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Biodegradation of Multiple Substrates in a Batch Reactor

By
Nilesh Naik

Thesis is submitted to the faculty of the Graduate School of the New Jersey Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in
ENVIRONMENTAL ENGINEERING
1986

APPROVAL SHEET

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ABSTRACT

Title of Thesis: Biodegradation of Multiple Substrate in a Batch Reactor

Nilesh Naik : Master of Science, 1986

Directed by : Dr. Gordon A. Lewandowski
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The biological degradation of multiple substrates was studied at room temperature in aerated 5-liter batch reactors using mixed liquor from the Passaic Valley Sewerage Commissioners wastewater treatment plant (Newark, New Jersey).

Two substrate mixtures were used (with initial concentration indicated in parenthesis): (1) phenol(100ppm) + nitrobenzene(10ppm) + 2,6-dichlorophenol(10ppm); (2) 2-chlorpphenol(20ppm) + nitrobenzene(10ppm) + 2,6-dichlorophenol(10ppm). From concentration versus time data, kinetic rate constants for zero-order, first-order, and Monod models were determined. Most of the data were best fit by either the Monod or zero-order model. For all compounds tested, biodegradation was the primary removal mechanism, and in many cases the rate of biodegradation was significantly faster than those measured when the individual compounds were the sole carbon source.

ACKNOWLEDGEMENTS

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The author expresses his deep appreciation to his family for their help and encouragement which made this thesis possible.

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INTRODUCTION

Past work in this laboratory has concentrated on single substrate degradation by a mixed microbial population. As an extension of this effort, the present study considers multiple substrate biodegradation.

The mixed microbial population comes from the Passaic Valley Sewerage Commissioners (PVSC) wastewater treatment plant in Newark, New Jersey. This plant handles approximately 250 million gallons per day of wastewater, of which about 18% by volume (55% on BOD basis) comes from industrial sources. The plant receives an average of about 500 lb/day of phenol (equivalent to an influent concentration of 0.25 ppm).

The compounds utilized in present study have already been examined as sole carbon sources(2,5), and in 2-compound mixtures(7) in this same laboratory. Therefore, the present work was intended to extend those studies to 3-compound interactions.

Wastewater are generally complex chemical mixtures, and there are little data available regarding their interactions with heterogeneous microbial populations. The present study is part of an effort to build up a body of information to elucidate those interactions.

OBJECTIVE

The object of this study was to obtain concentration versus time data for the biodegradation of two mixed substrates: (1) phenol(100ppm) + 2,6-dichlorophenol(10ppm) + nitrobenzene(10ppm); (2) 2-chlorophenol(20ppm) + 2,6-dichlorophenol(10ppm) + nitrobenzene(10ppm), in a batch reactor using mixed liquor from the PVSC plant. Concentration versus time data were to be used to calculate the kinetic rate constants for zero-order, first-order, and Monod models. The effect of pre-acclimation to phenol on the behavior of the microbial population was also to be investigated.

Various parameters like temperature, ammonia concentration, mixed liquor suspended solids (MLSS), and chemical oxygen demand (COD), which might effect biodegradation, were also monitored during the course of the experiments.

LITERATURE REVIEW

A computer literature search using key words like biodegradation and multicomponent was made to obtain the published results of other researchers who have investigated the ability of activated sludge in municipal wastewater treatment plants to degrade toxic organic chemicals. Based on this and other searches conducted in the same laboratory(2,3,4,5,7), it was apparent that there has not been much data collected for multicomponent systems. Even for single component studies, different types of reactors, different and usually undefined microbial populations, failure to consider compound solubility and vapor pressure, and use of a wide variety of units and kinetic models made it very difficult to draw conclusions and compare the results.

Grau, Dohanyos, and Chudoba (1974) presented a kinetic model for multicomponent substrate removal by activated sludge. The model was based on zero-order kinetics, which is a special case of the Monod equation. Simultaneous and sequential removal mechanisms were both treated by the model. When checked experimentally, it was found that the predicted rates of substrate removal were 3-5 times higher than the experimental values. No explanation was offered.

Grady (1983) concluded that some chemicals do influence the degradation rate of other substrates. A chemical that would not biodegrade if present alone, might be degraded if another more readily utilized carbon source. His studies also reported that most degradations are affected by the presence of other chemicals, although there are some exceptions.

Beltrame, Beltrame, Carniti, and Demetrio (1981) studied the kinetics of biodegradation of mixtures containing 2,4-dichlorophenol, phenol, and glucose in a continuous stirred reactor. Their studies found that nither substrate was inhibition when glucose+phenol or phenol+2,4-dichlorophenol were used in the feed solution. The order of biodegradation was found to be glucose > phenol > 2,4-dichlorophenol. The first order equation was the best fit for phenol, and the Monod equation was the best fit for 2,4-dichlorophenol.

EXPERIMENTAL APPARATUS AND ANALYTICAL EQUIPMENT

Figure 1 illustrates the experimental setup. It consists of a five-liter clear plastic cylinder, with an 8 inch diameter. The lid is made of 9" x 9" clear plastic, with two 1/4" holes (one for venting and the other for the air line).

Laboratory compressed air was supplied to all the reactors through a stone diffuser. The air was filtered through a filter made of activated carbon and glass wool. Rotameters were used to control the air flow rate at about 1 scfm. From previous work in this laboratory(11), this aeration rate kept the dissolved oxygen level in the reactor well above 2 mg/liter. No additional agitation was considered necessary to keep the contents well mixed.

Thermometer and pH probes were periodically inserted to monitor these variables.

The analytical equipment consisted of the following:

1. Gas Chromatograph : Tracor 560

   Operating Temperature

Injection	-	300 ℃
Detector	-	300 ℃
Oven	-	Substrate Dependent

   Gas Flow Rate

Nitrogen	-	40 cc/min
Hydrogen	-	30 cc/min
Air	-	400 cc/min

2. Automatic Sampler : Tracor, model 770

3. Automatic Injector : Varian, Aerograph

4. G. C. Column : Varian, 6' 1/8" SS 10% SP2100 on 100/200 Supelcoport

5. Electronic Integrator : Hewlett-Packard 3390A

6. pH Meter : Orion Research Model 701 Digital Ionalyzer

7. pH Electrode : Orion Research, Model 91-04

8. Ammonia Electrode : Orion Research, Model 95-10

9. COD Reactor : Hach, Model 16500-10

EXPERIMENTAL PROCEDURE

A. Degradation Runs

Activated sludge was obtained from the Passaic Valley Sewerage Commissioners (PVSC) municipal wastewater treatment plant in Newark, New Jersey. The sample of mixed liquor was taken from the recycle stream of the PVSC monitoring laboratory.

Immediately after the sample was brought to our laboratory, 2 liters of the sludge were poured into each of two batch reactors and provided with air. Duplicates experiments were then run at the same time. To each batch reactor(2 liters) was added one of the following two sets of chemicals (no additinal nitrogen or phosphorus was added):

Set 1

20 ml of 10000 ppm Phenol

20 ml of 1000 ppm Nitrobenzene

20 ml of 1000 ppm 2,6-Dichlophenol

Set 2

40 ml of 1000 ppm 2-chlorophenol

20 ml of 1000 ppm nitrobenzene

20 ml of 1000 ppm 2,6-dichlorophenol

A sample was taken periodically for substrate analysis, until the concentration of last the compound to be degraded fell below the detection limit (1ppm by GC analysis). As with previous studies in this laboratory(2,3,4,5,7), an internal standard was added to each sample, along with a biocide (copper sulfate), and the samples were stored in a refrigerator, until they could be analyzed.

B. Acclimation to Phenol

Some degradation runs were also made after pre-acclimation of the mixed liquor to phenol. Two liters of PVSC sludge were placed in a five-liter batch reactor. A 10,000 ppm phenol stock solution was used to acclimate the sludge. The reactor was spiked with 20ml of the phenol stock solution (as before, no additional nitrogen or phosphorus was added), and the concentration (initially 100ppm in a 2 liter volume) was monitored periodically until it fell below the detection limit (1ppm). The sludge was then respiked with 20 ml of the stock solution. In this fashion the sludge was acclimated to phenol for three days (about 4 spikes). This procedure has been shown previously(3,12) to achieve an acclimated population.

ANALYTICAL PROCEDURE

A. Substrate Analysis

The samples obtained from degradation experiments were stored in the refrigerator until they could be analyzed by gas chromatography. The oven temperature of the gas chromatograph was set at 160C when the first set of compounds was used, and at 150C when the second set was used.

Two sets of standard solutions were prepared to calibrate the gas chromatograph, as follows:

Set 1

100	ppm phenol
10	ppm nitrobenzene
10	ppm 2,6-dichlorophenol
45.45	ppm thymol

Set 2

20	ppm o-chlorophenol
10	ppm nitrobenzene
10	ppm 2,6-dichlorophenol
45.45	ppm thymol

Thymol was used as the internal standard and is present at the same concentration in all samples.

After calibrating the gas chromatograph, the samples were automatically injected, with an injection volume of 3 microliters. A sample of the integrator output is shown in figure 30.

B. Mixed Liquor Suspended Solids (MLSS)

A modification of the Standard Method (3) was used, in which a 10 ml sample was pipetted to a pre-weighed aluminum dish. The dish was then placed in an oven for 5 hours at 103C, in order to dry. The weight difference was used to calculate the suspended solids concentration.

C. Ammonia Concentration

Free ammonia was liberated by adding caustic to the samples. The ammonia concentration was then measured using a gas electrode. Since the only source of available nitrogen came with the original mixed liquor sample, it was assumed that this would be largely in the form of dissolved ammonium salts.

D. Chemical Oxygen Demand (COD)

To obtain an indication of the extent of oxidation of the compounds tested, the chemical oxidation demand was determined. However, previous studies in this laboratory(3,4), concluded that there is an error of about 10 to 20 ppm in the COD test. Therefore, this parameter was only measured in the phenol runs (where the initial substrate concentration was 100ppm). The procedure used was identical to that reported previously (2,3,4), and is a modification of the Standard Method.

RESULTS AND DISCUSSION

A. Adsorption

Based on octanol/water partition coefficients (6), none of the compounds tested would be expected to adsorb onto the biological flocs to any significant extent. This conclusion was supported by the experimental results, which showed no decrease in the initial slope of the substrate removal curves on successive exposure.

B. Air Stripping

All of the compounds used have low vapor pressures and modest activity coefficients (6). This would imply a slow rate of air stripping for the compounds studied, and this has been verified experimentally (3,4,5). As a result, biodegradation was by far the dominant removal mechanism in all experiments.

C. Mixed Liquor Suspended Solids:

Mixed liquor suspended solids (MLSS) is generally used as an indication of the number of viable organisms present in the reactor. Tables 15 to 26 in and Figures 10 to 17 show the MLSS data. These indicate a roughly constant MLSS during each experiment. However, the relatively short duration of each experiment, the fact that detritus is being measured along with viable organisms, and the inaccuracies in the method (trying to measure a net solids weight of 25 mg with a tore weight of about 1 gram), causes these results to have a limited value.

The MLSS was much lower during the second runs because approximately 1 liter of distilled water was added to replace the liquor used as samples and to bring the total volume of mixed liquor back up to 2 liters.

D. Ammonia Concentration

These are reported in Tables 15 to 26 and Figures 18 to 25. They indicate periods of growth and lysis in the reactor. During growth, the concentration of ammonia was low, but once the substrate was exhausted lysis appears to have taken place during endogenous respiration and the ammonia concentration generally rose toward the end of the experiments. Except for Tables 16 and 18, the ammonia concentration never fell below 10ppm, and nitrogen was not a limiting nutrient. Even for the data represented by Tables 16 and 18, the carbon:nitrogen ratio was lower than 50:14 (the E.coli ratio(1)).

