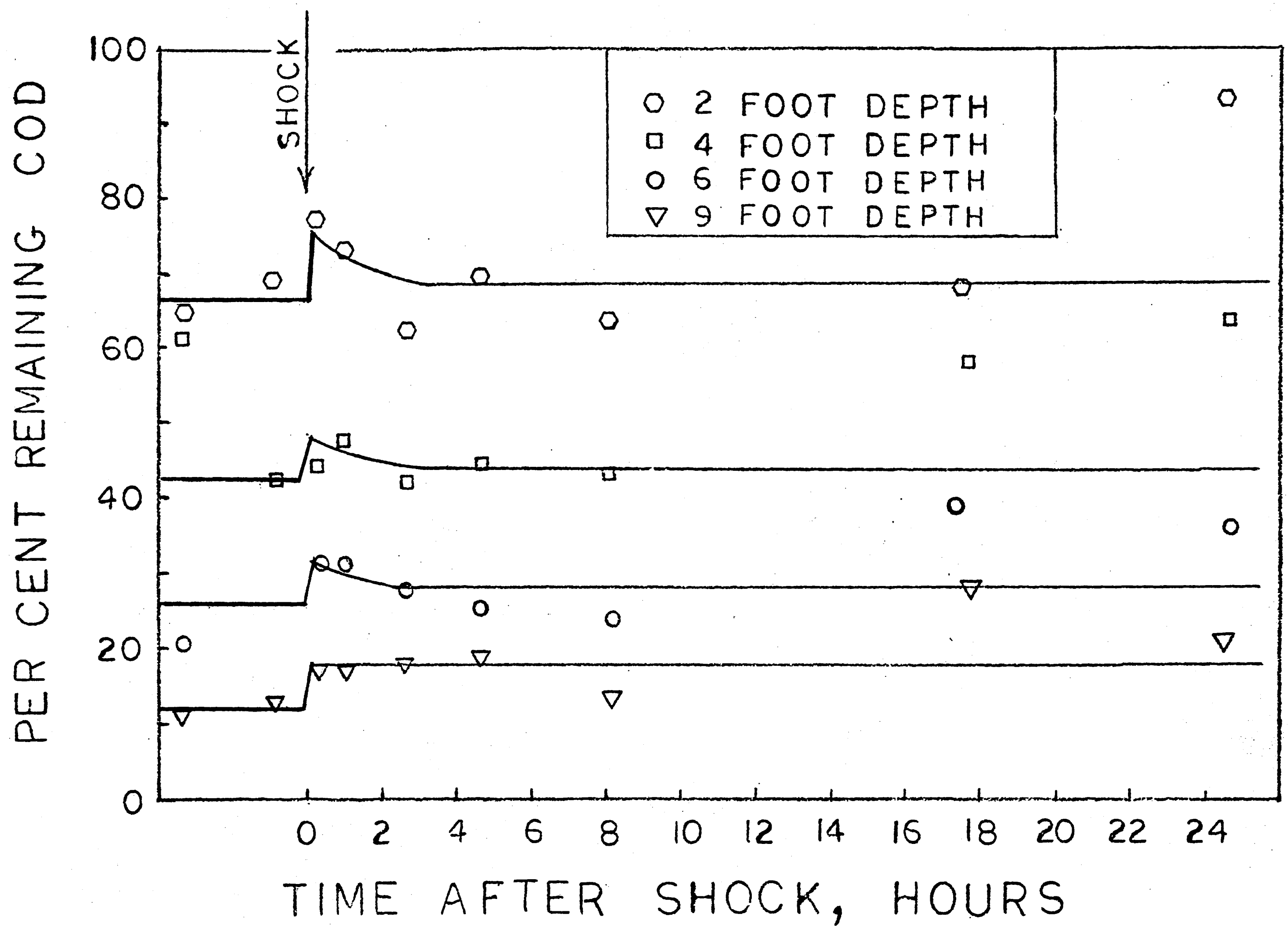

Figure 3. Response to a Shock Load From 350 to 650 mg/l at a Constant 500 gal/day/ft^2 as Percent Remaining COD vs. Time

TABLE III

RESPONSE TO A SHOCK LOAD OF 3 TIMES THE ORIGINAL SUBSTRATE CONCENTRATION

Time	Flow	Feed COD	Depth in Filter							
			2 feet		4 feet		6 feet		9 feet	
hr:min	gal/day	mg/l	COD	% Remain	COD	% Remain	COD	% Remain	COD	% Remain
-24:00	500	340	231	68	160	47	92	27	75	22
0:00	500									
0:10	500	1050	792	75	687	65	442	42	320	30
0:55	500	1050	840	80	670	64	493	47	411	39
1:35	500	1000	823	82	687	69	514	51	442	44
3:00	500	1070	860	80	677	63	462	43	398	37
5:55	500	1070	830	77	636	59	405	38	292	27
9:10	500	1100	816	74	580	52	408	37	268	24
20:10	500	970	683	70	517	53	363	37	241	25
28:30	500	1070	812	76	612	57	435	41	309	29
44:45	500	1250	903	76	801	64	534	43	415	33
69:45	500	1100	772	70	578	52	359	33	247	22

