A STUDY OF PHENOL REMOVAL BY THE ROTATING BIOLOGICAL CONTACTOR

By

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DEDICATED TO MY PARENTS
MY WIFE AND DAUGHTER

A STUDY OF PHENOL REMOVAL BY
THE ROTATING BIOLOGICAL
CONTACTOR

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In the name of Allah, the Beneficent, the Merciful.

"Praise be to Allah, the Lord of the Worlds, the Beneficent, the Merciful, Master of the Day of Judgment. Thee (alone) we worship ; Thee (alone) we ask for help. Show us the straight path, the path of those whom Thou hast favoured; Not the (path) of those who earn Thine anger nor of those who go astray." (*The Holy Qur'an*)

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CHAPTER I

INTRODUCTION

People were interested in protecting water long before 1986. Some centuries back Emperor Ashoka of India drafted environmental legislation containing a number of regulations of which we could be envious.

Water is a precious resource which is taken for granted by most people except in Arid and Semi Arid regions. Water easily passes between cities or even countries, and in this way also chemical pollutants are carried with the water from city to city, from country to country and from man to the organisms living in the fresh and salt water environment.

Pollution is defined by Cairns and Lanza (1), as the appearance of some environmental quality for which the exposed community has inadequate information and is thus incapable of an appropriate response. For the past fifteen to twenty years there has been increasing concern about the number and nature of organic compounds polluting surface water, mainly because of potential public health risks resulting from direct re-use of the water but also because of possible adverse effects of the pollutants on aquatic life. In the U.S., as elsewhere, the situation has been aggravated by the increasing need to use low-land rivers as sources of water for public supply in order to meet the growing demand for water. While it is relatively easy to ensure that supplies derived from such sources are free from pathogenic organisms, it is becoming increasingly difficult to guarantee that the treated waters are free of organic compounds which, if ingested over a long period of time might be harmful to health. In recent years there has been noticeable evidence of increased regulatory concern by federal, state and local environmental protection authorities oriented toward the definition and resolution of waste management problems associated with many industrial discharges. The removal of pollutants from industrial waste water is becoming the most challenging field in environmental engineering practice today. One of the most recent processes of treatment used in this field is the Rotating Biological Contactor process. Due to its easy maintenance, low power consumption, resistance to shock loads and low detention time, the Rotating Biological Contactor could be the most economically feasible treatment process.

The Rotating Biological Contactor is a fixed film reactor which consists of large diameter discs of lightweight plastic media mounted on a horizontal shaft. The media is placed in a semi-circular tank where it is partially submerged in the waste water. The shaft rotates at a constant speed allowing the media to alternate between the bulk of the liquid and the air and a thin biological film is built up on the surface of the media. Aeration and substrate transfer take place in this film. In addition, the rotation of the disc imparts a shear force to the biological film, keeping its thickness relatively constant.

This investigation was done to look at the feasibility of removing phenol as one of the priority pollutants by using a small-scale, seven inch diameter Rotating Biological Contactor and evaluate the overall and stage substrate removal under different organic loading.

CHAPTER II

LITERATURE REVIEW

Process Development History

The Rotating Biological Contactor (R.B.C) is a development of the trickling filter concept. Development of trickling filters was begun in Germany by Bach, the former chief chemist of the Emscher Society(2) . Activated sludge plants at that time were troubled by sludge bulking. Bach wanted to encourage activated sludge to adhere to very small particles, which would then be held in aerated basins. Such plants were built in the 1920's which-utilized small particles of grit, brushwood, wood, cork, etc. They were very effective in treating the most heavily polluted waste water, e.g. water with high phenol contents (2).

To reduce the power consumption of biological treatment plants, cylindrical filters were first used in 1900 by Weigand(2) . A wooden cylinder with slatted walls was filled with brushwood, half submerged in the waste water and then rotated. Batch and Imhoff(2) were the prime investigators of this work. These plants worked efficiently but it was not possible to keep the cylinders entirely free of blocking with sludge, which caused these plants to become anaerobic. It was necessary to regularly remove and strip down these cylinders for cleaning. Meanwhile, other biological forms of treatment had been developed to act as roughing stages so that the urgency of finding a solution to the technical problem of these plants was deferred. In the U.S. the first Rotating Biological Contactor was tested by Doman in 1929 using metal discs(3). However the results were not encouraging and no further work was done.

In Germany research into the performance of rotating disc plants was carried out by various establishments. The first plants to which this research was applied were those still using asbestos cement plates as the disc material. This material had a very long life but the weight of the discs proved a hindrance to the economic operation of such plants. The development which led to the use of light expanded polystyrene was accomplished in 1958 by Hartmann and Popel in West Germany (4). A few years later the process gained acceptance readily in both the U.S. and several European countries and has been used since(5).

Some Research Studies on R.B.C

The Rotating Biological Contactor has been widely used in this country. Process information concerning municipal waste treatment has been fairly well established. However, information on the process treatability and feasibility assessment in treating industrial waste is getting more of the researchers attention in the recent years.

Stover and Kincannon (6) used a slaughterhouse waste and synthetic waste to observe the removal efficiency and the relationship of organic and hydraulic loading. They found that the response of the Rotating Biological Contactor to the treatment of various types of wastewater varies with the different constituents and characteristics. They also found that the removal efficiencies decrease and approach constant minimum values as the organic loading increases. Another study on the Treatment of slaughterhouse waste by using Rotating Biological Contactor has been reported by Chittenden and Wells (7), in which they examined the effects of hydraulic loading and organic loading on the removal characteristics of the contactors using slaughterhouse anaerobic lagoon effluent. On scale-up and design of Rotating Biological Contactor Stover and Kincannon (8) have reported that treatment efficiency, in terms of lbs BOD removed/day/1000 ft^2 is independent of media diameter below total loading of about 1.0 to 1.5 lbs BOD/day/1000 ft^2. They also found there were no oxygen limitation below 1.0 to 1.5 lbs BOD/day/1000 ft^2 loading, indicating no problems in direct scale-up of full scale systems below these loading rates. therefore, they recommended that in order to avoid oxygen transfer problems during scale-up the first stage(s) must not be loaded over 1.0 to 1.5 lbs BOD/day/1000 ft^2. They have also concluded that unless surface area available is not adequate to provide an adequate biomass to substrate ratio, the organic removal rate in any fixed bed reactor will be eventually oxygen limited. Kincannon (9) has shown analyses of plastic media biological tower to yield the same conclusions for the Rotating Biological Contactor. When plotting BOD removed versus surface area or volume of filter media, the same types of results were observed with the higher organic loading yielding apparent zero order reaction kinetic. Step-by-Step design Procedures for Rotating Biological Contactor and Biological tower were also presented by Kincannon and Stover (10), In which they have summarized the design methodology for the rotating Biological Contactor which follows the concepts that they have been presenting since the early 1970's. Corneille and Oshaughnessy's (11) research was involved in evaluation of different operational parameters when treating the highly carbohydrate synthetic apple waste,(similar to waste from apple processing facilities). their evaluations for the effects of staging, detention time, hydraulic loading rates, and organic loading rates had led to the following conclusions. Soluble BOD removal in excess of 97 percent was consistently maintained after six stages of treatment. Stage one removal amounted to at least 95 percent of the total BOD removed. The effect of detention time is an indirect Rotating Biological Contactor process parameter. Efficiency of removal does decrease slightly with increasing hydraulic loading rate. Another study (12) shows that total removal efficiencies approaching 95 percent for BOD_5 can be obtained with two-stage Rotating Biological Contactor treatment of shellfish processing wastewater. The investigation also indicated that treatment of shellfish processing wastewater by the Rotating Biological Contactor process was quite feasible. Another study (13) was conducted using a threestage Rotating Biological Contactor unit with 7.5 inch discs on bottling plant wastewater. Previous test had shown the process had the capability of 94 percent BOD_5 removal under variable loading conditions including periods which can be considered as shock loading. In addition the unit recovered well after power failures and long week-ends. The 94 percent of BOD removal was obtained while operating at average loading rates of 5.3 lbs BOD_5 applied per 1000 ft^2 of media surface. Applications of the Rotating Biological Contactor process in the dairy food industry have included treatment of a synthetic dairy waste on lab units (14-16), pilot-scale (17) and full-scale treatment (18). In all the previous studies the Rotating Biological Contactor was found to be very satisfactory.

Water Pollutants

There is common agreement that a synthetic industrial chemical compound is more likely to be a serious pollutant if it fulfills most, if not all, of the following criteria (19).

1. Large industrial production
2. Use which makes environmental leakage likely
3. Persistence

4. Bioaccumulation

5. Toxicity

These criteria can be considered a good set of features characterizing a compound as a water pollutant. An initial list of 114 organic compounds of concern called the "priority pollutant" list has been developed for investigations. The majority of the preliminary investigations to date have consisted of analytical methods development and screening of wastewater for assessment of presence and magnitude of contamination of these various chemical compounds (20).

Phenolic Waste

Phenol (C_6H_5OH). The monohydroxy derived of benzene is known as phenol and is known to the layman as carbolic acid. It can be quite toxic to bacteria in concentrated solution. It has been used widely as a germicide and disinfectant (21).

The antibacterial activity of phenol is increased by halogen or alkyl substituents on the ring, which increase the polarity of the phenolic OH group and decrease solubility in water. Since one end of the molecule thus becomes increasingly hydrophilic and the other increasingly hydrophobic, the molecule as a whole becomes more surface-active and the antibacterial potency may be increased a hundredfold or more (22).

Phenol is recovered from coal tar and considerable amounts are manufactured synthetically. It is used extensively in the synthesis of organic products, particularly phenolic-type resins. It occurs as a natural component in industrial wastes from the coal-gas, coal-coking, and petroleum industries as well as in a wide variety of industrial wastes from processes involving the use of phenol as a raw material (21).

Phenol is classified as a biodegradable compound, and its range of concentration depends on the type of water in which it exists. A European source (23) has reported the range of phenol concentration in µg/L is (5-2,290,000) in industrial effluent, (0.03-20) in sewage effluent, and (0.03-30) in surface water.