E. Chemical Oxygen Demand:

Results are given in Tables 15 to 20 and Figures 26 to 29. They show an expected decrease in COD as the phenol concentration decreased, indicating mineralization. However, the residual COD may be an indication of the method's inaccuracy, rather than production of oxidizable metabolic products.

F. Substrate Concentration and Kinetics

Time versus concentration data for individual compounds are reported in Tables 3 to 14 and Figures 2 to 9.

Four mathematical models were used to correlate the experimental data. Kinetic rate constants were determined using the linear regression programs in the Appendix

Zero-order:

The zero-order model assumes that the rate of substrate removal, dS/dt, is constant and independent of substrate concentration:

$$-dS/dt = K_o \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The integrated form is:

$$S_o - S = K_o t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where

S = Substrate concentration at time t (ppm)

S_o = Initial substrate concentration (ppm)

K_o = Zero-order rate constant (ppm/hr)

t = Time (hr)

First-order:

The first-order kinetic model assumes that the rate of substrate removal, dS/dt, is directly proportional to substrate concentration:

$$-dS/dt = K_1 S \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The integrated form is:

$$\ln(S_o) - \ln(S) = K_1 t \quad \ldots\ldots\ldots\ldots \quad (4)$$

where

S = Substrate concentration at time t (ppm)

S_o = Initial substrate concentration (ppm)

K_1 = First-order kinetic rate constant (1/hr)

t = Time (hr)

Monod:

The Monod rate equation, with an assumption of constant biomass, is represented by equation 5.

$$-dS/dt = (K_1 S)/(K_2 + S) \quad \ldots\ldots\ldots\ldots \quad (5)$$

The integrated form is:

$$(S_o - S) + K_2 (\ln(S_o) - \ln(S)) = K_1 t \quad \ldots \quad (6)$$

where

S = Substrate concentration at time t (ppm)

S_o = Initial substrate concentration (ppm)

K_1 = Rate constant (ppm/hr)

K_2 = Substrate utilization constant (ppm)

t = Time (hr)

Haldane:

The Haldane equation adds an inhibition term to the Monod expression. Again for constant biomass, the rate expression is:

$$-dS/dt = (K_1 S)/(K_2 + S + S^2/K_3) \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

The integrated form is:

$$(S_o - S) + K_2\left[\ln(S_o) - \ln(S)\right] + (1)/2K_3(S_o - S) = K_1 t \quad \ldots \quad (8)$$

where

S = Substrate Concentration at time t (ppm)

S_o = Initial Substrate Concentration (ppm)

K_1 = Rate Constant (ppm/hr)

K_2 = Substrate Saturation Constant (ppm)

K_3 = Inhibition Constant (ppm)

t = Time (hr)

Average Absolute Residuals (AAR):

Average absolute residuals were used to determine the best model for the experimental data:

$$AAR = |Scal - Sexp|/(N-1) \quad \ldots\ldots\ldots\ldots \quad (9)$$

Although the average absolute residuals for the Haldane model were generally small, most of the constants were negative, which is physically meaningless. In addition, it was doubtful that the data could justify a 4 constant model (Haldane). For these reasons, only the results for zero-order, first-order, and Monod models are listed in Tables 27 to 38.

Table 2 summarizes the best fit kinetic models, based on the average absolute residuals. This shows that the Monod and zero-order models fit the data best in virtually every case. To properly distinguish Monod kinetics from zero-order kinetics a large number of data points are needed at the beginning and at the end of the reaction. The detection limit of the gas chromatograph was about 1ppm. An error of +/- 1ppm during the analysis leads to further uncertainty regarding the best fit models. By arbitrarily adding or subtracting 1ppm from the experimental data, the Monod and zero-order models were interchangeable.

Table 1 compares the zero-order rate constants for the individual compounds in the multiple substrate experiments, with the zero-order rate constants of single substrate experiments(2,3,4,5), and two carbon sources(7). It is known that a chemical that would not biodegrade if present alone, might be degraded if another more readily utilized carbon source were present. This might explain why nitrobenzene was much more rapidly degraded when phenol or 2-chlorophenol was present. The extremely rapid removal rates for 2-chlorophenol after phenol acclimation cannot be explained.

A long lag time was evident before 2,6-dichlorophenol was degraded. This lag time did not appear when 2,6-dichlorophenol was the sole carbon source(2). However, the simultaneous presence of phenol in the present study meant that a more readily available food source was present which degraded first.

CONCLUSIONS

1. Results of the kinetic analyses are summarized in Tables 1 and 2. Table 1 compares the zero-order rate constants for the individual compounds in the multiple substrate experiments, with the zero-order rate constants of single substrate experiments(2,3,4,5), and for two carbon sources(7).
2. The extremely rapid removal for 2-chlorophenol after phenol acclimation, and the enhanced removal rates for nitrobenzene when multiple substrate were used, are difficult to explain.
3. A long lag time was evident before 2,6-dichlorophenol degraded. Studies by Pak (1985) on single substrate degradation did not reveal such a lag time in degradation of 2,6-dicholorophenol. The rates were much faster for the second run with the same organisms, during which the lag time for 2,6-dichlorophenol was reduced by more than half.
4. When the sludge was pre-acclimated to phenol for three days, degradation rates improved considerably. The lag time for 2,6-dichlorophenol was cut from about 77 hours to 20 hours. It was noticed that phenol pre-accclimation produced even faster degradatiom than spiking the sludge with the same three chemicals for a second time.
5. Table 26 summarizes the best fit kinetic models, based on the average absolute residuals. This shows that the Monod and zero-order models fit the data best in virtually every case.

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TABLE 1

Comparison of Degradation Rates of Mixed and Single Substrates

(Zero-Order Rate Constants, ppm/hr)

Exposure	Phenol (2) (alone)	2-CP (2) (alone)	2,6-DCP (2) (alone)	N.B. (5) (alone)
First	4.0	0.3	0.1	0.035*
Second	15.7	0.7	0.4	
Third	----	---	---	
AFP+	94.0	9.0	0.1	

Exposure	Phenol + 2-CP(7)		Phenol + 2,6-DCP(7)		Phenol + N.B.(7)	
First	4.8	0.45	4.0	0.1	4.5	0.06 **
	10.0	1.00	8.0	2.0	1.2	1.64
Second	8.8	0.80	3.9	0.4	4.6	0.13
Third	14.3	2.20	4.6	0.45	3.9	0.10
Fourth	19.1	2.90	---	----	---	----

Exposure	Phenol + N.B. + 2,6-DCP			2-CP + N.B. + 2,6-DCP		
First	10.13	0.13**	0.21	0.40	0.16**	0.68
	11.03	0.14	0.22	0.39	0.20	0.65
Second	14.98	0.18	0.70	2.54	0.28	0.83
	14.54	0.25	0.82	2.75	0.27	1.00
AFP+	54.76	0.19	1.56	35.40	1.03	0.56
	50.68	0.22	1.37	34.40	0.73	0.49

* First-order rate constant for air stripping.
** First-order rate constant for overall removal of nitrobenzene.
\+ After phenol pre-acclimation

TABLE 2

Best-Fit Model Based on Average Absolute Residuals

Experiment	Phenol	2,6-DCP	2-CP	N.B
1: First Run:	Monod*	Monod*		First
Second Run:	Monod	Monod*		First
2: First Run:	Monod*	Zero		Monod**
Second Run:	Monod	Monod*		First
3 Phenol Pre: Acclimated:	Monod	Zero		Monod*
4 Phenol Pre: Acclimated:	Monod	Monod		Monod*
5: First Run:		Zero	First	Monod
Second Run:		Zero	Monod	Monod
6: First Run:		Zero	First	Monod
Second Run:		Zero	Monod	Monod
7 Phenol Pre: Acclimated:		Monod*	Monod	Monod
8 Phenol Pre: Acclimated:		Monod*	Monod	Monod

* Negative rate constant, and zero-order was next best fit.

** Negative rate constant, and first-order was next best fit.

TABLE 3

Time Versus Concentration Data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)

Experiment 1
Run 1
(Unacclimated sludge, Temp. 78 °F)

Time (hr)	S(phenol) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	97.3	9.0	8.1
1	96.1	7.8	7.7
2	86.8	6.4	7.9
3	74.4	5.0	7.8
5	52.7	4.3	7.0
7	30.2	3.7	7.7
19	< 1.0	< 1.0	7.5
22			7.9
26			7.6
42			7.8
48			7.9
54			8.0
67			7.5
77			7.7
91			6.6
96			4.8
97			3.9
99			2.6

Experiment starting date: 6-19-1985

TABLE 4

Time Versus Concentration Data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 1
Run 2
(Unacclimated sludge, Temp. 78 °F)

Time (hr)	S(phenol) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	100.7	8.6	7.3
1	80.5	7.8	7.2
2	58.3	5.9	7.4
3	25.2	4.7	7.0
5	5.6	3.8	7.0
7	0.2	2.4	7.7
19		< 1.0	7.4
21			6.5
22			6.1
23			5.2
24			4.5
25			3.8
26			2.4

Experiment starting date: 6-19-1985

TABLE 5

Time Versus Concentration Data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)

Experiment 2
Run 1
(Unacclimated sludge, Temp. 78 °F)

Time (hr)	S(phenol) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	100.3	9.7	8.7
1	94.0	8.2	7.9
2	84.7	7.1	7.9
3	73.8	6.0	8.2
5	55.8	4.8	7.8
7	21.7	3.5	7.7
19	< 1.0	< 1.0	7.9
22			7.8
26			8.1
42			8.0
48			7.9
54			8.1
67			7.9
77			7.7
91			6.5
96			4.6
97			3.5
99			2.3

Experiment starting date: 6-19-1985

TABLE 6

Time Versus Concentration Data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 2
Run 2
(Unacclimated sludge, Temp. 78°F)

Time (hr)	S(phenol) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	99.3	9.3	7.9
1	81.7	8.2	8.0
2	50.2	6.0	8.1
3	27.4	4.5	7.9
5	7.8	3.1	7.8
7	0.4	2.0	8.0
19		< 1.0	7.9
21			6.6
22			6.0
23			5.3
24			4.2
25			3.4
26			2.1

Experiment starting date: 6-19-1985

TABLE 7

Time Versus Concentration Data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 3
Run 1
(Phenol acclimated sludge, Temp. 78 °F)

Time (hr)	S(phenol) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	100.0	10.0	8.5
0.5	84.5	9.4	9.3
1.0	55.3	9.6	8.7
1.5	8.7	10.0	9.6
2.0	1.0	9.6	9.5
2.5	< 1.0	8.7	9.3
3.0		8.4	9.4
4.0		7.4	9.2
5.0		6.7	9.2
6.0		4.9	9.5
7.0		4.4	9.2
8.0		2.4	9.0
20.0		< 1.0	9.3
23.0			9.3
24.0			9.4
26.0			6.1
28.0			3.2
29.0			1.5

Experiment starting date: 6-14-1985

TABLE 8

Time Versus Concentration Data

(Phenol+Nitobenzene+2,6-Dichlorophenol)
Experiment 4
Run 1
(Phenol-acclimated sludge, Temp. 78°F)

Time (hr)	S (phenol) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	94.0	10.5	8.7
0.5	78.8	10.1	8.8
1.0	49.1	9.9	8.7
1.5	10.8	10.0	8.6
2.0	1.3	9.6	8.7
2.5	< 1.0	8.9	8.6
3.0		8.6	8.7
4.0		7.4	8.6
5.0		6.3	8.6
6.0		4.9	8.6
7.0		3.7	8.5
8.0		2.1	8.2
20.0		< 1.0	8.2
23.0			8.4
24.0			8.3
26.0			5.7
28.0			2.4
29.0			1.7