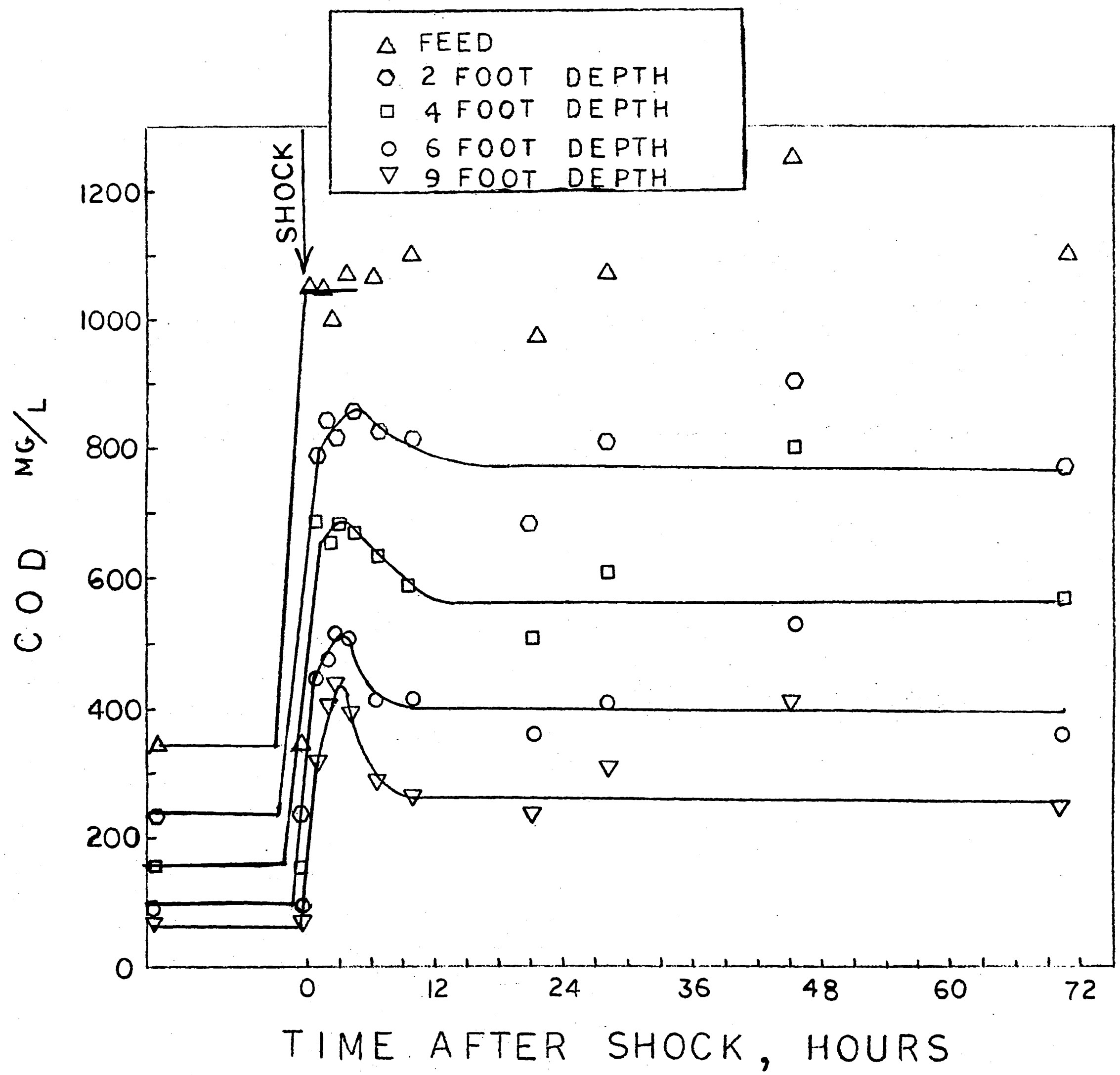

Figure 4. Response to a Shock Load From 350 mg/l to 1050 mg/l at a Constant 500 gal/day/ft^2 as COD vs. Time

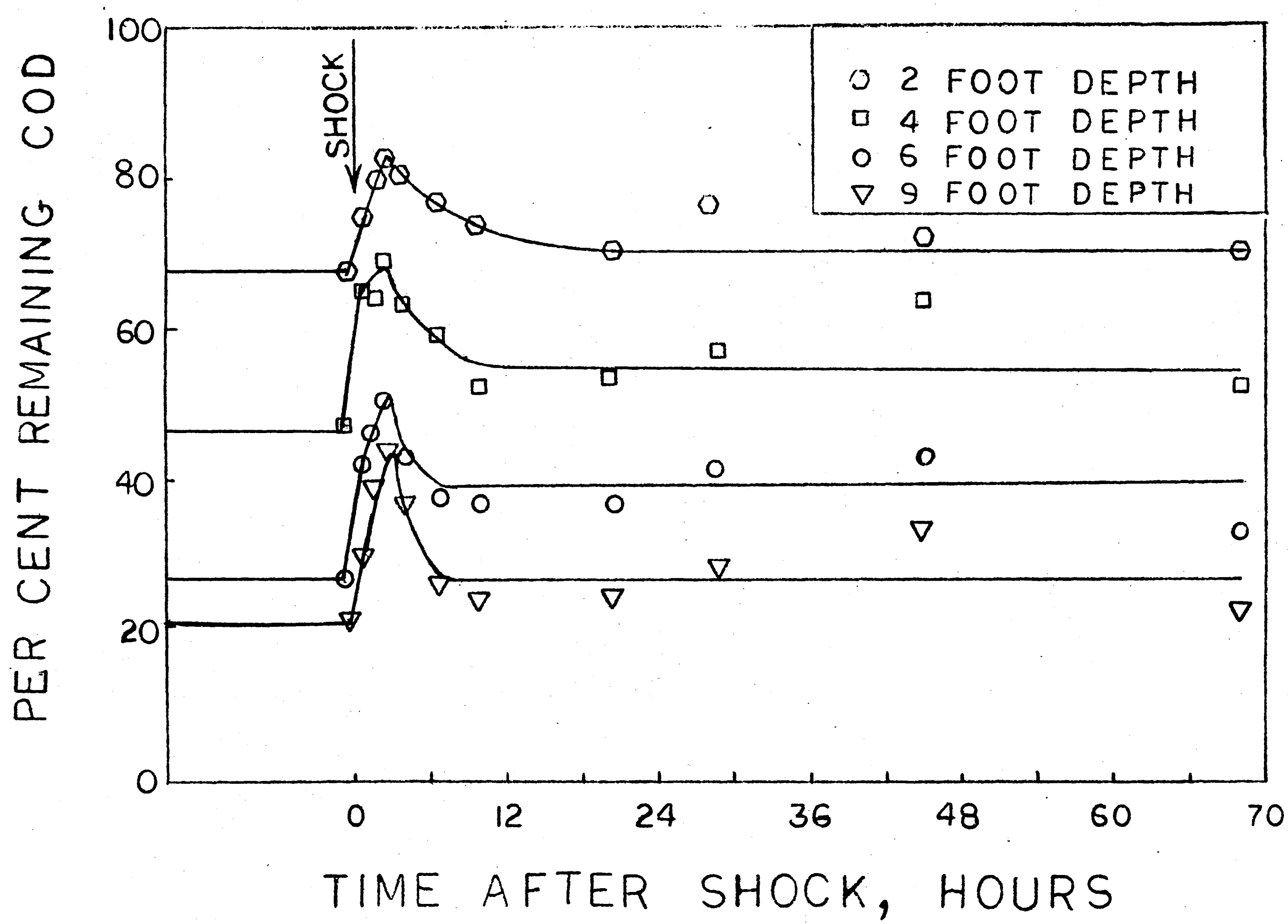

Figure 5. Response to a Shock Load From 350 mg/l to 1050 mg/l at a Constant 500 gal/day/ft^2 as Percent Remaining COD vs. Time

the steady state it would later achieve. Removal became less with time for around three hours. At three hours, remaining COD was very high, 150 mg/l (15%) higher than the final steady state. Treatment improved for the next three hours until a new steady state was achieved.

Response to a shock load of 4 times the original substrate concentration is shown in Table IV and Figures 6 and 7. This shock also produced a definite upset. The final steady state removes less per foot of depth than lighter loadings. This is indicative of an overload condition.

B. Response to a Hydraulic Shock Load

Hydraulic shock loads were run at 2 times and 2.6 times the normal 500 gal/day/ft^2. The substrate concentration remained the same at approximately 300 mg/l.

Response to a change in flow from 500 gal/day/ft^2 to 1000 gal/day/ft^2 is shown in Table V and Figures 8 and 9. From these figures we can see that although the system took some time to respond, the upset was very small.

Response to the hydraulic shock load from 500 to 1300 gal/day/ft^2 is shown in Table VI and Figures 10 and 11. Response was similar to the 2 times hydraulic shock load.

The biological tower responded well to both the hydraulic shock loads administered to it. A small upset in COD removal was observed for around 6 hours after both of the shocks, but the upset was not large. Larger hydraulic loadings could not be run due to equipment limitations.

TABLE IV

RESPONSE TO A SHOCK LOAD OF 4 TIMES THE ORIGINAL SUBSTRATE CONCENTRATION

Time	Flow	Feed COD	Depth in Filter							
			2 feet		4 feet		6 feet		9 feet	
hr:min	gal/day	mg/l	COD	% Remain	COD	% Remain	COD	% Remain	COD	% Remain
-24:00	500	320	247	77	199	62	121	38	92	29
-0:45	500	340	257	76	213	63	155	44	106	31
0:00	500									
0:05	500	1478	1278	86	1164	79	961	65	806	54
0:30	500	1487	1289	87	1205	81	1057	71	925	62
1:15	500	1487	1328	89	1224	82	1063	71	1020	68
2:15	500	1498	1355	90	1230	82	1134	76	1020	68
4:15	500	1552	1331	86	1206	78	1050	69	872	56
7:40	500	1546	1355	88	1224	79	1034	67	---	--
20:00	500	1373	1236	90	1012	74	967	70	913	60
27:00	500	1430	1298	91	1128	79	919	64	842	59
46:15	500	1409	1248	88	1146	81	949	67	770	55

