A STUDY OF FOUR PRIORITY POLLUTANTS, PHENOL, M-CRESOL, 2,4-DICHLOROPHENOL, AND 2,4-DINITROPHENOL, CONCERNING THEIR FATE AND EFFECT IN THE ACTIVATED SLUDGE SYSTEM

By

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Bachelor of Science in Civil Engineering

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Stillwater, Oklahoma

1984

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, 1986

A STUDY OF FOUR PRIORITY POLLUTANTS, PHENOL, M-CRESOL, 2,4-DICHLOROPHENOL, AND 2,4-DINITROPHENOL, CONCERNING THEIR FATE AND EFFECT IN THE ACTIVATED SLUDGE SYSTEM

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ACKNOWLEDGEMENTS

I wish to thank my principle adviser, Dr. Don F. Kincannon, for his guidance, patience, and assistance. I would also like to express my appreciation to Dr. John N. Veenstra and Dr. William F. McTernan for serving on my committee.

My thanks also go to my fellow students in the water and waste water research center for their friendship and help.

A sincere expression of gratitude is extended to my mother, Amina Y. Jamouse. Without her love, encouragement and support none of this would have been possible. I dedicate this work to her. I would also like to sincerely thank my brothers, Mahmoud and Zuhair and my sister Entissar for their encouragement and support.

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CHAPTER I

INTRODUCTION

A large amount of money and effort have been spent dealing with cleaning up and improving waters that have been contaminated with different types of priority pollutants. Phenolic compounds such as Phenol, 2,4-Diclorophenol, 2,4-Dinitrophenol, and m-Cresol are some of the acid extractable organic compounds that has been listed by the EPA under priority pollutant (Total of 129 element and compounds).

Biological treatment methods, such as activated sludge, trickling filter, RBC, and biological tower, are the methods that have been widely used for the treatability of waters that contain organic priority pollutants. Of these biological treatment methods, the activated sludge system has become very popular among researchers and practicing engineers. The reasons for it's popularity are (1) high treatment efficiency, (2) flexibility of treating variable wastewater generated by municipal and industrial sources, and (3) operational control features.

The objectives of this research are to study (1) the feasibility of activated sludge system for the treatability of a combination of four phenolic compounds, (2) the

compatibility of phenolic compounds with the treatment of synthetic wastewaters utilizing the activated sludge process, and (3) the effect of mean cell residence time on the treatability of wastewater containing four phenolic compounds.

CHAPTER II

LITERATURE REVIEW

A. Mean Cell Residence Time

Mean cell residence time (SRT) has been established as a useful parameter because of its basic relationship to bacterial growth in the activated sludge basin and its accuracy on design calculations. For these reasons, mean cell residence time has been considered in many of the present activated sludge design models. The mean residence time is equal to the mass of the microorganisms in the process divided by the rate at which the microorganisms are wasted from the process, including the microorganism which might leave the system with the effluent. The mean cell residence time is also equal to the reciprocal of the specific growth rate, which is used as a parameter in some design equations.

In 1968, Jenkins and Garrison (1) showed that effluent quality and nitrification could be regulated by controlling the sludge age. Lawrence and McCarty (2) applied the mean cell residence time as a primary parameter to control treatment plant design. Also, by the use of material balance approach to describe biological reactions, food to

microorganism ratio (F/M), and specific utilization rate (U) were shown to be functions of mean cell residence time.

B. Phenolic Wastes

The four phenolic compounds selected for this investigation were phenol, m.cresol, 2,4-dichlorophenol, and 2.4-dinitrophenol. Compounds whose common functional group is a hydroxyl attached to a benzene ring are classed as phenols. Other functional groups may also be present in a given phenol (3). Phenol (C_6H_5OH), also known as carbolic acid, is the simplest form of the phenolic compounds and is extremely toxic to bacteria in a concentrated solution. Research involved with phenol showed that phenol concentration of 2000 mg/l was bactericidal but that lower concentrations could be degraded (4).

Phenol reacts with chlorine to produce mono, di-,or trichlorophenoles which can cause taste and odor problems to drinking water (5). Phenol also reacts with nitrogen dioxide to produce mono, di-, or trinitrophenols. Other phenolic compounds are cresols, which are also known as methylphenols.

Creosote oil, which can be obtained by the distillation of coal tar and beechwood tar, contains a large amounts of phenols and cresols. It is widely used as a wood preservative. In general, phenolic compounds exist as natural compounds in industrial wastes from coal-gas, coal-coking, and petroleum industries as well as in a wide

variety of industrial wastes from processes that involve the use of phenol as a raw material.

Beginning in 1940, the U.S. Public Health Service imposed a recommended standard of 1 μg/l for phenols in water. The term "phenols" in general includes phenols, cresols, and xylenols (6). The drinking water standard of 1 μg/l was based on the relatively low taste and odor threshold concentrations of the chlorophenols. Phenols can cause taste and odor problems in drinking water, particularly when water is chlorinated (7). One study (8) reported taste threshold concentration for chlorophenol and 2,4-dichlorophenol of 4 and 8 μg/l, respectively.

C. Priority Pollutants Treatability

For the past few years the removal of organic pollutants from industrial wastewaters has been getting a great deal of consideration in terms of specific organic pollutants rather than only BOD, COD, or TOC. Among the five treatment schemes considered by the EPA for priority pollutants treatability, biochemical oxidation offers the potential advantages for the priority pollutants treatment. In an investigation conducted to determine the fate of priority pollutants subjected to biological treatment, eight of the organic pollutants in the effluent were reduced by at least 50% in the effluent (9). Coe reported a phenol removal efficiency between 90% and 95% for a refinery waste water containing 100 mg/l phenol, which was treated in an

activated sludge process at hydraulic detention time of 9-12 hours (10).

In a study in the biological treatment of coke plant wastewaters (11), an activated sludge powdered activated carbon unit was operated. The unit was operated at mean cell residence times of 7, 15.7, and 45 days and at a hydraulic residence times of 16.5, 18.2, and 29 hours respectively. The study showed that effluent quality was independent of SRT. In all the conditions tested, BOD was reduced to 4-8 mg/l and phenol was reduced by approximately 99.9%. The influent BOD ranged from 1235-1268 mg/l and the influent phenol concentrations were 386 mg/l for SRT of 7 days and 565 mg/l for SRT of 45 days.

Kincannon, et al. conducted an investigation dealing with the compatibility of semiconductor industrial wastewater with municipal activated sludge systems (12). Part of their study was the treatment of industrial wastes that contained 18 organic pollutants, which including phenol and 2,4-dinitrophenol. Their investigation showed that the increase of the industrial wastewater concentration from 0.5% to 3% had no effect on the removal efficiency of TOC. TOC removal efficiency of 90% was achieved.

In another investigation in predicting treatability of multiple organic priority pollutant wastewaters from single-pollutant treatability studies (13), bench-scale, continuous flow activated sludge systems were used to treat synthetic wastewater containing priority pollutants. This investiga-

tion was conducted to study the treatability of priority pollutants on both single and combined priority pollutants. Table I summarizes some of the results achieved.

In removing priority pollutants from a pharmaceutical wastewater (14) study, Kincannon and Esfandi reported activated sludge removal efficiencies of 95.8% for phenol, 93.8 for 2-nitrophenol, 89.4% for 4-nitrophenol, 94.2% for 1,1,2-trichloroethane, and 94.5% for 1,1-dichloroethylene.

Stover and Kincannon (15) had conducted research dealing with the biological treatability of specific organic compounds found in chemical industry wastewaters. Bench-scale activated sludge systems were used for their research, and the systems were operated at SRT values of 2, 4, and 6 days. Their study showed that the twelve individual specific organic compounds were removed by at least 95% (highest of 99.9%). Changes in the SRT value were found to have little or no effect on the specific organic compounds except for Tetrachloroethane, nitrobenzene, and dichloro-phenol where the removal efficiencies were decreased for smaller SRT values. Influent BOD were shown to be removed by at least 95.6% under all conditions.

In a study conducted to treat a wood preserving effluent containing pentachlorophenol by activated sludge (16), Jank and Fowlie were able to reduce the influent phenol concentration by over 99% while obtaining a BOD removal efficiency of 97%. Initial phenol concentration was 225 mg/l and BOD of 570 mg/l. They were also able to

TABLE I

TOXIC ORGANIC PERCENT REMOVAL
ACHIEVED BIOLOGICALLY

Compound	Single Units	Combined Units
Group I		
Tetrachloroethane	33.8	30.1
Nitrobenzene	97.8	33.8
2,4-Dichlorophenol	95.2	77.1
Group II		
Phenol	99.9	99.9
1,2-Dichlorobenzene	78.2	99.9
1,2-Dichloroethane	0.0	0.0
Group III		
2,4-Dinitrophenol	99.3	99.2
1,3-Dichlorobenzene	0.0	0.0
1,1,1-Trichloroethane	0.0	0.0

Source ref. 13

achieve phenol removal efficiency of 97% when the initial phenol concentration was 570 mg/l, but the BOD removal efficiency was as low as 88% when the initial influent BOD was 1400 mg/l.

CHAPTER III

MATERIALS AND METHODS

To study the removal efficiency and the effect of four phenolic compounds in the activated sludge system, two complete-mix, bench scale, continuous flow activated sludge reactors were operated under closely controlled conditions. The first reactor was the control unit which was fed with no phenolic compounds. The second reactor was fed with four phenolic compounds.

The two units were operated at a constant flow rate of 6.5 ml/min, and at mean cell residence time (SRT) of 4 and 8 days.

A schematic of the bench-scale activated sludge system is shown in figure 1.