CHAPTER III

MATERIALS AND METHOD

The bench scale Rotating Biological Contactor unit employed for these investigations was made with a semicircular plexiglass tank approximately 9.5 inches in width and 31.75 inches long. The unit was separated into five stages with four baffles each with a submerged semicircular opening at the base approximately 1 inch in diameter. The discs were one-eighth inch thick polyethylene and cut to a diameter of 7 inches, closely conforming to the bottom of the plexiglass tank. The center to center spacing of the discs was 5 1/8 inches, leaving a clear opening of 1/2 inch. The discs were mounted on a horizontal shaft, which ran through the five stages. Each stage contained six discs, which yielded a surface area of 3.2 ft^2 per stage and a total surface area of 16 ft^2 for the system. The discs were approximately 37 percent submerged in the liquid bulk. The flow of synthetic waste was pumped to the unit through plastic tubing parallel to the shaft or perpendicular to the rotation of the discs. To insure complete mixing in the liquid bulk and to keep the solids in suspension, small styrofoam spacers were placed in between the discs at intervals of approximately 90 degree.

A summary of physical properties of the unit appears in table 1.

Synthetic Waste

The waste used in this experiment was a synthetic substrate using a commercial diet drink called "Sego",which contained sugar and cellulose as the carbon source. The other ingredients of Sego which made it a buffer solution were magnesium sulfate, magnesium oxide and ferric orthophosphate. The nutrients (ammonium chloride, phosphoric acid) were added in proportion to the carbon source, sego (table II). The amount of each synthetic constituent to achieve the required organic feed concentration was calculated and made in a stock solution. The amount of each synthetic waste constituent was placed in the carboy and diluted with tap water to a volume of twenty liters.

The waste was pumped into the holding basin at the head of the rotating disc unit, where it was led into the first stage through plastic tubing. Then the waste flowed through each of the next five stages into the effluent carboy placed in the other side of the unit.

The above operation was done in the initial period of this investigation where some data were recorded. Later in

TABLE I

PHYSICAL PROPERTIES OF LABORATORY
R.B.C UNIT

PARAMETER	VALUE
1. Rotating biological Contactor media	1/8 inch thick polyethylene
2. Spacing of discs	1/2 inch clear from disc surface to disc surface
3. Diameter of discs	7 Inches
4. Number of discs per stage	6
5. Number of stages	5
6. Surface area per stage	3.2 ft^2
7. Total surface area of the system	16.0 ft^2
8. Net volume per stage*	0.048 ft^3
9. Net volume of the media	0.39 ft^3
10. Net volume of the water in the system*	0.24 ft^3
11. Specific surface area	40.9 ft^2/ft^3
12. Rotation speed	10 RPM
13. Linear velocity	18.3 ft/min

* RBC with no growth(i.e.,clean discs).

TABLE II

COMPOSITION OF SYNTHETIC WASTE

CONSTITUENT	CONCENTRATION
SEGO	3ml/l
NH_4CL	0.09mg/l
H_3PO_4	0.1ml/l
TAB WATER TO VOLUME	

this investigation phenol was added (as priority pollutant) to the influent carboys to obtain a concentrations of 10, 50 and 100 mg/L. It should be pointed out that the initial feed average $sBOD_5$ reading without the phenol was 219 mg/L and the final feed average $sBOD_5$ reading which contained 100 mg/L of phenol was 413 mg/L. This variation in the average $sBOD_5$ reading was due to phenol which is a carbon source too.

Experimental And Analytical Procedures

The unit was seeded with sewage and run for three days as a batch process. Within the first three days of operation, a thin layer of microorganisms was beginning to build up on the discs surfaces. The unit was then fed synthetic waste with a continuous flow of 10.1 ml/min for the rest of this investigation. Two weeks of operation was allowed prior to any testing to insure a good growth on the discs. It was then assumed that the unit had reached the steady state condition. Six different locations of samples were collected at each sampling period. The first sample was collected directly from the feed carboy. For stages 1 through 5, the samples were taken at the end of each stage with the aid of a glass tube connected to a rubber hose. Approximately 350 ml of wastewater was collected at each stage. To ensure a steady state condition, the samples at these stages were collected at two hour intervals.

PH

Throughout this investigation, the pH values of the RBC system were found to stay within the range of 6.5-7.5 .

BOD

On the same day of collection, the samples were filtered using a fiberglass membrane. The BOD of the filtrate was performed in accordance with Standard Methods (24).

Extractions

Samples for Gas Chromatograph (GC) analysis of phenol were collected at the same locations of the BOD samples. Using a fiberglass membrane, a volume of 80 ml of the filtrate was used for this analysis. The filtrate was then adjusted to pH 2 or less by adding 50% concentration of phosphoric acid and placed in a 100 ml long neck flask with a tight cover. 30 mg of sodium chloride ($NaCl_2$) was then added to the flask and agitated until most of the salt was dissolved. To extract the phenol from the solution in the flask, one milliliter of iso-propyl ether was injected into the flask and agitated for 2 minutes constantly. After setting the flask for 3 minutes, a half inch thick layer of iso-propyl ether with the extracted phenol will be floating at the top of the solution in the narrow neck of the flask. Using a 10μl syringe, a 3μl sample of this layer was injected into the GC for analysis. The above procedure was repeated for all the analyzed samples.

External extracted percent recovery curves were used for identification and quantity. Injections were 3ul and were repeated as necessary according to retention time shifts or abnormally high or low responses.

Gas Chromatograph

The Gas Chromatograph (GC) used for phenol analysis was a Perkin-Elmer Sigma 3B equipped with a 3 fT glass column of 1240-DA and Perkin-Elmer integrator and flame ionization detector. The temperature program was 70-175°C increasing at a rate of 8°C/min, then held until completion of a 16 minutes total run-time.

CHAPTER IV

RESULTS

The results of this investigation are tabulated in tables III and IV. The average values of each organic loading are calculated to be used for the rest of this investigation. $sBOD_5$ removal characteristics with three different phenol concentration, at a hydraulic loading of 0.24 GPD/ft^2 as a function of stage, are shown in figures 1 and 2. It can be seen from figure 1 that a very small amount of $sBOD_5$ is remaining after the first stage. Thereafter, only a minor removal of $sBOD_5$ has been achieved through the rest of the stages. Figure 2 shows the relationship of percent $sBOD_5$ removed versus stage with an apparent total removal of 99% . About 98% of this removal was achieved at the first stage.

Figure 3 shows the relationship of $sBOD_5$ applied versus $sBOD_5$ removed by this process for the synthetic waste alone and with three different concentrations of phenol. A straight line is drawn through these values which very clearly shows a very high removal efficiency of the system. It also shows the variation of the applied load of (0.44-0.83) lbs/day/1000 ft^2 resulted in no changes in the removal load efficiency. It should also be noted that only the average values for the first stage were considered in

TABLE III

SUMMARY OF RBC REMOVAL OF $sBOD_5$ HYDRAULIC LOADING OF 0.24 GPD/ft^2

DESIRED PHENOL CONC. mg/l	INF $sBOD_5$ mg/l	STAGE 1 $sBOD_5$ mg/l	STAGE 2 $sBOD_5$ mg/l	STAGE 3 $sBOD_5$ mg/l	STAGE 4 $sBOD_5$ mg/l	EFF $sBOD_5$ mg/l
	215	3	2	1	1	1
0	209	5	4	4	3	2
	232	3	2	2	1	1
AVERAGE	219	4	3	2	2	1
	312	5	3	2	2	2
	261	5	4	3	3	2
	288	4	3	2	2	1
10	266	5	4	4	3	3
	259	6	4	4	3	3
	260	5	4	3	3	3
AVERAGE	274	5	4	3	3	2
	380	6	4	3	3	2
	386	6	4	3	3	2
50	400	6	4	3	2	2
	280	6	4	4	4	2
AVERAGE	362	6	4	3	3	2
	427	7	6	6	4	3
100	402	7	6	6	high	high
	410	7	6	6	5	3
AVERAGE	413	7	6	6	5	3

TABLE IV

SUMMARY OF RBC REMOVAL OF PHENOL AT HYDRAULIC LOADING OF 0.24 GPD/ft^2

DESIRED INF. PHENOL CONC. mg/l	ACTUAL INF. PHENOL CONC. mg/l	STAGE 1 PHENOL CONC. mg/l	STAGE 2 PHENOL CONC. mg/l	STAGE 3 PHENOL CONC. mg/l	STAGE 4 PHENOL CONC. mg/l	EFF. PHENOL CONC. mg/l
	9.66	0.066	0.013	<1μl	<1μl	<1μl
10	9.66	0.048	0.003	<1μl	<1μl	<1μl
	12.1	0.030	0.012	<1μl	<1μl	<1μl
	7.55	0.085	0.008	<1μI	<1μl	<1μl
AVERAGE	9.74	0.057	0.009			
	48.3	0.085	0.015	<1μl	<1μl	<1μl
50	48.3	0.085	0.018	<1μl	<1μl	<1μl
	48.3	0.085	0.015	<1μl	<1μl	<1μ1
AVERAGE	48.3	0.85	0.016			
100	96.6	0.187	0.02	0.002	<1μl	<1μl
	102.7	0.187	0.019	0.002	<1μl	<1μl
AVERAGE	99.8	0.187	0.02	0.002		