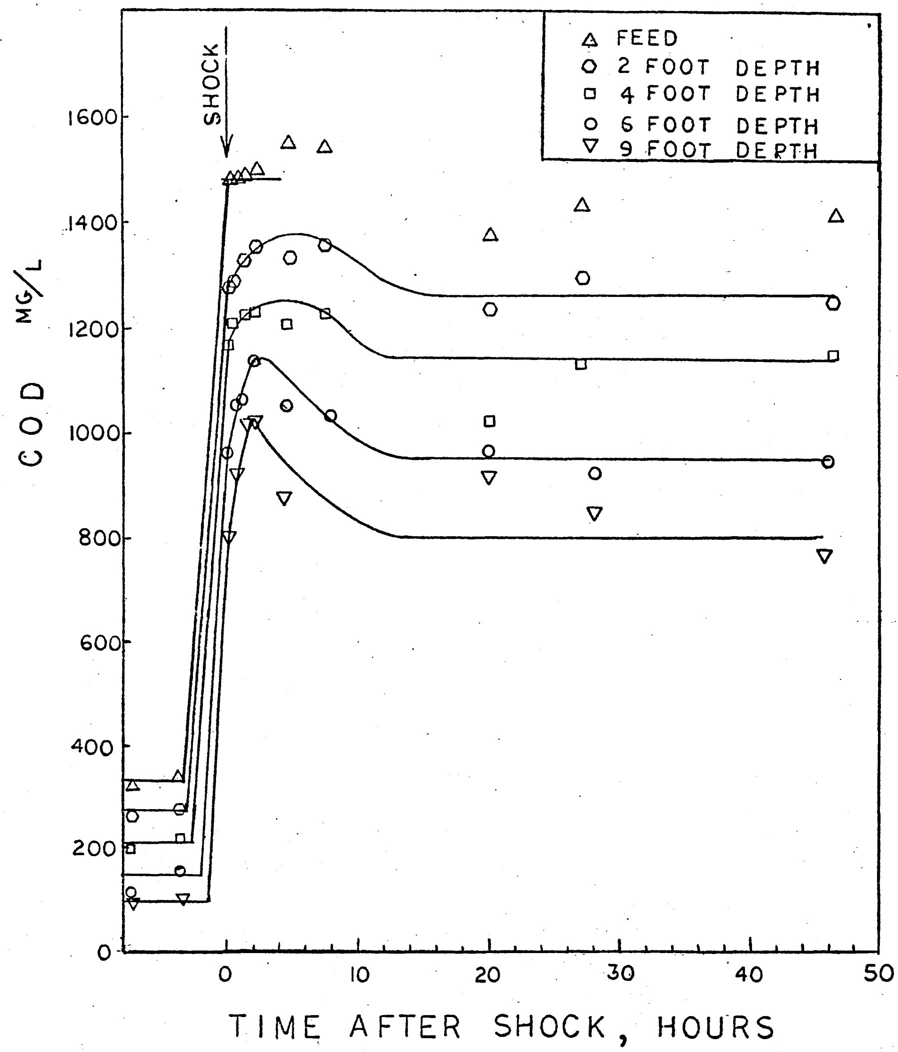

Figure 6. Response to a Shock Load From 350 mg/l to 1400 mg/l at a Constant 500 gal/day/ft^2 as COD vs. Time

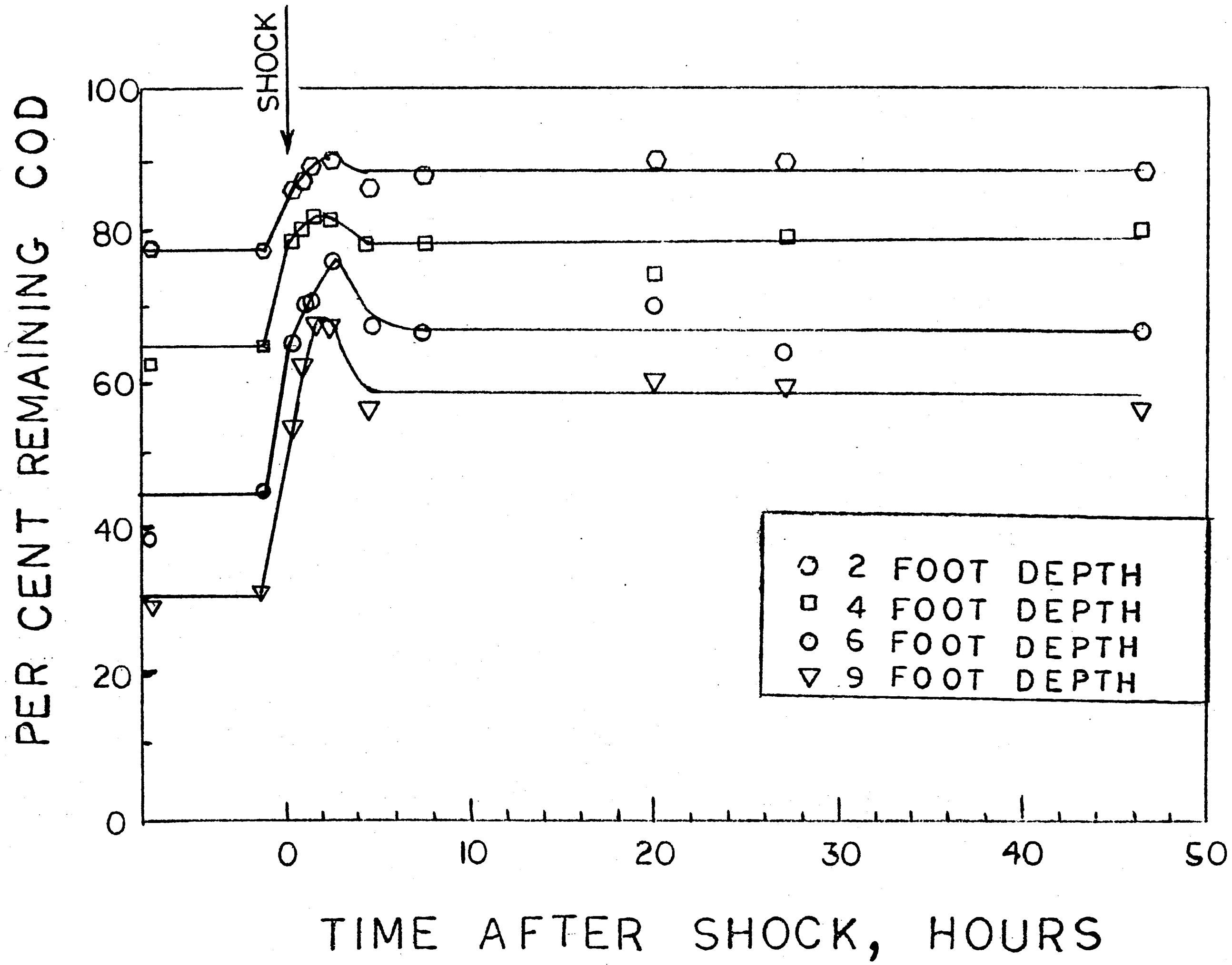

Figure 7. Response to a Shock Load From 350 mg/l to 1400 mg/l at a Constant 500 gal/day/ft^2 as Percent Remaining COD vs. Time

TABLE V

RESPONSE TO A HYDRAULIC SHOCK OF 2 TIMES THE ORIGINAL FLOW

Time	Flow	Feed COD	Depth in Filter							
			2 feet		4 feet		6 feet		9 feet	
hr:min	gal/day	mg/l	COD	% Remain	COD	% Remain	COD	% Remain	COD	% Remain
-0:25	500	373	267	71	185	50	98	26	84	22
0:00										
0:10	1000	306	233	76	170	55	117	38	117	38
0:40	1000	364	238	65	209	57	141	39	112	31
2:15	1000	350	272	78	204	58	151	43	122	35
5:15	1000	359	272	76	224	62	151	43	113	31
9:15	1000	484	291	60	204	42	161	33	132	27
13:15	1000	325	233	72	170	52	141	43	108	33
23:45	1000	325	243	75	166	51	132	41	108	33
30:45	1000	300	209	70	151	50	103	34	79	26