A. Description of The Bench Scale Units

The two reactors were constructed of steel material. Each reactor consist of two compartments, the aeration chamber with 3.1 liter volume and the settling basin with 3.2 liter volume, separated by an adjustable baffle.

The aeration chamber was supplied with air from two fine bubble air diffusers. An airflow rate in excess of 2 liter per minute, monitored through a Gelman air flow

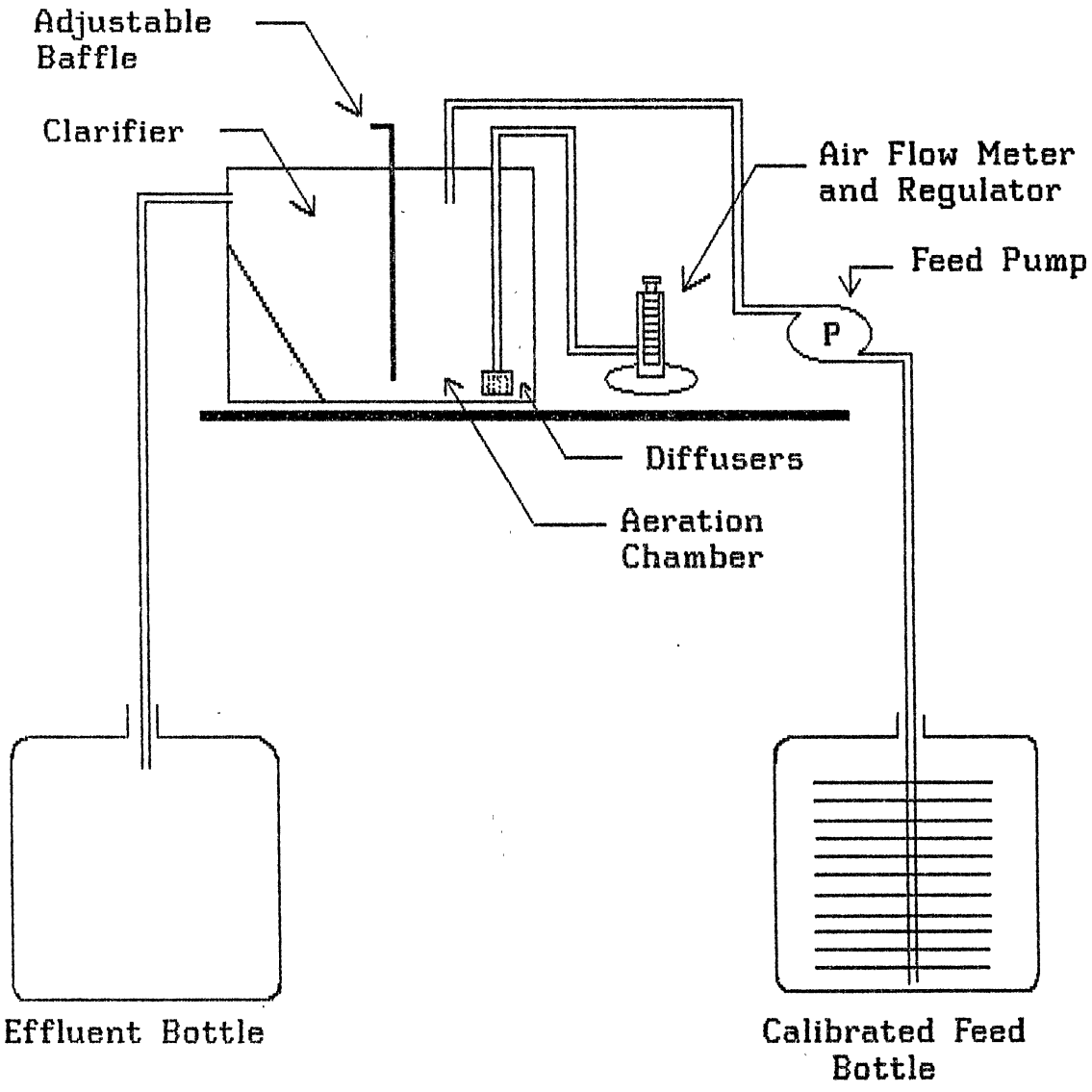

Figure 1. Experimental Reactor

meter, was used to provide sufficient dissolved oxygen,good mixing, and a good recycle in the aeration chamber.

Piston type pumps were used to provide continuous feed to the system. P.V.C. type tubes were used to deliver the feed to the pump and then to the reactor.

Calibrated glass bottles were used to hold the feed and and the effluent. To prevent bacterial growth, the bottles and the tubes were regularly cleaned with chlorinated water and rinsed out with tap water.

B. Synthetic Wastewater

The chemical composition of the wastewater and nutrients are listed in Table I. Stock solutions of the chemicals listed in Table II were made and mixed in a 25 liter capacity bottle, and the mixture was diluted to 20 liters with tap water to makeup a feed solution for 2 days. The feed pumped to the control unit,which had no phenolic compounds in it, was designed to have a chemical oxygen demand of approximately 250 mg/l. The feed pumped to the phenol unit will have a chemical oxygen demand higher than 250 mg/l due to the phenolic compound which is a source of carbon.

The nutrients (ammonium chloride, phosphoric acid, magnesium sulfate, manganese sulfate, calcium chloride, and ferric chloride) were added in proportion to the carbon source of the dextrose only.

TABLE II

COMPOSITION OF SYNTHETIC WASTEWATER

Constituent	Concentration
Carbon Mix:	
Dextrose	417 mg/l
Phenol*	0.0255 ml/l
m-Cresol	00.00484 ml/l
2,4-Dichlorophenol	10.0 mg/l
2,4-dinitrophenol	10.0 mg/l
Salt Mix:	
Ammonium Chloride, NH_4Cl	125 mg/l
Phosphoric Acid**, H_3PO_4	19.6 mg/l
Magnesium Sulfate, $MgSO_4.H_2O$	41.6 mg/l
Manganese Sulfate, $MnSO_4.H_2O$	4.17 mg/l
Calcium Chloride, $CaCl_3$	4.17 mg/l
Ferric Chloride, $FeCl_3.{}_6H_2O$	0.417 mg/l

*Liquidized Phenol (91.7% Phenol)
**Phosphoric Acid concentration of 85%

The pH of the feed and the mixed liquor was checked and adjusted if required. The pH of the system was maintained within the range of 6.8 to 7.5.

C. Initial acclimation and Startup

The initial seed of microorganisms was taken from a bench-scale activated sludge system (similar to the one previously described, but acetic acid, ethyl alcohol, ethylene glycol phenol, and glucose were its sole carbon source). The seed of microorganisms was divided between the control unit, where dextrose was the sole carbon source, and the phenolic unit, where dextrose, phenol, m-cresol, dichlorophenol, and dinitrophenol were the carbon source. Since the concentration of the phenolic compounds in the feed was not very high, there was no need to reduce their concentration in order to start the reactors. Wasting of the mixed liquor was postponed until the solids concentration had built up to the desired value and the effluent solids reduced to an appropriate level.

D. Operation of Pilot Plant

The sludge age (SRT) was maintained constant during the operation period by controlling the rate of wastage. Wasting from the reactor was made once a day according to the following equation.

$$F_w = \frac{VX/SRT - FX_e}{X_r - X_e}$$

where

F_w = wasting rate (l/day)

V = reactor volume (liters)

X = mixed liquor suspended solids (mg/l)

SRT = sludge retention time (days)

F = influent flow rate (l/day)

X_e = effluent solid concentration (mg/l)

X_r = recycled solid concentration (mg/l)

X_r = X

The baffle, which separate the aeration basin from the settling tank, was adjusted to approximately half an inch away from the bottom of the reactor.

The system was allowed to acclimate for a month before data were collected. Also, when settling was bad during the period of study, data were not collected.

E. Analytical Procedure

The experimental data necessary to investigate this research consisted of biological suspended solids concentration (S.S), five day biochemical oxygen demand (BOD_5), pH, and phenolic compounds concentration.
The following techniques and equipment were used to measure these parameters.

1. Biological Suspended Solids

Biological suspended Solids determination were performed daily by using fiber glass filters (45-μ pore

size). The filter pads were placed in an aluminum tare pans in a desiccator at room temperature. The initial weight of the tare pans, including the filters, were measured by using a Mettler Instrument Corporation balance. After the filtration of a known sample volume, the tare pans were placed in an oven to dry their contents at 103°C for at least one hour. The tare pans were then returned to the desiccator to cool off, and weighed to obtain the final weights.

Hence,

$$S.S = \frac{\text{final weight - initial weight}}{\text{volume of sample}}$$

2. Biochemical Oxygen Demand

Feed and effluent samples were obtained at the time the feed was made. The samples were filtered by using fiber glass filters. BOD_5 for the feed and effluent were obtained in accordance with standard methods (17). The samples that contained phenolic compounds were seeded from the mixed liquor of the phenolic unit; while the samples that did not contain phenolic compounds were seeded from the control unit mixed liquor.

3. pH

The pH of the reactor was obtained by using a Beckman Expandomatic SS-2 pH meter.

4. Phenolic Compounds

The feed and the effluent samples to be analyzed were collected at the same time the feed was made. Samples were then filtered by using fiber glass filters.

In order to obtain the concentration of the phenolic compounds in the sample by using the gas chromatograph (GC), the samples had to be extracted. The extraction method used in this research was the "mini-extraction" method . The "mini-extraction" method consisted of the following procedures:

1. 80 ml of the sample was placed in a flask and the pH was brought to 2 or less by adding 50% concentration phosphoric acid.

2. The sample was then placed in a 100 ml long neck flask.

3. 30 gram of sodium chloride was added to the sample and the sample was shaken until most of the salt dissolved.