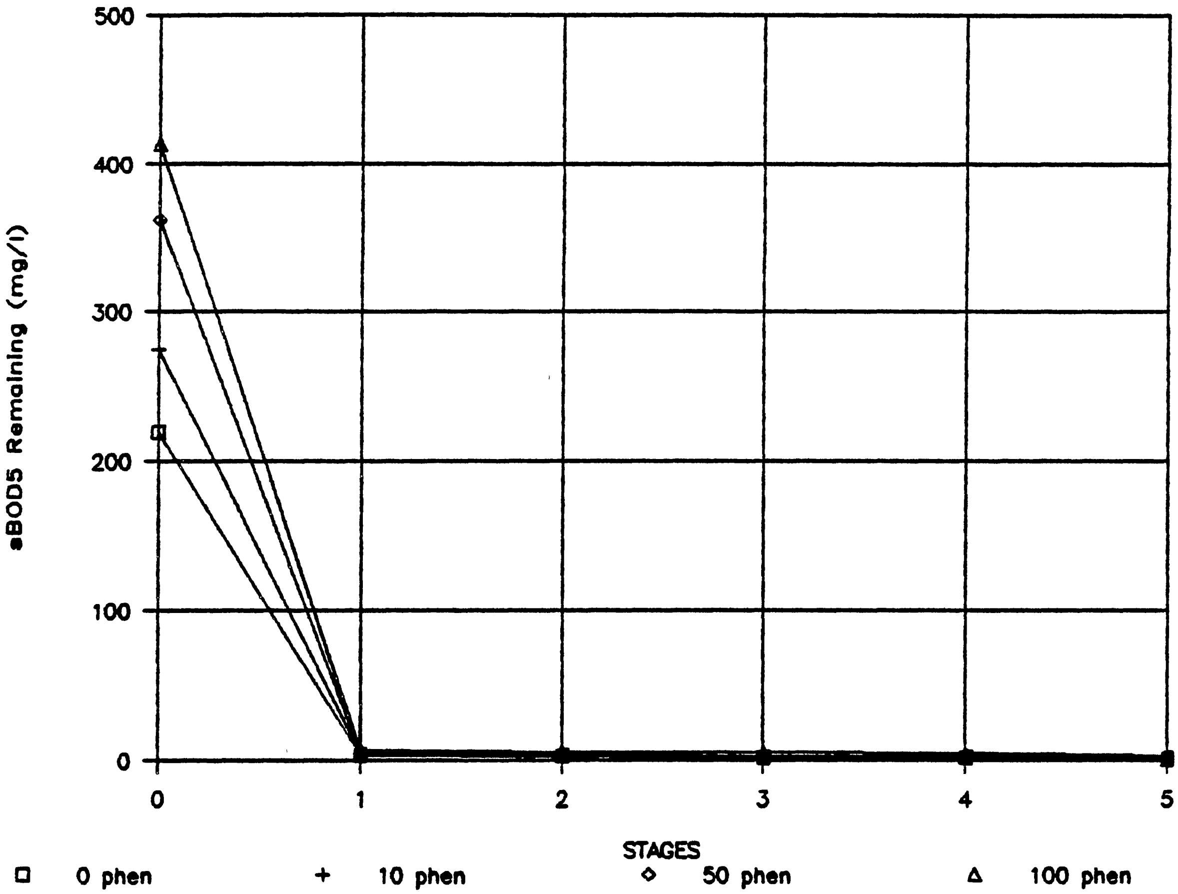
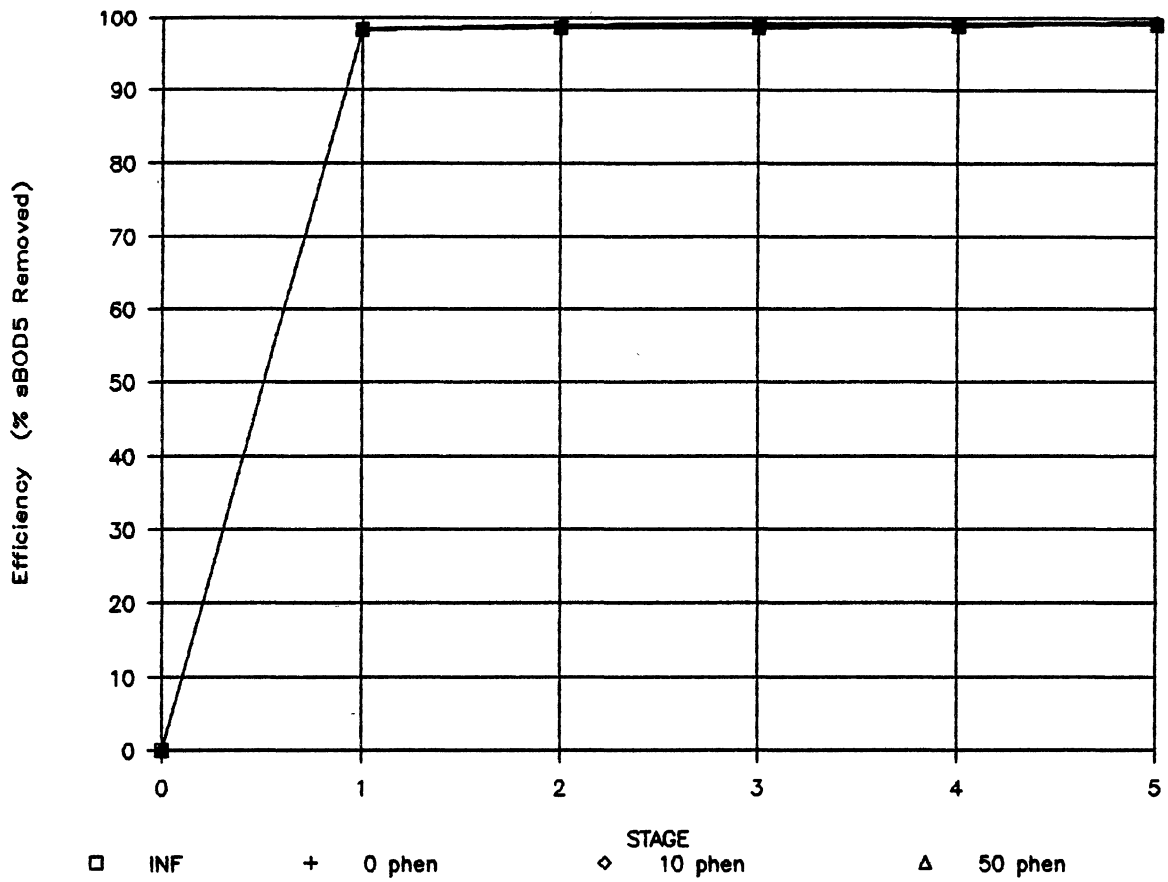
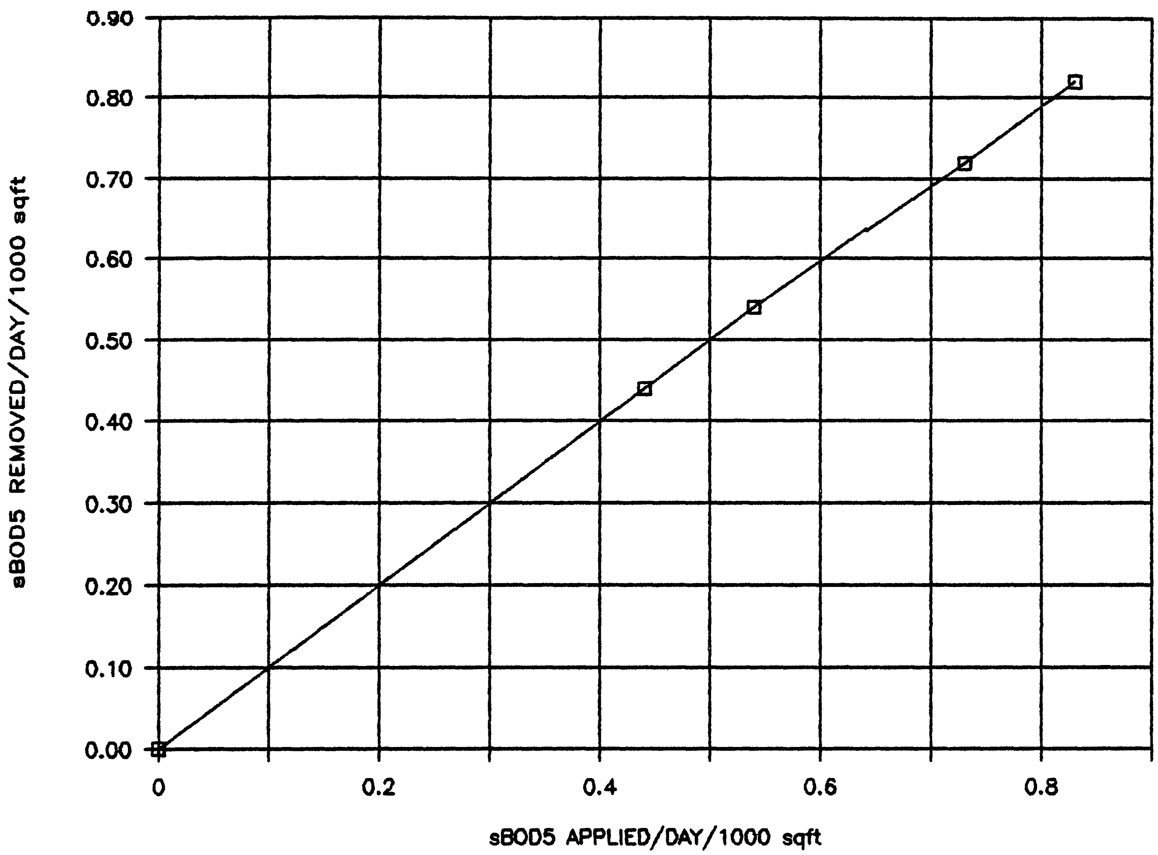


Figure 1. $sBOD_5$ Remaining versus Stage for Different Phenol Concentrations at Hydraulic Loading of 0.24 GPD/ft^2



Figer 2. Percent $sBOD_5$ Removed versus Stage for Different Phenol Concentrations at Hydraulic Loading of 0.24 GPD/ft^2



Figer 3. First Stage $sBOD_5$ Removed (LB/day/1000ft^2) Versus $sBOD_5$ Applied (LB/day/1000ft^2) for Phenol Concentrations of (0,10,50,100) mg/l at Hydraulic loading of 0.24 GPD/ft^2

calculating the organic loading, since the additional $sBOD_5$ throughout the remainder of the system was negligible. Figure 4 describes the performance of the unit at 0.24 GPD/ft^2. The unit has achieved $sBOD_5$ removal of 98% for the first stage at all different applied loads. The applied and removed $sBOD_5$ in lbs/day/1000 ft^2 for different phenol concentrations are shown in table V. Again, the values for the removal load of $sBOD_5$ in this table are calculated with respect to the first stage removal only.

The initial substrate removal rate, K_1, was determined for each organic loading. For the reason explained previously, only the first stage removal rate was calculated. The derivation of the kinetic equation, as reported by Stover (25), is shown below.

$$ds/d\,(stage) = -ks$$

$$ds/s\,(-k) = d\,(stage)$$

$$\ln s/s_o = -k\,(stage - stage_o)$$

$$-k = (\ln s/s_o)/(stage - stage_o)$$

k= substrate removal rate ($stage^{-1}$)

s= substrate

For the K_1 values determined, only one stage was used, reducing the equation to: $-k = \ln s/s_o$.