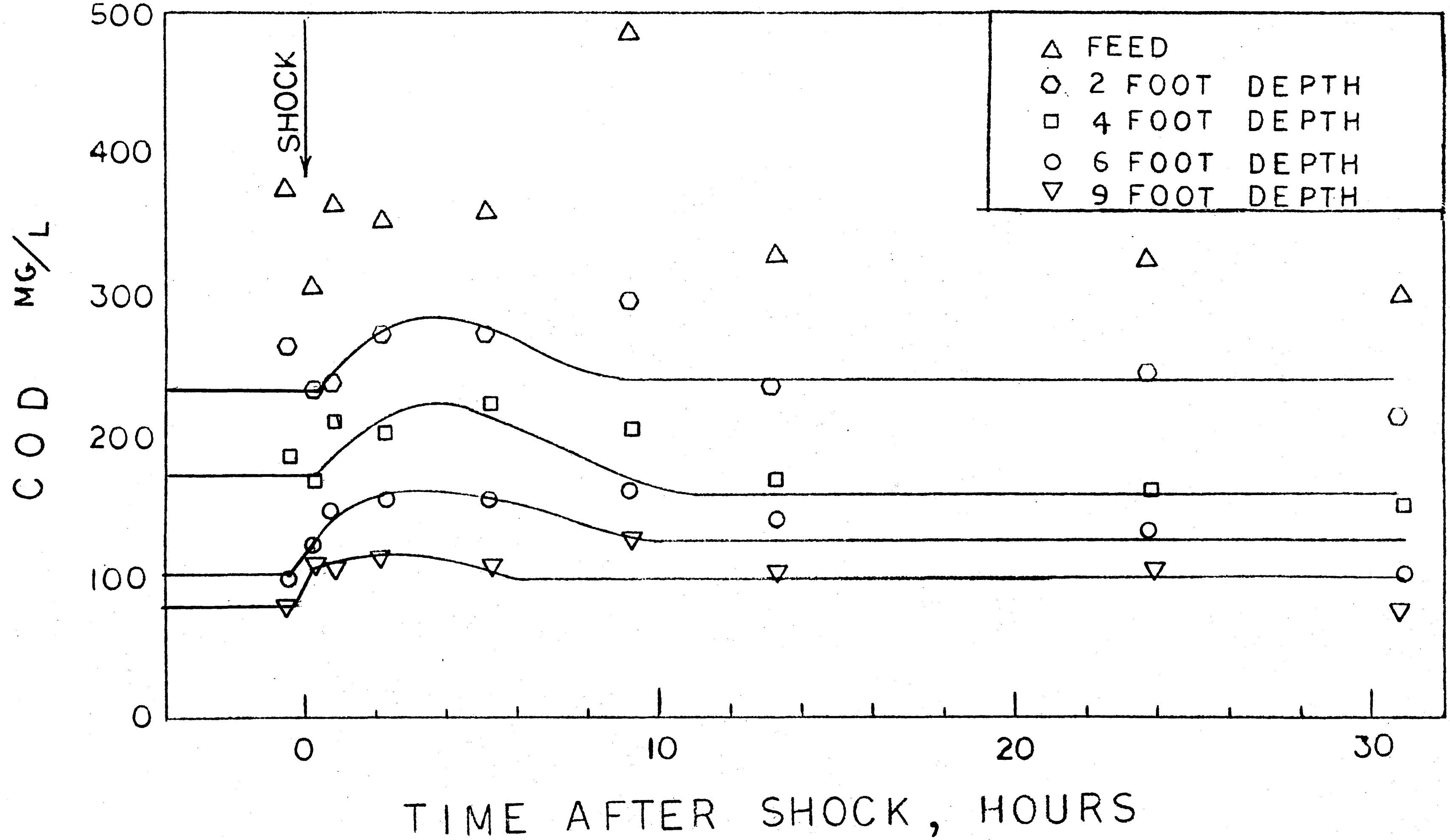

Figure 8. Response to a Hydraulic Shock From 500 to 1000 gal/day/ft^2 at a Constant 300 mg/l COD as COD vs. Time

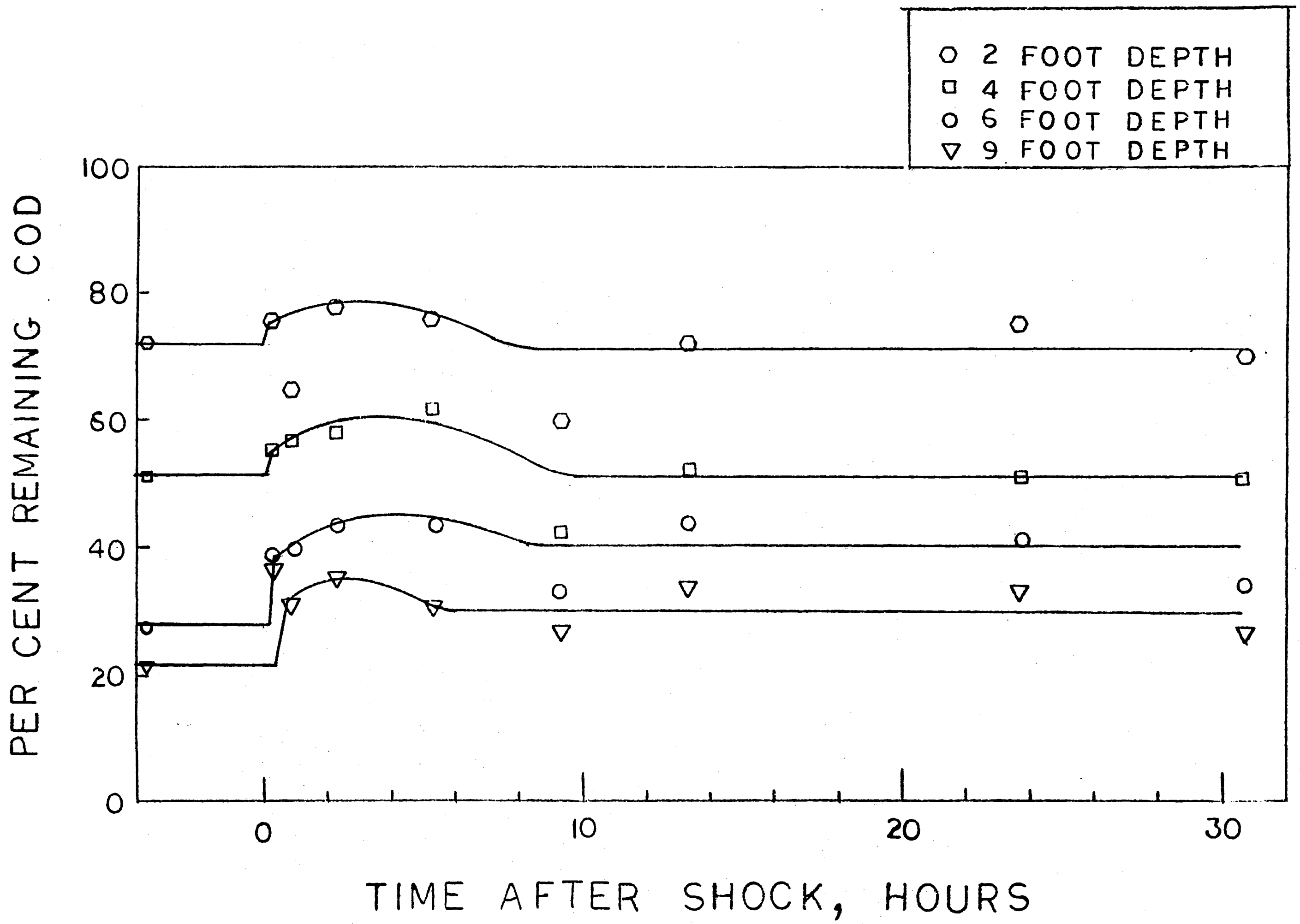

Figure 9. Response to a Hydraulic Shock From 500 to 1000 gal/day/ft^2 at a Constant 300 mg/l COD as Percent Remaining COD vs. Time