4. 1 ml of iso-propyl ether was injected into the sample, the flask was closed with tight cover and shaken for two minutes

5. Less than one millimeter of the floated iso-propyl ether was withdrawn from the neck of the flask by using one milliliter syringe, and placed in a 2 millimeter tightly closed Glass bottle.

The percent recoveries obtained from the mini-extraction method were 63.8%, 89.6%, 98.0%, and 39.0% for

phenol, m-cresol, 2,4-dichlorophenol, and 2,4-dinitrophenol respictively.

3 ul of the extracted sample was then injected into the gas chromatograph to obtain the concentration of the phenolic compounds in the sample.

Perkin-Elmer Sigma 3B, flame ionization detector, gas chromatograph was used for the analysis of the samples. The gas chromatograph was equiped with a glass column filled with 1% sp-1240DA. A computerized integrator was also employed to print out directly the detention time and the area corresponding to each compounds. The specific conditions of the GC analysis are listed in Table III.

TABLE III

SPECIFIC CONDITIONS OF THE GC

parameter	Value
Inject Temp.	200°C
Detector Temp.	200°C
Initial Oven Temp.	70°C
Initial Time	2 minutes
Temp. Icreasing Rate	8°C/min
Final Oven Temp.	175°C
Final Time	10 minutes
Hydrogen Flow	20 Ib/in
Nitrogen Flow	20 Ib/in
Air flow	30 Ib/in

Under the specific conditions listed in Table III, the integrator print out showed that phenol appears after 11.1 minutes at a temperature of 142°C, m-Cresol appears after 12.3 minutes at a temperature of 153°C, dichlorophenol appears after 12.9 minutes at a temperature of 173°C, and dinitrophenol appears after 22.2 minutes at a temperature of 175°C.

Standard curves for the influent and the effluent concentration of each of the phenolic compounds were obtained. Each compound was injected into the GC at several concentrations and the areas for the corresponded concentrations were plotted. Eye measured best fitted line was applied through the plotted points. The standard curves for each compound were then used to determine the specific organic compound concentrations in the influent and the effluent.

CHAPTER IV

RESULTS

Two bench-scale activated sludge units were operated under closely controlled conditions. Mean cell residence time was used as the operating parameter for this research. A hydraulic detention time of 8 hours was maintained throughout the study period. The influent substrate concentration in the control unit was maintained at approximately 240 mg/l BOD while the influent substrate concentration of the phenolic unit was maintained at approximately 280 mg/l BOD. The two units were operated at mean cell residence time of 8 days and later at mean cell residence time of 4 days. Tables IV and V summarize the data obtained for the control and phenolic units respectively.

A. BOD Removal Performance

Changes in the mean cell residence time appeared to have no effect on the effluent BOD of the two units. Adding phenolic wastes to one of the units appeared to have no effect on the effluent BOD. Both the control units and the phenolic unit appeared to have an average BOD removal

TABLE IV

SUMMARY OF STEADY STATE DATA FOR THE CONTROL UNIT

Control Unit	SRT, Days 4	8
Influent BOD_5, mg/L	243	237
Effluent BOD_5, mg/L	3	3
BOD_5 Removal Efficiency, %	99	99
MLSS, mg/L	1333	2936
Effluent Suspended Solids, mg/L	12	12
Solid wastage, mg/Day	981	1027
Specific Utilization Rate, Day^{-1}	0.544	0.240
Food to Microorganism Ratio, Day^{-1}	0.550	0.244

TABLE V

SUMMARY OF STEADY STATE DATA FOR THE PHENOLIC UNIT

Phenolic Unit	SRT, Days 4	8
Influent BOD_5, mg/L	277	278
Effluent BOD_5, mg/L	4	3
BOD_5 Removal Efficiency, %	99	99
MLSS, mg/L	1447	3159
Effluent Suspended Solids, mg/L	12	8
Solid wastage, mg/Day	1026	1159
Specific Utilization Rate, Day^{-1}	0.566	0.260
Food to Microorganism Ratio, Day^{-1}	0.573	0.263
Influent Phenol Conc., mg/L	24.7	24.8
Effluent Phenol Conc., µg/L	448	102
Removal Efficiency, %	98.2	99.6
Influent m-Cresol Conc., mg/L	5	5
Effluent m-Cresol Conc., µg/L	190	66
Removal Efficiency, %	96.2	98.7
Influent 2,4-dich. Conc., mg/L	9.91	9.96
Effluent 2,4-dich. Conc., µg/L	180	78
Removal Efficiency, %	98.2	99.2
Influent 2,4-din. Conc., mg/L	9.54	9.57
Effluent 2,4-din Conc., µg/L	144	<25
Removal Efficiency, %	98.5	>99.7

efficiency of approximately 99% at both mean cell residence times. Figure 2 shows that the BOD removal efficiencies for SRT of 4 days were more consistant than those for SRT of 8 days were variable between 97.3% and 99.7%. Figures 3 and 4 show the effluent BOD versus each sampling day at SRT of 4 and 8 days respectively. The average effluent BOD_5 for the control unit was 3 mg/l at both SRTS, with the difference of extremes being 5 mg/l; while the average for the phenolic unit was 3 mg/l at SRT of 8 days and 4 mg/l at SRT of 4 days, with the difference of extremes being 6 mg/l.

B. Phenolic Wastes Removal Performance

Changes in the mean cell residence time appeared to have little effect on the concentration of phenolic wastes removal efficiency for SRT of 4 and 8 days. Summaries of the phenolic wastes concentration in the influent and the effluent for SRT of 4 and 8 days are presented in table V.

Phenol: Average removal efficiencies of 99.6% and 98.2% were achieved for SRT of 8 and 4 days respectively. The average concentrations of phenol in the effluent were 102 µg/l for SRT of 8 days and 448 µg/l for SRT of 4 days.

M-Cresol: Average removal efficiencies of 98.7% and 96.2% were achieved for SRT of 8 and 4 days respictively. The average concentrations of m-cresol in the effluent were 66 µg/l for SRT of 8 days and 190 µg/l for SRT of 4 days.

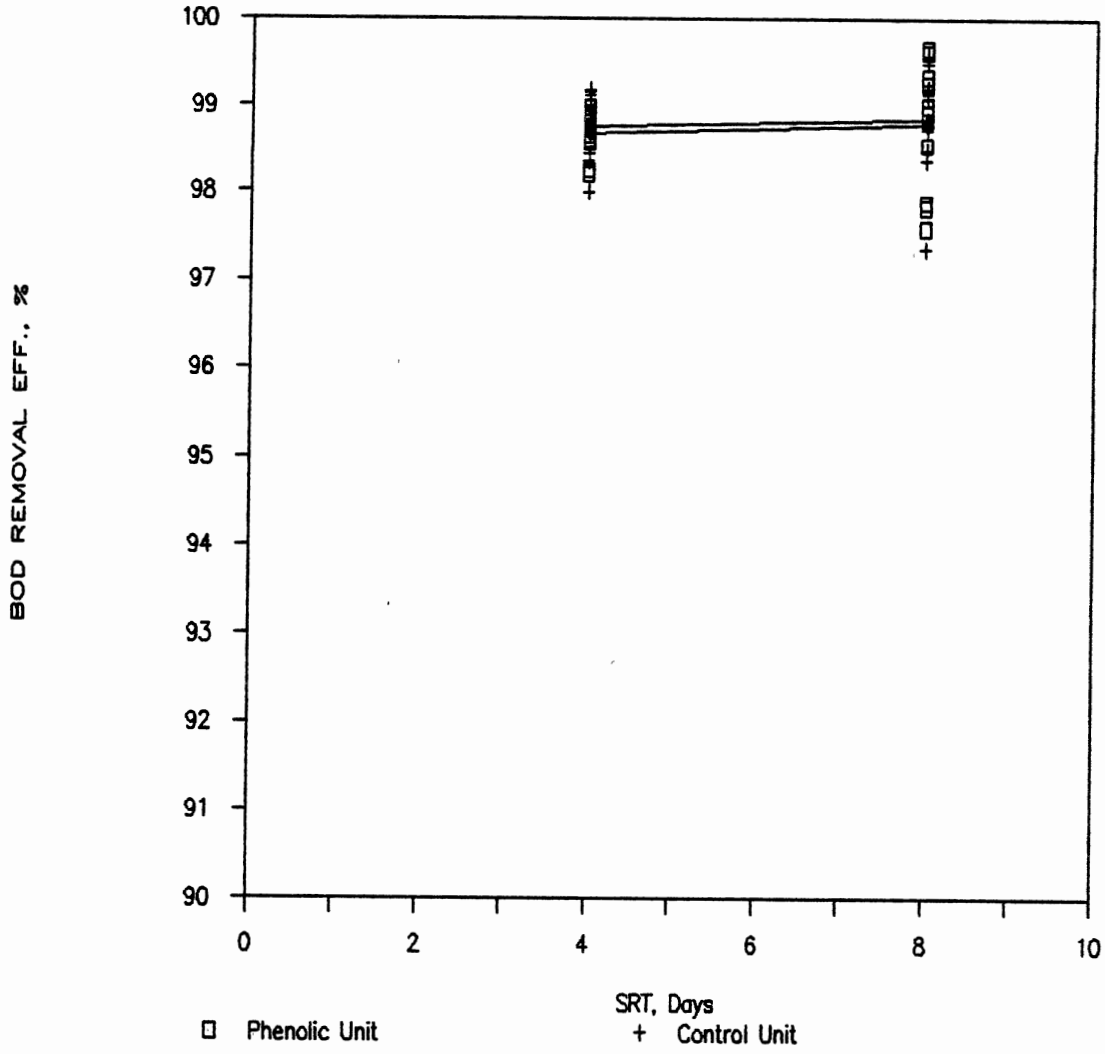

Figure 2. BOD_5 Removal efficiency versus SRT for the Control and the Phenolic Units