The values obtained are also shown in table V. plots of K_1 values vs $sBOD_5$ applied (lbs/day/1000 ft^2) for each

TABLE V

SUMMARY OF ORGANIC LOADING APPLIED, ORGANIC LOADING REMOVED, SUBSTRATE REMOVAL RATE FOR $sBOD_5$

DESIRABLE PHENOL CONC. mg/L	$sBOD_5$ APPLIED LBS/day/1000ft^2	$sBOD_5$ REMOVED LBS/day/1000ft^2	K1
	2.15	2.12	4
0	2.09	2.04	4
	2.32	2.29	4
	3.12	3.07	4
	2.61	2.56	4
	2.88	2.84	4
10	2.66	2.61	4
	2.59	2.53	4
	2.66	2.55	4
	3.80	3.74	4
	3.86	3.80	4
50	4.00	3.96	4
	2.80	2.74	4
	4.27	4.20	4
	4.02	3.95	4
	4.01	4.03	4

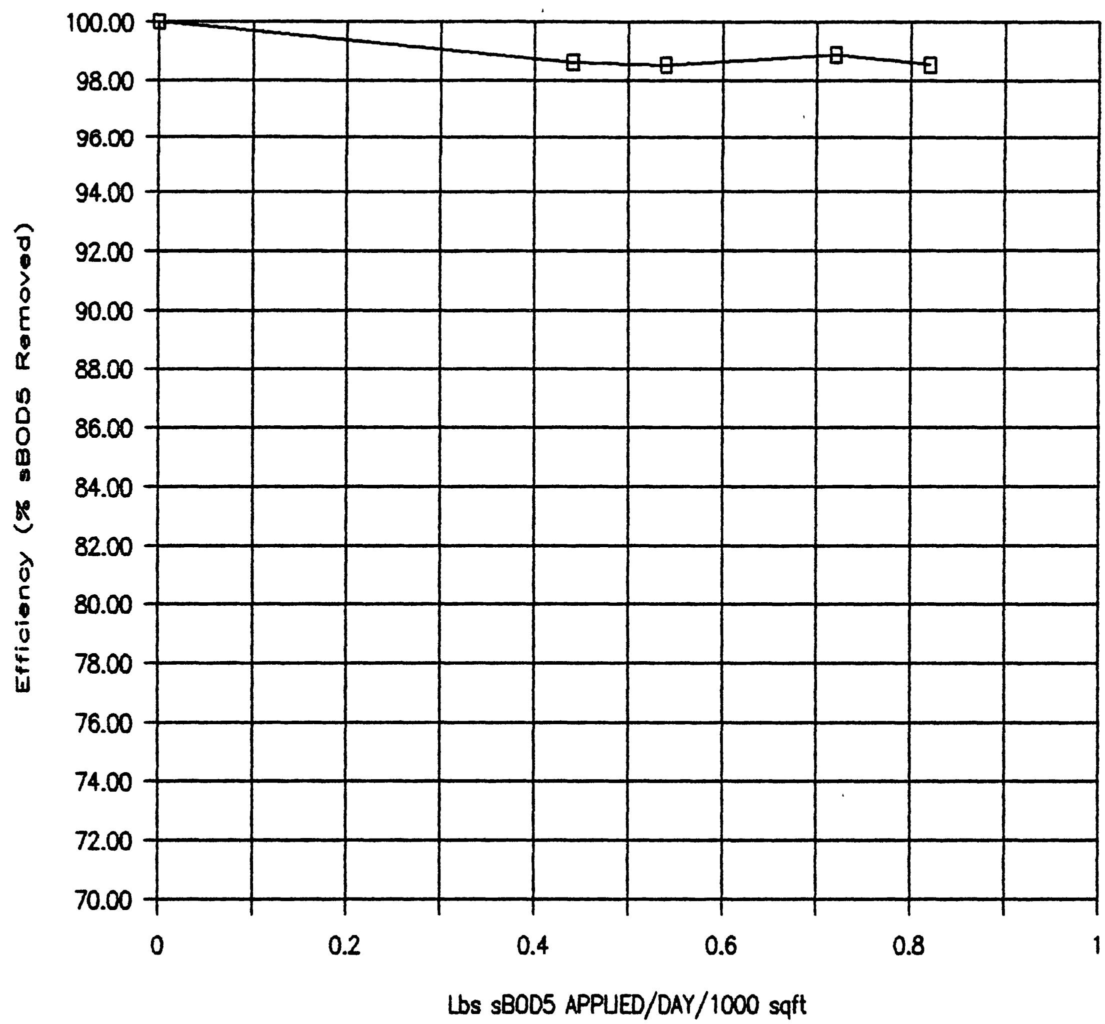


Figure 4. First Stage Percent sBOD5 Removed Versus sBOD5 Applied (LB/day/1000ft²) for Phenol Concentrations of (0,10,50,100) mg/l at Hydraulic Loading of 0.24 GPD/ft²

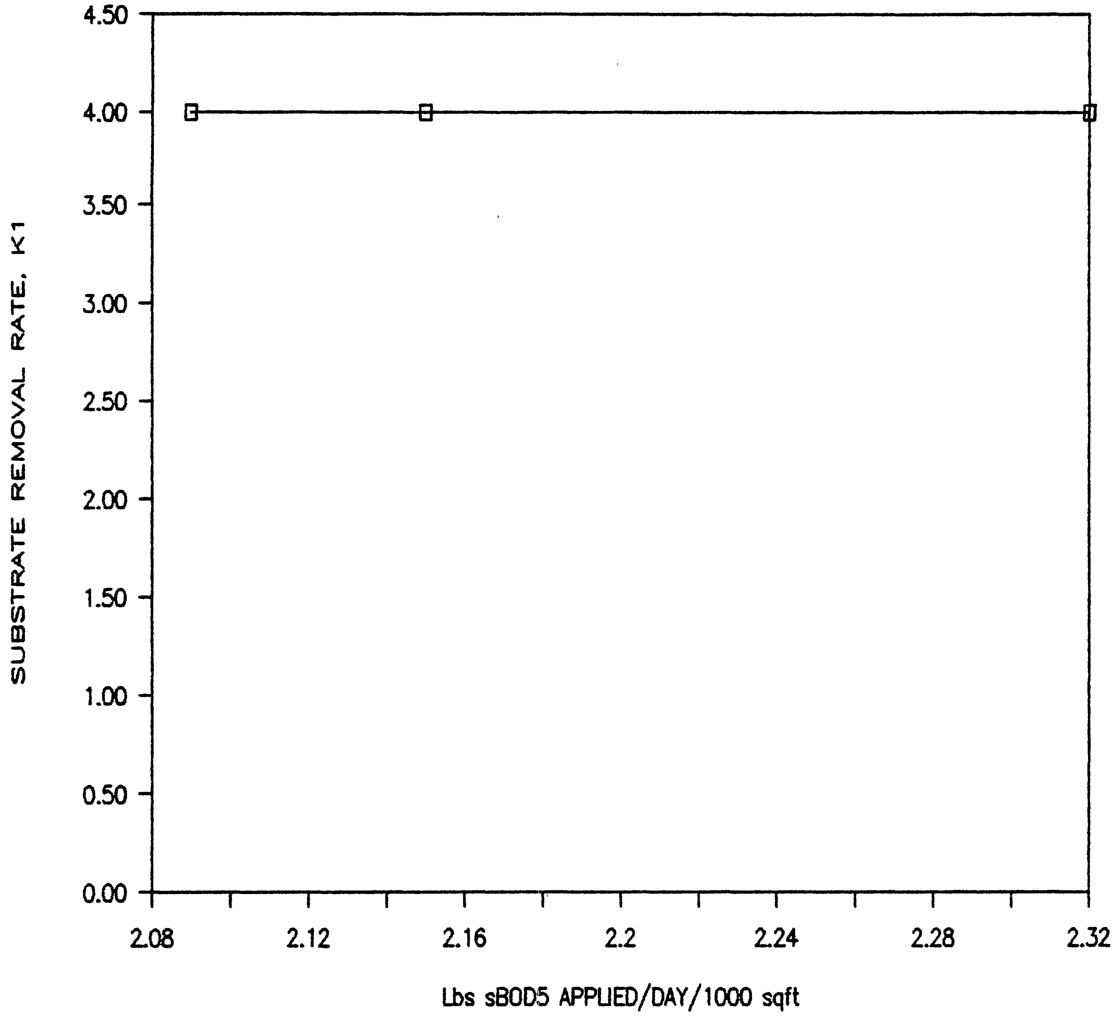


Figure 5. FIrst Stage Substrate Removal Rate (k_1) Versus $sBOD_5$ Applied (LB/day/1000ft^2) for Phenol Concentrations of (0) mg/l at Hydraulic Loading of 0.24 GPD/ft^2

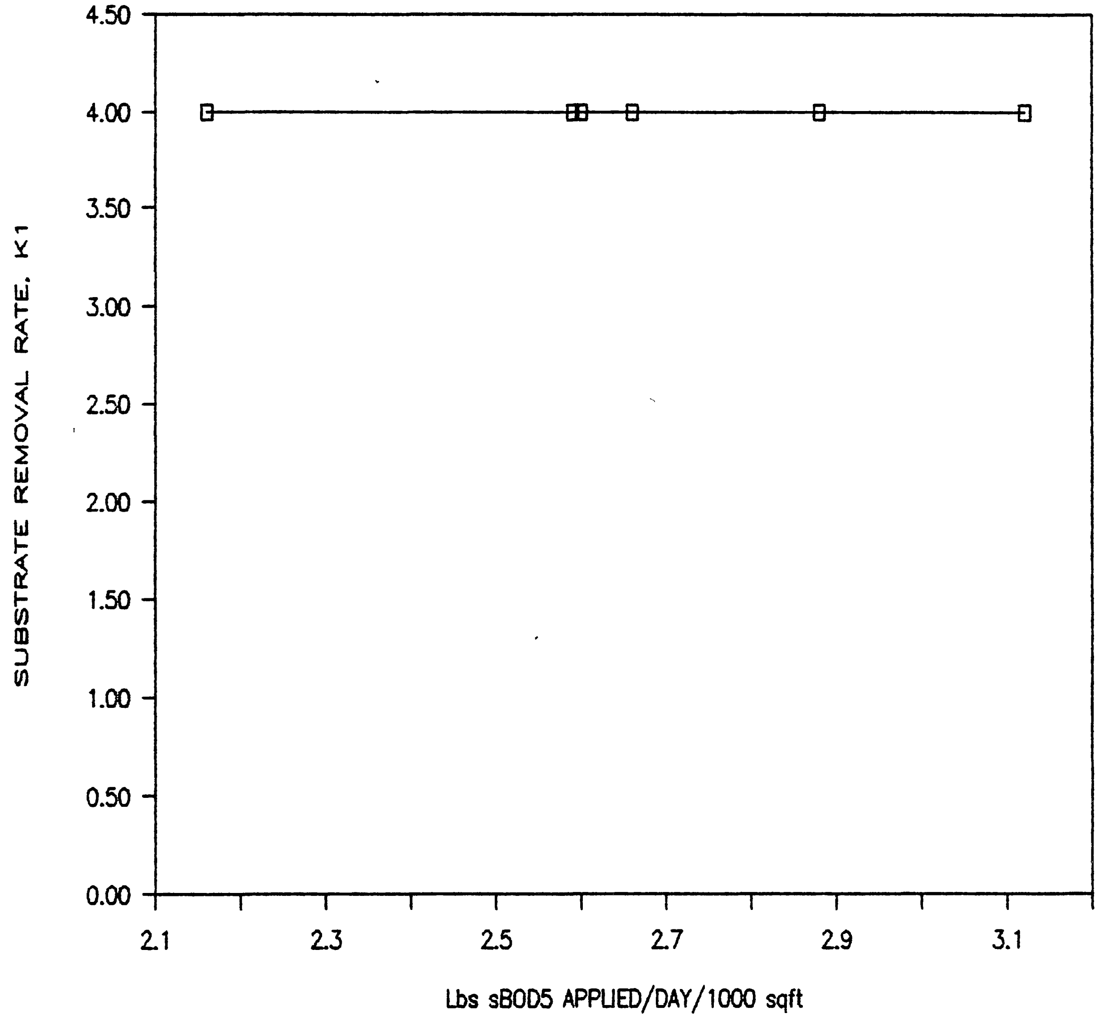


Figure 6. FIrst Stage Substrate Removal Rate (k_1) Versus $sBOD_5$ Applied (LB/day/1000ft^2) for Phenol Concentrations of (10) mg/l at Hydraulic Loading of 0.24 GPD/ft^2

