LONG-TERM EFFECTS OF CHROMIUM AND COPPER ON THE ROTATING BIOLOGICAL CONTRACTOR

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Dedicated to my mother, Behjat Keihani

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CHAPTER I

INTRODUCTION

To exist is to pollute in some form or another, and to exist at a high level of wealth is to be a superpolluter. Strictly speaking, talk of "cleaning up the environment," "pollution free" cars, products, or industries is a scientific absurdity because, according to the law of conservation of matter-energy, nothing is created or destroyed but only transformed from one form to another (1). As population increases, the demand for water increases and as a result, the amount of wastewater will be increased.

The disposal of human wastes has constituted serious problems. From the standpoint of public health and aesthetics, the treatment of waste became necessary. Nature itself is a treatment system and has the ability, to a certain extent, to handle waste material; it has been known that natural bodies of water can oxidize the organic material existing in the waste without creating any nuisance condition. But with the expansion of industries and great variety of wastes produced by these industries, the streams cannot handle this shockload, and biological treatment processes are needed in the treatment of polluted waters.

Treatment and disposal of industrial wastes, because of variety and complexity, is of great importance in environmental engineering. Some of these industries, such as galvanization, metal fabricating and plating industries, dealing with some metallic ions which are toxic for stream biosystems and can cause serious problems for public health and aquatic life (2). So the concentration of these metallic ions must be controlled and removed before being discharged into the stream. An allowable concentration of any of these metallic ions is recommended by the United States Department of Public Health. For example, concentrations of 0.1 mg/l of chromate have a toxic effect on human beings, and concentrations of less than 0.03 mg/l are allowed as a criterion in potable water (3).

The purpose of this study was to determine the long-term effect of these toxic metallic ions (heavy metals), especially hexavalent chromium and divalent copper, on the removal efficiency of biological treatment processes. Different concentrations of these metallic ions were fed, and in the long-term investigation, COD (chemical oxygen demand), BOD (biochemical oxygen demand), and TOC (total organic carbon) tests were run. The extent of removal of these metallic ions by microorganisms has also been determined.

CHAPTER II

LITERATURE REVIEW

The effects of copper, chromium, zinc, and nickel have been investigated at the Robert A. Taft Sanitary Engineering Center (4). This study resulted from a suggestion by the National Technical Task Force Committee on industrial waste. Barth et al. (4) used a complete activated sludge pilot plant. Data from individual studies show that primary settling has two effects on metals before their entry into the aeration tank. First, the total metal content of the primary effluent is less than that of the sewage because part of it is removed by sludge in a primary clarifier. Second, the physical and chemical characteristics of the sewage alter the form of the soluble metal that enters the reactor. Barth et al. indicated that copper present as a continuous concentration of 0.4 mg/l did not decrease treatment efficiency significantly. However, a concentration of 1.2 mg/l showed a significant decrease in treatment efficiency. Copper was studied in both soluble cation form as sulfate, and also as soluble cyanide complexes (5). Results show that when the activated sludge acclimates to the continuous presence of either form of metal, there is no difference in effect or treatment efficiency. The reaction pattern of the activated sludge process was the same for each of the metals studied. A small dose of metal gives a significant reduction in the treatment efficiency, but substantially large doses do not further decrease the efficiency significantly (Figure 1).

The results of these studies show that the aeration phase of biological treatment can tolerate chromium and copper up to a total heavy metal concentration of 10 mg/l in the influent sewage with about five percent reduction in overall plant efficiency. Tarvin (6), working in municipal plants, reported this conclusion. Dawson and Jenkins (7) also indicate this range of concentration from laboratory investigations.

The inhibition of nitrification by heavy metals (8, 9, 10), has been studied. There was no evidence of acclimation of the nitrifying organisms to the metal; the oxygen requirement of metal-loaded sludge was less than in the control unit because no oxygen was utilized in the transformation of ammonia to nitrate. Metal toxicity is evidenced by the inhibition of the nitrifying process. A plant so affected would discharge all the influent nitrogen in excess of that needed for synthesis, mostly in the form of ammonia. Such effluent would require considerable chlorine. Nitrification would use large amounts of oxygen in the receiving stream.

Most toxicity of heavy metals is due to enzyme inhibition. Competitive inhibition refers to a reversible reaction in which an enzyme and an inhibitor are combined. A necessary characteristic of competitive inhibition is the decrease in inhibitory effect with an increase in substrate concentration and excess food will reduce the toxic effect of heavy metals (9).

Chromium

Chromium salts have different effects on different units of a

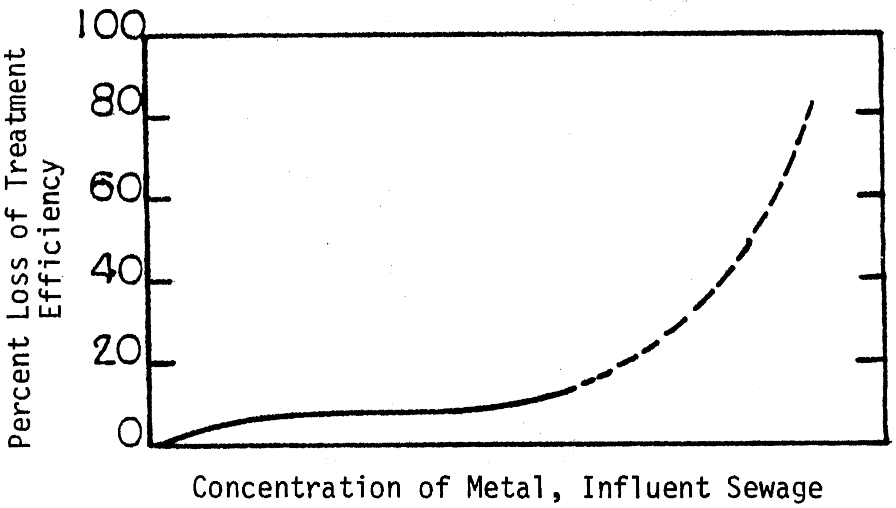

Figure 1. Response of System to Metal Dosage

sewage treatment plant. Chromium in the trivalent form will precipitate in an alkaline solution such as sewage, and will be removed as sludge to digestion tanks, where digestion will be retarded or practically stopped (11). This will not cause much trouble in the secondary treatment process. Chromium in the form of hexavalent will not behave like trivalent in this condition, and is much more toxic. The tolerance concentration is controversial; it has been reported that quantities up to 25 ppm can be handled continuously. Edwards (12) found that shock loads of about 40 ppm slowed up nitrification and caused deterioration in the appearance of activated sludge effluent (8, 9). The quantity of chromium which is permissible in sewage depends upon the following conditions:

1) type of chromium, trivalent, or hexavalent
2) type of sewage treatment, such as primary or secondary
3) continuous flow versus shock load over a period of a few hours

Jenkins and Hewitt also studied the effect of chromium compounds on the operation of trickling filters and activated sludge processes (13). They found that 1 ppm of chromium had a slight effect, 10 ppm reduced the quality of effluent noticeably, and 100 ppm reduced nitrification by 66 to 78 percent and produced an effluent containing twice as much organic matter as the control unit. In the activated sludge process, however, they found that 2 ppm will deteriorate nitrification. Higher concentrations of chromium will accelerate the process inhibition. The ability of activated sludge to oxidize organic matter and to flocculate dispersed solids is reduced in the presence of chromium. The process of nitrification may be stopped even without killing the organisms. It seems that aeration of a chromate-treated sewage is the most effective way of restoring nitrification activity.

Chromium in sufficient amounts to color the aeration liquor will cause poor settling of activated sludge and low efficiency of treatment. The chromate caused the DO values to be high and interfered with the bacterial life. The Tallmans Island activated sludge plant in New York City (12) received during a two-day period 430 ppm chromium with a pH of 4.2 the first day and 1,440 ppm with a pH of 4.0 the second day and, as a result, DO increased and remained at a much higher level. It was reported that this was because of a reduction in the activity of organisms.

It was found that respiration of activated sludge with a high food-to-sludge ratio was depressed by 70 percent from small concentrations of chromate (10 ppm) (13, 14). Recently, Ingols and Fetner (14) reported that moderate concentrations of chromate produce chromosomal aberrations in developing neuroblast cells that have a radiometic effect and are considered to be important because of the possibility of long-term genetic effects.

Chromate concentrations of 500 mg/l prevent the growth of bacteria to an extent that they do not compete for food and space in the agar plate (14). Molds, however, are greatly resistant to the chromate at this concentration.

In aerobic studies, Ingols and Hilly (15) used a mixed culture. In this study, it was noted that a sludge containing a predominance of Sphaerotilus or zoogloeal masses gave different responses to the same concentrations of chromate. To evaluate the degree of acclimatization, the sludge was dosed with chromate. They noticed that the sludge became very bulky from filamentous growth (10). Because of different sludge responses, different toxicities, and different responses of molds and bacteria at 500 mg/l chromate in agar, it was considered important to use pure cultures to evaluate the effect of chromate for respiration and to count the organisms surviving the respiration. So, E. coli were used for this purpose. E. coli will produce carbon dioxide under aerobic conditions. Results show up to 10 mg/l of chromate had no effect on the respiration of E. coli, and only one percent of the organisms as a colony were possible to be counted. The same results were obtained with yeast cells, with 99 percent of the yeast recovered as colony-producing viable organisms. The bacteria are much less able to produce visible colonies on the nutrient agar than is the yeast. A similar experiment was repeated using protozoa. The results were similar to those with the yeast.

When similar studies of respiration versus colony-producing organisms from the respiring suspension were made with trivalent chromic ion instead of hexavalent chromate ion, an excellent correlation was observed between respiration and surviving organisms with all three of the organisms tested. This shows that under experimental conditions the chromic ion has no effect on genetic material in the living cells.

Copper

Copper could be present in domestic sewage and industrial waste mixtures in several forms, depending upon its source and subsequent reactions (5, 16). In most common electroplating processes, copper is deposited from cyanide baths. Copper in the form of copper sulfate is used for the manufacture of copper articles by deposition from solution (electrodeposition), for recovery of copper from ore (electrorefining), and, to a lesser extent, for electroplating.

The effect of copper was studied by McDermott et al. (5), and Placak (8). McDermott and coworkers studied 10, 15, and 25 mg/l copper sulfate. The effluent of the unit was predominantly of lower quality than the control unit.

The rate and extent of biological acclimation to copper has an important bearing on the experiment and actual occurrences. In the case of cyanides, not only is acclimation involved, but the rate of development of bacteria capable of utilizing the cyanide influences the extent and duration of damaging effects.