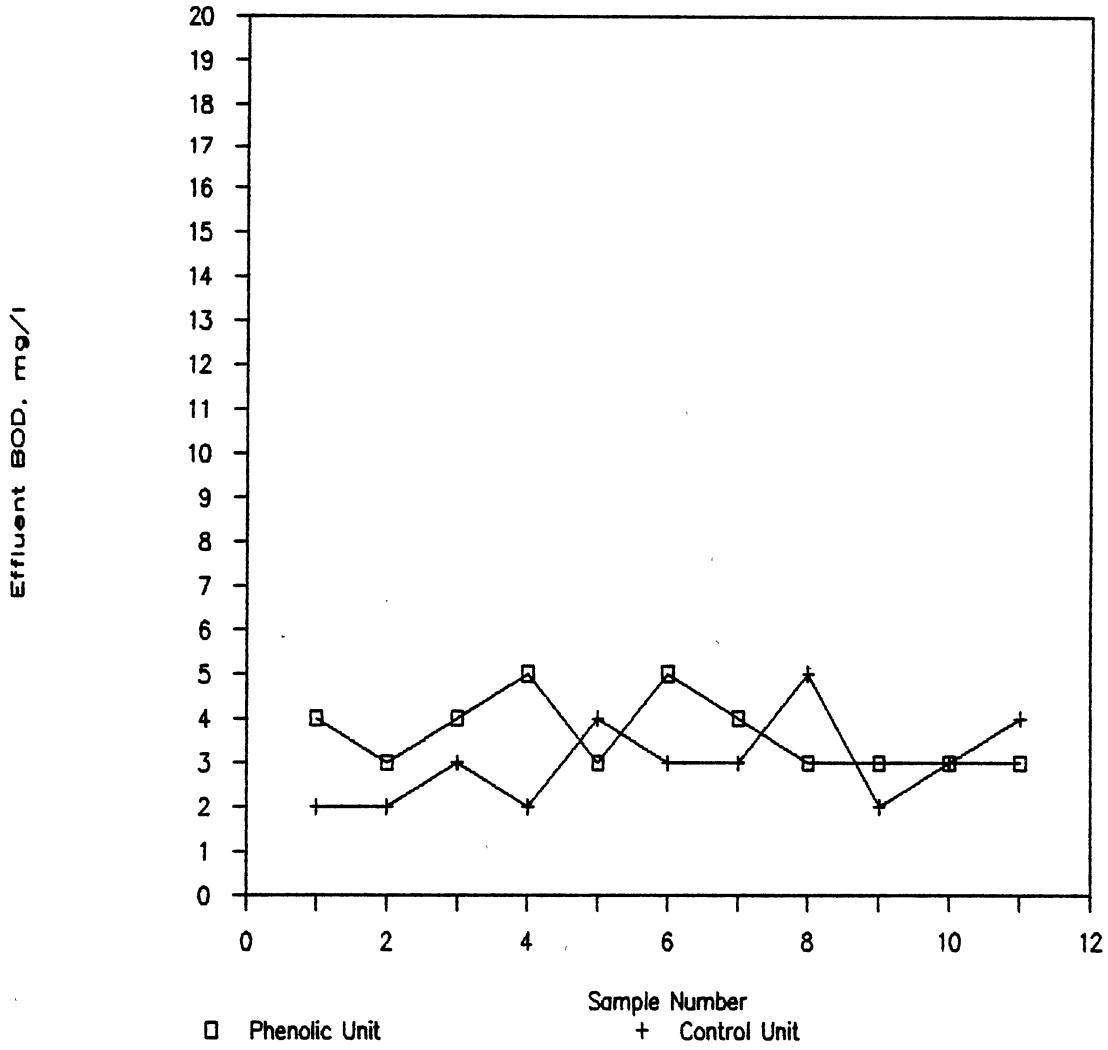

Figure 3. Effluent BOD_5 versus Each Sample Collected at SRT of 4 Days for the Control and the Phenolic Units

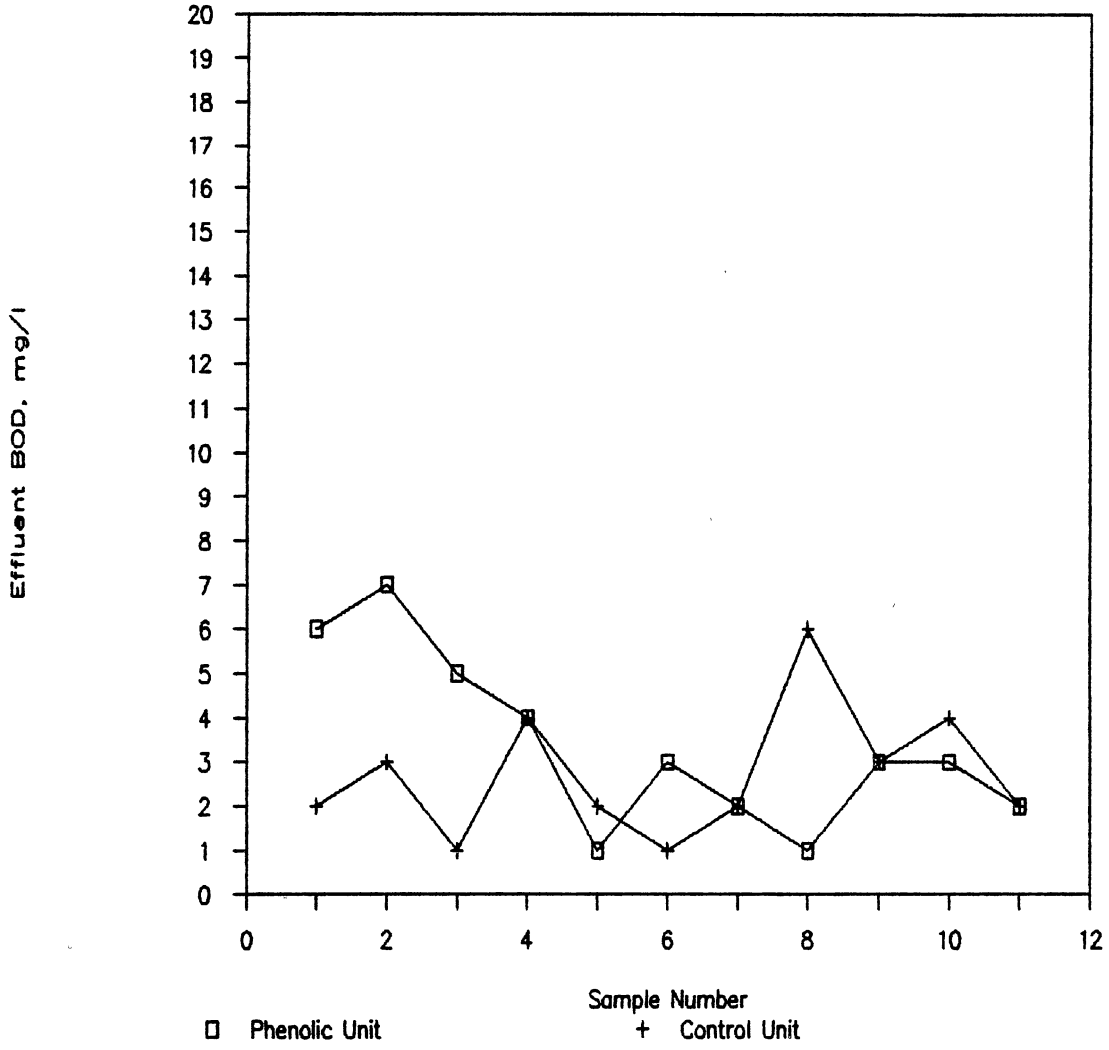

Figure 4. Effluent BOD_5 versus Each Sample Collected at SRT of 8 Days for the Control and the Phenolic Units

2,4-Dichlorophenol: Average removal efficiencies of 99.2% for SRT of 8 days and 96.2% for SRT of 4 days. The average effluent concentration of 2.4-Dichlorophenol was 78 µg/l for SRT of 8 days and 180 µg/l for SRT of 4 days were achieved.

2.4-Dinitrophenol: Removal efficiency over 99.74% was achieved for SRT of 8 days and an average of 98.5% removal efficiency was achieved for SRT of 4 days. The effluent concentration of 2,4-dinitrophenol was less than 25 µg/l for SRT of 8 days and an avreage of 144 µg/l for SRT of 4 days.

Figure 5 illustrate the percentage removal efficiencies for each phenolic waste for SRT of 4 and 8 days. A graphical presentation of percentage removal efficiencies for phenol, m cresol, 2,4-Dichlorophenol, 2,4-Dinitrophenol for each sampling day are found in Figures 6, 7, 8, and 9 respectively.