Periment starting date: 6-14-1985

TABLE 9

Time Versus Concentration Data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 5
Run 1
(Unacclimated sludge, Temp. 80 °F)

Time (hr)	S(2-CP) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	20.5	7.1	8.3
1	18.6	6.2	8.3
2	15.9	5.0	8.1
3	14.7	4.7	7.9
4	13.2	3.9	8.3
5	11.8	3.2	8.2
6	10.7	2.8	8.1
7	10.1	< 1.0	8.4
22	7.0		8.1
27	5.5		8.3
33	4.3		8.6
44	< 1.0		8.7
49			8.5
57			8.4
68			8.4
70			7.8
73			6.6
76			3.5
79			1.1

Experiment starting date: 7-8-1985

TABLE 10

Time Versus Concentration Data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 5
Run 2
(Unacclimated sludge, Temp. 80°F)

Time (hr)	S(2-CP) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	18.4	9.3	8.3
1	15.4	8.2	7.7
2	12.9	6.9	8.1
3	10.1	5.7	7.9
4	6.9	4.7	8.4
5	4.2	3.4	8.2
6	2.6	2.1	8.1
7	1.3	1.2	8.0
22	< 1.0	< 1.0	7.9
23			7.1
25			6.2
26			5.3
27			4.2
28			3.1
29			1.9

Experiment starting date: 7-8-1985

TABLE 11

Time Versus Concentration Data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 6
Run 1
(Unacclimated sludge, Temp. 80°F)

Time (hr)	S(2-CP) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	19.6	8.1	8.6
1	18.3	7.2	8.5
2	15.7	5.7	8.4
3	14.8	4.5	8.5
4	13.5	3.8	8.3
5	11.5	3.1	8.6
6	10.3	2.5	8.2
7	9.4	< 1.0	8.4
22	7.0		8.7
27	5.6		8.4
33	4.1		8.6
44	< 1.0		8.7
49			8.5
57			8.5
68			8.4
70			7.8
73			6.7
76			3.8
79			1.4

Experiment starting date: 7-8-1985

TABLE 12

Time Versus Concentration Data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 6
Run 2
(Unacclimated sludge, Temp. 80°F)

Time (hr)	S(2-CP) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	19.6	8.9	9.3
1	16.4	8.2	8.7
2	13.7	6.5	8.9
3	11.0	5.5	8.9
4	7.2	4.2	9.0
5	4.5	3.3	8.8
6	2.3	2.0	8.9
7	1.1	1.4	8.8
22	< 1.0	< 1.0	8.9
23			8.1
25			7.0
26			5.7
27			4.5
28			3.3
29			1.7

Experiment starting date: 7-8-1985

TABLE 13

Time Versus Concentration Data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 7
Run 1
(Phenol-acclimated sludge, Temp. 80°F)

Time (hr)	S(2-CP) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	18.1	7.0	8.9
0.25	6.9	4.8	8.8
0.50	0.4	4.2	8.5
1.00		3.6	8.6
1.50		1.9	8.8
2.00		0.7	8.8
4.00			8.4
6.00			8.8
9.00			8.6
22.00			8.8
26.00			8.6
28.00			8.2
30.00			7.6
32.00			5.9
34.00			2.9
36.00			1.3

Experiment starting date: 7-8-1985

TABLE 14

Time Versus Concentration Data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 8
Run 1
(Phenol-acclimated sludge, Temp. 80°F)

Time (hr)	S(2-CP) (ppm)	S (N.B.) (ppm)	S (2,6-DCP) (ppm)
0	17.6	7.9	7.9
0.25	4.7	5.8	7.9
0.50	0.4	4.2	8.0
1.00		3.8	8.1
1.50		2.9	7.8
2.00		1.5	8.2
4.00		< 1.0	8.1
6.00			8.0
9.00			7.9
22.00			7.8
26.00			7.6
28.00			7.2
30.00			5.8
32.00			4.9
34.00			3.0
36.00			1.0

Experiment starting date: 7-8-1985

TABLE 15

MLSS, Ammonia Conc., and COD data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 1
Run 1
(Unacclimated sludge, Temp. 78°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)	COD (ppm)
0	6100	66.6	133.5
2.0		20.9	101.2
5.0		14.3	80.3
6.0	5767		50.6
18.0	5800	12.1	30.1
24.0		15.0	
25.0	5667		
30.0	5633	15.0	
42.0	5467	17.0	
54.0	5467	22.9	
66.0	5367	23.3	
72.0		28.7	
79.0	5367	24.0	
90.0	5400	16.5	
99.0	5400	17.5	26.6

Experiment stating date: 6-19-1985

TABLE 16

MLSS, Ammonia Conc., and COD data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 1
Run 2
(Unacclimated sludge, Temp. 78 °F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)	COD (ppm)
0	2633	16.8	135.7
1.0		14.1	106.2
2.0		12.6	79.4
3.0	2667	7.5	54.1
5.0	2733	6.1	31.4
7.0	2733	5.9	29.7
19.0	2767		
21.0	2733	6.8	
23.0	2800	6.5	
26.0	2767	6.6	

Experiment stating date: 6-19-1985

TABLE 17

MLSS, Ammonia Conc., and COD data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 2
Run 1
(Unacclimated sludge, Temp. 78°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)	COD (ppm)
0	6367	43.7	136.7
2.0		22.9	103.2
5.0		15.2	82.8
6.0	5700		49.3
18.0	5767	13.5	28.7
24.0		14.8	
25.0	5767		
30.0	5733	14.9	
42.0	5767	17.9	
54.0	5767	25.3	
66.0	5733	26.3	
72.0		29.7	
79.0	5767	26.3	
90.0	5800	20.1	
99.0	5767	21.5	25.5

Experiment stating date: 6-19-1985

TABLE 18

MLSS, Ammonia Conc., and COD data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 2
Run 2
(Unacclimated sludge, Temp. 78 °F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)	COD (ppm)
0	2767	18.9	140.5
1.0		15.1	111.2
2.0		13.5	83.2
3.0	2733	8.9	57.1
5.0	2767	6.3	34.4
7.0	2767	5.9	30.8
19.0	2833		
21.0	2767	7.2	
23.0	2800	7.1	
26.0	2800	7.2	

Experiment stating date: 6-19-1985

TABLE 19

MLSS, Ammonia Conc., and COD data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 3
Run 1
(Phenol-Acclimated sludge, Temp. 78°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)	COD (ppm)
0	5367	50.8	132.3
0.5		47.1	109.0
1.0	5367		82.5
1.5		45.4	46.8
3.0	5367		28.7
4.0		40.6	
5.0	5300		
7.0	5433	40.0	
8.0		44.9	
20.0	5367	48.8	
22.0	5366	49.1	
24.0		49.6	
29.0	5433	52.4	24.4

Experiment stating date: 6-14-1985

TABLE 20

MLSS, Ammonia Conc., and COD data

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 4
Run 1
(Phenol-Acclimated sludge, Temp. 78°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)	COD (ppm)
0	5500	53.6	135.4
0.5		47.4	111.0
1.0	5367		83.7
1.5		43.6	47.4
3.0	5400		29.9
4.0		39.6	
5.0	5433		
7.0	5433	39.8	
8.0		43.3	
20.0	5467	45.1	
22.0	5433	48.7	
24.0		49.6	
29.0	5433	51.6	23.7

Experiment stating date: 6-14-1985

TABLE 21

MLSS, and Ammonia Conc. data

(2-Chlorophenol+Nitrobenzene+2,6,Dichlorophenol)
Experiment 5
Run 1
(Unacclimated sludge, Temp. 80°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)
0	4833	27.0
3.0		26.0
5.0		23.5
9.0	4833	23.3
21.0	4867	24.3
25.0		24.7
33.0	4933	24.8
45.0	5000	24.5
49.0		23.8
57.0	4933	23.9
69.0	5000	23.9
73.0		23.9
79.0	4967	23.9

Experiment stating date: 7-8-1985

TABLE 22

MLSS, and Ammonia Conc. data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 5
Run 2
(Unacclimated sludge, Temp. 80°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)
0	2333	23.8
2.0		23.6
4.0		23.1
7.0	2367	22.6
22.0	2333	22.8
25.0		22.1
27.0	2333	22.5
29.0	2333	22.6

Experiment stating date: 7-8-1985

TABLE 23

MLSS, and Ammonia Conc. data

(2-Chlorophenol+Nitrobenzene+2,6,Dichlorophenol)
Experiment 6
Run 1
(Unacclimated sludge, Temp. 80°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)
0	5233	29.4
3.0		24.0
5.0		22.2
9.0	4967	21.3
21.0	4967	22.6
25.0		23.7
33.0	5033	24.4
45.0	5000	24.3
49.0		23.9
57.0	4967	24.0
69.0	5000	24.1
73.0		24.2
79.0	4967	24.2

Experiment stating date: 7-8-1985

TABLE 24

MLSS, and Ammonia Conc. data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 6
Run 2
(Unacclimated sludge, Temp. 80°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)
0	2600	28.7
2.0		22.9
4.0		20.1
7.0	2633	19.4
22.0	2633	19.5
25.0		19.6
27.0	2667	20.1
29.0	2633	20.4

Experiment stating date: 7-8-1985

TABLE 25

MLSS and Ammonia Conc. data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 7
Run 1
(Phenol-acclimated sludge, Temp. 80°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)
0	5400	17.1
0.5		15.6
1.0		12.0
1.5		10.7
2.0		10.8
3.0	5400	
4.0		15.5
8.0	5400	13.3
12.0	5367	14.3
23.0	5433	18.2
27.0	5400	19.7
32.0		20.9
36.0	5333	20.3

Experiment stating date: 7-11-1985

TABLE 26

MLSS and Ammonia Conc. data

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 8
Run 1
(Phenol-acclimated sludge, Temp. 80°F)

Time (hr)	MLSS (ppm)	Ammonia (ppm)
0	5567	22.1
0.5		18.6
1.0		14.2
1.5		12.9
2.0		12.8
3.0	5600	
4.0		14.5
8.0	5633	14.3
12.0	5633	16.3
23.0	5667	16.9
27.0	5667	17.7
32.0		19.5
36.0	5633	19.6

Experiment stating date: 7-11-1985

TABLE 27

RESULTS

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 1
Run 1
(Unacclimated sludge, Temp. 78 °F)

Compound	Kinetic Model	Constants	Absolute Average Residual
Phenol	Zero-order	K0= 10.1382	13.1477
Lag: 0 hr		S0=103.3313	
	First-order	K1= 0.1696	72.1548
		S0=112.5788	
	Monod	K1= 7.5749	8.7868
		K2=-15.7969	
		S0=102.1421	
N.B.	Zero-order	K0= 0.7529	0.4596
Lag: 0 hr		S0= 8.2922	
	First-order	K1= 0.1296	0.2154
		S0= 8.4661	
	Monod	K1= -0.5145	
		K2= -9.6947	0.8957
		S0= 10.9262	
2,6-DCP	Zero-order	K0= 0.2063	0.8338
Lag:77 hr		S0= 8.2149	
	First-order	K1= 0.0403	1.3194
		S0= 8.7347	
	Monod	K1= 0.0768	0.4750
		K2= -3.3755	
		S0= 8.0350	

Units:

Zero-order: K_c (ppm/hr)
First-order: K_1 (1/hr)
Monod: K_1 (ppm/hr)
K_s (ppm)
S_o (ppm)