Dodge (17) reports that the Ann Arbor, Michigan, treatment plant received a heavy discharge. This increased the suspended solids from 225 ppm to 625 ppm. Continuation of this waste for four days caused the retardation of the aeration process (4). Sierp and Fransemeier (18) consider that the safe maximum concentration of copper in sewage to be treated by activated sludge is about 1 ppm. Kalabina (19) found that 0.5 ppm of copper sulfate as copper was toxic to all microorganisms and 0.1 ppm was toxic only to bacteria. The rate of ammonia formation is retarded if copper is above 0.5 ppm. Nitrification is inhibited significantly by concentration above 0.5 ppm copper (8, 9, 10, 13). Placak (8) reported that amounts of copper as low as 0.01 ppm were found to affect the biochemical oxygen demand (BOD). When 0.05 ppm was present, the recoverable 5-day BOD was about 80 percent of the control.

CHAPTER III

MATERIALS AND METHODS

Unit Description

The rotating biological contactor used in this study was a plexiglass tank with six stages or compartments. Each stage consisted of four polyethylene discs and was separated by baffles. These baffles, with openings at the base to allow flow from one stage to the next, served to foster a predominance of different microorganisms in each compartment (Figure 2). The thickness and diameter of each disc were 1/8 inch and six inches, respectively. This resulted in a total surface area for microbial growth of 9.43 square feet. Small plexiglass paddles were placed between the discs for complete mixing of wastewater and also to keep the mixed liquor in suspension. The volume of the tank was 7.7 liter, and a hydraulic loading of 2 gal/day/ft^2 was maintained during this study. To maintain this hydraulic loading, a constant head tank which received a continuous flow of tap water from a faucet was used. The flow from the constant head tank was adjusted with a valve and flowmeter on the tank outlet. This allowed a controlled flow rate so that the water flowed by gravity into the wet well. The concentrated synthetic waste was pumped into the wet well by a Cole-Parmer Masterflex Tubing pump. The flow rate of synthetic waste was adjusted to give the desired loading after mixing with tap water (4 ml/min). The mixture of tap water and synthetic waste from

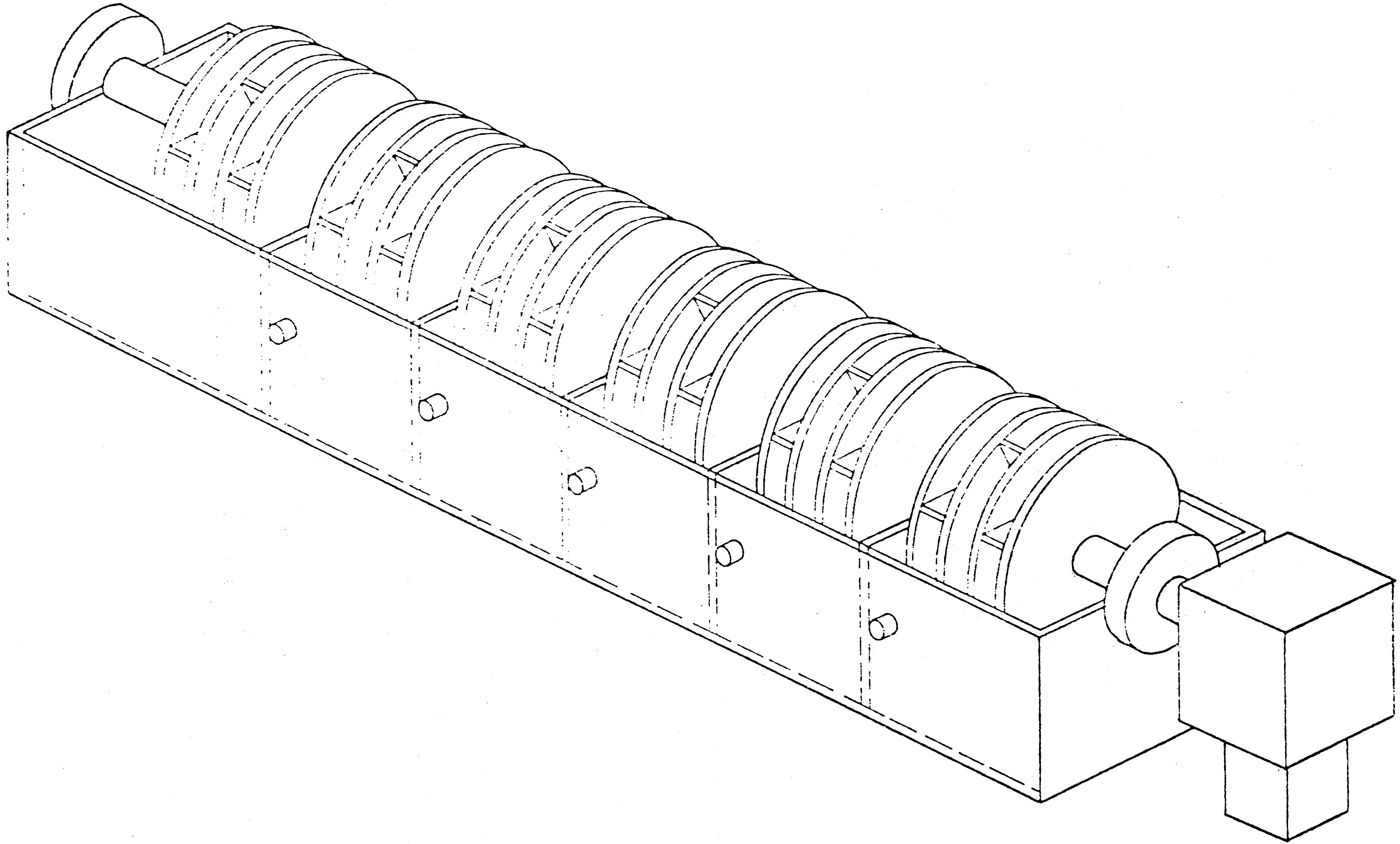

Figure 2. Rotating Biological Contactor **Laboratory Unit**

the wet well flowed by gravity into the unit (Figure 3). To mix the synthetic waste and water, a magnetic stirrer was used. The rotational speed of the discs was 10 rpm, and this was set by a 1/15 horsepower motor with a variable speed control.

Synthetic Waste

The synthetic waste used in this investigation contained glucose as the carbon source, buffer solution, trace elements, and ammonium sulfate. By maintaining the concentration of other nutrients and buffer at a certain level, the carbon was the limiting factor for growth (Table I). The flow rate of concentrated waste was adjusted so that after dilution with tap water in the wet well, the desired influent concentration was obtained. This concentration was maintained at 400 mg/l during this study.

Operational and Analytical Procedures

The test unit containing sewage was run as a batch process for two weeks. After this period it was converted to continuous flow operation and fed with synthetic waste. It took about two to three weeks to reach a steady state condition with enough growth on the discs. COD, TOC, and BOD tests were run, and those values were used as controls. After the unit reached equilibrium, different concentrations (1 mg/l, 5 mg/l, and 10 mg/l) of hexavalent chromium (as potassium dichromate, $K_2cr_2O_2$) were fed into the unit for five months. After this period, the unit was washed out and started over with the new sewage and run as a batch and then continuous process until equilibrium was reached. Then different concentrations (3 mg/l and 10 mg/l) of

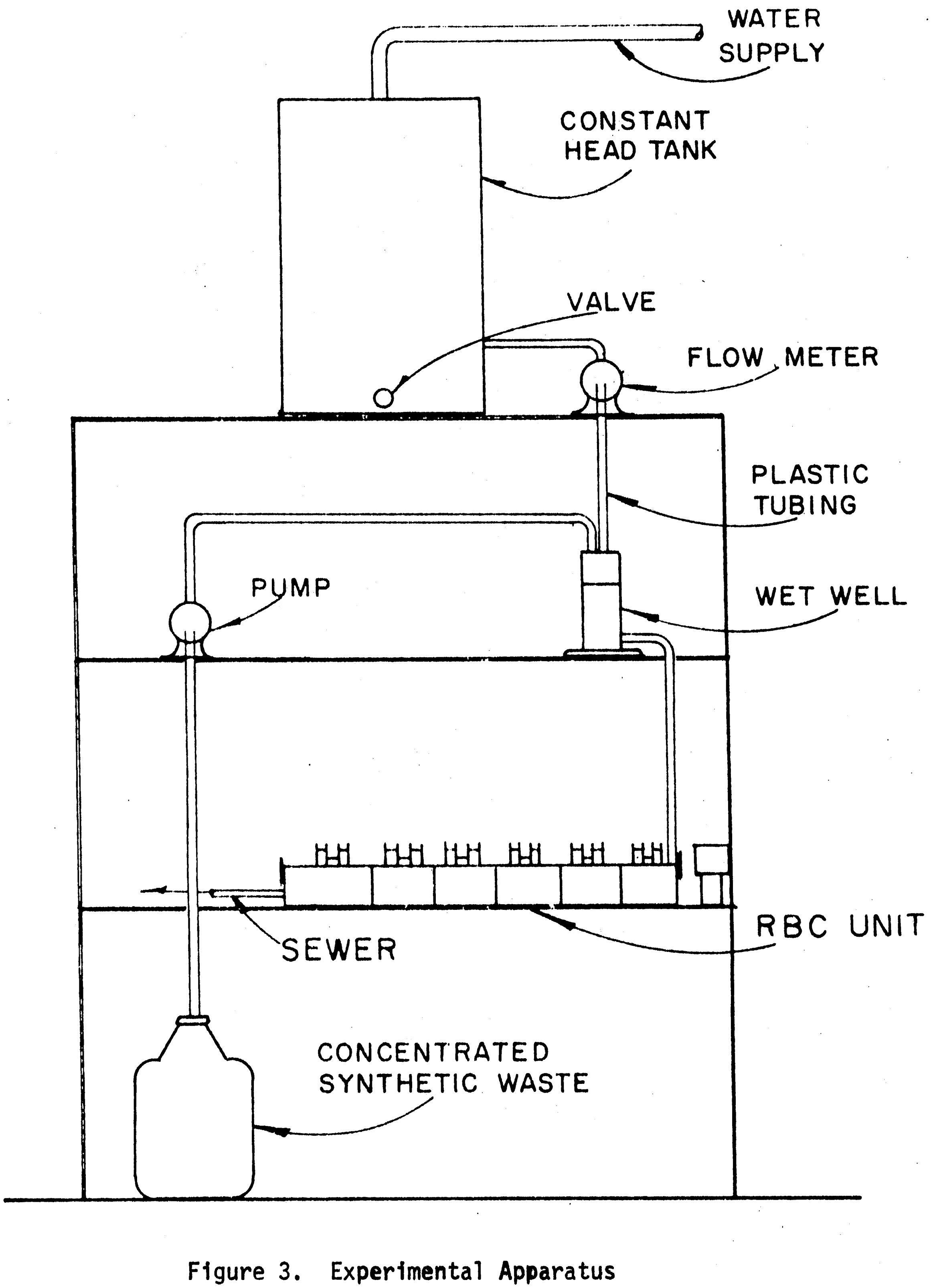

Figure 3. Experimental Apparatus

TABLE I

COMPOSITION OF SYNTHETIC WASTE FOR 4900 mg/l GLUCOSE CONCENTRATION

Constituent	Concentration
Glucose	4900 mg/l
$(NH_4)_2$	2450 mg/l
$MgSO_4$	490 mg/l
$FeCl_3 \cdot 6H2_0$	2.45 mg/l
$CaCl_2 \cdot 2H_2O$	36.75 mg/l
$MnSO_4$, H_2O	49 mg/l
KH_2PO_4	1898.75 mg/l
K_2HPO	6100.5 mg/l
Tap water	to volume