C. Specific Substrate Utilization Rate

Specific substrate utilization rate (U) is the rate of substrate utilized per day to microorganism concentration. The following equation was used to calculate the values of the specific substrate utilization rate.

$$U = \frac{F\ (S_i - S_e)}{X\ V}$$

where

F = influent flow rate, l/day

S_i = influent BOD_5, mg/l

S_e = effluent BOD_5, mg/l

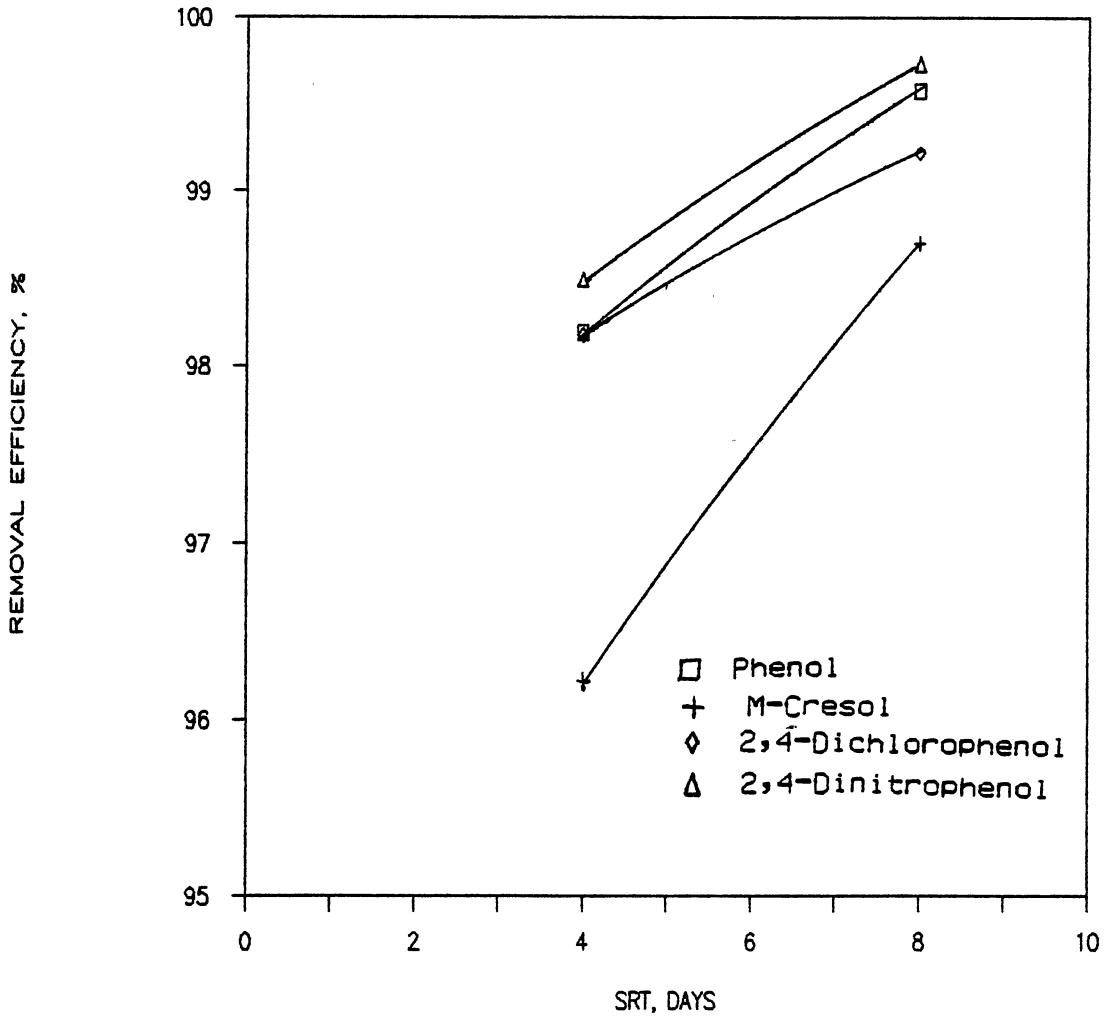

Figure 5. Phenolic Wastes Removal Efficiencies versus SRT

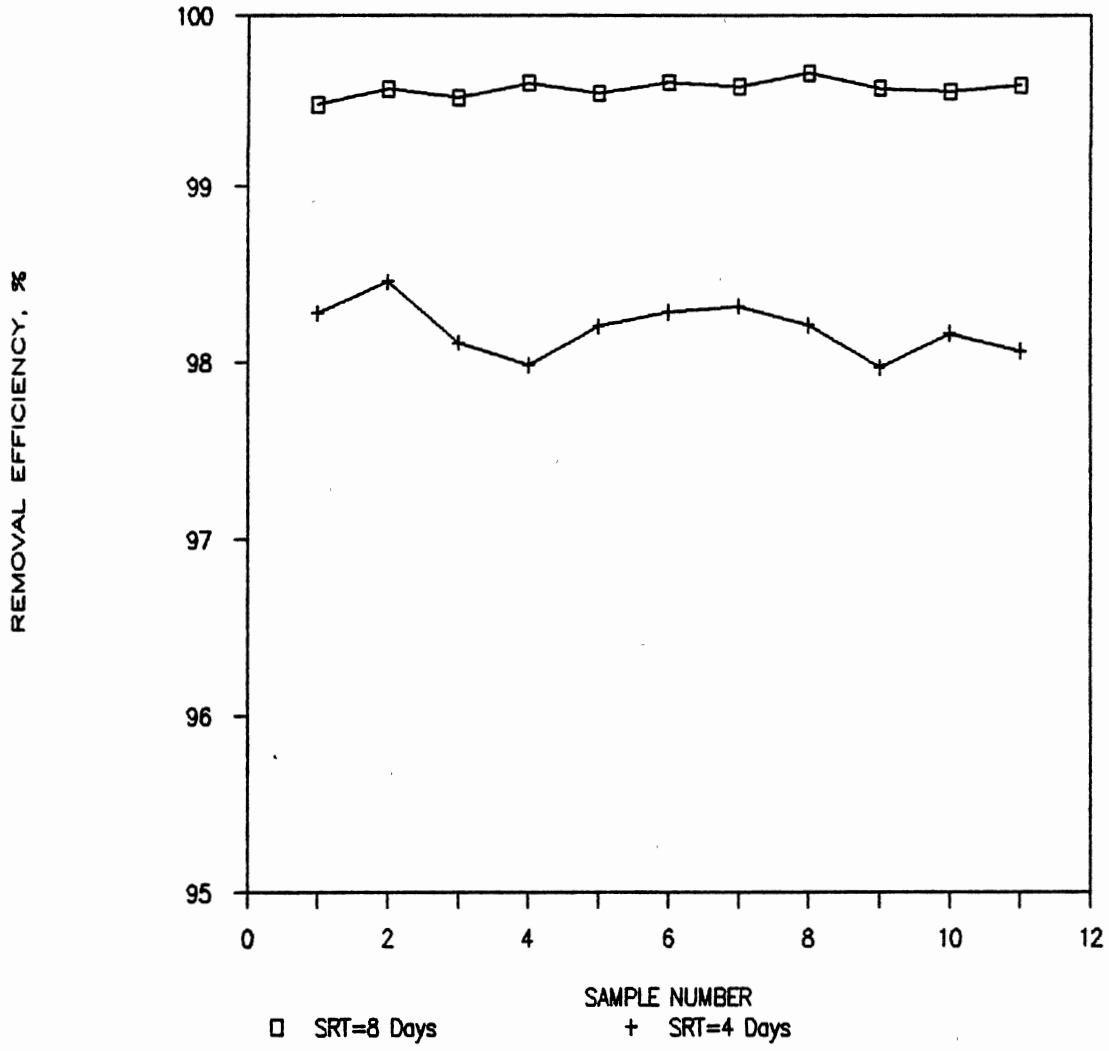

Figure 6. Phenol Removal Efficiency for the Collected Samples at SRT of 4 and 8 Days

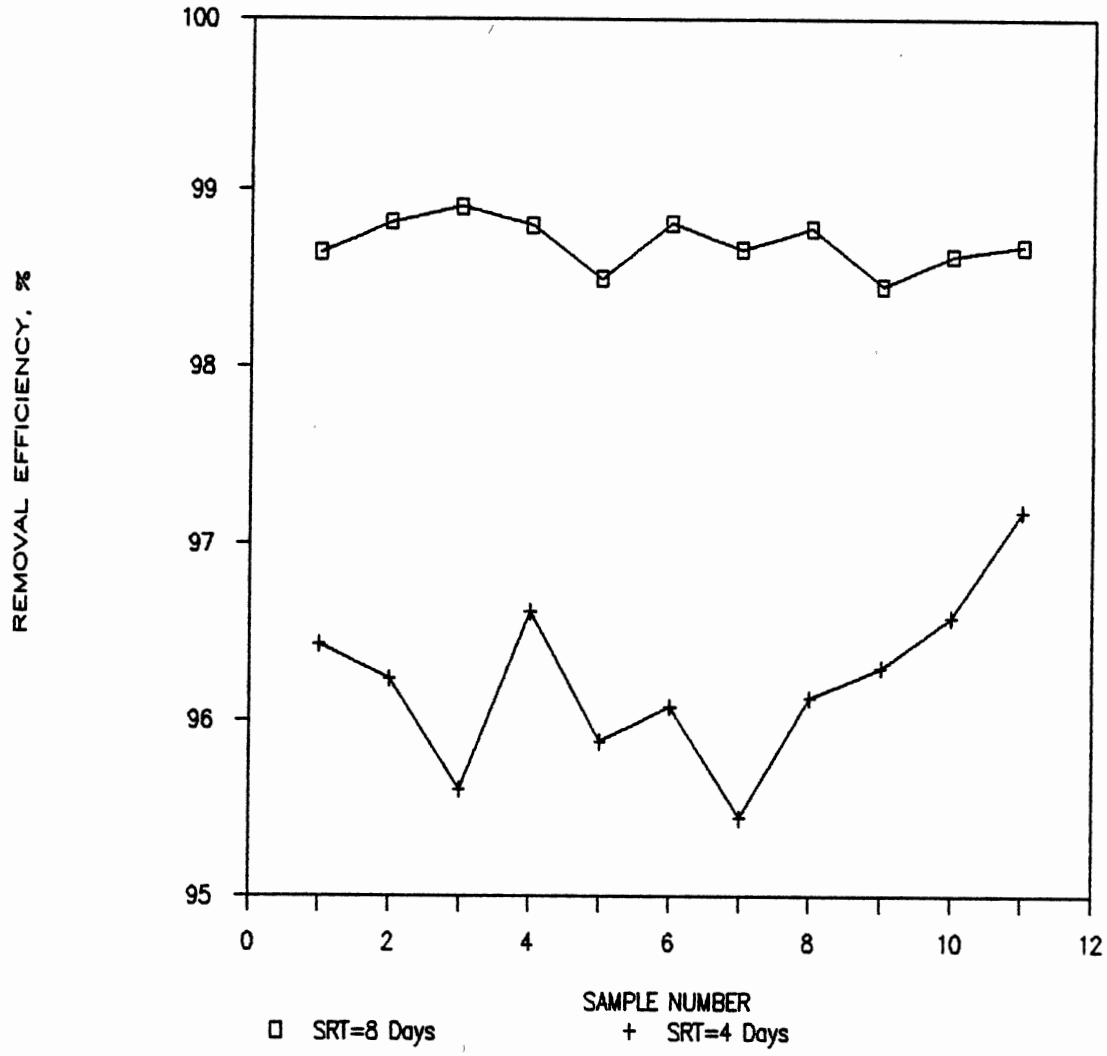

Figure 7. M-Cresol Removal Efficiency for the Collected Samples at SRT of 4 and 8 Days