TABLE VI

RESPONSE TO A HYDRAULIC SHOCK OF 2.6 TIMES THE ORIGINAL FLOW

Time	Flow	Feed COD	Depth in Filter							
			2 feet		4 feet		6 feet		9 feet	
hr:min	gal/day	mg/l	COD	% Remain	COD	% Remain	COD	% Remain	COD	% Remain
-0:15	500	330	281	85	174	53	114	34	91	27
0:00										
0:20	1300	333	257	77	210	63	145	43	125	37
1:00	1300	340	280	82	225	66	157	46	132	39
2:30	1300	330	284	86	225	68	162	49	145	44
5:00	1300	330	280	85	201	61	157	47	112	34
7:45	1300	320	262	82	187	58	135	42	115	36
11:30	1300	333	252	76	181	54	132	40	112	32
24:30	1300	333	217	65	191	57	143	43	114	34
33:30	1300	341	252	74	181	53	135	39	110	32

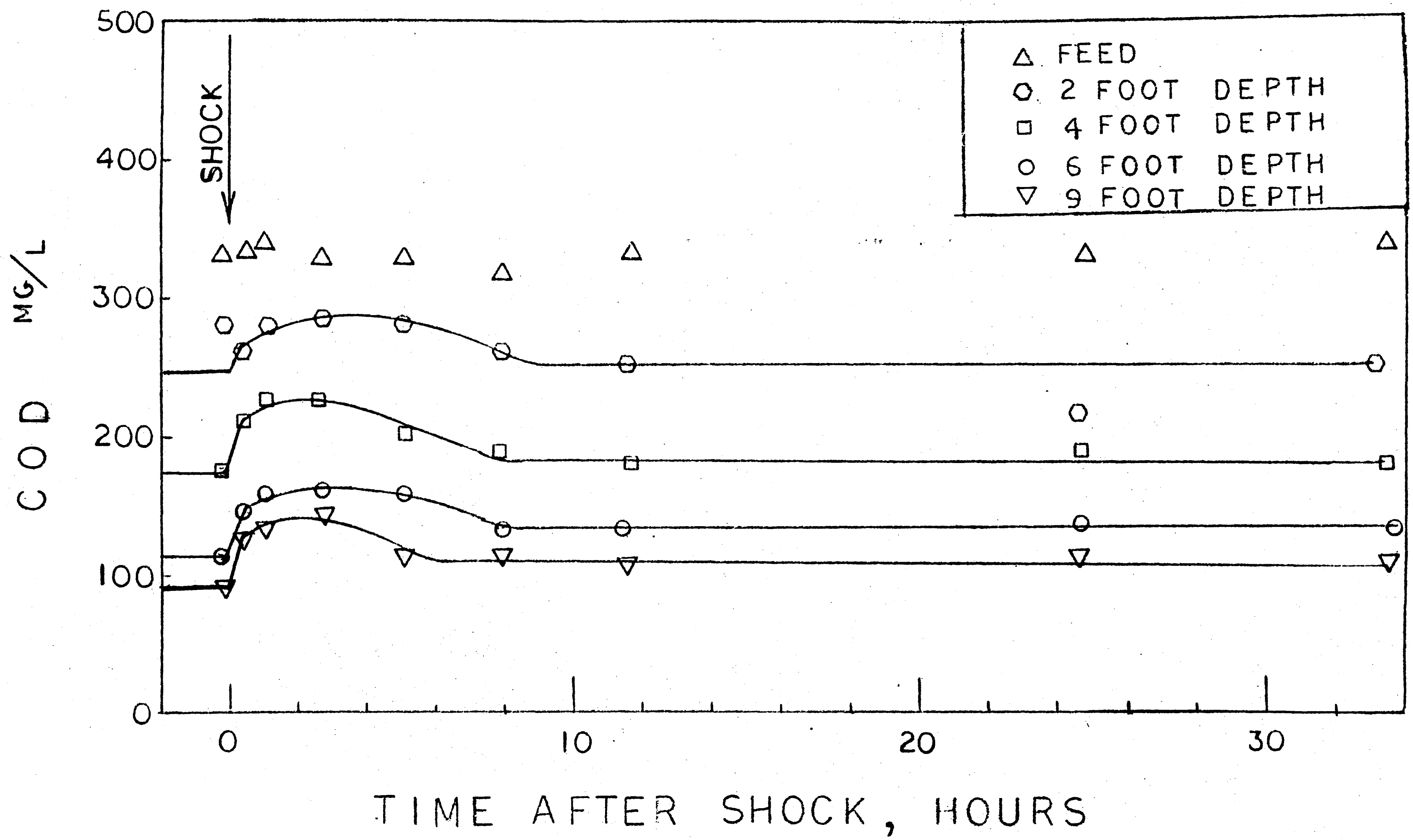

Figure 10. Response to a Hydraulic Shock From 500 to 1300 gal/day/ft^2 at a Constant 300 mg/l COD as COD vs. Time