divalent copper (as copper sulfate, $CuSO_4$) were fed for two months. To observe the immediate effect of these metallic ions on removal efficiency, the day after starting the new concentration, COD, TOC, and BOD tests were run. The samples were taken from the influent and the end of each stage and the sixth stage represented the unit effluent. In addition to COD, TOC, and BOD tests, a TOD (total oxygen demand) test was run, but because of interference of sulfate and nitrate that released oxygen, the TOD was lower than it was supposed to be. So this test was eliminated from this investigation. In addition to the above described tests, pH and concentration of chromium or copper in the effluent were also measured. Metal determination was made to measure the amount of removal of these metals by microorganisms.

Analytical Procedures

pH

pH of the influent and effluent was determined by a Beckman pH meter. The pH meter had been adjusted before use by buffer compounds 4 and 7.

Metal Determination

Chromium and copper concentrations were measured in the influent and filtrate effluent, using a Hach dr/2 spectrophotometer analyzer.

COD

COD of the filtrate was measured using the procedure outlined in Standard Methods (20).

BOD

Because depletion of the unit caused by taking too much sample was not desirable, the BOD test was run only on stages 1, 2, 4, and 6. Samples were left to settle for a while; then the supernatant of that solution which contained sufficient seed was used for this test. Some seed was added to the influent. For each stage, three different dilution rates were used. The procedure is outlined in Standard Methods (20).

TOC

The Beckman 915 TOC analyzer was used for this test.

TOD

The Ionics Analyzer Model 1248 was used for this test.

CHAPTER IV

RESULTS AND DISCUSSION

Chromium

Hexavalent chromium (as potassium dichromate) was fed at 1, 5, and 10 mg/l concentrations. At each concentration, COD, TOC, and BOD tests were run at different time intervals.

The results for 1 mg/l chromium have been summarized in Tables II - IV. COD, TOC, and BOD removal characteristics as a function of this stage are shown in Figures 4 - 6, respectively. As can be seen from these plots, the effect of 1 mg/l chromium on removal efficiency is not changed significantly by time. The only effect that can be seen is on COD 52 days after initiation of this concentration. This effect on COD removal is in intermediate stages, and the quality of effluent has not been changed by time.

The 5 mg/l concentration of chromium was fed for 40 days; the results are summarized in Tables V - VII; the removal characteristics are shown in Figures 7 - 9.

Figure 7 describes the effect of 5 mg/l chromium on COD removal. It is obvious that the great changes are in the first and last stages. The COD removal by the RBC is decreased as time passes. The COD of the effluent is almost 2.5 times greater after 40 days; the same changes can be seen on TOC removal (Figure 8). The quality of the

TABLE II

SUMMARY OF COD RESIDUAL VALUES AT 1 mg/l CHROMIUM CONCENTRATION

Stage	1 day	10 day	28 day	52 day
Influent	470	456	491	398
1	208	185	175	206
2	90	82	63	189
3	78	67	52	156
4	51	56	48	123
5	43	49	26	47
6	35	38	22	40

TABLE III

SUMMARY OF TOC VALUES FOR 1 mg/l CHROMIUM CONCENTRATION

Stage	1 day	10 day	52 day
Influent	285	220	190
1	65	71	62
2	30	43	23
3	32	35	19
4	24	22	13
5	26	22	14
6	21	18	13

TABLE IV

SUMMARY OF BOD_5 VALUES FOR 1 mg/l CHROMIUM CONCENTRATION

Stage	1 day	10 day	28 day	52 day
Influent	220	218	240	231
1	114	110	115	123
2	48	57	65	70
4	6	16	22	52
6	11	9	3	10