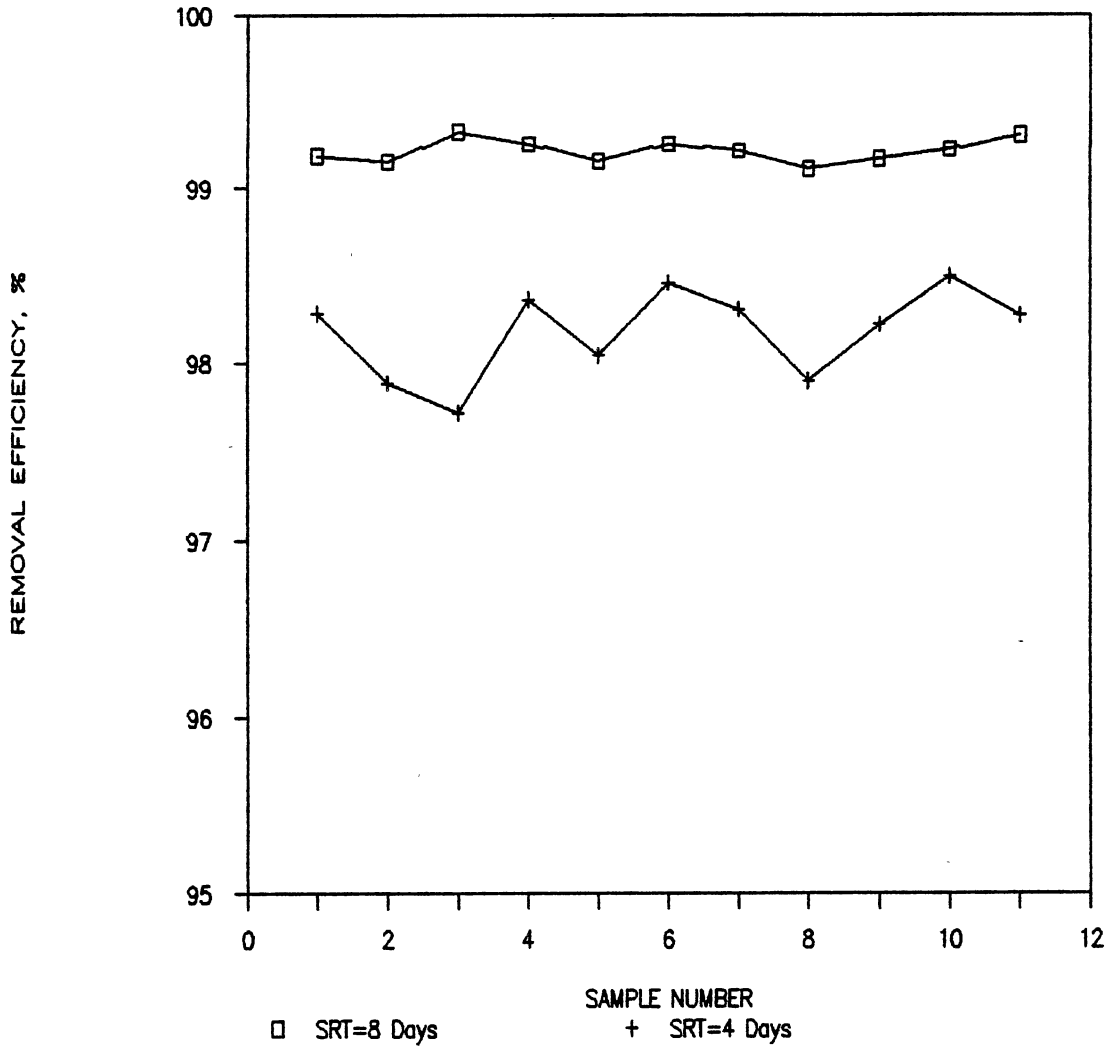

Figure 8. 2,4-Dichlorophenol Removal Efficiency for the Collected Samples at SRT of 4 and 8 Days

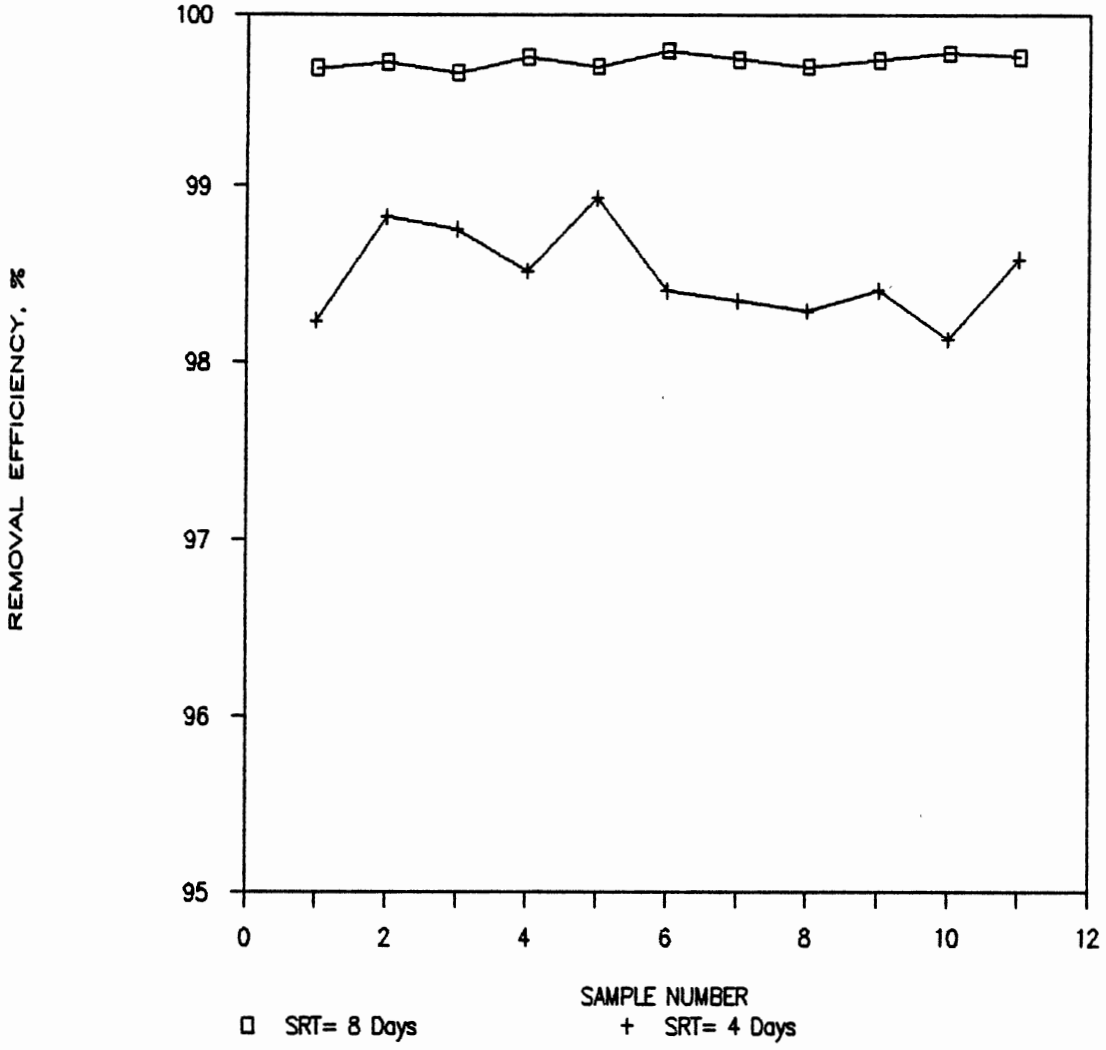

Figure 9. 2,4-Dinitrophenol Removal Efficiency for the Collected Samples at SRT of 4 and 8 Days

X = mixed liquor suspended solids, mg/l

V = reactor volume, l

The relationship between specific utilization rate and observed growth rate (1/SRT) for the control unit and the phenolic unit are given in Figures 10 and 11 respectively. The value of U for the control unit and the phenolic unit appeared to be the same for SRT of 4 and 8 days.

The fraction of substrate converted to new cells (Y_t) was determined to be 0.5 for the control unit and 0.46 for the phenolic unit. The decay coefficient (K_d) was determined to be 0.012 for the control unit and 0.01 for the phenolic unit.