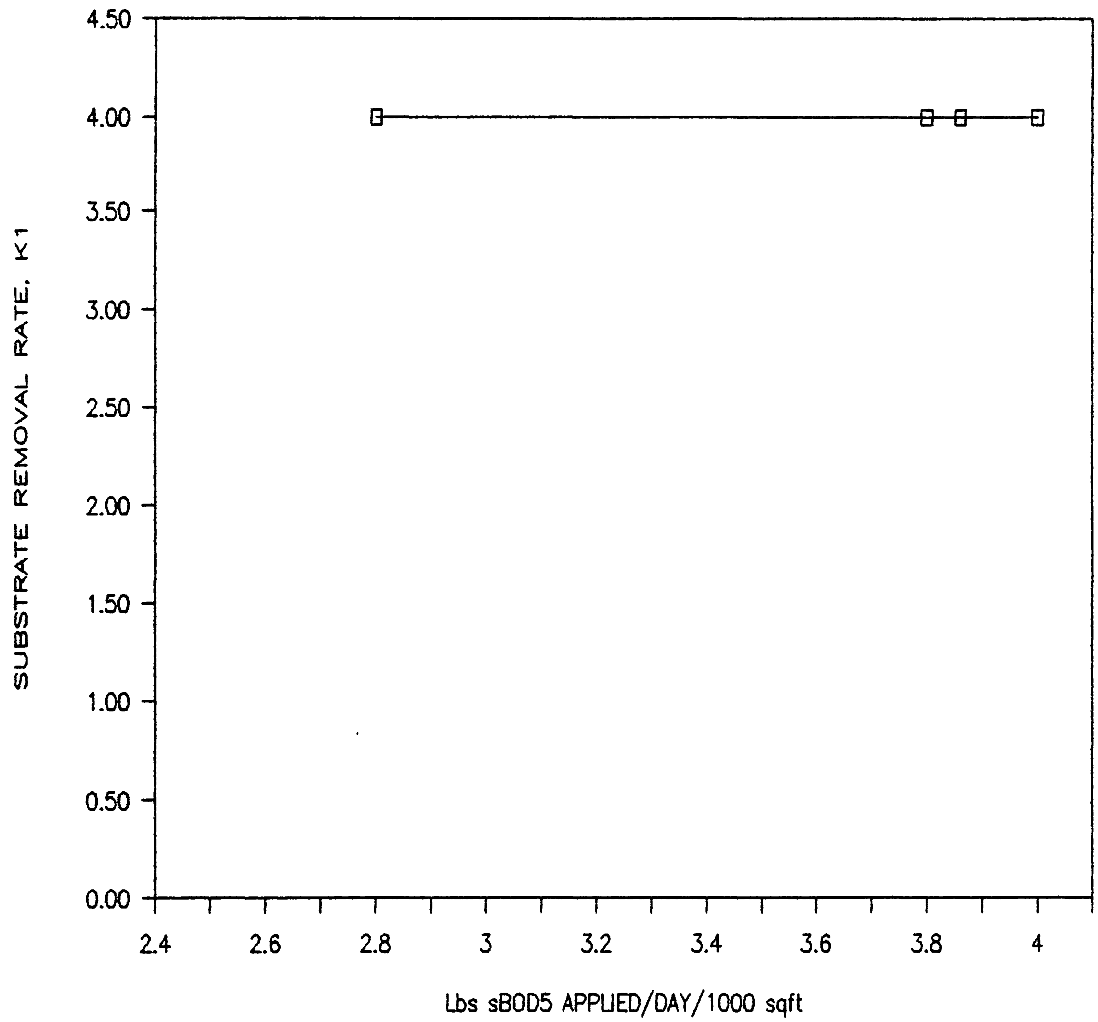


Figure 7. FIrst Stage Substrate Removal Rate (k_1) Versus $sBOD_5$ Applied (LB/day/1000ft^2) for Phenol Concentrations of (50) mg/l at Hydraulic Loading of 0.24 GPD/ft^2

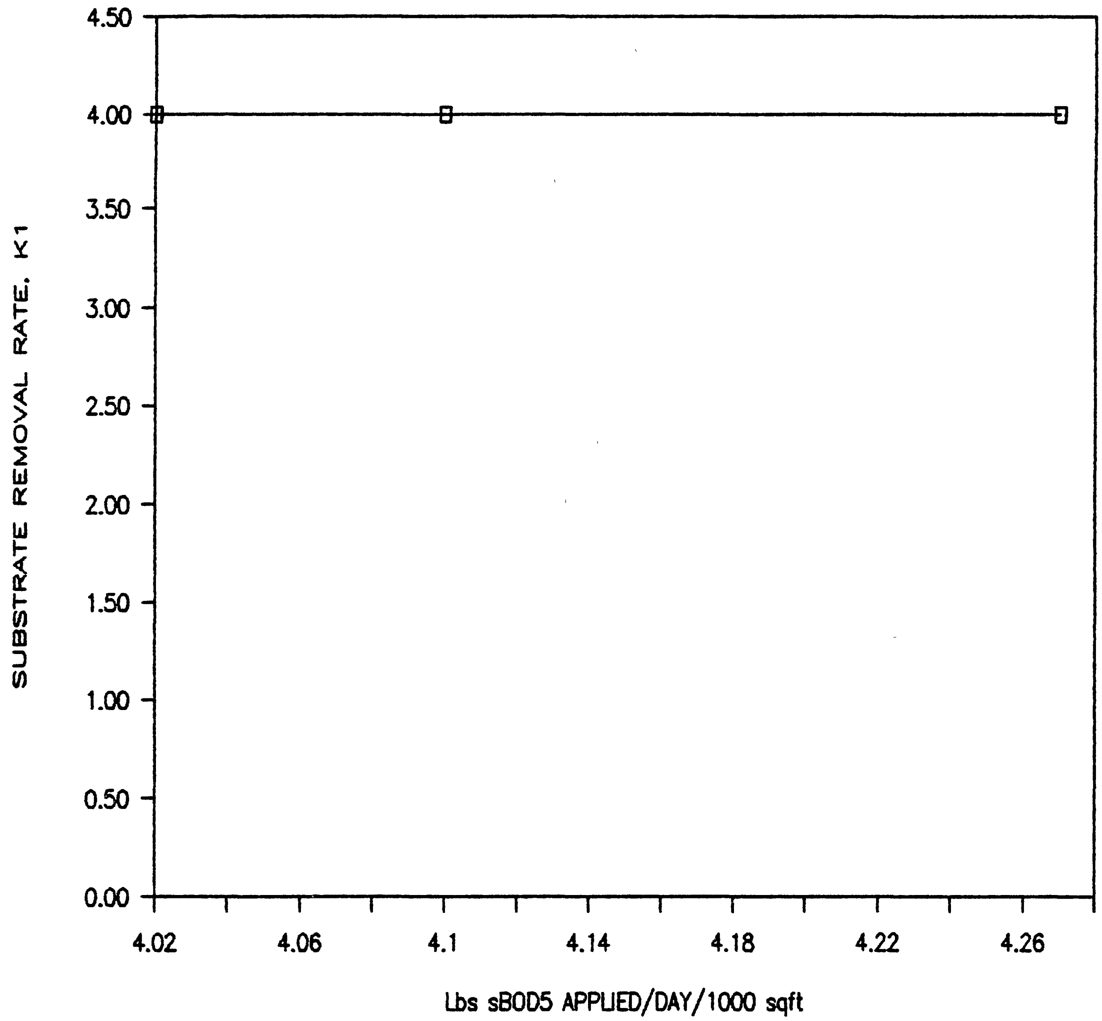


Figure 8. First Stage Substrate Removal Rate (k_1) Versus $sBOD_5$ Applied (LB/day/1000ft^2) for Phenol Concentrations of (100) mg/l at Hydraulic Loading of 0.24 GPD/ft^2

phenol concentration of (0,10,50,100) are show in figures (5,6,7,8) respectively. As shown in these Figures, the response of the Rotating Biological Contactor in terms of the substrate removal rate to the treatment of different organic loading applied is the same.

The reciprocal organic loading removed versus reciprocal organic loading applied plots for the phenol concentrations of (0,10,50,100)mg/l are shown in Figures (9,10,11,12) respectively. Kincannon and Stover fixed-film reactor design model were used to calculate the kinetic constants of maximum substrate utilization rate, U_{max} and substrate loading at which the rate of substrate utilization is one-half the maximum rate, k_B, for the RBC (8-9). Only the first stage data were used in this analysis since the latter four stages did not achieve a considerable amount of substrate removal. The Procedure to determine the values of U_{max} and K_B from each graph is shown below.

$$\text{Y Intercept} = 1/U_{max}$$

$$\text{Slop of line} = K_B/U_{max}$$

The values of U_{max} and K_B at different phenol concentrations are shown in Table VI. The data of the phenol concentration as a function of stage was plotted in Figure 13. The results were very similar with sBOD removal. Most of the removal was done at the first stage and a negligible amount of removal was achieved at the latter stages. The removal efficiency of the first stage is 98% for all three different phenol concentrations. Therefore, only first stage data were used for the rest of the analysis.