Experiment starting date: 6-19-1985

TABLE 28

RESULTS

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 1
Run 2
(Unacclimated sludge, Temp. 78°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
Phenol Lag: 0 hr	Zero-order	K0= 14.9823 S0= 90.0304	171.8035
	First-order	K1= 0.8727 S0=211.1085	2562.7745
	Monod	K1= 32.2690 K2= 19.5869 S0=104.3921	16.5462
N.B. Lag: 0 hr	Zero-order	K0= 0.8853 S0= 8.1892	0.3092
	First-order	K1= 0.1814 S0= 8.7343	0.1055
	Monod	K1=-13.1343 K2=-76.1922 S0= 8.8790	0.1105
2,6-DCP Lag:19 hr	Zero-order	K0= 0.6963 S0= 7.8143	0.1156
	First-order	K1= 0.1486 S0= 7.8452	0.4426
	Monod	K1= 0.3529 K2= -2.3272 S0= 7.5104	0.0543

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 6-19-1985

TABLE 29

RESULTS

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 2
Run 1
(Unacclimated sludge, Temp. 78 °F)

Compound	Kinetic Model	Constants	Absolute Average Residual
Phenol Lag: 0 hr	Zero-order	K0= 11.0353 S0=104.8225	20.2052
	First-order	K1= 0.2058 S0=119.4130	142.1039
	Monod	K1= 6.5210 K2=-21.9891 S0=101.2231	1.0673
N.B. Lag: 0 hr	Zero-order	K0= 0.8520 S0= 9.1088	0.1759
	First-order	K1= 0.1423 S0= 9.5035	0.0204
	Monod	K1= -5.3688 K2=-43.6300 S0= 9.6269	0.0111
2,6-DCP Lag:77 hr	Zero-order	K0= 0.2215 S0= 8.2428	0.9254
	First-order	K1= 0.0452 S0= 8.8760	1.5648
	Monod	K1= 0.0901 K2= -3.1133 S0= 8.1228	0.9777

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 6-19-1985

TABLE 30

RESULTS

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 2
Run 2
(Unacclimated sludge, Temp. 78°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
Phenol	Zero-order	K0= 14.5382	163.4447
Lag: 0 hr		S0= 88.0814	
	First-order	K1= 0.7669	1360.4824
		S0=180.3440	
	Monod	K1= 32.0959	12.8979
		K2= 22.6502	
		S0=101.6297	
N.B.	Zero-order	K0= 1.2143	0.2846
Lag: 0 hr		S0= 8.9571	
	First-order	K1= 0.2524	0.1505
		S0= 9.8830	
	Monod	K1= -6.3948	
		K2=-32.9581	0.1540
		S0= 9.8521	
2,6-DCP	Zero-order	K0= 0.8156	0.0748
Lag:19 hr		S0= 8.2172	
	First-order	K1= 0.1773	0.5467
		S0= 9.2882	
	Monod	K1= 0.5077	0.0134
		K2= -1.7441	
		S0= 7.9516	

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 6-19-1985

TABLE 31

RESULTS

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 3
Run 1
(Phenol-acclimated sludge, Temp. 78°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
Phenol Lag: 0 hr	Zero-order	K0= 54.7600 S0=104.6600	82.0840
	First-order	K1= 2.2968 S0=208.5872	3327.7514
	Monod	K1= 69.9244 K2= 5.5171 S0=110.6229	75.5304
N.B. Lag: 0 hr	Zero-order	K0= 1.1102 S0= 10.0900	0.0974
	First-order	K1= 0.1928 S0= 11.0508	0.4911
	Monod	K1= 0.8157 K2= -1.5635 S0= 9.9448	0.0577
2,6-DCP Lag:20 hr	Zero-order	K0= 1.5627 S0= 9.3474	0.0098
	First-order	K1= 0.3493 S0= 10.6433	0.8822
	Monod	K1= 1.5729 K2= 0.0255 S0= 9.3543	0.0099

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 6-14-1985

TABLE 32

RESULTS

(Phenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 4
Run 1
(Phenol-acclimated sludge, Temp. 78°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
Phenol Lag: 0 hr	Zero-order	K0= 50.6800	56.5560
		S0= 97.4800	
	First-order	K1= 2.1098	2145.5610
		S0=181.0985	
	Monod	K1= 63.9258	44.0293
		K2= 5.5586	
		S0=102.1605	
N.B. Lag: 0 hr	Zero-order	K0= 1.2011	0.0400
		S0= 10.2367	
	First-order	K1= 0.2179	0.6422
		S0= 11.4474	
	Monod	K1= 0.9333	
		K2= -1.2344	0.0084
		S0= 10.0832	
2,6-DCP Lag:20 hr	Zero-order	K0= 1.3745	0.0860
		S0= 8.3051	
	First-order	K1= 0.3279	0.5550
		S0= 9.1842	
	Monod	K1= 1.6862	0.0665
		K2= 0.9080	
		S0= 8.4219	

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 6-14-1985

TABLE 33

RESULTS

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 5
Run 1
(Unacclimated sludge, Temp. 80°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
2-CP	Zero-order	K0= 0.4004	5.6422
Lag: 0 hr		S0= 16.0300	
	First-order	K1= 0.0416	3.7368
		S0= 16.4647	
	Monod	K1= -0.4379	5.5390
		K2=-19.9724	
		S0= 14.0331	
N.B.	Zero-order	K0= 0.7143	0.0524
Lag: 0 hr		S0= 6.8429	
	First-order	K1= 0.1558	0.0206
		S0= 7.1476	
	Monod	K1= 5.5300	
		K2= 30.6307	0.0200
		S0= 7.1144	
2,6-DCP	Zero-order	K0= 0.6825	0.3910
Lag:68 hr		S0= 9.0290	
	First-order	K1= 0.1771	3.0428
		S0= 11.0730	
	Monod	K1= 0.5015	20.0281
		K2= -1.1083	
		S0= 8.8632	

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 7-8-1985

TABLE 34

RESULTS

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 5
Run 2
(Unacclimated sludge, Temp. 80°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
2-CP Lag: 0 hr	Zero-order	K0= 2.5357 S0= 17.8500	0.4831
	First-order	K1= 0.3713 S0= 24.2222	6.3636
	Monod	K1= 3.6653 K2= 3.0218 S0= 18.6656	0.0820
N.B. Lag: 0 hr	Zero-order	K0= 1.1750 S0= 9.3000	0.0089
	First-order	K1= 0.2793 S0= 11.4760	1.0011
	Monod	K1= 1.2299 K2= 0.1924 S0= 9.3435	0.0074
2,6-DCP Lag:22 hr	Zero-order	K0= 0.8319 S0= 8.1899	0.1424
	First-order	K1= 0.1847 S0= 9.1950	0.7222
	Monod	K1= 0.5033 K2= -1.8065 S0= 7.9448	0.3118

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 7-8-1985

TABLE 35

RESULTS

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 6
Run 1
(Unacclimated sludge, Temp. 80°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
2-CP	Zero-order	K0= 0.3907	5.4224
Lag: 0 hr		S0= 15.7068	
	First-order	K1= 0.0414	3.6397
		S0= 16.1269	
	Monod	K1= -0.4412	87.8408
		K2=-19.7275	
		S0= 15.7870	
N.B.	Zero-order	K0= 0.9607	0.1076
Lag: 0 hr		S0= 7.8679	
	First-order	K1= 0.2006	0.0360
		S0= 8.4105	
	Monod	K1= 10.2310	
		K2= 46.0227	0.0293
		S0= 8.3409	
2,6-DCP	Zero-order	K0= 0.6500	0.3688
Lag:68 hr		S0= 9.0000	
	First-order	K1= 0.1565	2.3041
		S0= 10.6430	
	Monod	K1= 0.4403	4.1870
		K2= -1.4208	
		S0= 8.7963	

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 7-8-1985

TABLE 36

RESULTS

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 6
Run 2
(Unacclimated sludge, Temp. 80°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
2-CP Lag: 0 hr	Zero-order	K0= 2.7548 S0= 19.1167	0.4956
	First-order	K1= 0.4017 S0= 27.2606	10.9084
	Monod	K1= 3.7033 K2= 2.3374 S0= 19.8866	0.1190
N.B. Lag: 0 hr	Zero-order	K0= 1.1238 S0= 8.9333	0.0566
	First-order	K1= 0.2655 S0= 10.6980	0.6148
	Monod	K1= 1.4460 K2= 1.1894 S0= 9.1423	0.0351
2,6-DCP Lag:22 hr	Zero-order	K0= 1.0018 S0= 9.3210	0.2081
	First-order	K1= 0.2101 S0= 10.7980	1.3107
	Monod	K1= 0.6489 K2= -1.7121 S0= 9.0424	0.3572

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 7-8-1985

TABLE 37

RESULTS

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 7
Run 1
(Phenol-acclimated sludge, Temp. 80°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
2-CP Lag: 0 hr	Zero-order	K0= 35.4000 S0= 17.3167	1.8408
	First-order	K1= 7.6214 S0= 24.7745	27.4602
	Monod	K1= 54.4264 K2= 2.4955 S0= 18.1000	< 0.0001
N.B. Lag: 0 hr	Zero-order	K0= 2.7874 S0= 6.1389	0.3069
	First-order	K1= 1.0311 S0= 10.6980	0.3983
	Monod	K1= 5.2043 K2= 2.1345 S0= 6.5576	0.2912
2,6-DCP Lag:22 hr	Zero-order	K0= 0.5568 S0= 10.4807	1.7080
	First-order	K1= 0.1257 S0= 13.7535	6.5532
	Monod	K1= 0.3380 K2= -2.1440 S0= 10.2399	1.0216

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 7-8-1985

TABLE 38

RESULTS

(2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol)
Experiment 8
Run 1
(Phenol-acclimated sludge, Temp. 80°F)

Compound	Kinetic Model	Constants	Absolute Average Residual
2-CP Lag: 0 hr	Zero-order	K0= 34.4000 S0= 16.1667	6.1633
	First-order	K1= 7.5684 S0= 21.2953	7.9405
	Monod	K1= 91.3192 K2= 7.3207 S0= 17.6000	< 0.0001
N.B. Lag: 0 hr	Zero-order	K0= 2.7411 S0= 6.7480	0.5899
	First-order	K1= 0.7265 S0= 7.2418	0.3064
	Monod	K1= 47.8413 K2= 59.3669 S0= 7.4503	0.3244
2,6-DCP Lag:22 hr	Zero-order	K0= 0.4930 S0= 9.1320	0.9070
	First-order	K1= 0.1285 S0= 12.0828	4.4775
	Monod	K1= 0.3129 K2= -1.6310 S0= 8.8433	0.3810

Units:

Zero-order: K0 (ppm/hr)
First-order: K1 (1/hr)
Monod: K1 (ppm/hr)
K2 (ppm)
S0 (ppm)