D. Food to Microorganism Ratio

Food to microorganism ratios (F/M) were calculated according to the following equation.

$$F/M = \frac{F\ S_i}{V\ X}$$

The avreage F/M value for the control and the phenolic units are listed in Table IV and V respictively.

E. Total Reactor Microorganism Concentration

The relationship between the average total reactor microorganism concentration (MLSS) for the control and the phenolic units versus mean cell residence time are shown in Figure 12.

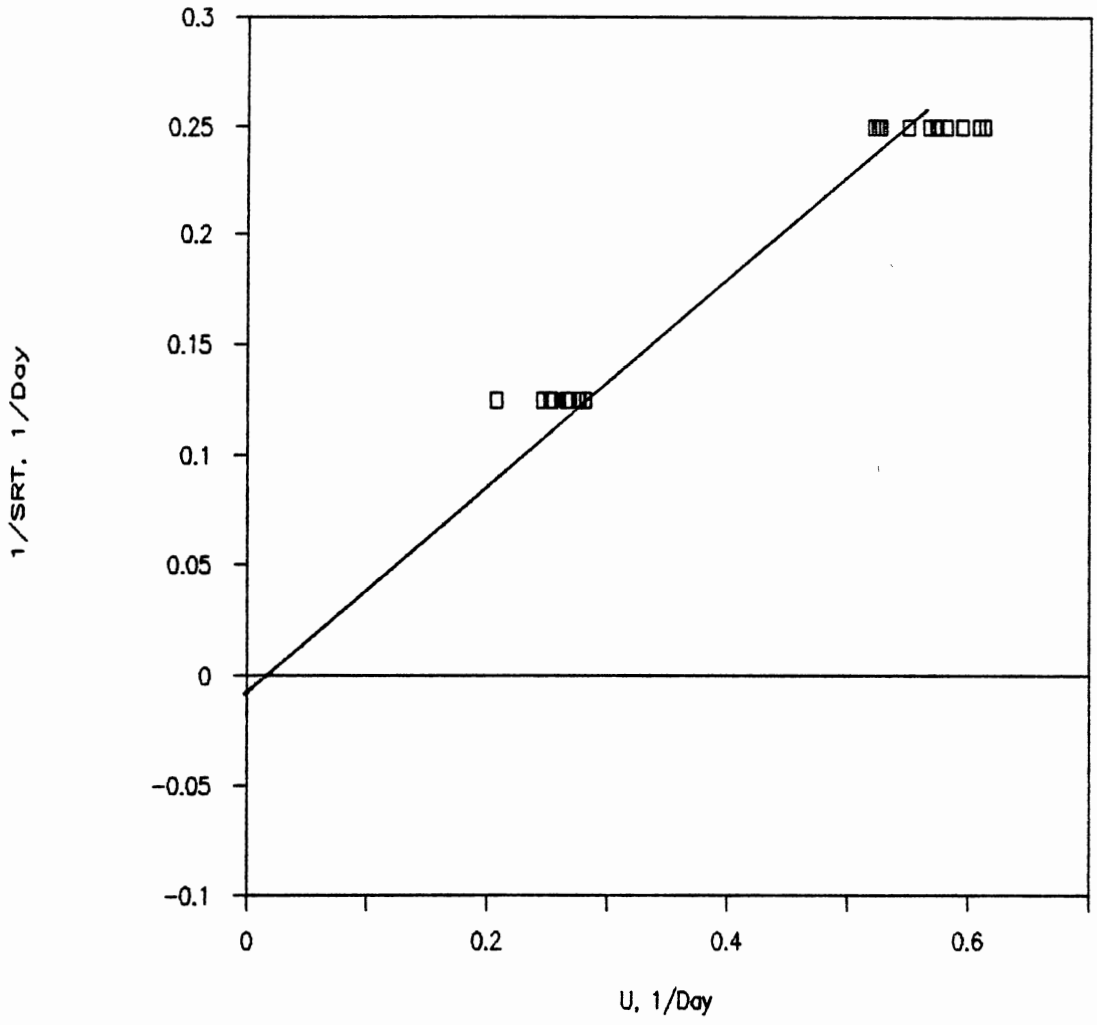

Figure 10. Observed Growth Rate versus Specific Utilization Rate for the Control Uint

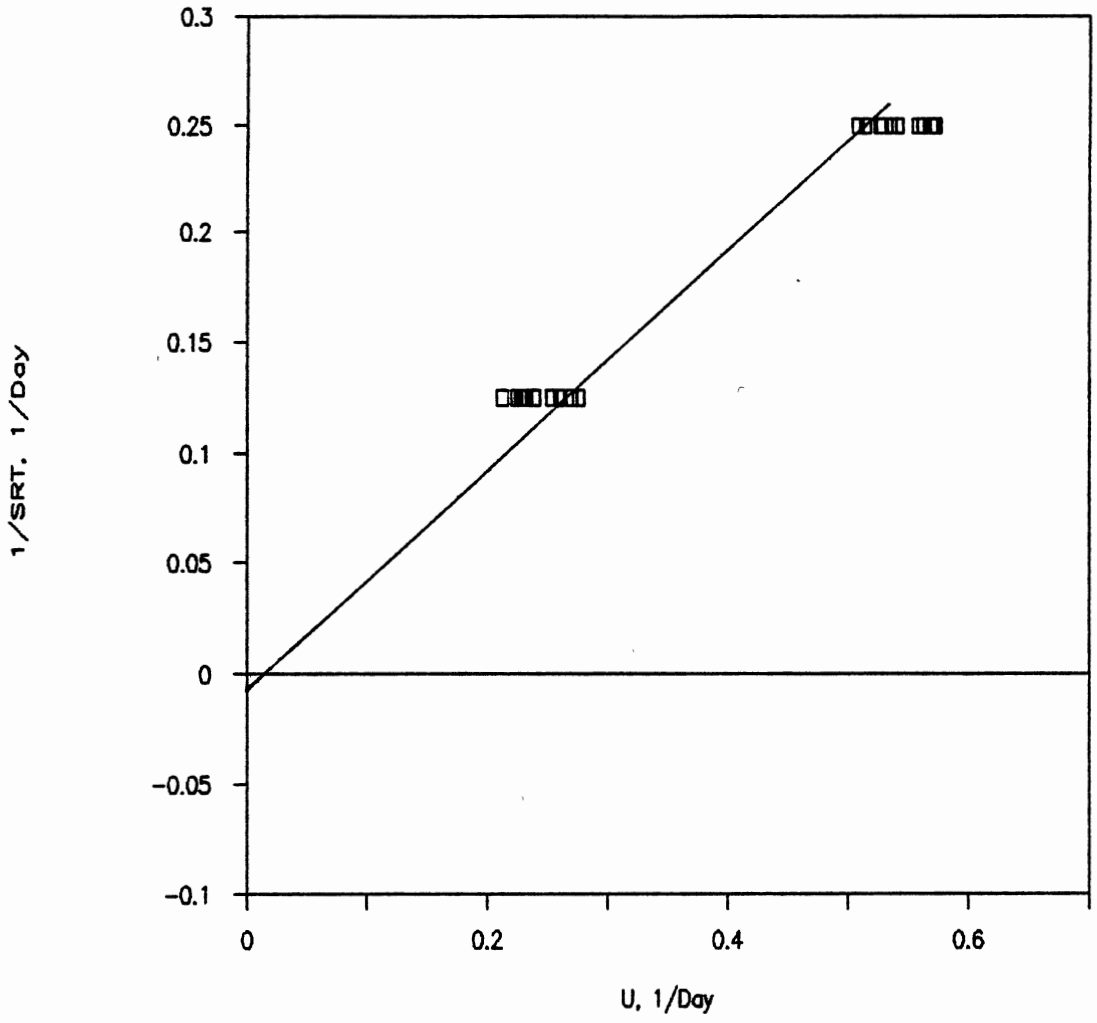

Figure 11. Observed Growth Rate versus Specific Utilization Rate for the Phenolic Uint