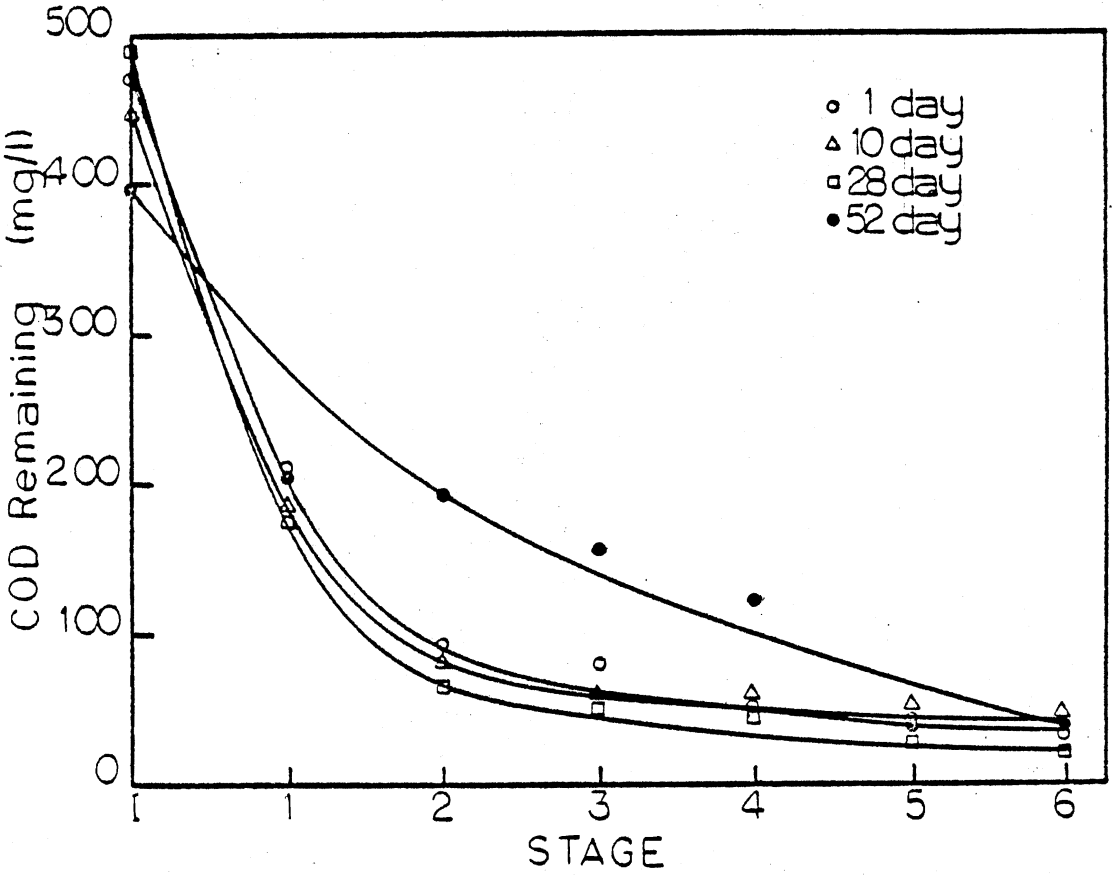

Figure 4. COD Remaining vs. Stage for 1 mg/l Chromium Concentration

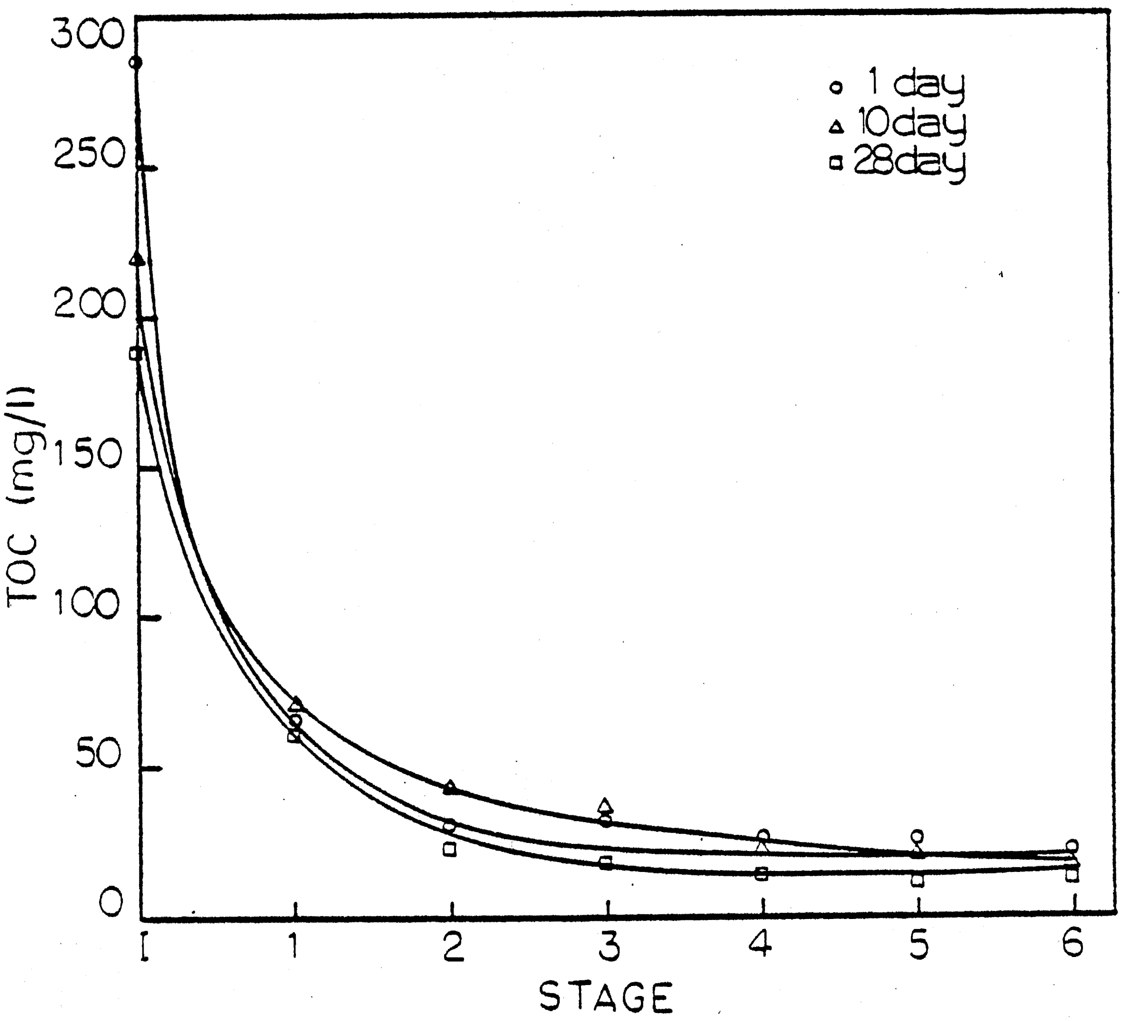

Figure 5. TOC vs. Stage for 1 mg/l Chromium Concentration

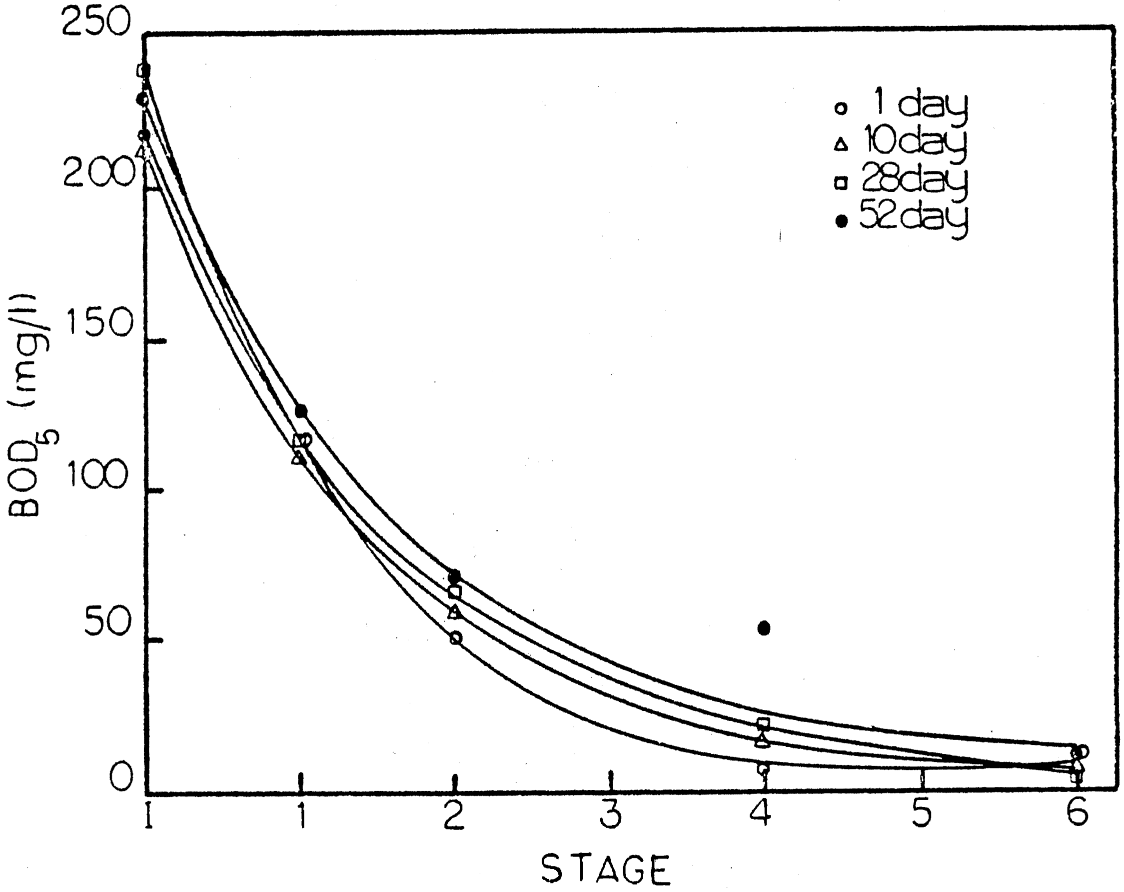

Figure 6. BOD_5 vs. Stage for 1 mg/l Chromium Concentration

TABLE V

SUMMARY OF COD RESIDUAL VALUES FOR 5 mg/1 CHROMIUM CONCENTRATION

Stage	1 day	10 day	35 day	40 day
Influent	467	472	432	424
1	265	376	280	412
2	210	220	220	192
3	160	172	188	184
4	128	136	136	144
5	51	104	132	128
6	47	56	116	120

TABLE VI

SUMMARY OF TOC VALUES FOR 5 mg/l CHROMIUM CONCENTRATION

Stage	1 day	10 day	33 day	38 day
Influent	205	205	208	203
1	84	95	100	101
2	58	65	82	68
3	42	57	60	27*
4	37	30	33	37
5	16	21	25	25*
6	10	13	82*	40*

*There was some mold in the sample.

TABLE VII

SUMMARY OF BOD$_5$ VALUES FOR 5 mg/l CHROMIUM CONCENTRATION

Stage	1 day	10 day	33 day	38 day
Influent	191	172	202	177
1	164	168	150	189
2	76	73	75	78
4	60	58	55	65
6	51	20	61	59