The amount of phenol removed (lbs/day/1000 ft^2) Vs. the amount of phenol applied (lbs/day/1000 ft^2) for the three phenol concentrations is shown in Figure 8. A straight line is drawn through these values which also represents a very high removal of phenol in this system. The values of the applied and removed phenol are listed in table VII; alongside these values the phenol removal rate for the first stage, P_1, was also calculated by the same equation used in calculating. K_1 values. The phenol removal rate is drawn as a function of applied phenol (lbs/day/1000ft^2) in figure 15. The results shows that there was lower phenol removal rate at low amount of phenol applied (10mg/l) and had higher removal rate at higher amount of phenol applied (50 mg/l, 100 mg/l). The removal rate seems to reach the same value at the higher amount of the applied phenol.

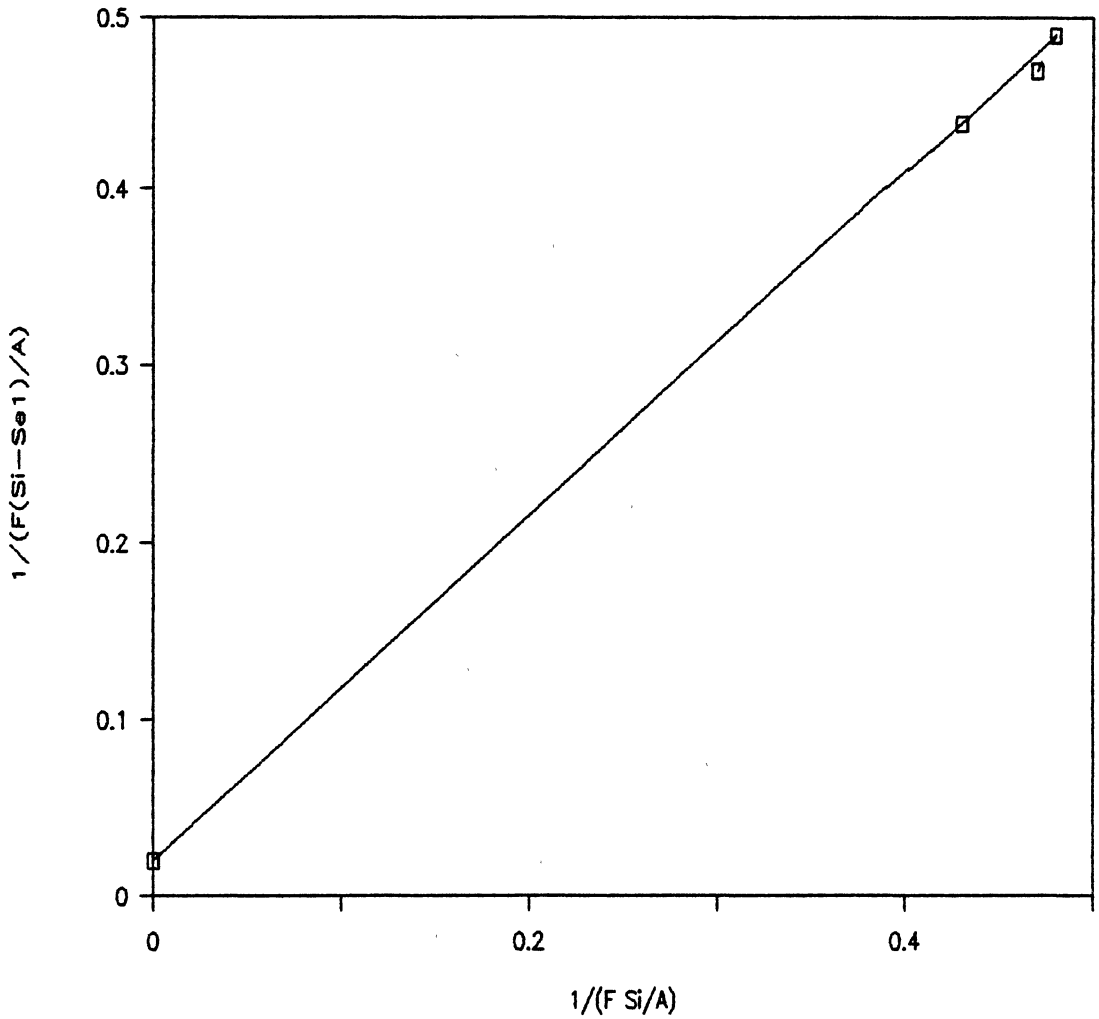


Figure 9. Graphical Determination of U_{max} and K_b for Kincannon and Stover Design Model With Phenol Concentration of(0) mg/l

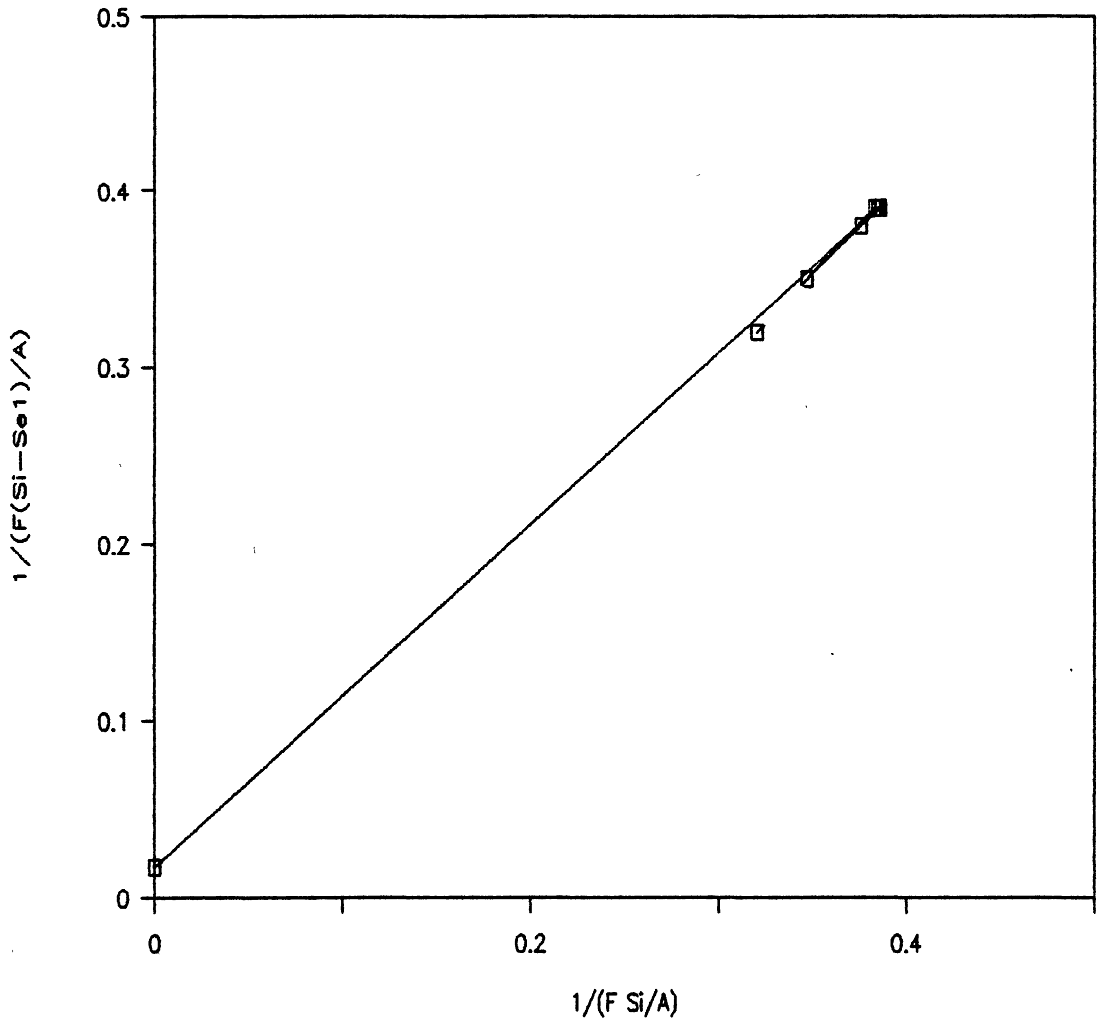


Figure 10. Graphical Determination of U_{max} and K_b for Kincannon and Stover Design Model With Phenol Concentration of(10) mg/l

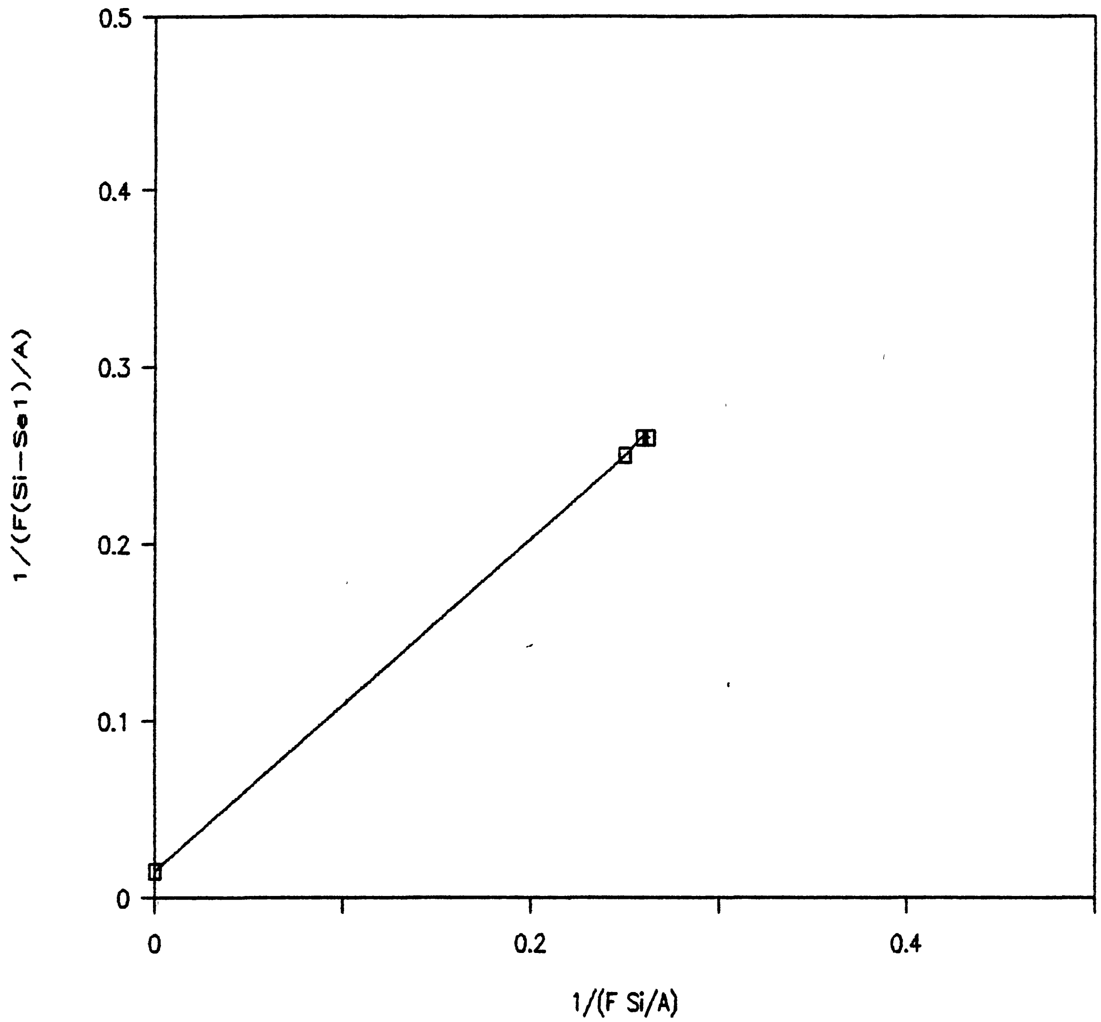


Figure 11. Graphical Determination of U_{max} and K_b for Kincannon and Stover Design Model With Phenol Concentration of(50) mg/l