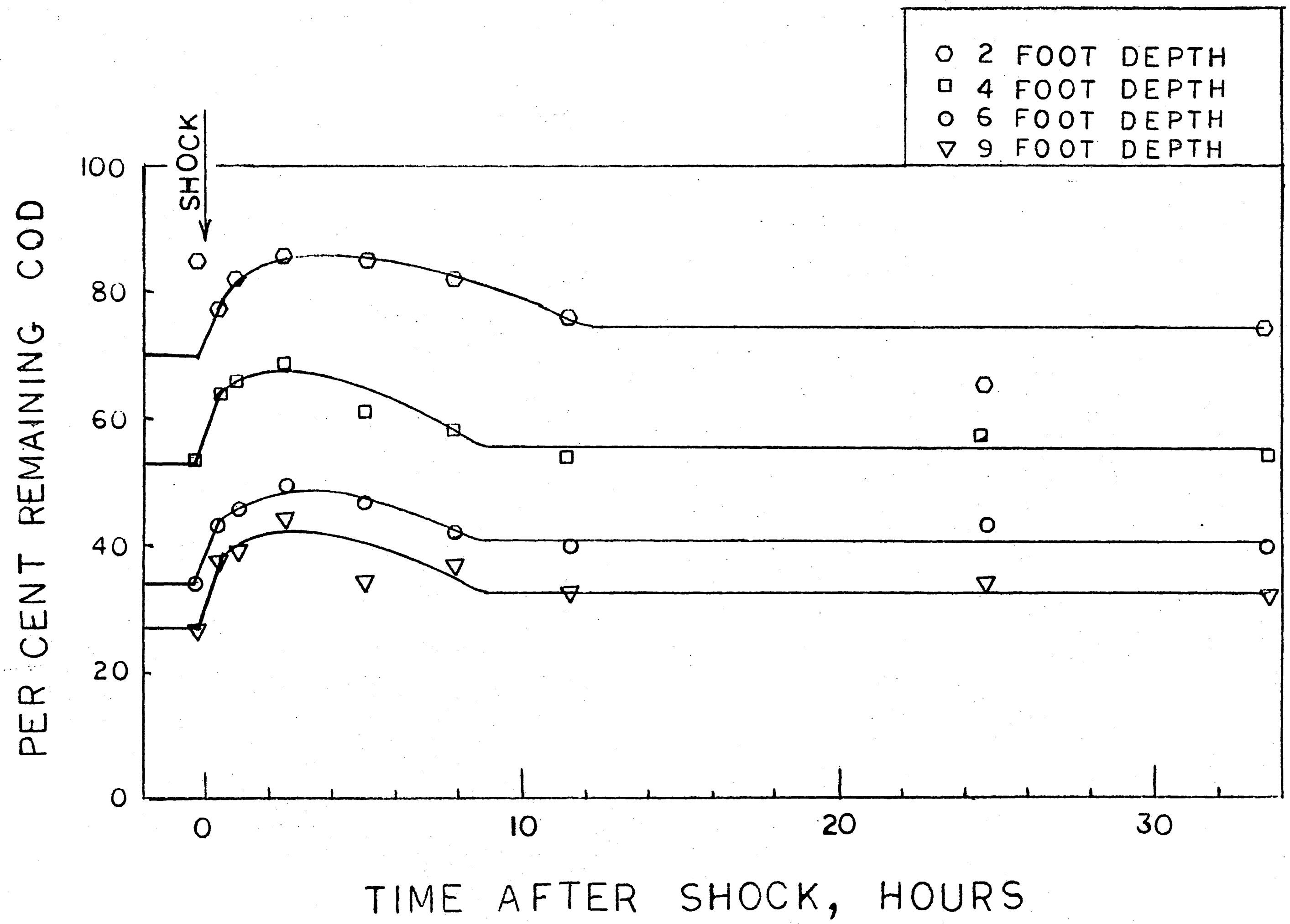

Figure 11. Response to a Hydraulic Shock From 500 to 1300 gal/day/ft^2 at a Constant 300 mg/l COD as Percent Remaining COD vs. Time

C. Production of Non-Carbohydrate Intermediates

Production of metabolic intermediates is evidenced in Cook's (17) data. The anthrone test for carbohydrates was run on several samples during the 2 times and 3 times quantitative shock loads. From this and COD data, the non-carbohydrate portion could be determined.

The data from this analysis was not consistent. Some data indicated low levels of intermediate production, however the majority of the data indicated intermediate production to be insignificant.

D. Analysis of Steady States Achieved

Data from the steady states achieved after the shock load is presented in Table VII. This data represents the graphical average of the data presented in Tables II through VI and Figures 2, 4, 6, 8, and 10. Steady state data was analyzed as a secondary purpose because it was useful in understanding the kinetics of the system and was thought to be useful in predicting new steady states. In addition, the OSU Laboratory biological tower had not been operated at extremely high loadings before.

Figure 12 shows a log plot of the data in Table VII as total organic load vs. depth. In general, first order kinetics are followed. In addition, equal total organic loadings tended to produce equal removal. This is displayed by the similarity of the 350 mg/l 1000 gal/day/ft^2 line and that of the 650 mg/l 500 gal/day/ft^2 line. Both of the high hydraulic loadings displayed poor removal in the last section, in contrast with first order removal displayed in other sections.

TABLE VII

STEADY STATE DATA

FEED	FLOW gal/day	500	500	500	500	500	1000	1000
	COD mg/l	300	340	650	1050	1430	350	330
	Total Organic Load gr/day/ft^2	568	643	1230	1987	2706	1324	1624
2 ft. depth	COD mg/l	210	240	470	770	1260	237	250
	Total Organic Load gr/day/ft^2	397	454	889	1457	2384	897	1230
	% TOL Remaining	70	71	72	73	88	68	76
	% TOL Removed per ft. depth	15	15	14	13	6	16	12
4 ft. depth	COD mg/l	150	150	330	560	1140	170	180
	Total Organic Load gr/day/ft^2	284	284	624	1060	2157	643	885
	% TOL Remaining	50	44	51	53	80	48	54
	% TOL Removed per ft. depth	14	19	15	14	5	14	14

TABLE VII (Continued)

6 ft. depth	COD mg/l	90	100	200	400	950	125	135
	Total Organic Load gr/day/ft^2	170	189	378	757	1797	473	664
	% TOL Remaining	30	29	31	38	66	36	41
	% TOL Removed per ft. depth	20	17	19	14	8	13	13
9 ft. depth	COD mg/l	40	70	110	260	820	100	110
	Total Organic Load gr/day/ft^2	78	132	208	492	1552	378	541
	% TOL Remaining	13	20	17	25	57	28	33
	% TOL Removed per ft. depth	18	10	22	12	5	10	6

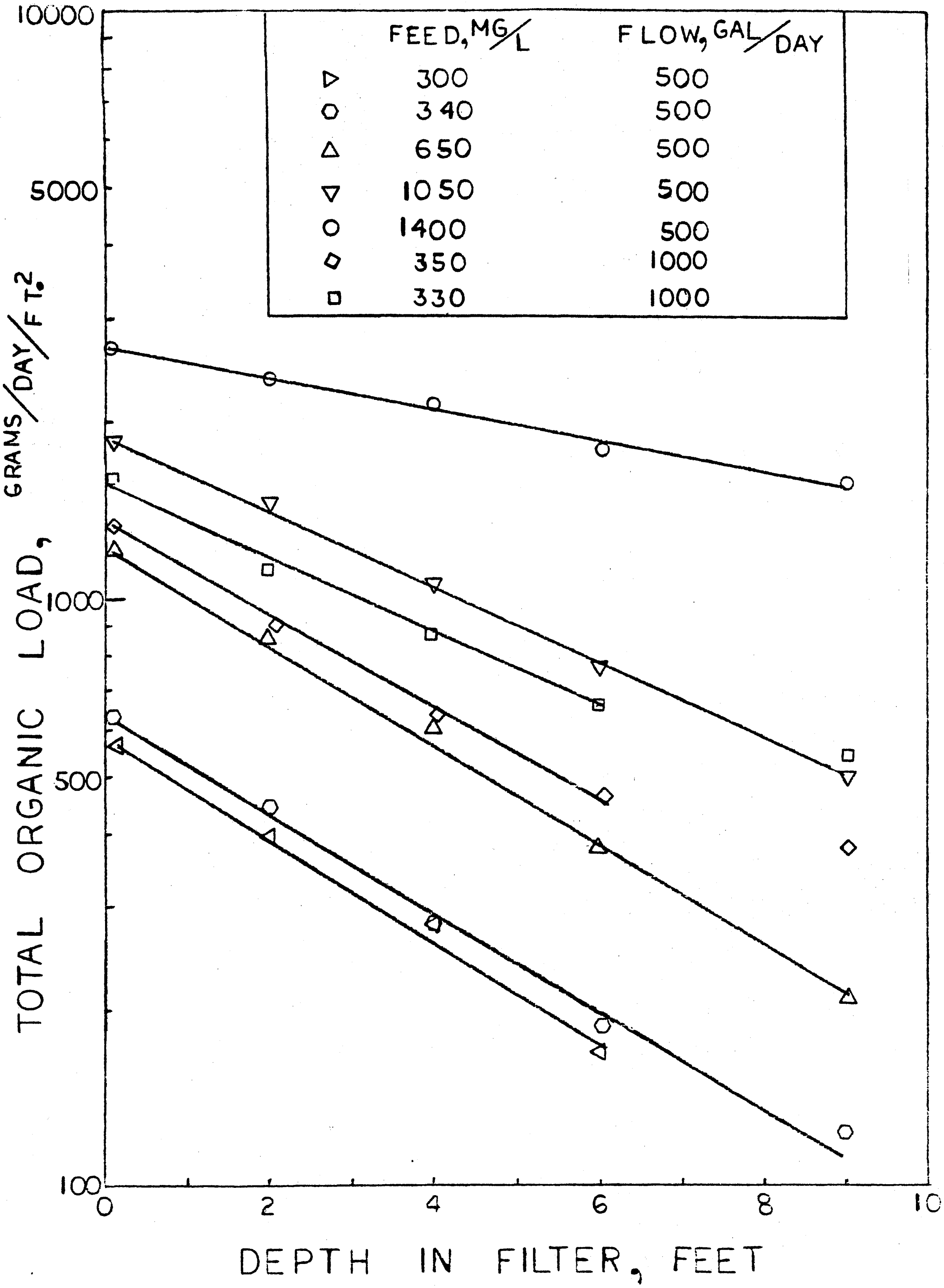

Figure 12. Steady State Substrate Removal as Log Total Organic Load vs. Depth

Figure 13 shows COD vs. depth for several loadings, all at 500 gal/day/ft^2. The 1200 mg/l loading appears to follow different kinetics than the other loadings. This is an indication of the saturation phenomena described by McKinney (21). Zero order kinetics describe removal under these overload conditions.