Experiment starting date: 7-8-1985

Figure 1

Diagram of Reactor Setup

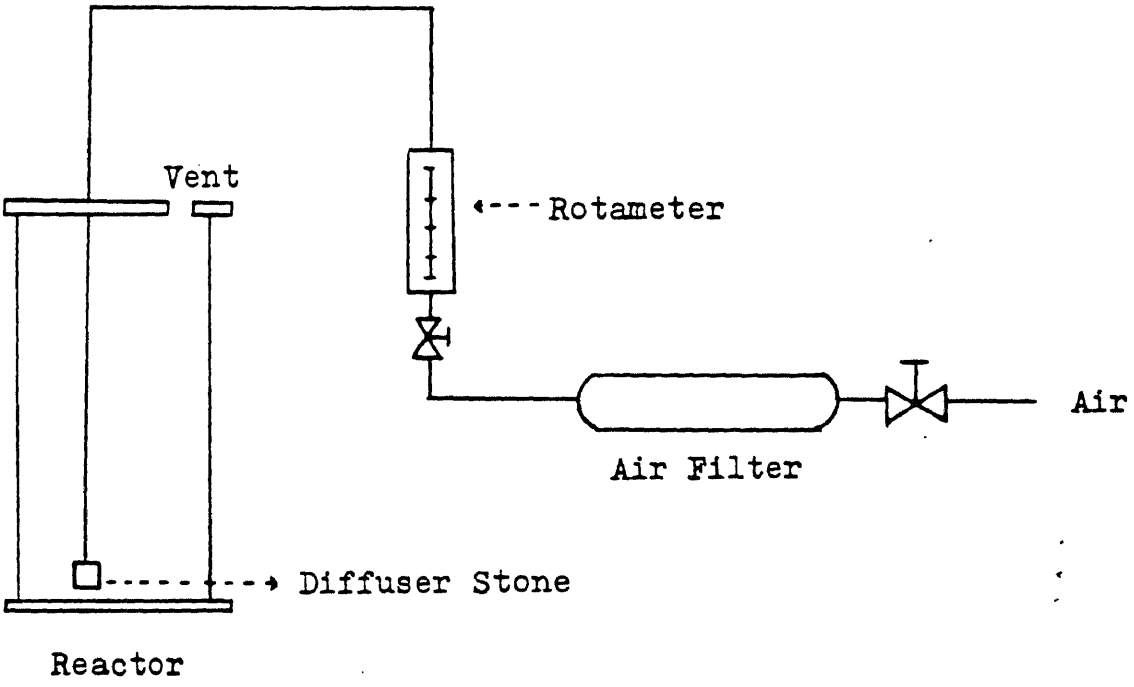


Figure 2-A

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 1

Data for Phenol Concentration vs. Time

(Unacclimated sludge, Temp. 78 °F)

o .. Run 1 (Best fit: Zero-order equation)

x .. Run 2 (Best fit: Monod equation)

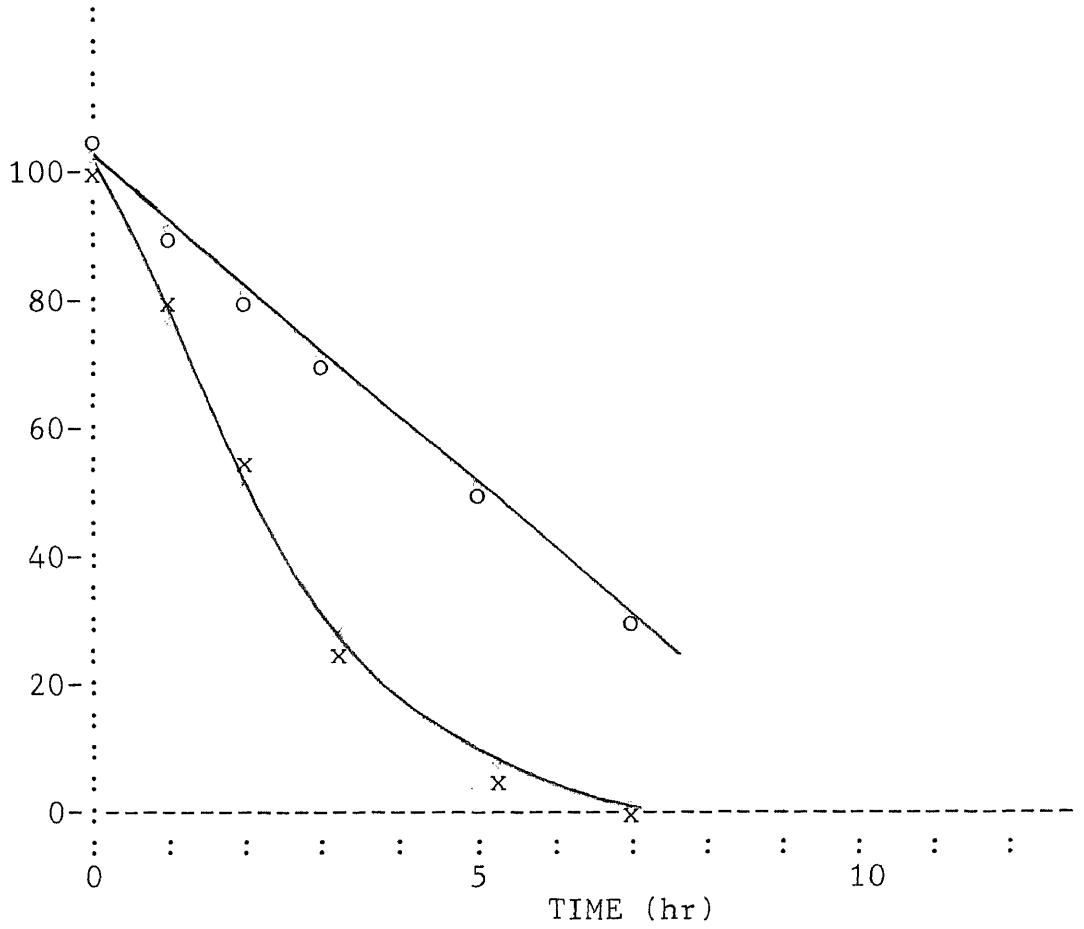


Figure 2-B

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 1

Data for Nitrobenzene Concentration vs. Time

(Unacclimated sludge, Temp. 78 °F)

o ... Run 1 (Best fit: First-order equation)
x ... Run 2 (Best fit: First-order equation)

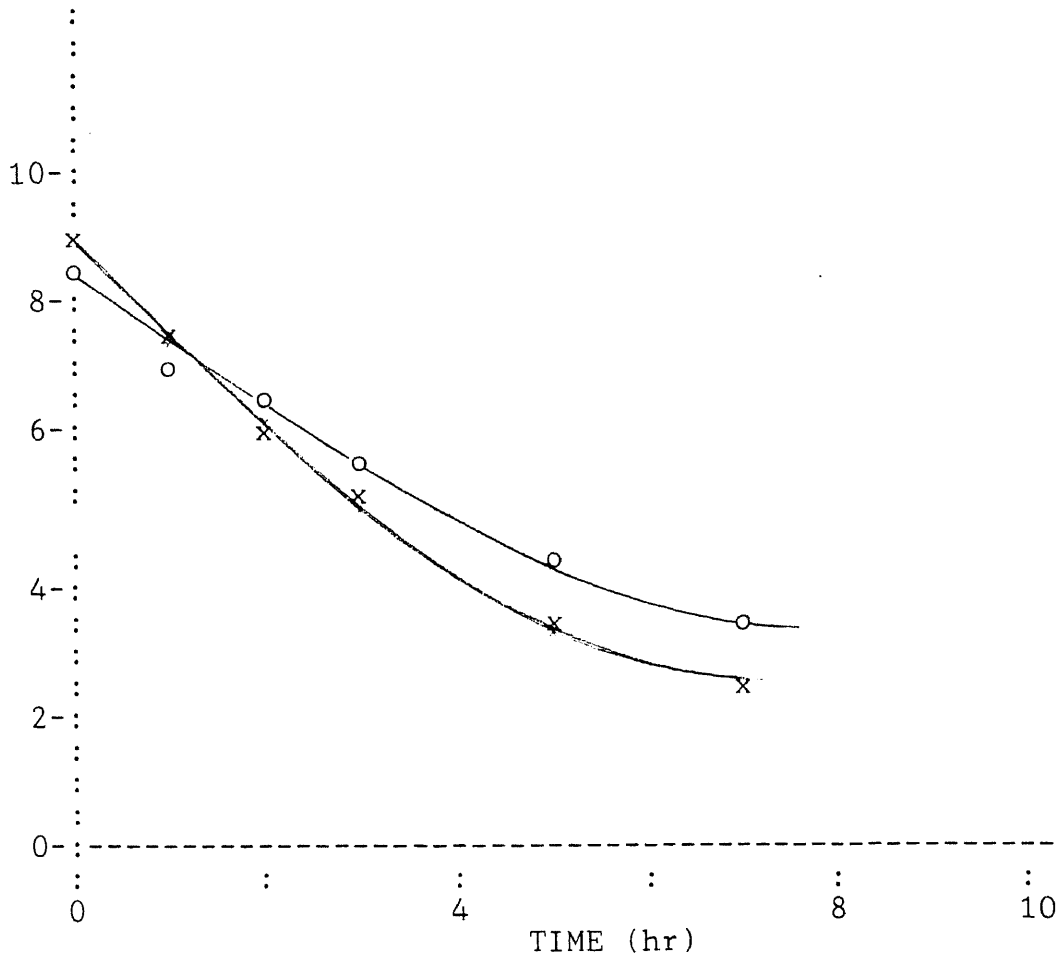


Figure 2-C

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 1

Data for 2,6-Dichlorophenol Concentration vs. Time

(Unacclimated sludge, Temp. 78°F)

o ... Run 1 (Best fit: Zero-order equation)
x ... Run 2 (Best fit: Zero-order equation)

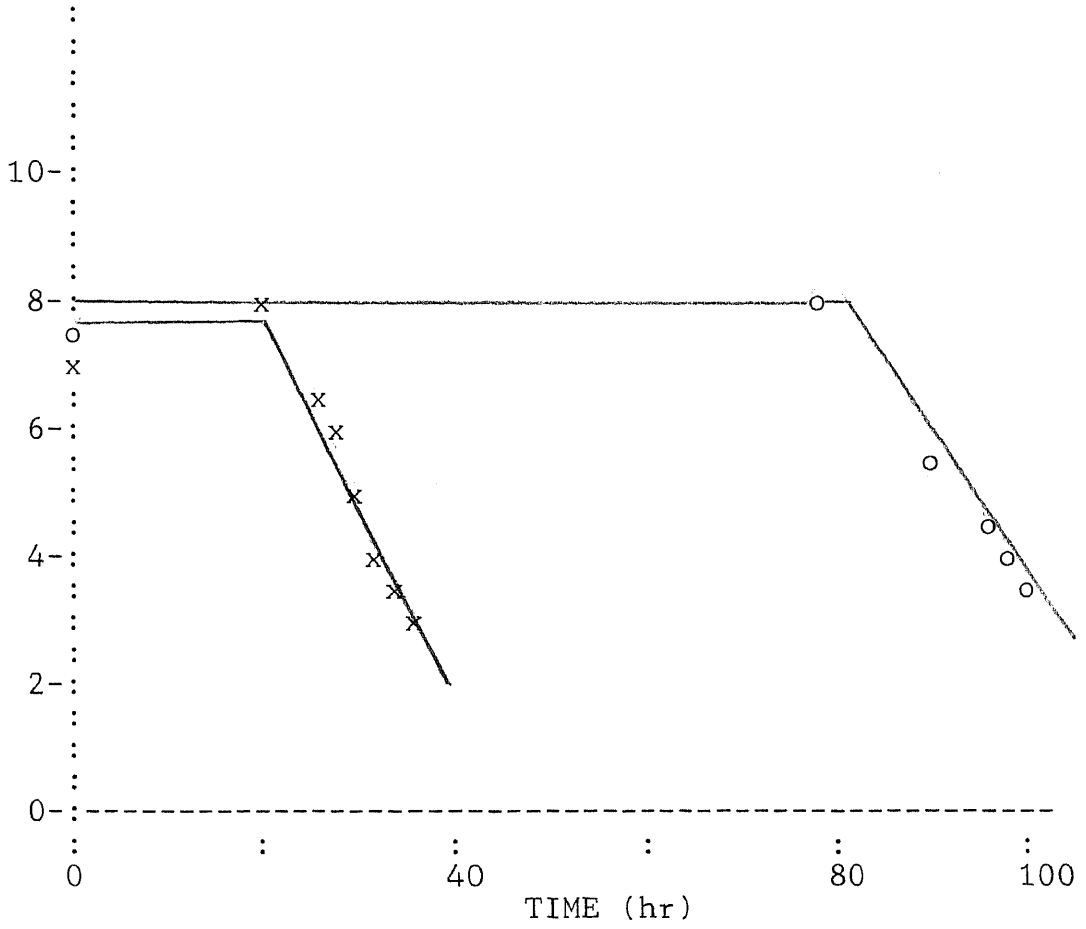


Figure 3-A

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 2

Data for Phenol Concentration vs. Time

(Unacclimated sludge, Temp. 78°F)

o .. Run 1 (Best fit: Zero-order equation)

x .. Run 2 (Best fit: Monod equation)