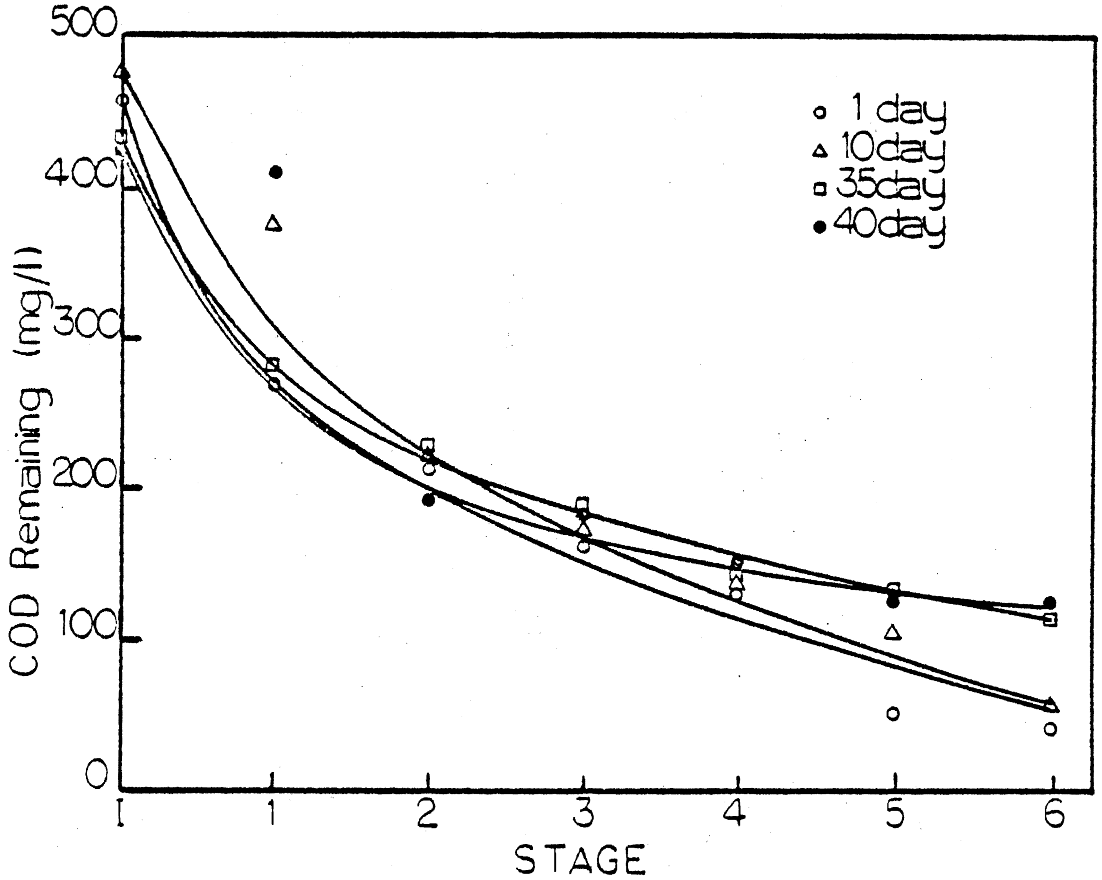

Figure 7. COD Remaining vs. Stage for 5 mg/l Chromium Concentration

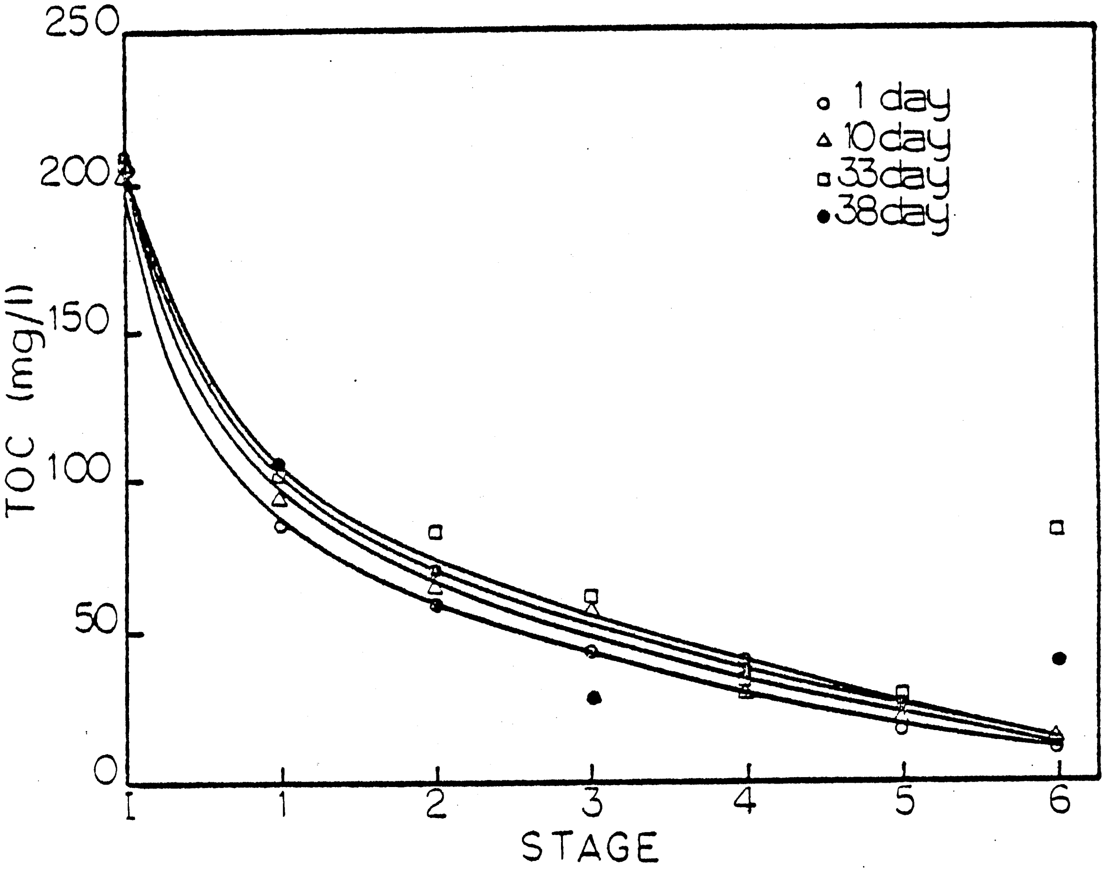

Figure 8. TOC vs. Stage for 5 mg/l Chromium Concentration

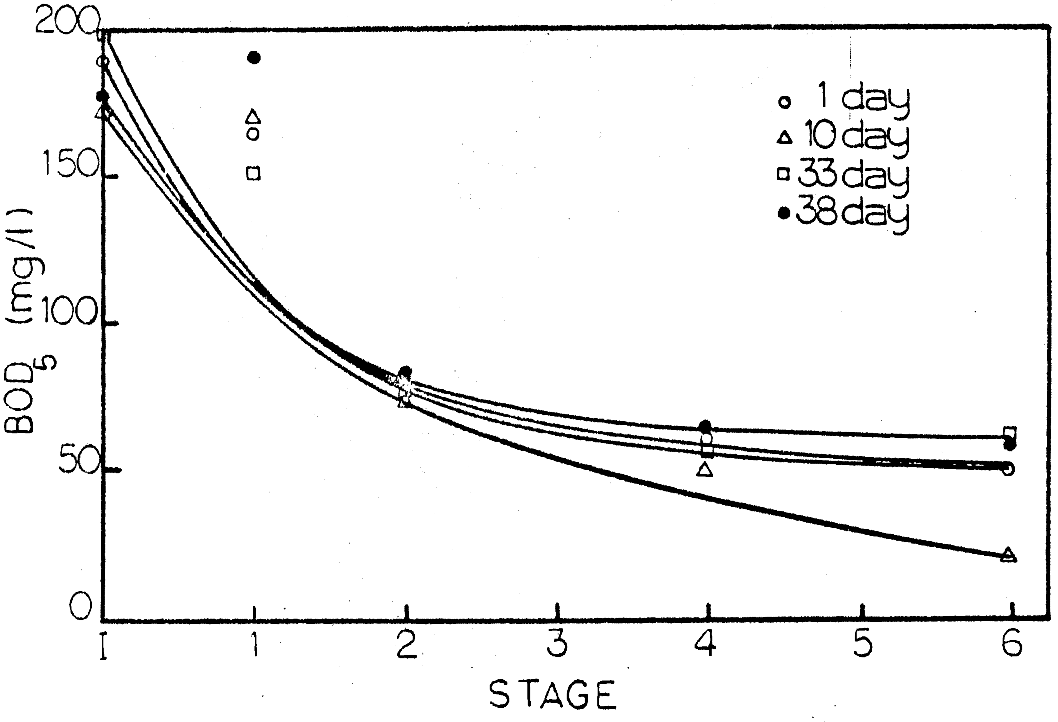

Figure 9. BOD$_5$ vs. Stage for 5 mg/l Chromium Concentration

effluent was reduced dramatically. These changes could have been because of the presence of mold and growth in the sample due to refrigeration of the sample for a long period of time. The major effect of chromium on BOD removel (Figure 9) was in the first stage and the microorganisms could never recover. The BOD remained high at this stage for the entire period, and in some cases even more than the influent BOD. In other stages, BOD remained almost constant during this period.

The results of 10 mg/l chromium concentrations are shown in Tables VII - X; COD, TOC, and BOD removal characteristics as a function of this stage are shown in Figures 10 - 12. The period of experience was 20 days.

As can be seen from Figure 10, 10 mg/l chromium has a detrimental effect on the system. The overall removal efficiency is much less than for other concentrations. However, there is very little change over the 17-day period studied.

Figure 11 describes the effect of chromium on TOC removal. This concentration of chromium had a significant effect on the qaulity of each stage, and the results of each stage have increased after 15 days of experience. As is shown in Table IX, the TOC has increased about 100 percent and the bacteria could never recover removal efficiency.

After the 15-day period, the BOD of the unit had increased significantly; the results are summarized in Table X. It can be seen (Figure 12) that 1-day, 5-day, and 10-day results give the same effluent, while in intermediate states, these results are vastly different and have increased as time progressed.

To study the removal of chromium by the RBC, the amount of chromium was measured during each day that the tests were run. These

TABLE VIII

SUMMARY OF COD RESIDUAL FOR 10 mg/l CHROMIUM CONCENTRATION

Stage	1 day	5 day	7 day	10 day	15 day	17 day
Influent	494	440	488	448	456	464
1	263	312	392	384	304	384
2	216	268	288	256	212	292
3	169	236	260	200	184	276
4	122	168	192	156	156	164
5	90	152	160	144	132	140
6	82	144	132	108	116	136

TABLE IX

SUMMARY OF TOC VALUES FOR 10 mg/l CHROMIUM CONCENTRATION

Stage	1 day	5 day	10 day	15 day
Influent	205	200	205	208
1	86	107	163	145
2	75	86	130	95
3	56	72	100	123
4	42	60	51	86
5	31	50	48	68
6	20	78	52	47

TABLE X

SUMMARY OF BOD_5 VALUES FOR 10 mg/l CHROMIUM CONCENTRATION

Stage	1 day	5 day	10 day	15 day
Influent	201	219	202	246
1	144	192	194	255
2	114	165	117	192
4	64	101	80	118
6	52	57	53	74