Figure 14 shows the percent of total organics removed as a function of the total organics applied per foot of depth. The figure indicates that within a wide range each one foot section removes 14% of the total organic load applied to the section, regardless of the hydraulic load. This is true only within a restricted range, as points under light loading or overload conditions do not fall on the line.

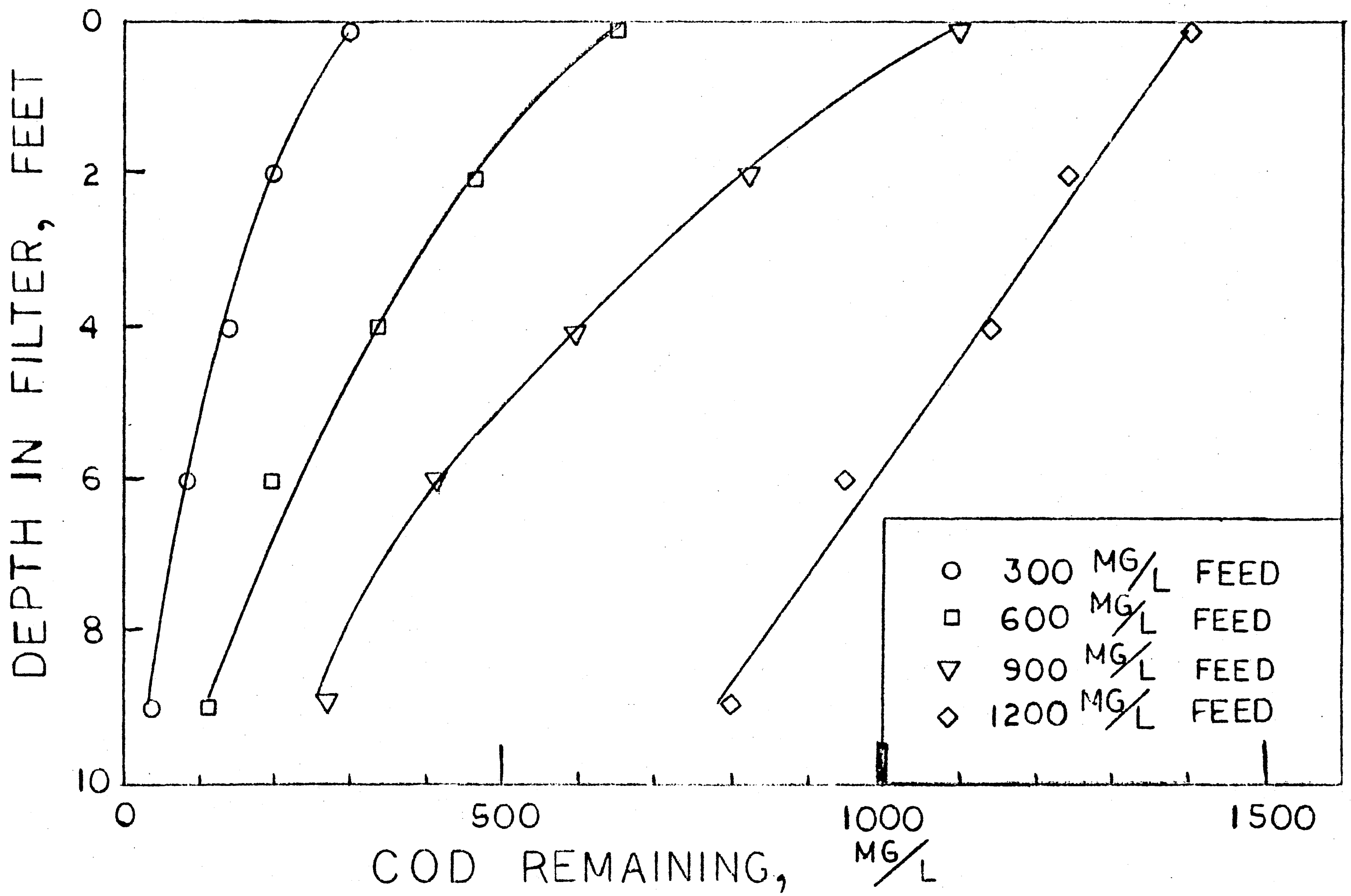

Figure 13. COD vs. Depth in Filter, Steady State

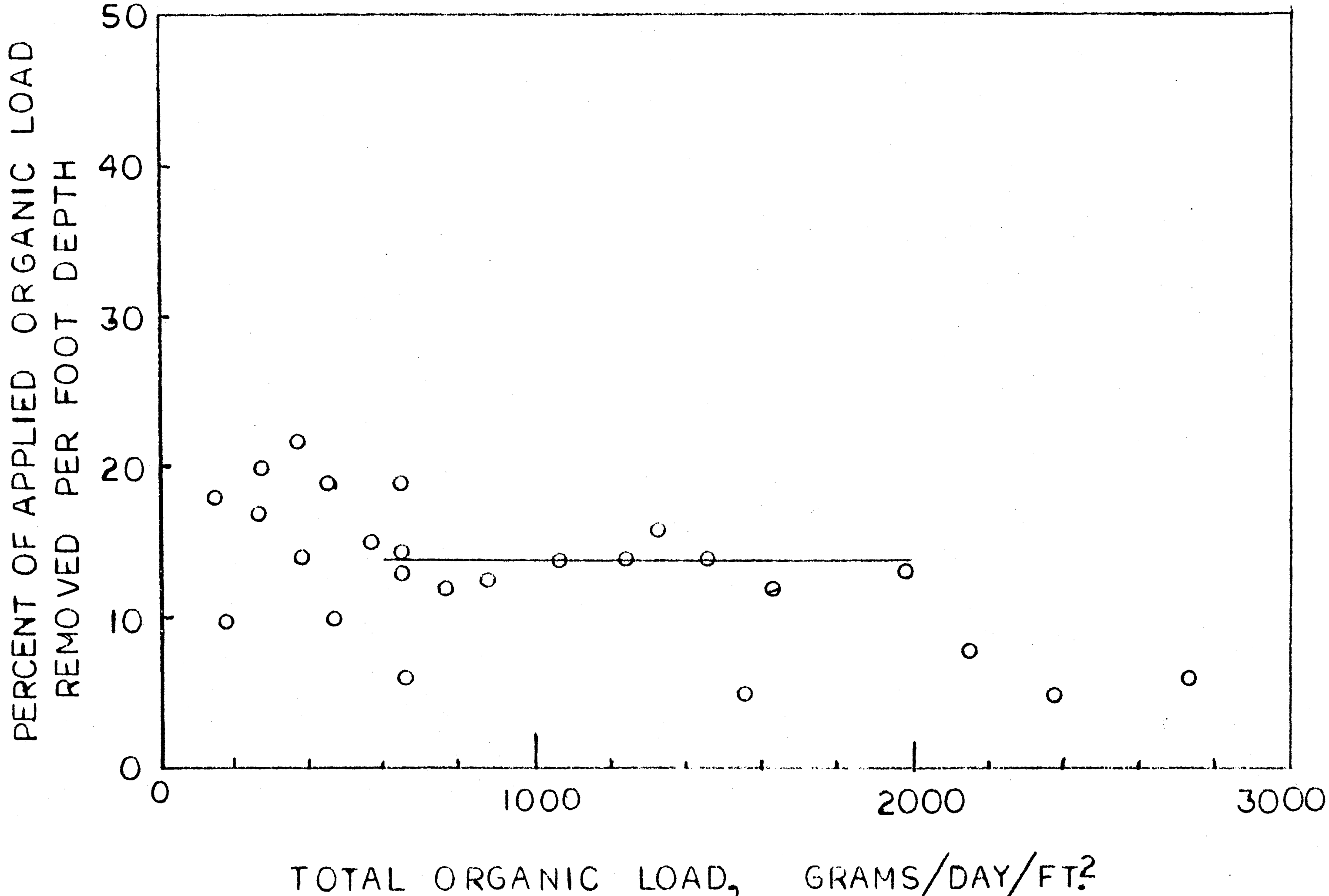

Figure 14. Percent of Applied Organics Removed vs. Total Organic Loading

CHAPTER V

DISCUSSION

A. Response to Shock Loads

The several figures of shock load response indicate that the severity of the upset during response time is proportional to the severity of the shock. The 600 mg/l shock produced almost no difference between removal immediately after the shock and the final steady state. The 900 mg/l shock produced a definite upset in treatment. A bell-shaped curve was produced as a response to this shock (Figures 4 and 5). The 1400 mg/l shock producd an even larger upset in treatment (Figures 6 and 7). Both hydraulic loads also caused some disturbance to the system, but neither of these loads were as severe as the 900 mg/l or 1400 mg/l shocks which represented a greater total organic loading.

A shock load produces a change in the growth rate of the micro-organisms. Monod's equation is:

$$\mu = \mu_m \left(\frac{S}{K_s + S}\right) \tag{5}$$

where

μ = growth rate

μ_m = maximum growth rate

S = concentration of substrate near micro-organisms

K_s = Monod's constant = S at the point where $\mu = \mu_m/2$

We can see that when S is very large, $\mu = \mu_m$. The micro-organism mass may be assumed to be constant in the system, since the surface area is fixed and since depths above 70 μ have been shown not to improve treatment. Since the micro-organism concentration is constant, changes in substrate removal must be a function of the type of cells, the wasting rate of the cells, and the specific utilization of the cells.

Gaudy and Englebrecht (7) demonstrated that while under shock load conditions, cells could store food for later use. This could explain the good treatment achieved directly after each of the shock loads. Later on as cells reached a limit of substrate intake, treatment became less. During this period growth rate was very high. Since the media could only support a limited number of cells the wasting rate was also increasing. After a time, the growth and wasting rates stabilized and treatment improved to the new steady state.

While the above explanation has theoretical basis, it cannot be proven to be the sole cause. Other explanations for the shape of the response curve are possible. The substrate removed by cells wasted may have become very low after the shock as a result of increased food availability reducing die off rate. A period of acclimation or a change in predominance could also have been responsible.

B. Prediction of Shock Load Response

More work is required before the upset of substrate removal under a shock load can be predicted. Knowledge of steady state kinetics is sufficient that the new steady state after a shock may be predicted, however. Two methods of predicting the new steady state will be presented here.

The mass balance equation for a trickling filter is:

$$S = S_i - \frac{\mu_m}{Y} X \frac{1}{Q} \left(\frac{S}{K_s + S}\right) \tag{3}$$

where

Y = yield

X = weight of micro-organisms

Q = flow

Kornegay and Andrews (15, 16) state that the values μ_m, Y, and X are constant over a range of S_i values and that they may be represented by a single term, P.

$$P = \frac{\mu_m}{Y} X \tag{6}$$

In order to find P, it is necessary to run solids determinations on the pilot plant.

Solids production was not run in this study. However, Cook and Bentley have analyzed solids production on the OSU trickling filter. Both found Y to be around 0.4. Cook assumed a growth rate of 0.2 hr^{-1} and a K_s of 34 mg/l. Bentley's data indicates that the minimum mean cell residence time is around 0.5 days, indicating a maximum growth rate of .083 hr^{-1}. Experimental data at 340 mg/l feed was substituted into equation 3, and a μ_m of 0.055 hr^{-1} was found to give results very close to the data. Equation 3 is in differential form and should not be expanded indiscriminately over depth. One foot was taken as the depth interval for constants derived by Bentley. The experimental data in this experiment was at a 2' interval, and constants were adjusted to this interval. For greater depths, equation 4 is recommended.