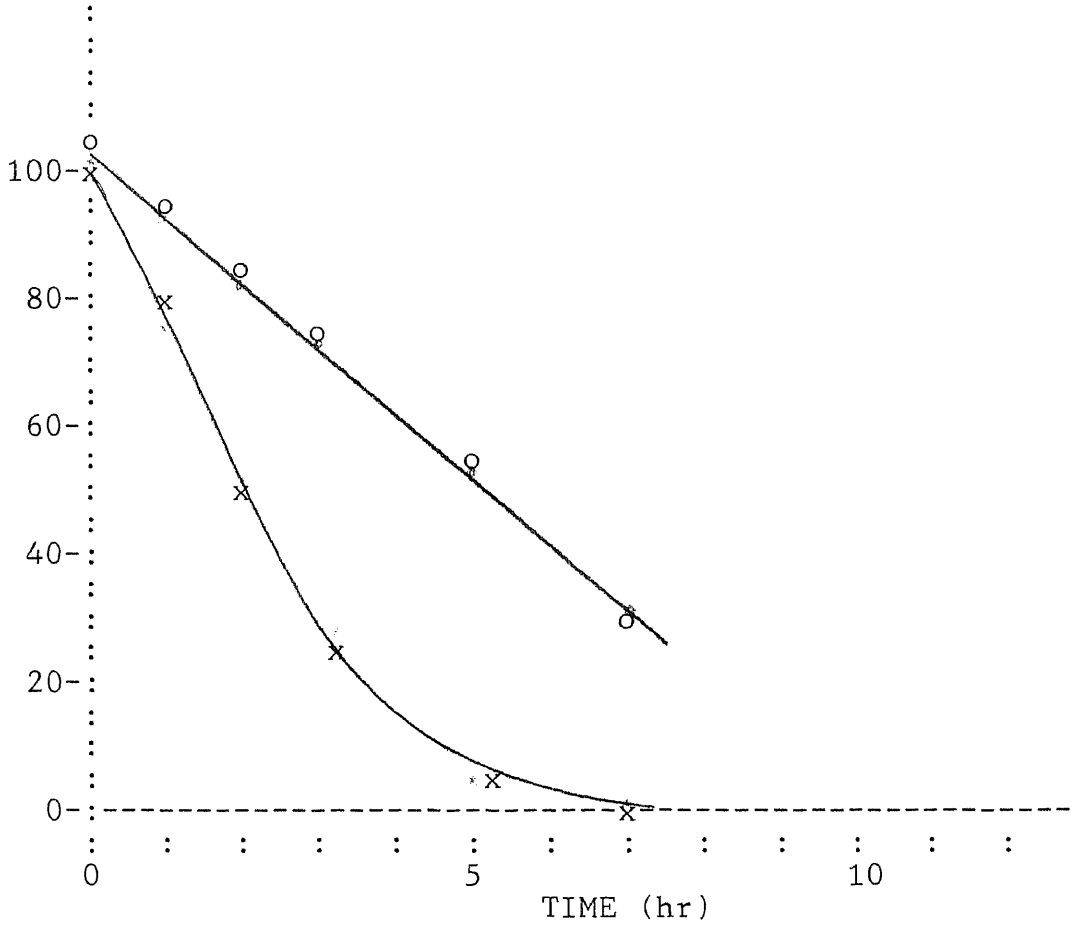


Figure 3-B

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 2

Data for Nitrobenzene Concentration vs. Time

(Unacclimated sludge, Temp. 78°F)

o ... Run 1 (Best fit: First-order equation)
x ... Run 2 (Best fit: First-order equation)

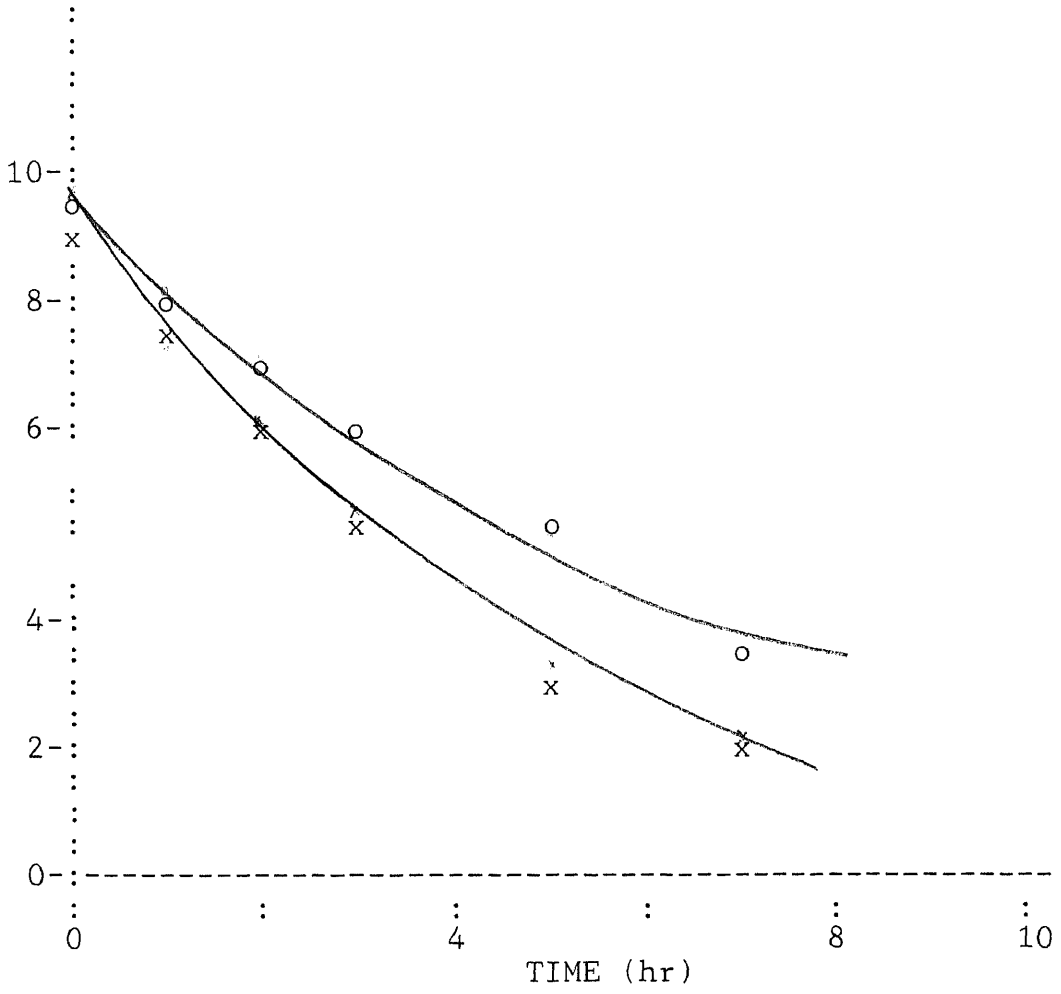


Figure 3-C

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 2

Data for 2,6-Dichlorophenol Concentration vs. Time

(Unacclimated sludge, Temp. 78°F)

o ... Run 1 (Best fit: Zero-order equation)
x ... Run 2 (Best fit: Zero-order equation)

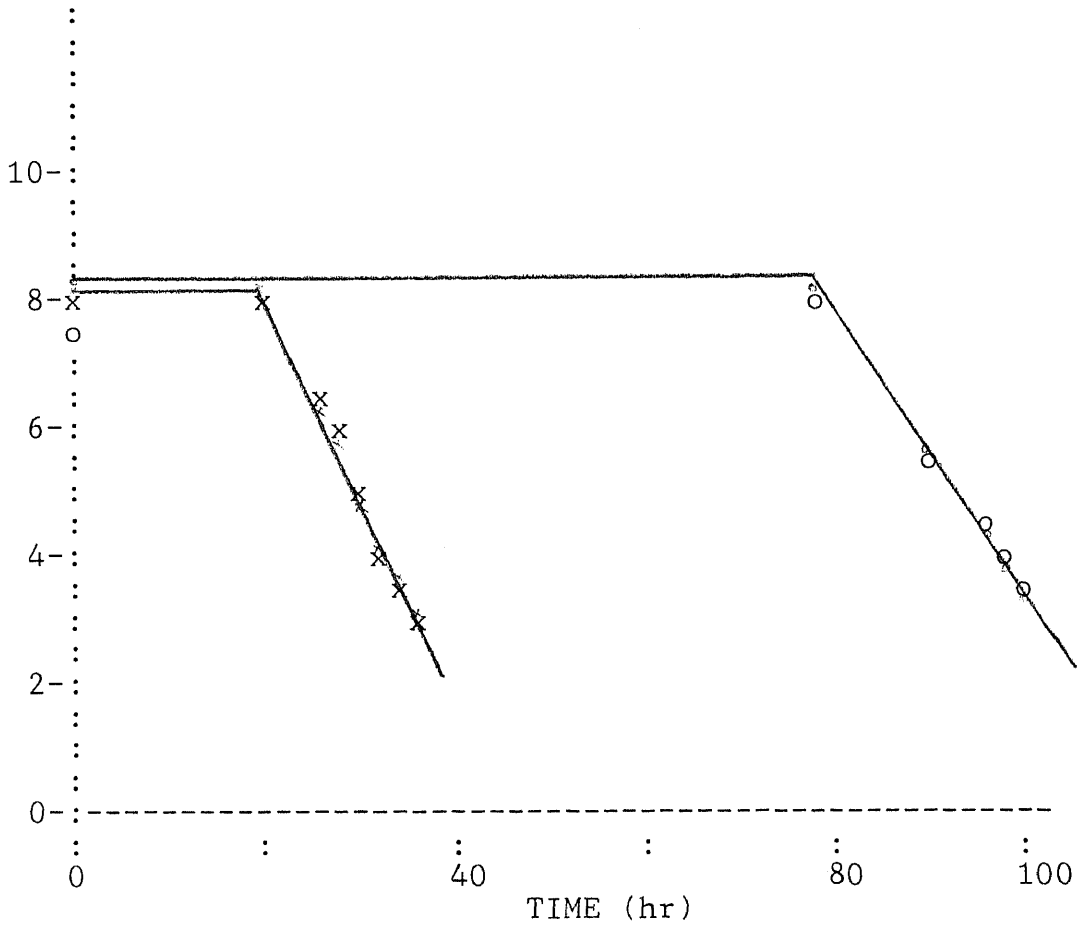


Figure 4-A

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 3

Data for Phenol Concentration vs. Time

(Phenol-acclimated sludge, Temp. 78°F)