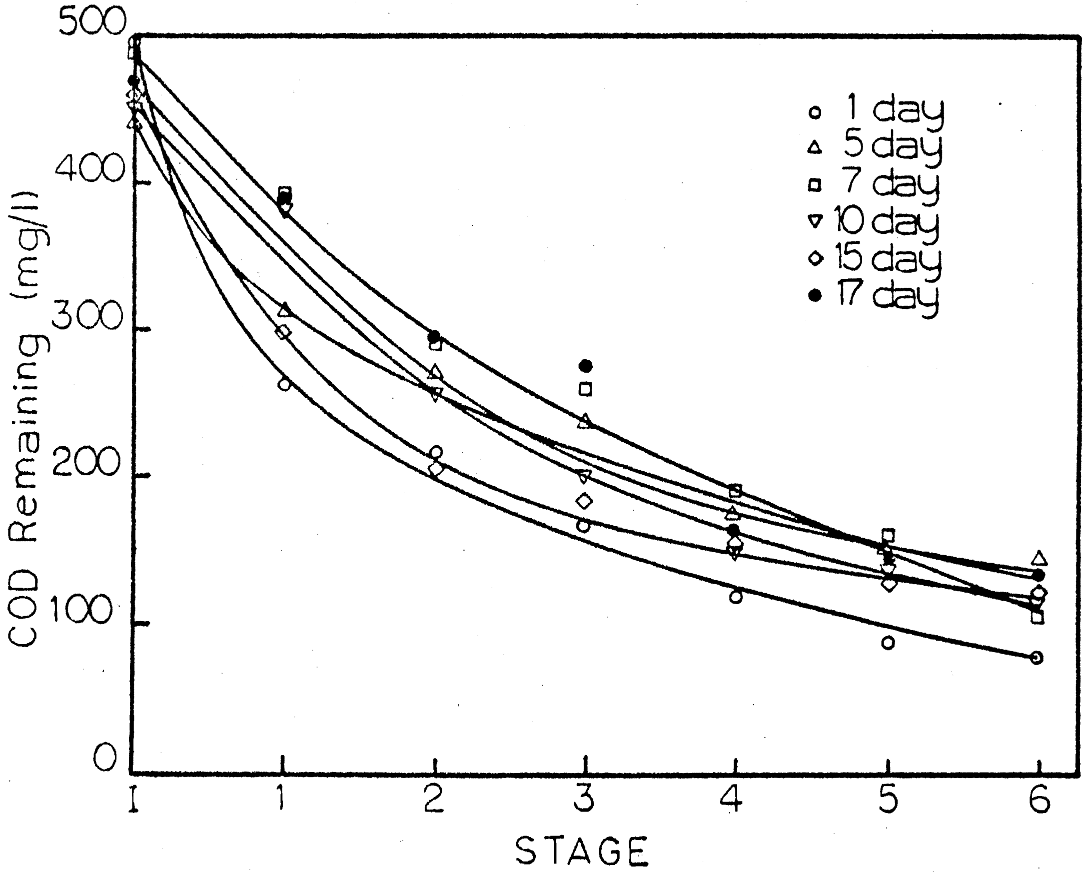

Figure 10. COD Remaining vs. Stage for 10 mg/l Chromium Concentration

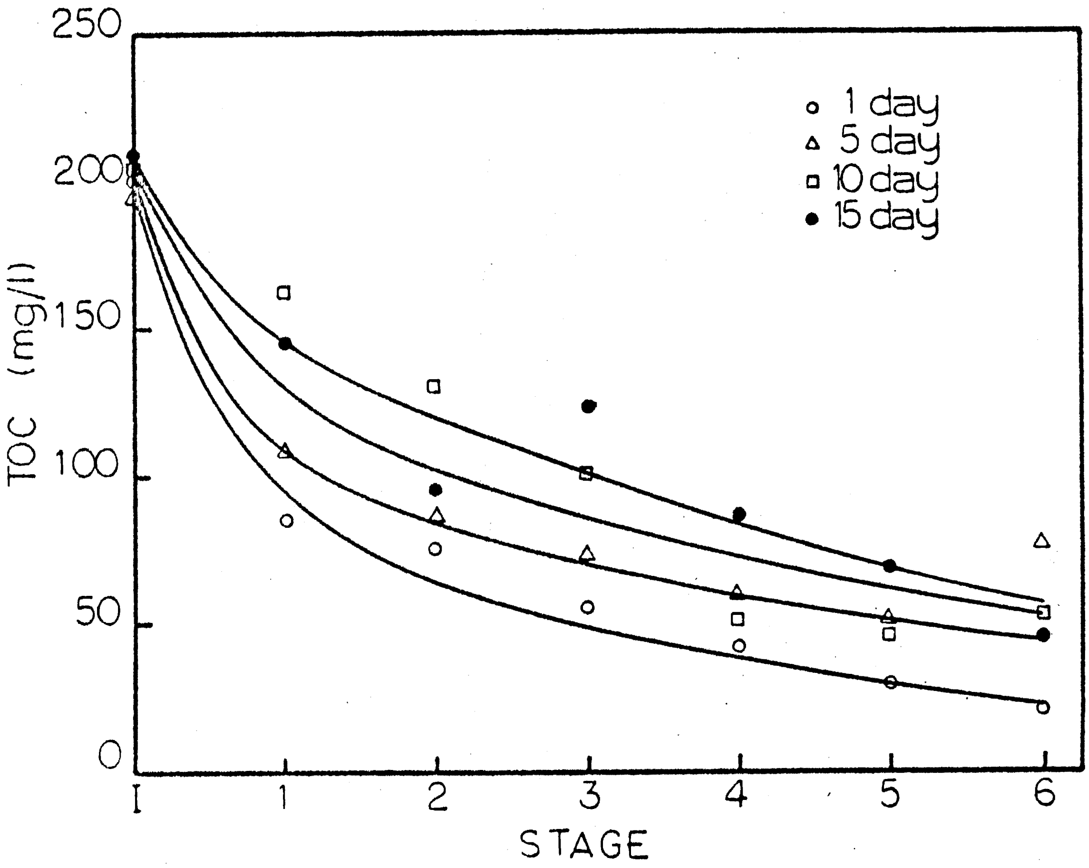

Figure 11. TOC vs. Stage for 10 mg/l Chromium Concentration

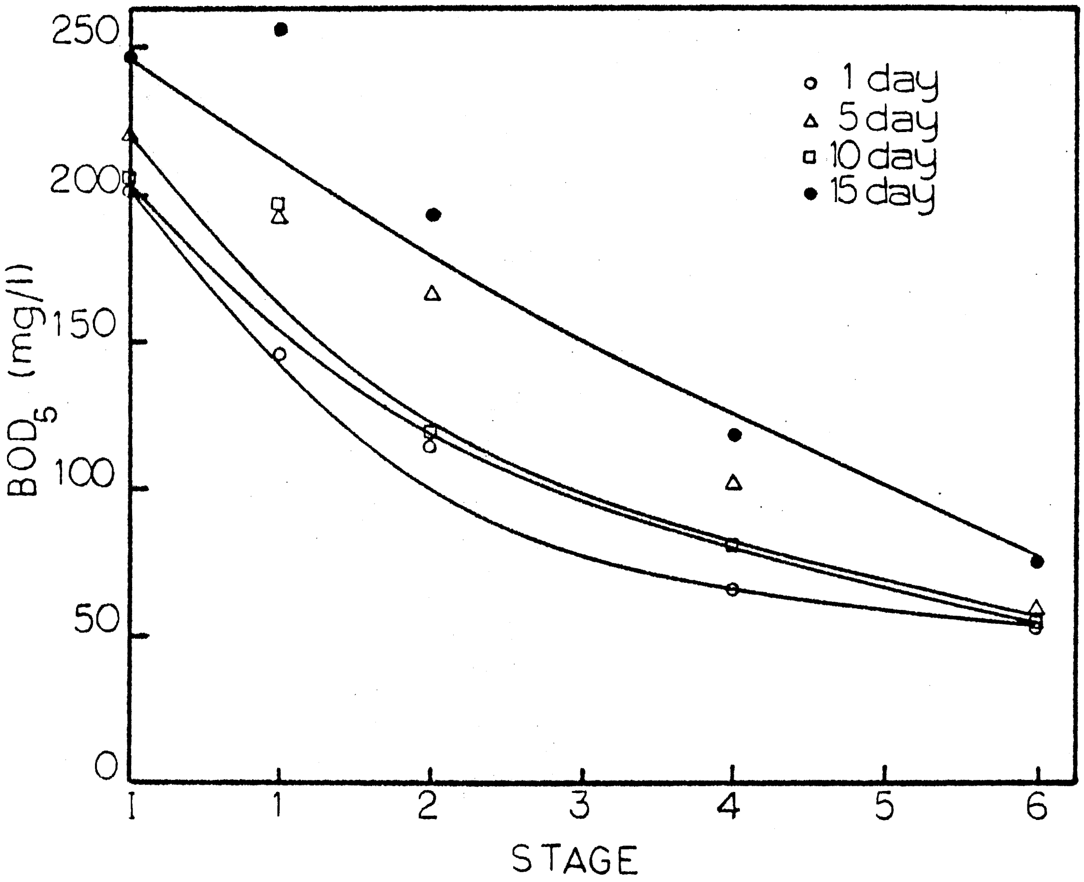

Figure 12. BOD$_5$ vs. Stage for 10 mg/l Concentration

results are summarized in Table XI. It can be seen that the removal of chromium averaged almost 95 percent. As a result, effects of chromium on the system's performance is not a function of time and the data obtained at 1 day after initiation of each concentration does not have a significant difference from that of the last day. However, 10 mg/l chromium deteriorated the system completely; this concentration had the greatest effect on the system. Chromium removal by the system averaged more than 90 percent in all three concentrations and during the entire period of analysis except in one case which is related to 10 mg/l after 15 day. This shows that removal of chromium is not reduced by time and the system acts the same in removing the metal.

Copper

Divalent copper (as copper sulfate) was fed at 3 and 10 mg/l to study the effect of copper on removal efficiency.

The COD, TOC, and BOD results for 3 mg/l copper concentration are shown in Tables XII - XIV. Figures 13 - 15 show the COD, TOC, and BOD removal characteristics as a function of stages.

It seems from Figures 13 and 14 that period of analysis does not have a significant effect on COD and TOC removal. During the period of 30 days, the results obtained for COD and TOC for each stage are close together and the quality of the effluent is almost the same during the period of analysis.

Figure 15 describes the effect of copper on BOD removal. Although the BOD of the effluent remains almost the same, but for other stages, especially the first stage, the results are scattered and as copper reaches the unit's effluent, its effect on BOD removal is reduced.

TABLE XI

PERCENT REMOVAL OF CHROMIUM AT DIFFERENT INFLUENT CHROMIUM CONCENTRATIONS

Period of Analysis	Influent (mg/l)	Effluent (mg/l)	Percent Removal
1 mg/l			
1 day	1	0.08	92
10 day	1	0.06	94
28 day	1	0.09	91
52 day	1	0.06	94
5 mg/l			
1 day	5	0.04	99.2
10 day	5	0.08	98.4
35 day	5	0.13	97.4
40 day	5	0.27	94.6
10 mg/l			
1 day	10	0.01	99.9
5 day	10	0.02	99.8
7 day	10	1.0	90.0
10 day	10	0.15	98.5
15 day	10	1.8	82.0
17 day	10	0.75	92.5

TABLE XII

SUMMARY OF COD RESIDUAL VALUES FOR 3 mg/l COPPER CONCENTRATION

Stage	1 day	5 day	10 day	20 day	25 day	30 day
Influent	448	453	462	433	455	470
1	180	173	261	273	219	251
2	136	119	82	118	126	124
3	92	58	82	45	45	76
4	56	41	53	98	24	60
5	52	49	53	33	16	48
6	44	53	74	45	28	72

TABLE XIII

SUMMARY OF TOC VALUES FOR 3 mg/l COPPER CONCENTRATION

Stage	1 day	5 day	10 day	20 day	25 day	30 day
Influent	202	202	208	202	183	203
1	73	72	84	79	63	97
2	44	43	30	29	35	54
3	26	22	32	16	17	35
4	19	17	18	21	11	26
5	15	29	19	19	9	22
6	10	19	29	17	15	33

TABLE XIV

SUMMARY OF BOD_5 VALUES FOR 3 mg/l COPPER CONCENTRATION

Stage	1 day	5 day	10 day	20 day
Influent	210	297	302	163
1	86	114	182	70
2	59	70	63	28
4	38	52	28	23
6	17	27	32	21