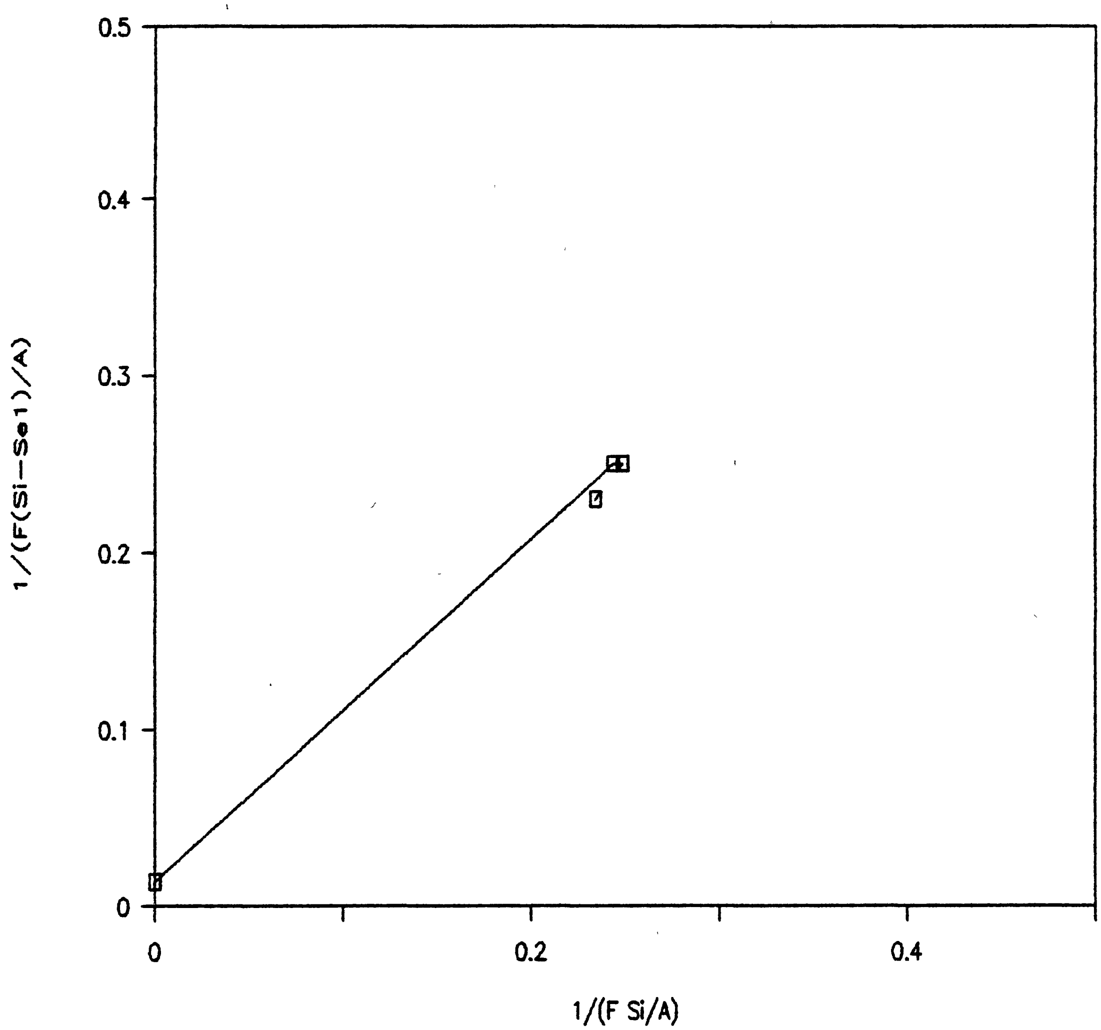


Figure 12. Graphical Determination of U_{max} and K_b for Kincannon and Stover Design Model With Phenol Concentration of(100) mg/l