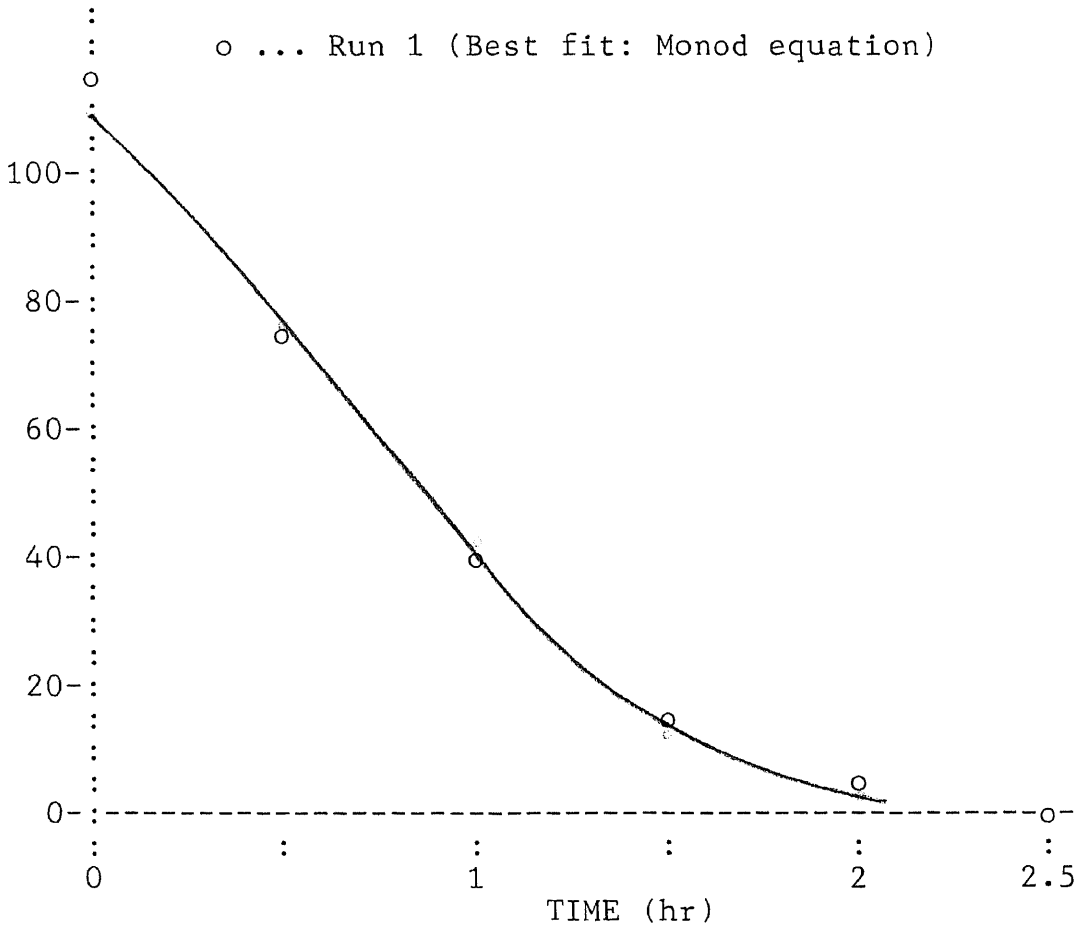


Figure 4-B

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 3

Data for Nitrobenzene Concentration vs. Time

(Phenol-acclimated sludge, Temp. 78 °F)

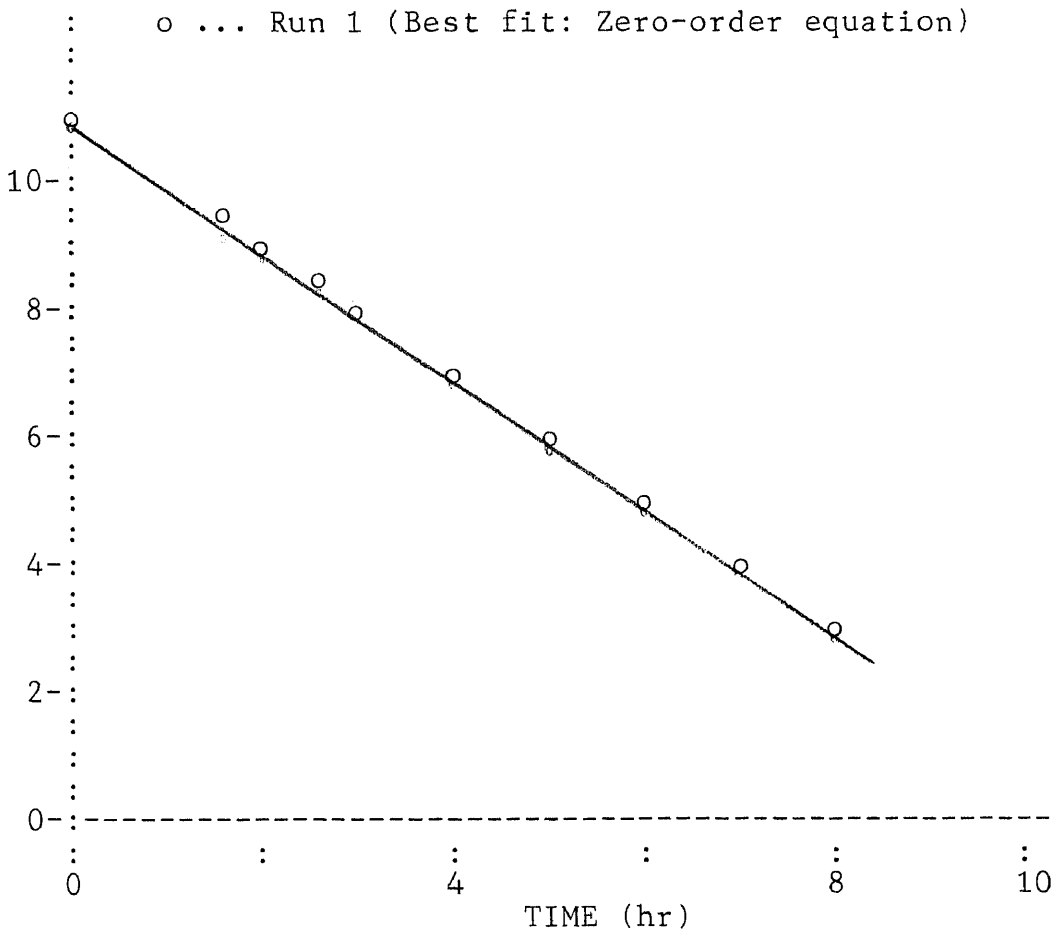


Figure 4-C

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 3

Data for 2,6-Dichlorophenol Concentration vs. Time

(Phenol-acclimated sludge, Temp. 78°F)

o ... Run 1 (Best fit: Zero-order equation)

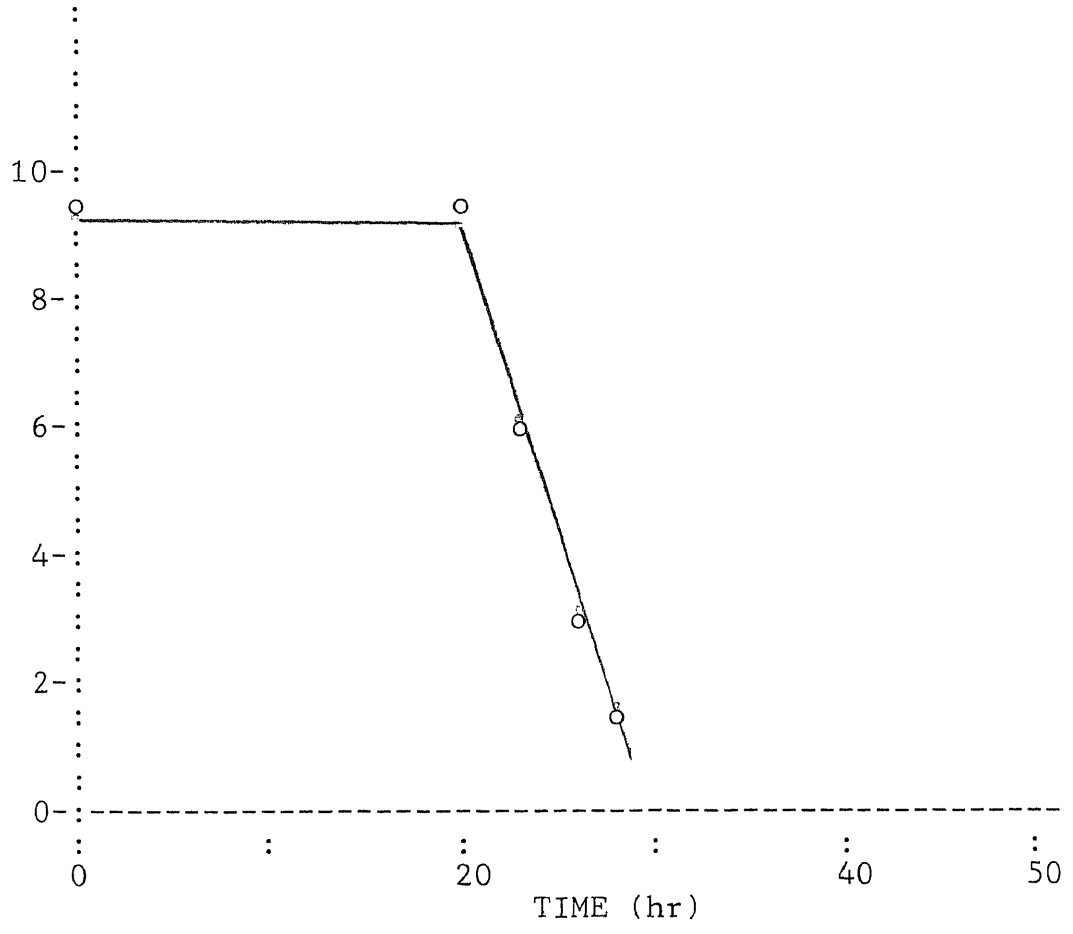


Figure 5-A

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 4

Data for Phenol Concentration vs. Time

(Phenol-acclimated sludge, Temp. 78°F)

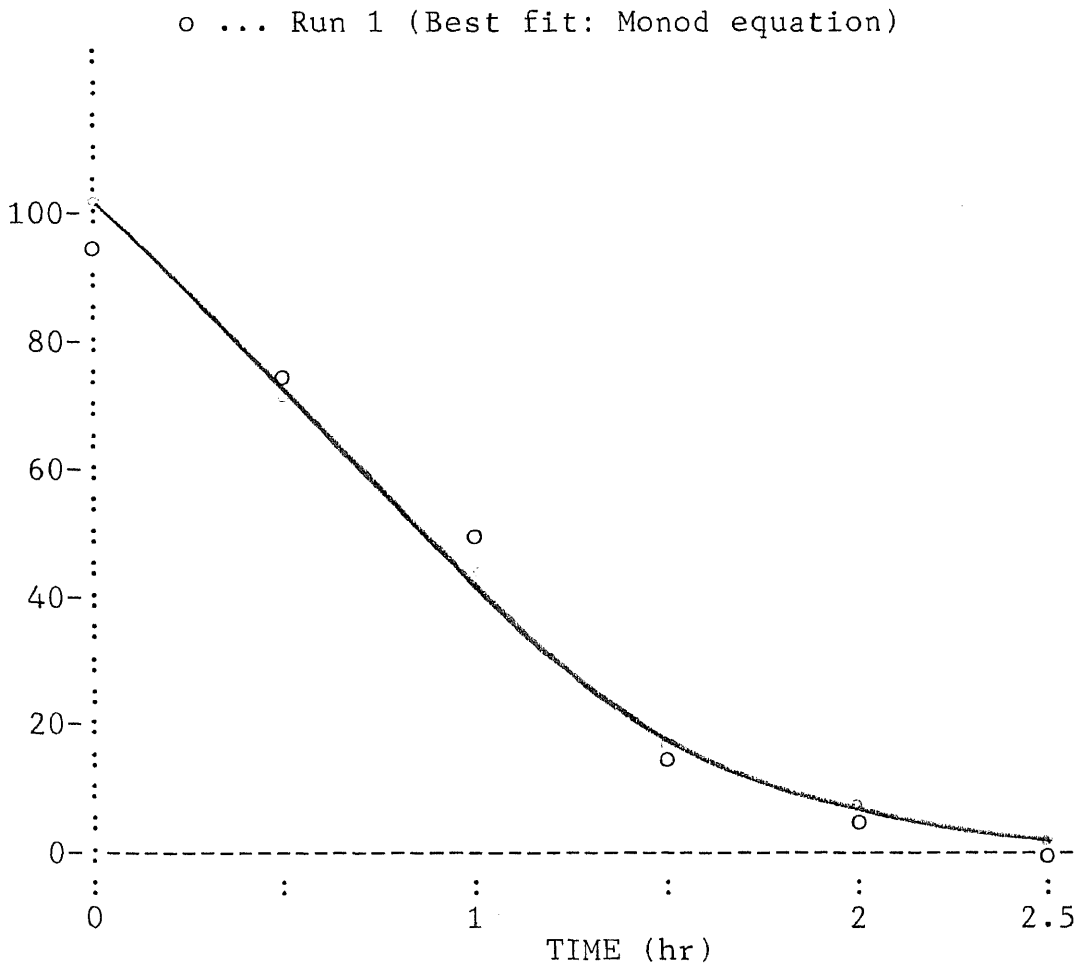


Figure 5-B

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 4

Data for Nitrobenzene Concentration vs. Time

(Phenol-acclimated sludge, Temp. 78 °F)