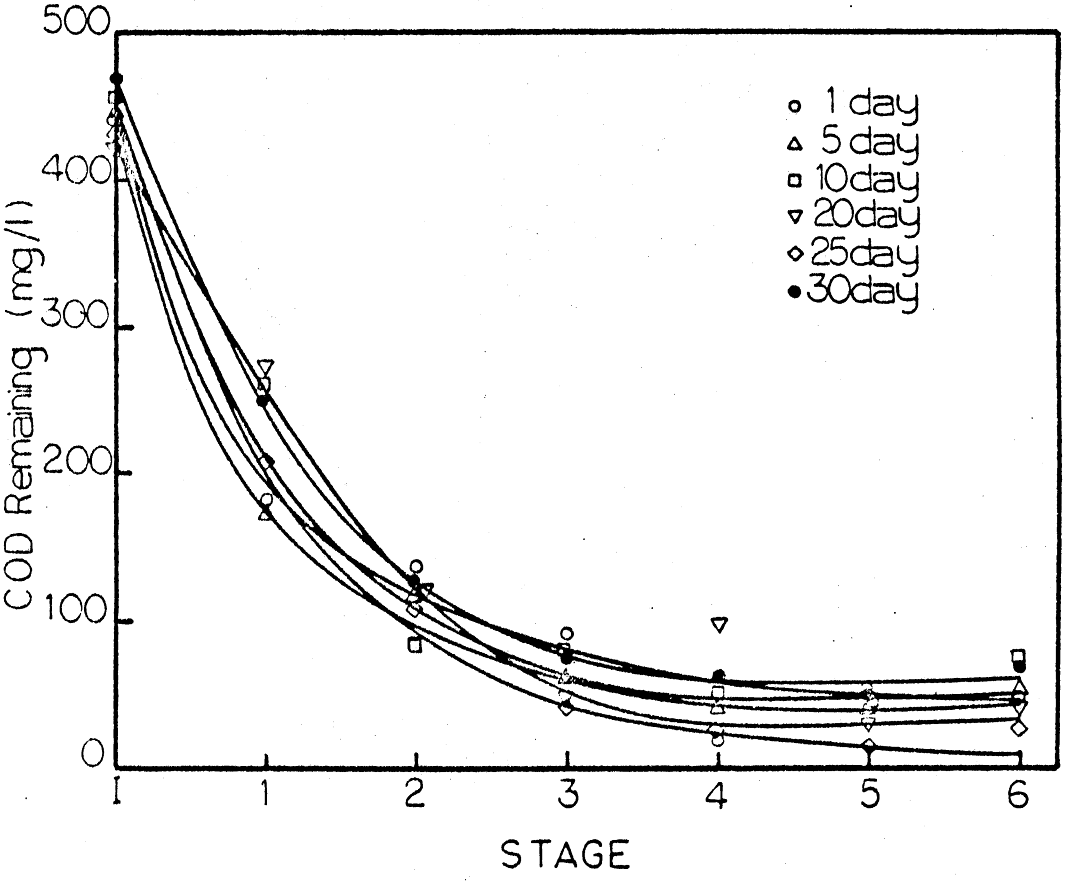

Figure 13. COD Remaining vs. Stage for 3 mg/l Copper Concentration

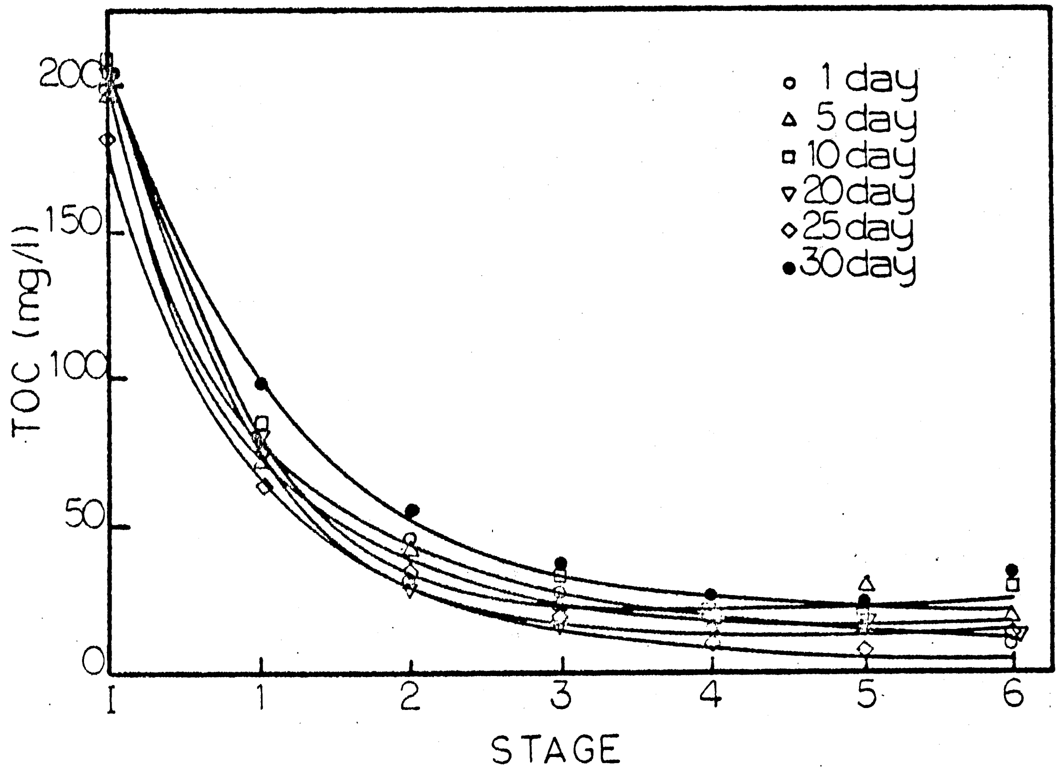

Figure 14. TOC vs. Stage for 3 mg/l Copper Concentration

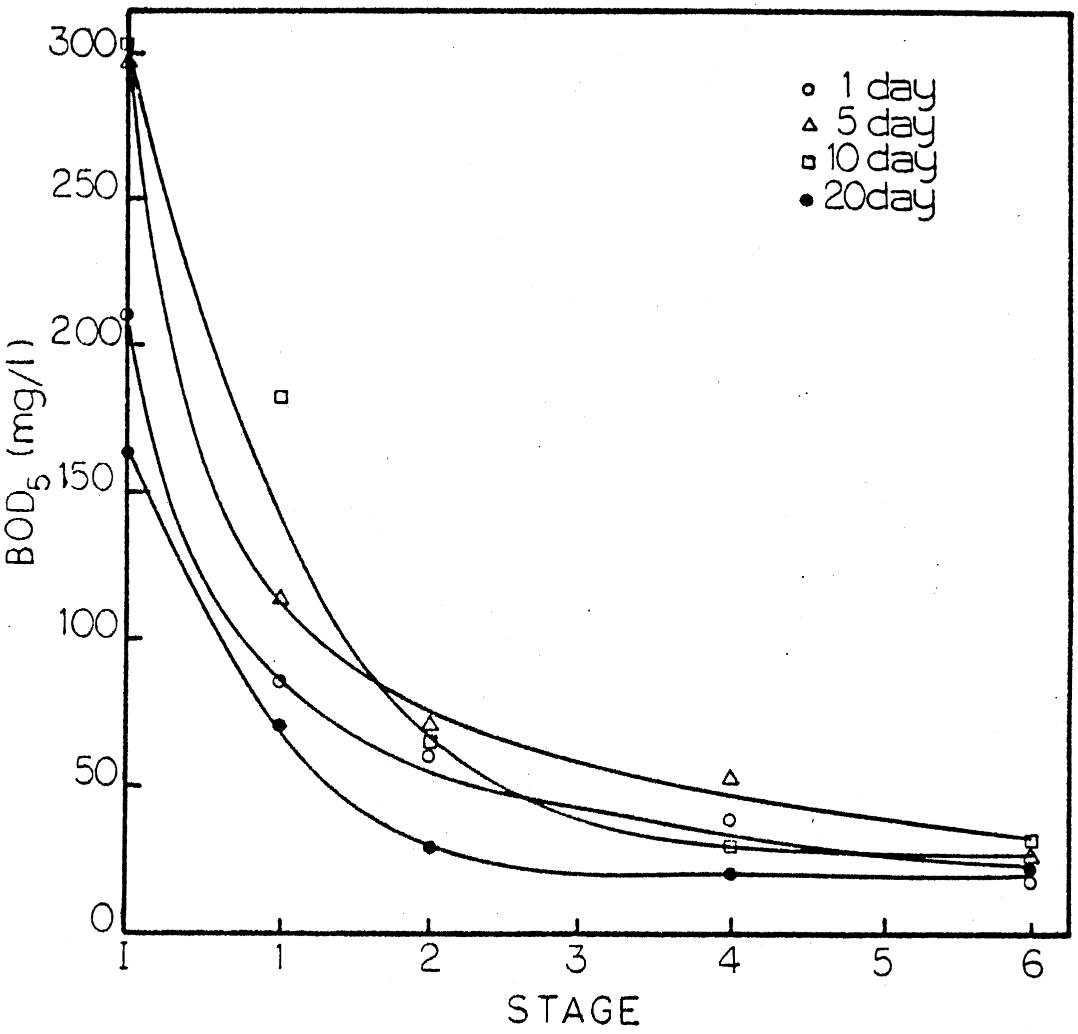

Figure 15. BOD_5 vs. Stage for 3 mg/l Copper Concentration

A 10 mg/l-concentration does not show an immediate effect on COD (Figure 16), but after five days the COD removal rate decreased and this is the only significant effect on COD removal during the 28-day period of analysis. The rest of the period gives almost the same effluent and a major change in the quality of the effluent is not seen.

The results obtained for TOC and BOD (Figures 17 and 18) show the same changes in the removal of TOC and BOD, and except for the 5-day data, the rest of the data are similar. This suggests that the copper had an effect on the RBC but it was able to acclimate and adjust to this effect. The summary of residual COD, TOC, and BOD is shown in Tables XV - XVII, respectively.

Table XVIII shows the influent and effluent copper concentrations. It can be seen that high removal of copper was achieved in all but one case. The 5-day 3 mg/l study showed a very low level of copper removal. However, in most cases, over 90 percent of the copper was removed by the RBC system.

The results obtained for copper do not show a major change in the system removal efficiency. It means that short-term and long-term effects of copper on system performance is not a function of time. Ten mg/l copper did upset the system; however, the effect did not increase with time. The system turned black and never returned to normal during the experience. The growth on the first two stages was so much that it prevented the system from rotating, so some of the sludge was removed from the system. Copper removal by the system was generally over 90 percent except in the case of the 5-day study of 3 mg/l.