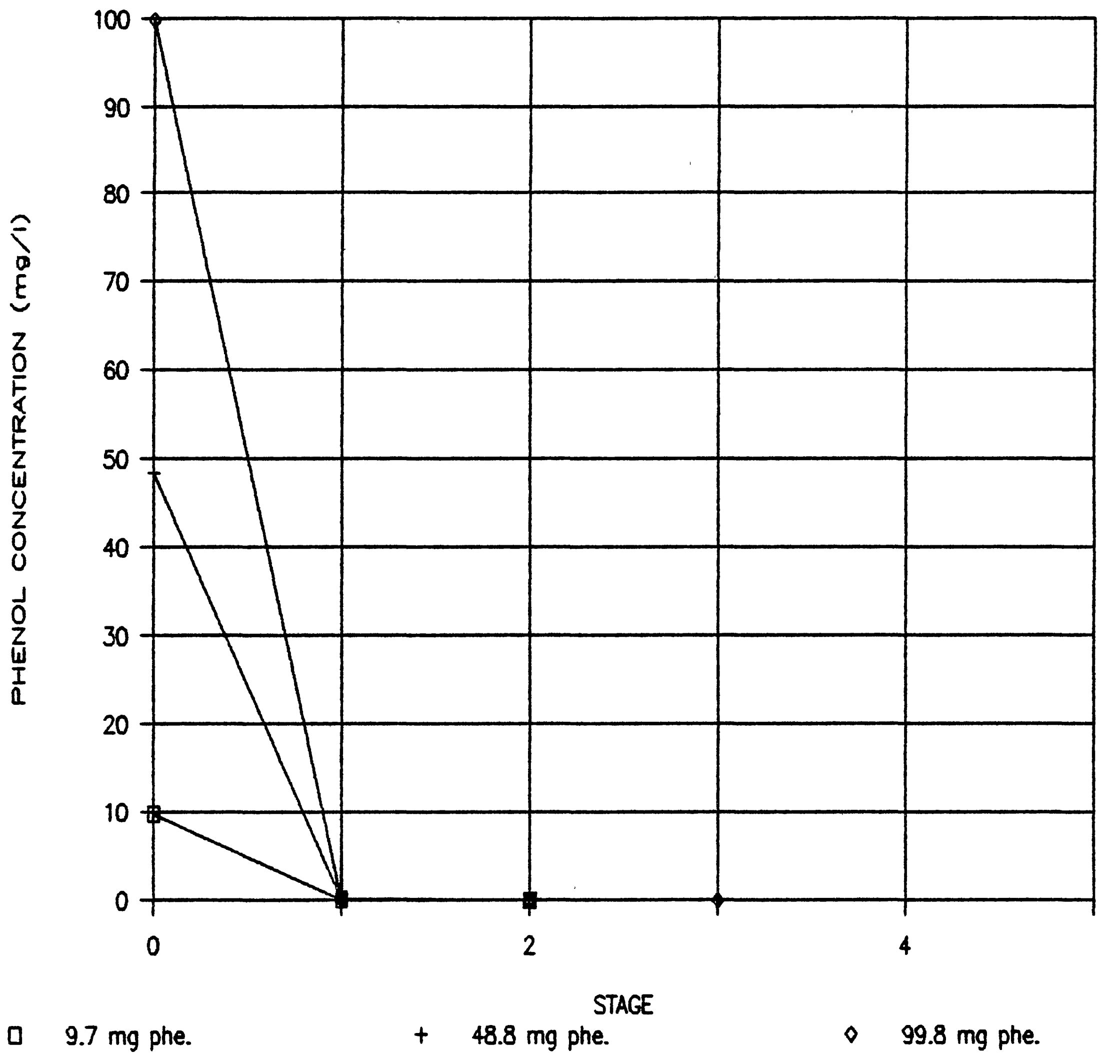


Figure 13. Phenol Concentration Versus Stage Hydraulic Loading of 0.24 GPD/ft^2

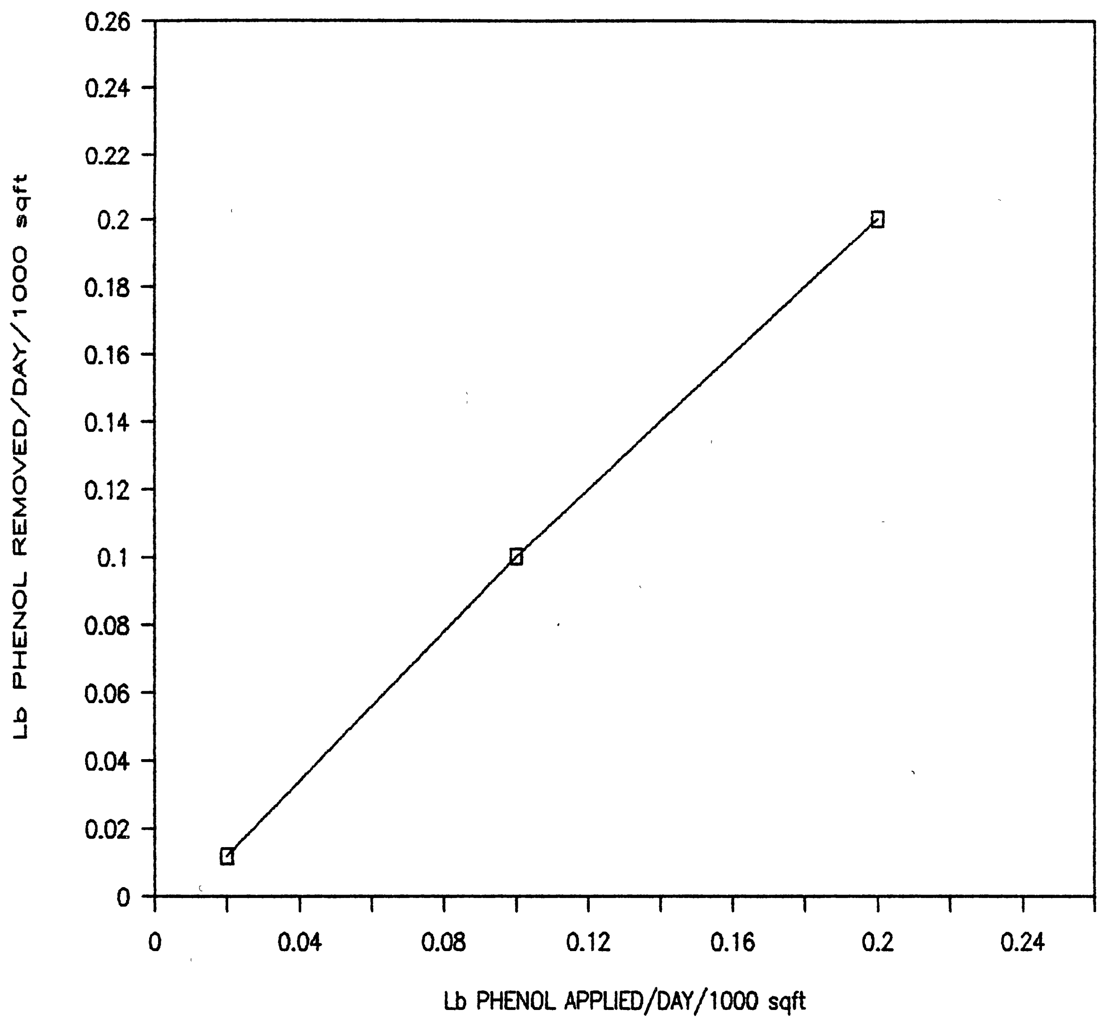


Figure 14. Phenol Removal (LB/day/1000ft²) Versus Phenol Applied (LB/day/1000ft²)at Hydraulic Loading of 0.24 GPD/ft²

TABLE VI

SUMMARY OF U_{max} and K_B FOR DIFFERENT PHENOL CONCENTRATIONS

DESIRABLE PHENOL mg/l	U_{MAX} Lb/Lb day	K_B Lb/Lb day
0	50	49.2
10	59	57.8
50	66.7	65.3
100	71.4	70

TABLE VII

SUMMARY OF ORGANIC LOADING APPLIED, ORGANIC LOADING REMOVED, SUBSTRATE REMOVAL RATE FOR PHENOL

DESIRABLE PHENOL mg/l	ACTUAL PHENOL mg/l	PHENOL APPLIED LB/day/1000ft²	PHENOL REMOVED LB/day/1000ft²	P1
10	9.74	0.02	0.012	5.1
50	48.3	0.1	0.1	6.3
100	99.8	0.2	0.2	6.3

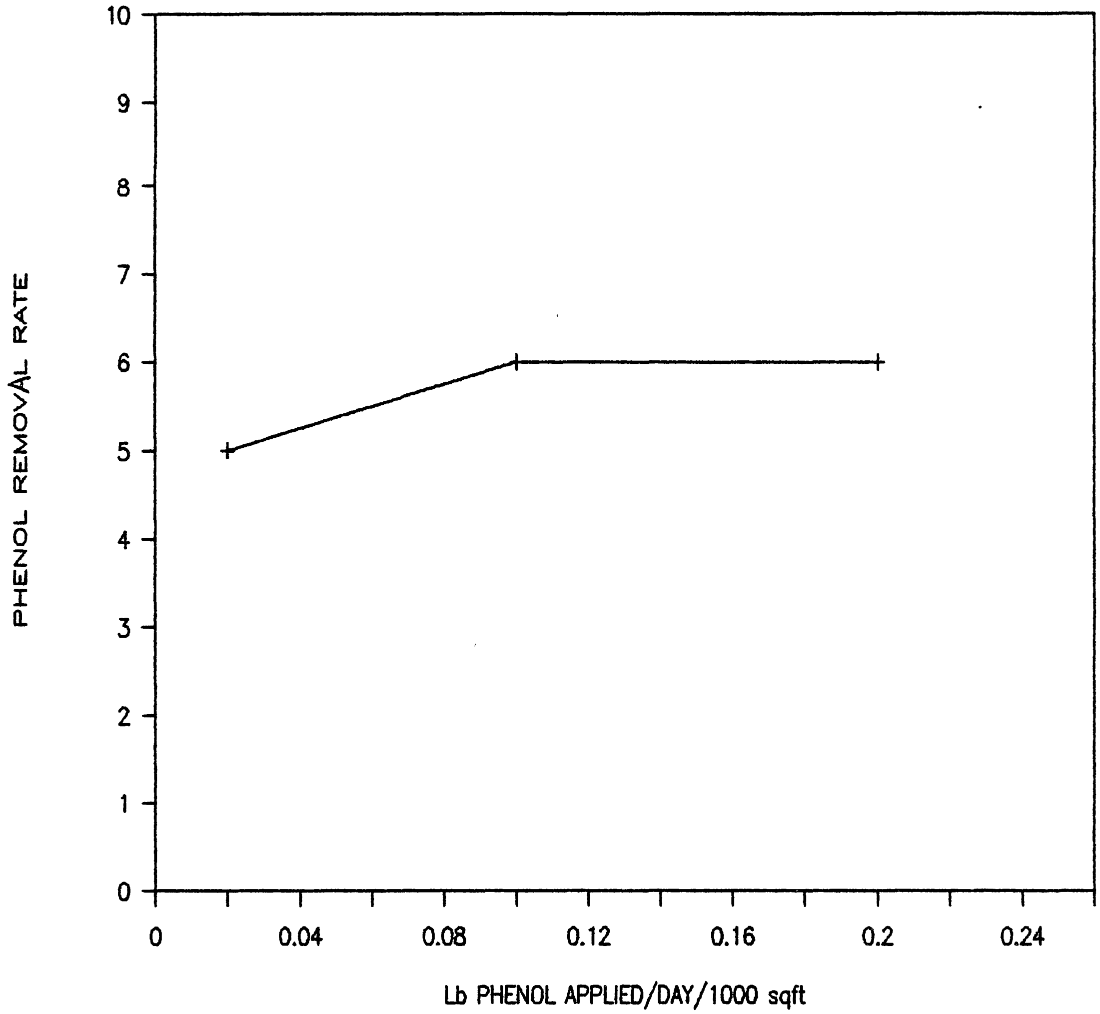


Figure 15. First Stage Phenol Removal Rate Versus Phenol Applied (LB/day/1000ft^2)

CHAPTER V

DISCUSSION

The purpose of this investigation was to study the removal characteristics of Rotating Biological Contactor process in terms of removing phenol as a pollutant along with other soluble organics existing in the waste.

The results obtained from this investigation provide a definite observation about the performance of Rotating Biological Contactor. Very little research, if any, has been conducted on the performance of RBC in treating priority pollutants found in the waste. This study provides encouraging results in looking at the Rotating Biological Contactor as one of the important design processes in treating polluted wastewater.

It can be seen in Figures 1 and 2 that all four $sBOD_5$ concentrations applied had a distinct slope change following the first stage of the system. Also in these graphs a zero order kinetics is shown after the first stage due to low amount of substrate remaining. The values of each of the four $sBOD_5$ concentrations remaining in the first stage, indicated in Table III, are almost the same, This indicates that the removal efficiency had increased with the increase of phenol in the waste. One factor which lead to such high removal was the small diameter of the unit. Kincannon and

Stover (8,10) reported that the smaller the diameter of the RBC, the higher the treatment efficiency with the same wastewater. Another main factor for such a high removal is the readily degradable form of the waste.

The information shown in Figure 3 for the organic loading removed as a function of the total organic loading applied, indicates that at $sBOD_5$ organic loading around 0.4 to 0.9 (lbs $sBOD_5$/day/1000 ft^2) the $sBOD_5$ organic removal is almost the same value. The removal efficiency for the four different applied loads seems to be 98% . The low organic loading on the unit was another factor in high removal efficiency. It can also be concluded that the phenol concentration at this load has no effect on the removal efficiency of the system.

Figures (5,6,7,8) shows that the substrate removal rate is the same in all the applied organic loads with different phenol concentrations, which very much prove that the phenol had no effect on the unit performance. The steady value of the substrate removal rate, K1,also indicate that the unit could still treat more polluted feed.

Using Kincannon and Stover model, the values of U_{max} and K_B were found for the concentrations of(0,10,50,100)mg/l as shown in Figures (9,10,11,12) respectively. The result shows that U_{max} and K_B was found to have higher values as the phenol concentration increase. This indication show that the phenol is a highly degradable compound and the microorganisms were able to remove most of the phenol.

The graphs obtained by GC analysis are very much consistent with the graphs obtained by $sBOD_5$ analysis. Most of the phenol has been removed in the first stage. Very small amounts existed in the second stage and it was below the detection limit in the third stage in most of this investigation (see Table IV). It is very clear that the microorganisms in the first stage are removing most of the phenol. In figure 14 the straight line represent a high removal treatability of the system and it also show that the phenol has been removed constantly by the microorganisms in the first stage. In figure 15 the change of the phenol removal rate to a lower value at a higher concentration of phenol could have been caused by the change of microbial predominance. It can also be noted in this graph, the phenol removal rate at concentrations of (50,100) mg/l had a higher value than the substrate removal rate values at these concentrations. This also due to the high degradation of phenol.

CHAPTER VI

CONCLUSIONS

The results of this study support the following conclusions:

1. The phenol is a highly degradable compound and can be definitely removed by the microorganisms if existed in the concentrations studied in this investigation.

2. The existence of phenol in the concentrations studied in this investigation had no effect on the treatment efficiency.

3. The Rotating Biological Contactor is an effective method of treating waste polluted with phenol.

SUGGESTIONS FOR FURTHER STUDY

Based on the finding of this study, the following suggestions are made for future study.

1. Run higher phenol concentrations to realize the changes in the removal efficiency.

2. Study the same investigation on a pilot or full scale unit and compare the performance.

3. Study the effect of hydraulic loading on the same investigation.

4. Run a combined of pollutants and study the systems performance.

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