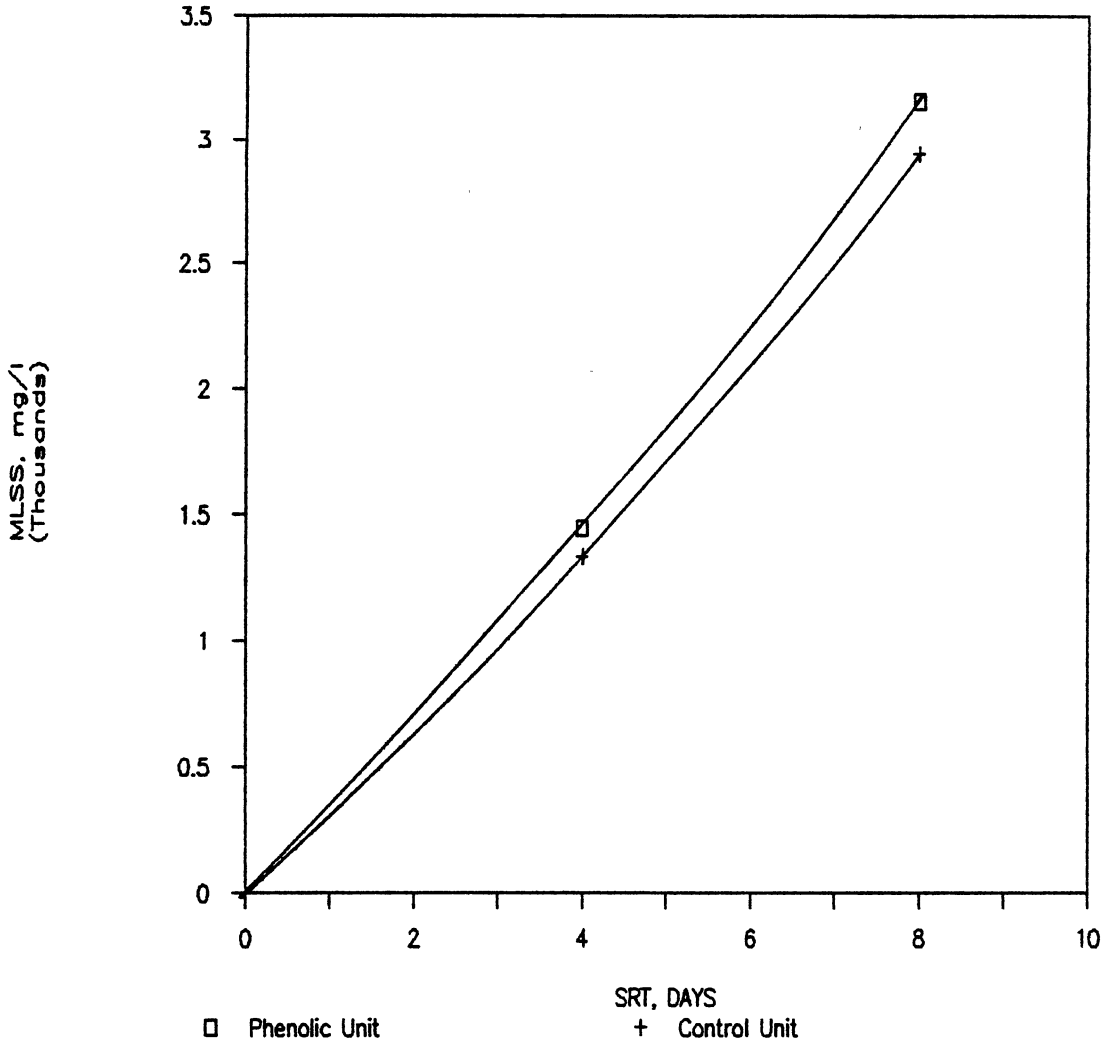

Figure 12. Total Reactor Microorganism Concentration versus SRT

CHAPTER V

Discussion

The objective of this study was to investigate the treatability and the fate of a combination of four phenolic wastes with the treatment of synthetic wastewater utilizing the activated sludge system. Mean cell residence time of 4 and 8 days were applied for this research.

Analysis of BOD_5 shown in Figures 2, 3, and 4 indicated that it is possible to biologically remove the four combined phenolic pollutants from synthetic wastewaters while maintaining a very high BOD removal efficiency level. This study also illustrated that with the existence of the phenolic wastes, BOD removal efficiency level of approximately 99% can be achieved for SRT of 4 and 8 days. The removal efficiencies obtained at SRT of 8 days (shown in Figure 2) were not consistent for both units. This could be due to the occurrence of some contamination during the preparation of BOD tests or could be related to sludge characteristics, since the study was carried with some sludge settling problems.

Gas chromatographic analysis of phenol, m-cresol, 2,4-dichlorophenol, and 2,4-dinitrophenol (Figure 6) show that the activated sludge system can be very effective in

removing a combination of four phenolic pollutants. Even though the removal efficiencies obtained from this investigation were different for each specific compound, high removal efficiencies were achieved.

This study also illustrated that by changing the mean cell residence time from 8 to 4 days, the removal efficiencies of the phenolic wastes were slightly decreased. It is found that by reducing SRT value from 8 to 4 days the removal efficiencies of phenol, m-cresol, 2,4-dichlorophenol, and 2,4-dinitrophenol decrease by approximately 1.5%, 2.5%, 1%, and 1% respectively. M-cresol shows a lower removal efficiency than the other compounds ,which could be related to the methyl (CH_3) attached to its ring. However, the effluent BOD_5 values remaine fairly steady at around 3 mg/l. It is apparent that the reduction in the removal efficiencies were different for each pollutant. Similar results were reported by Stover and Kinkannon (15), where some of the priority pollutants were shown to be affected by the change in SRT values.

Conclusions

The investigation of the treatibility of the combined priority polutants utilizing the complete-mix, bench scale, continuous flow activated sludge system, and SRT being the principal operational parameter have led to the following conclusions:

1. The activated sludge system was very effective in treating synthetic wastewaters containing four phenolic wastes.

2. The change of SRT value from 8 to 4 days had no effect on the BOD effluent quality.

3. The change of SRT value from 8 to 4 days had little effect on the specific pollutant removal efficiency.

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TABLE VI

CONTROL UNIT COLLECTED DATA

Vol=3.10 L Flow=6.5ml/min = 9.36 L/d

Date	SRT	pH	BOD Si	BOD Se	MLSS X	TSS Xe	Fw
	days		mg/L	mg/L	mg/L	mg/L	L/d
11-20-85	8.00		234	2	2934	11	0.354
11-22-85	8.00	7.30	256	3	2830	21	0.320
11-25-85	8.00		198	1	2796	19	0.326
11-27-85	8.00	7.50	267	4	2880	22	0.319
11-29-85	8.00		219	2	2821	16	0.336
11-30-85	8.00		240	1	2780	15	0.339
12-1-85	8.00	6.90	251	2	2967	7	0.366
12-4-85	8.00		227	6	2974	4	0.375
12-5-85	8.00		237	3	3103	7	0.367
12-7-85	8.00		245	4	3180	5	0.373
12-8-85	8.00		233	2	3029	9	0.361
1-4-86	4.00		243	2	1296	15	0.674
1-6-86	4.00	7.30	227	2	1323	12	0.696
1-9-86	4.00		251	3	1309	16	0.669
1-10-86	4.00		243	2	1278	18	0.652
1-12-86	4.00	7.10	257	4	1343	11	0.704
1-14-86	4.00		237	3	1392	9	0.719
1-16-86	4.00	7.10	245	3	1352	15	0.679
1-21-86	4.00		249	5	1321	13	0.690
1-22-86	4.00	7.20	237	2	1345	10	0.711
1-25-86	4.00		239	3	1332	8	0.723
1-27-86	4.00	7.10	242	4	1367	9	0.718

TABLE VII

PHENOLIC UNIT COLLECTED DATA

Vol=3.1 L flow=6.5ml/min = 9.36 L/day

Date	SRT	pH	BOD Si	BOD Se	MLSS X	TSS Xe	Fw	PHENOL Inf	PHENOL Eff	DICHLOROPH Inf	DICHLOROPH Eff	m-CRESOL Inf	m-CRESOL Eff	DINITROPHENO Inf	DINITROPHENO Eff
	days		mg/L	mg/L	mg/L	mg/L	L	mg/L	micrg/l	mg/L	micgr/l	mg/L	micgr/l	mg/L	micgr/l
11-20-85	8.00		283	6	3124	12	0.357	23.15	116.30	9.78	79.30	5.50	74.30	8.12	25.00
11-22-85	8.00	7.10	290	7	3011	13	0.352	24.02	101.20	10.30	87.20	5.13	80.70	9.15	25.00
11-25-85	8.00		230	5	3247	6	0.375	26.19	123.70	10.14	67.30	4.96	54.60	7.51	25.00
11-27-85	8.00	7.50	276	4	3212	8	0.374	25.40	98.30	9.45	69.50	4.60	55.20	10.24	25.00
11-29-85	8.00		261	1	3170	11	0.360	25.07	112.00	10.09	84.70	5.30	79.70	8.40	25.00
11-30-85	8.00		279	3	3076	7	0.371	22.79	87.70	9.56	70.40	5.06	60.30	12.02	25.00
12-1-85	8.00	6.80	300	2	3319	4	0.380	24.10	98.30	10.21	79.30	4.91	65.70	9.82	25.00
12-4-85	8.00		286	1	3206	5	0.377	23.60	77.90	9.87	87.20	4.70	59.70	8.42	25.00
12-5-85	8.00		301	3	3235	4	0.380	24.67	103.10	9.92	81.80	4.81	74.30	9.62	25.00
12-7-85	8.00		278	3	2980	6	0.373	25.36	110.30	10.20	78.30	5.14	70.60	11.30	25.00
12-8-85	8.00		269	2	3174	18	0.340	25.03	100.70	10.06	68.40	5.09	67.20	10.32	25.00
1-4-86	4.00		283	4	1457	12	0.711	24.60	423.00	9.73	167.00	5.12	183.00	8.94	158.00
1-6-86	4.00	7.40	265	3	1489	10	0.725	25.47	392.00	9.94	210.00	5.23	197.00	9.53	112.00
1-9-86	4.00		297	4	1476	13	0.706	24.21	457.00	9.47	216.00	4.89	215.00	9.87	123.00
1-10-86	4.00		284	5	1437	17	0.689	23.70	477.00	9.65	156.00	4.93	167.00	10.32	133.00
1-12-86	4.00	7.20	259	3	1472	9	0.730	25.17	452.00	10.13	198.00	5.12	211.00	8.74	93.00
1-14-86	4.00		277	5	1423	14	0.697	25.03	429.00	9.92	153.00	4.94	194.00	9.34	149.00
1-16-86	4.00	7.20	287	4	1393	16	0.683	24.78	417.00	9.37	167.00	5.07	231.00	9.89	163.00
1-21-86	4.00		254	3	1434	11	0.716	25.36	454.00	10.25	215.00	5.21	202.00	10.30	176.00
1-22-86	4.00	7.10	273	3	1470	9	0.730	23.96	486.00	9.90	176.00	4.75	176.00	9.12	145.00
1-25-86	4.00		278	3	1432	10	0.723	24.84	456.00	9.89	149.00	4.94	169.00	9.85	184.00
1-27-86	4.00	7.30	292	3	1411	13	0.703	25.23	488.00	10.21	176.00	5.07	143.00	9.34	132.00

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