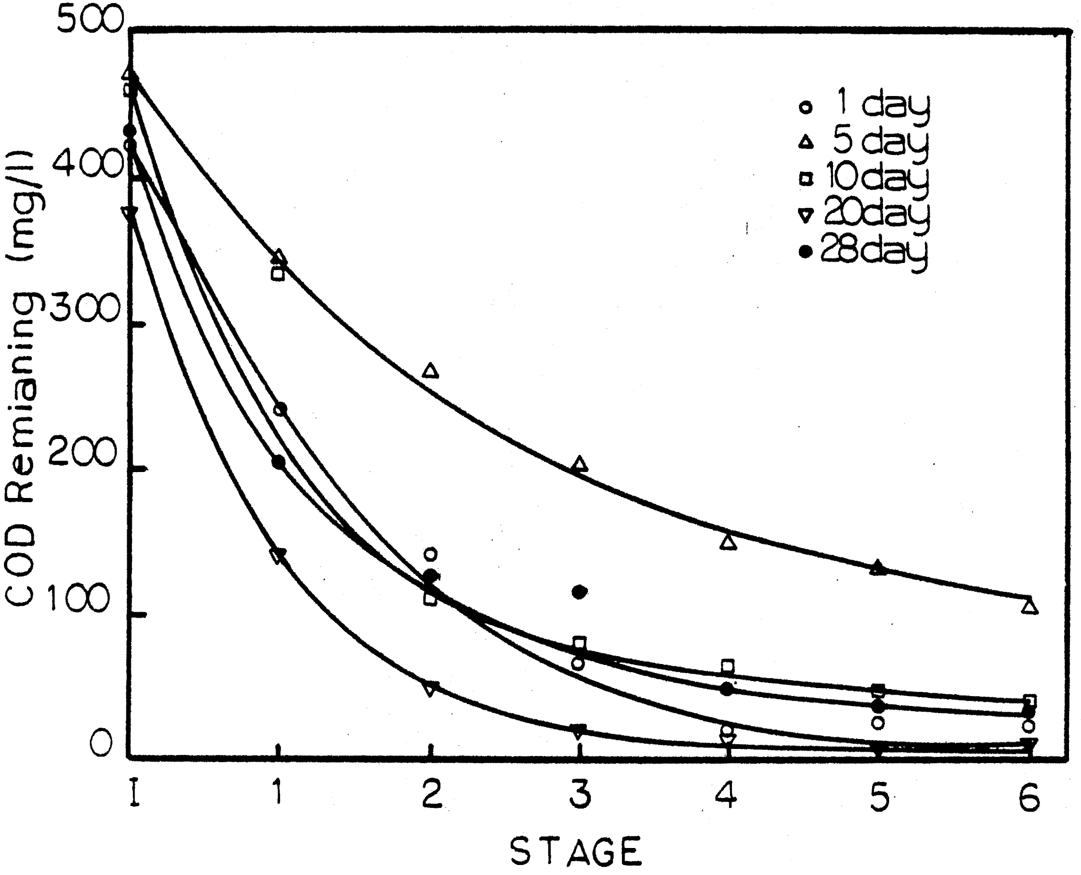

Figure 16. COD Remaining vs. Stage fpr 10 mg/l Copper

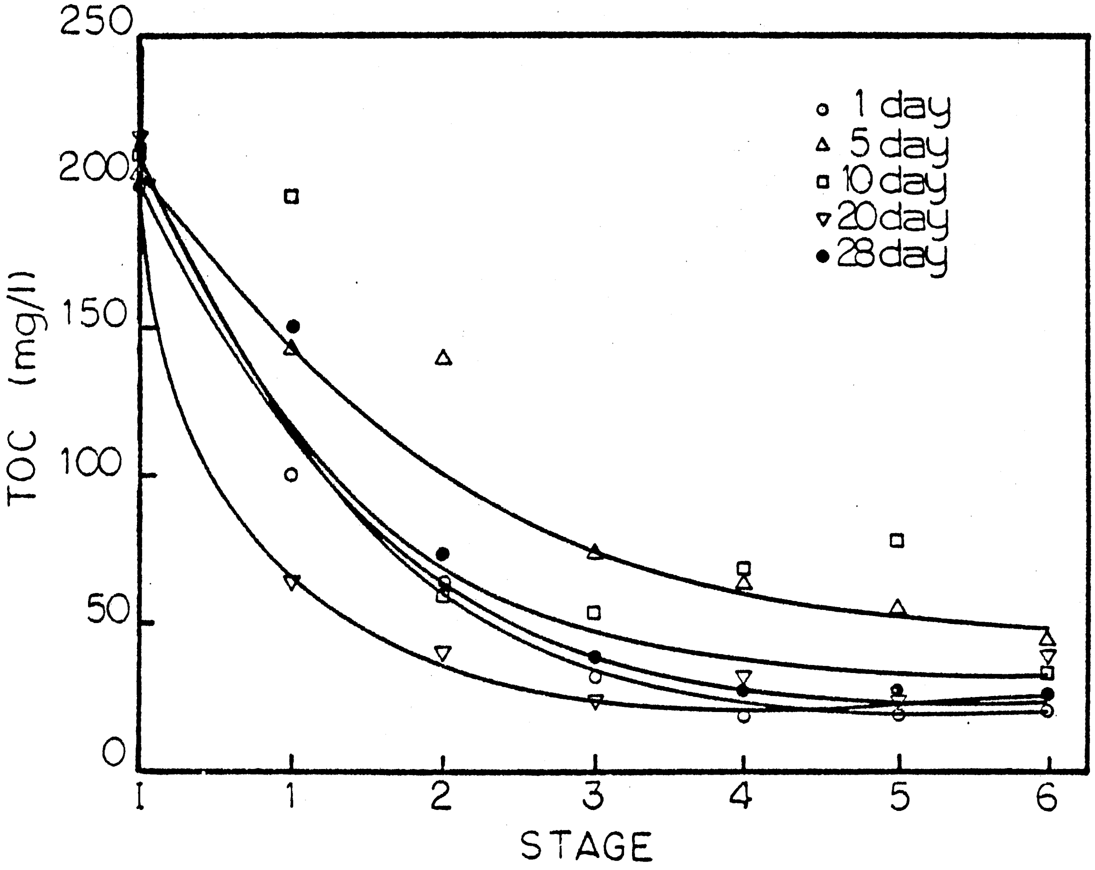

Figure 17. TOC vs. Stage for 10 mg/l Copper Concentration

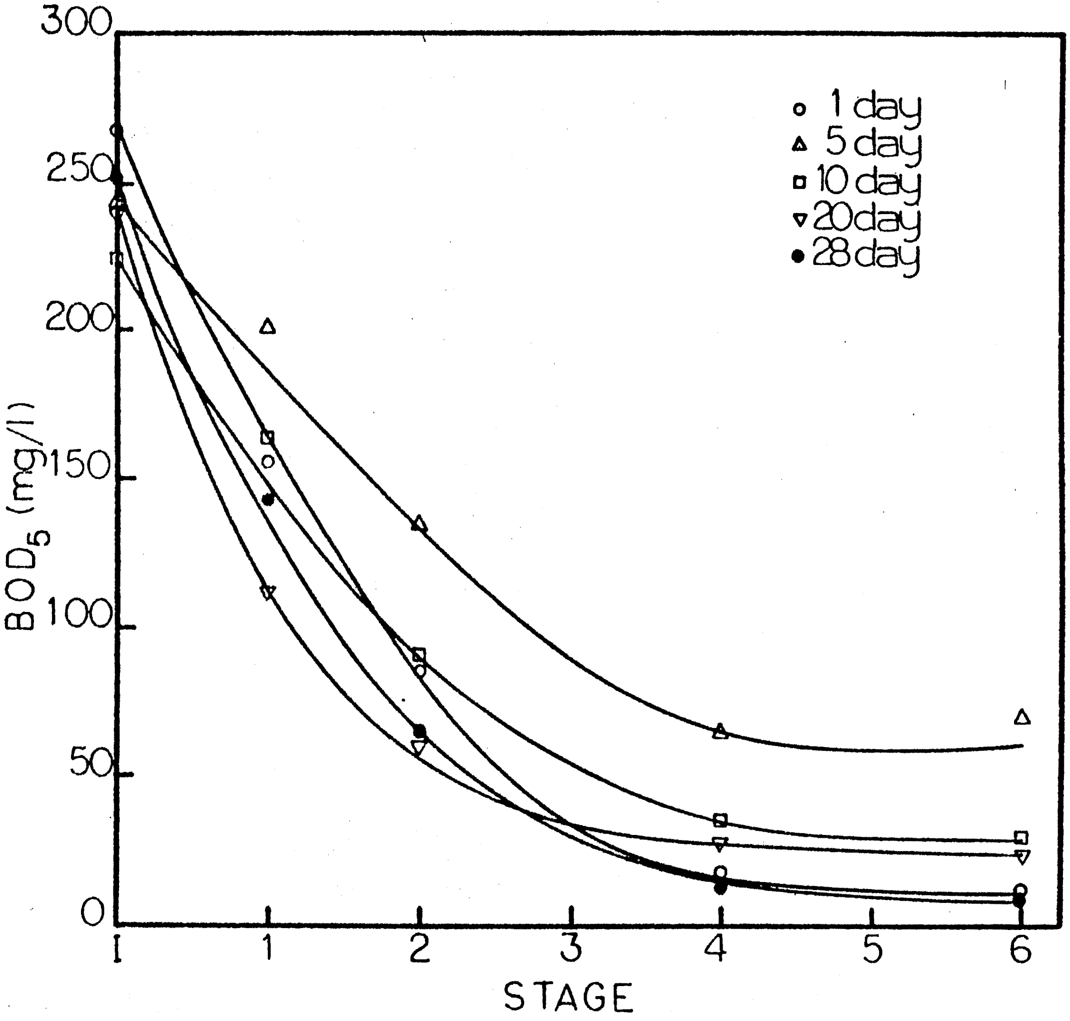

Figure 18. BOD_5 vs. Stage for 10 mg/l Copper Concentration

TABLE XV

SUMMARY OF COD RESIDUAL VALUES FOR 10 mg/l COPPER CONCENTRATION

Stage	1 day	5 day	10 day	20 day	28 day
Influent	422	474	464	380	436
1	243	344	335	140	202
2	139	265	110	47	124
3	64	198	75	19	121
4	16	150	63	8	47
5	24	130	43	4	35
6	28	107	39	12	31

TABLE XVI

SUMMARY OF TOC VALUES FOR 10 mg/l COPPER CONCENTRATION

Stages	1 day	5 day	10 day	20 day	28 day
Influent	210	203	210	212	200
1	100	145	195	64	150
2	62	140	58	39	72
3	32	72	54	24	36
4	19	65	66	29	27
5	20	55	78	22	24
6	21	43	35	40	22

TABLE XVII

SUMMARY OF BOD_5 VALUES FOR 10 mg/l COPPER CONCENTRATION

Stage	1 day	5 day	10 day	20 day	28 day
Influent	267	243	224	239	249
1	156	200	162	111	142
2	85	135	88	58	63
4	14	63	34	26	12
6	12	71	28	22	11

TABLE XVIII

PERCENT COPPER REMOVAL AT DIFFERENT INFLUENT COPPER CONCENTRATIONS

Period of Analysis	Influent (mg/l)	Effluent (mg/l)	Percent Removal
3 mg/l			
1 day	3	0.3	90
5 day	3	2.7	10
10 day	3	0.4	86.7
20 day	3	0.5	83.3
25 day	3	0.1	96.7
30 day	3	0.05	98.3
10 mg/l			
1 day	10	0.05	99.5
5 day	10	0.1	99
10 day	10	0.1	99
20 day	10	0.05	99.5
28 day	10	0.1	99

CHAPTER V

CONCLUSIONS

The results of this study support the following conclusions:

1. The long-term effect of chromium on the rotating biological contactor is the same as the short-term, and the system performance is not a function of tiem.

2. Ten mg/l chromium had the greatest effect and deteriorated the system completely; however, the results did not depend on time.

3. Chromium removal was over 90 percent during the period of analysis and did not change in time.

4. Copper seems to behave the same as chromium, and the effect on system efficiency does not change with respect to time.

5. Ten mg/l did degrade the system. The system turned black and remained this color for the entire period of analysis.

6. Finally, copper removal is over 90 percent in most cases, and this is not changed by time.

CHAPTER VI

SUGGESTIONS FOR FURTHER STUDY

1. Measurement of heavy metals and their correlation with removal efficiency at each stage.

2. Effect of heavy metals on kinetic constants.

3. Heavy metal, absorption by microorganisms, and determination of whether they have an inhibitory effect on bacteria activity.

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