$$P = \frac{2' \text{ depth x } 30800 \text{ mg. solids/ft}^3 \text{ x } .055 \text{ hr}^{-1}}{.4}$$

$$S = S_i - \frac{P}{Q} \left(\frac{S}{34 + S}\right)$$

Setting S_i = 340 mg/l and Q = 78.85 l/hr, S was found to be 245 mg/l after the 2' depth. This compares favorably with the 240 mg/l arrived at experimentally (Table VII). Setting S_i = 650 mg/l predicted an S of 461 mg/l. Experimental results indicated an S of 461 mg/l. Thus, the prediction was quite close.

This model failed to predict the removal for the 1050 mg/l loading, however. An S of 947 mg/l was predicted while an S of 770 mg/l was arrived at experimentally.

Thus, we can see that while the equation may offer prediction within a range, its predictive capacity is no better than the values of K_s and P which are used. In addition, the values of K_s and P can be found only by conducting solids analysis on the effluent. While a set of K_s and P values may make predictions within a range of S_i, the range is limited, and poor predictions were evidenced outside the range.

Perhaps a better method of predicting the new steady state after an increased loading would be to make use of the information in Figure 14. This indicates that each one foot section would remove 14% of the total organic load applied to the section, within a range. Output COD from a section may be expressed in terms of input COD:

$$S = S_i - .14\ S_i \text{ for 1 foot depth} \qquad (7)$$

The constants were actually determined for a 2' depth. Thus the removal in 2' would be 28%. Twenty-eight percent will be used for the constant for use with 2' data then. For large depths, the equation must be expanded, as the 14% removal is compounded over depth. The data from feed to 2' depth in Table VII was substituted as total organic load. This equation predicted the results for all removals with great accuracy, with the exception of overload conditions.

Thus, this method is the most promising for predicting a new steady state after a shock. It is reliable provided overload conditions do not occur. This equation may also have promise in design. It could be expanded over depth by integration or the use of compound interest tables. A pilot plant needs to be operated over a wide range of loadings to find the percent removal, but solids determination is not necessary.

C. Steady State Removal

The data for steady state removal in this experiment confirms the idea of treatment being determined by the total organic loading. First order kinetics were verified, with the exception of the two high hydraulic loads where treatment in the last section did not proceed at the same rate as in earlier sections. This may have been due to the presence of intermediates which were harder to break down than sucrose. No anthrone samples were taken at these higher loadings. Another explanation is that the substrate concentration was not high enough to provide a growth rate commensurate with the wash off rate at the high hydraulic loading. No conclusion can be made at this time as to why removal was poor in the last section under high hydraulic loadings.

CHAPTER VI

CONCLUSIONS

1. The fixed media system provides a good method of dealing with shock loads. A 2 times quantitative shock load produced a new steady state almost immediately. The upset caused by a 2 times hydraulic shock load was minimal.

2. Large shock loads of 3 times and 4 times the original substrate concentration produced a definite upset in treatment, and 6 or 8 hours passed before a new steady state was reached.

3. The new steady state may be predicted after a shock load, since each unit of depth tends to remove an equal percentage of the applied load.

4. Steady state removal followed first order kinetics although a slight variance was noted for high hydraulic flow with low COD. Total organic loading was verified as the important design parameter.

5. Overload conditions produced zero order removal kinetics.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

1. Periodic shocks should be administered to determine response to daily shocks encountered at treatment plants.

2. Large hydraulic loadings should be conducted to further study kinetics under these conditions. Intermediate production should be checked under large hydraulic loads.

3. A study on the effects of qualitative shock loads on trickling filters is necessary.

4. Solids production studies should be made while a trickling filter is operating under transient conditions.

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