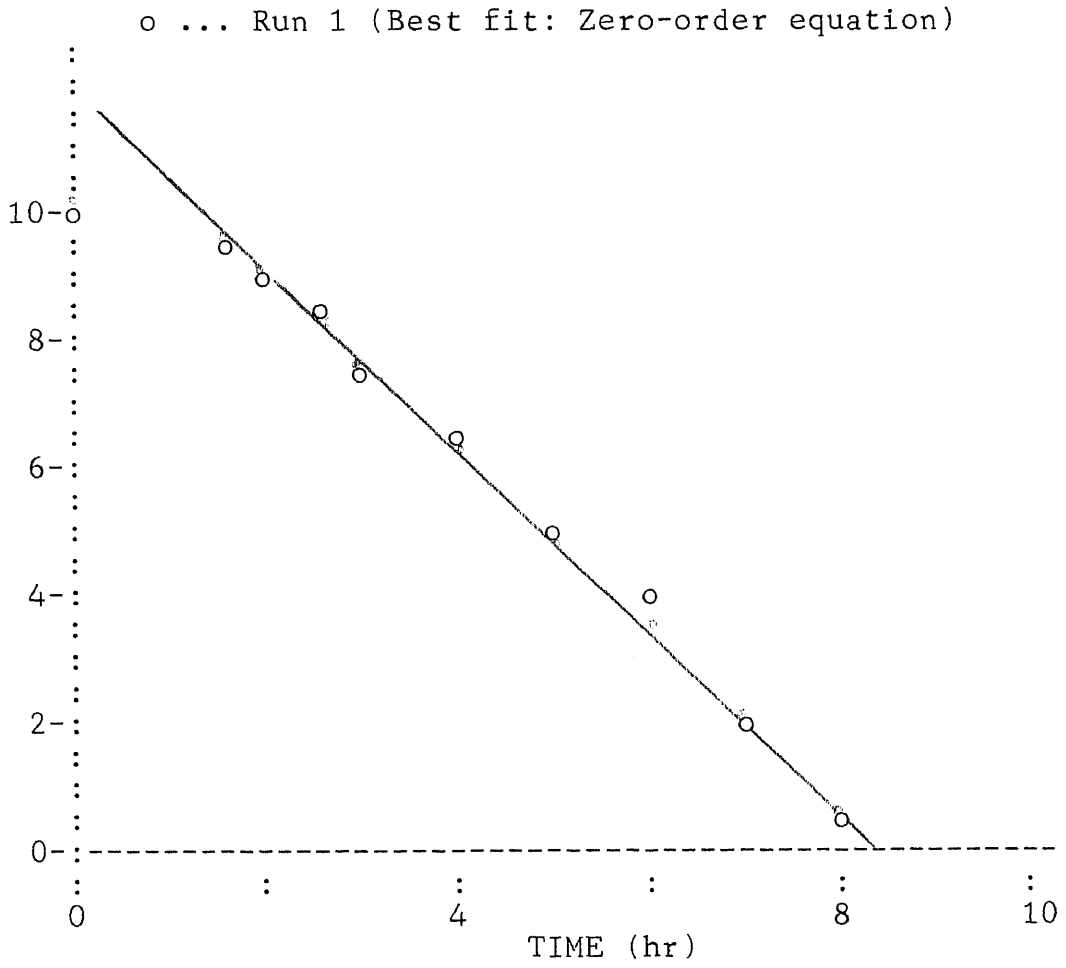


Figure 5-C

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 4

Data for 2,6-Dichlorophenol Concentration vs. Time

(Phenol-acclimated sludge, Temp. 78 °F)

o ... Run 1 (Best fit: Monod equation)

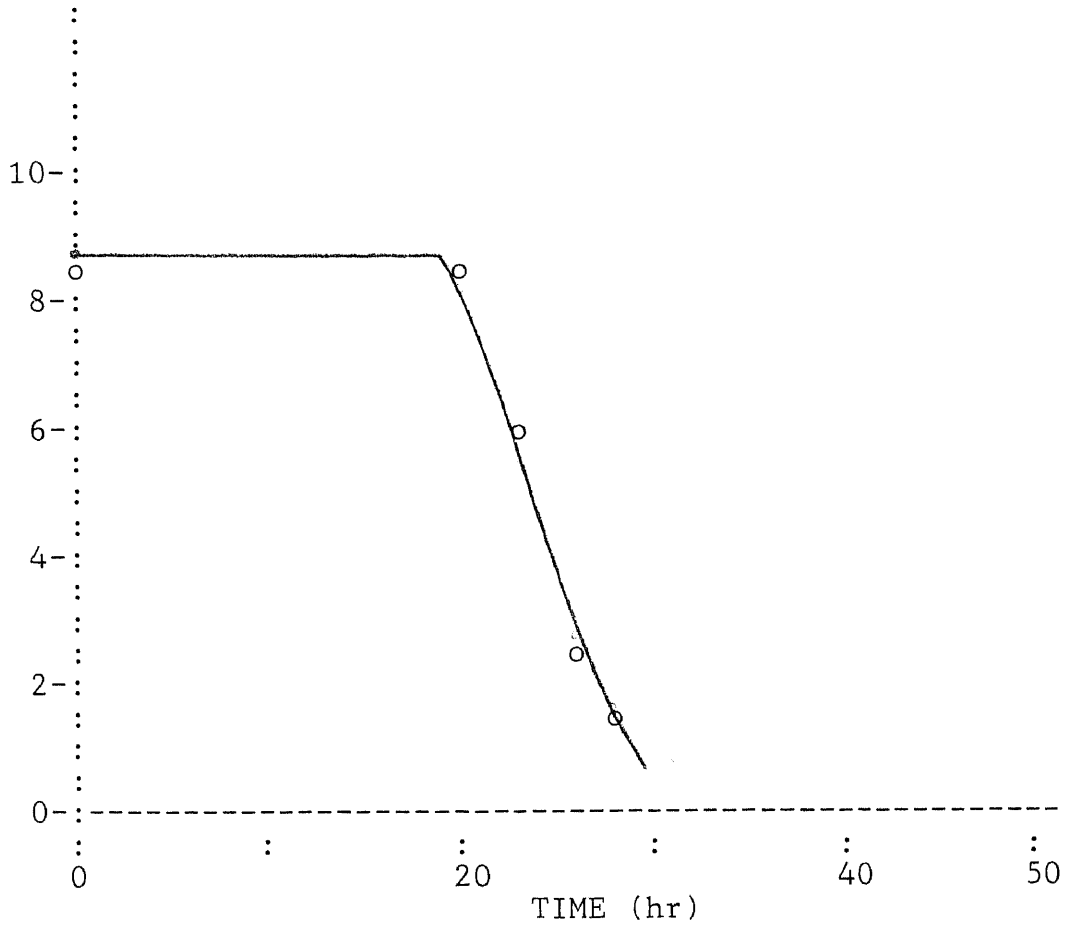


Figure 6-A

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 5

Data for 2-Chlorophenol Concentration vs. Time

(Unacclimated sludge, Temp. 80 °F)

o ... Run 1 (Best fit: First-order equation)
x ... Run 2 (Best fit: Monod equation)

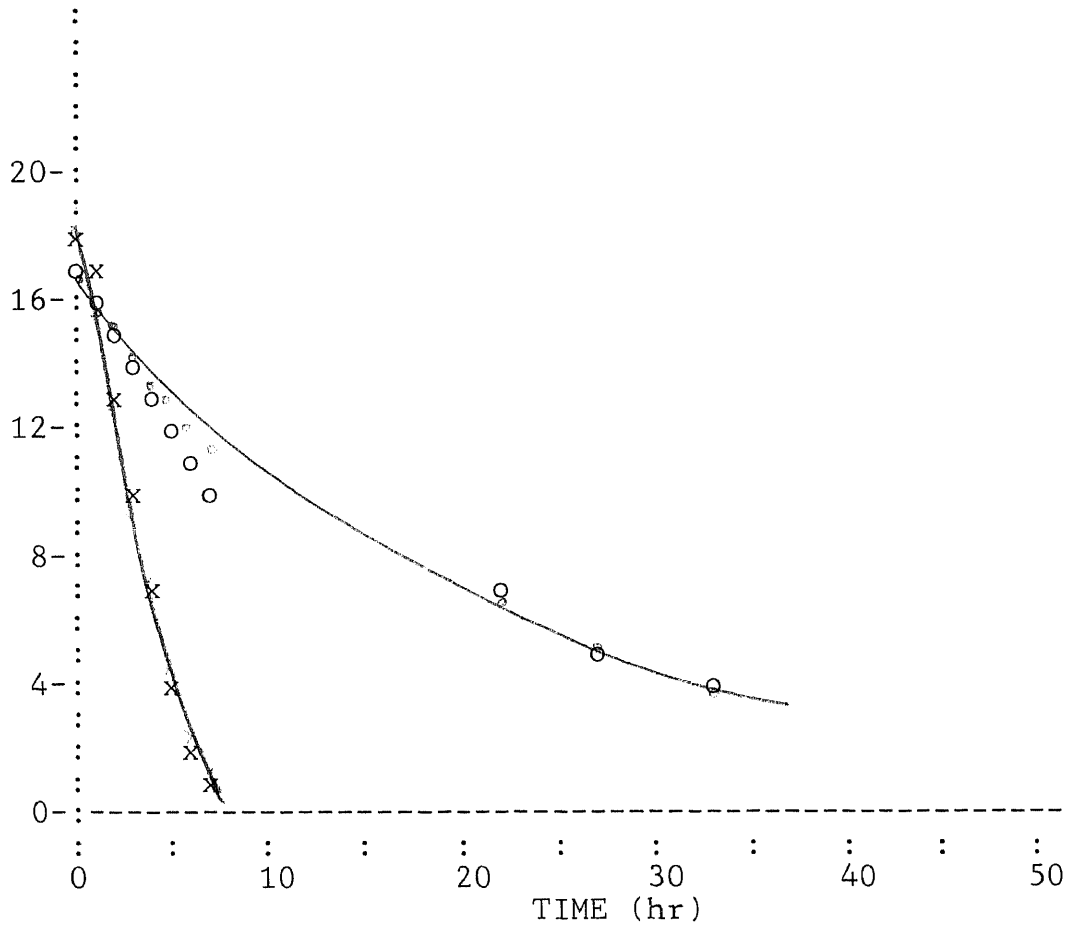


Figure 6-B

2-Chlorophenol+Nitorbenzene+2,6-Dichlorophenol, Experiment 5

Data for Nitrobenzene Concentration vs. Time

(Unacclimated sludge, Temp. 80 °F)

o ... Run 1 (Best fit: Monod equation)
x ... Run 2 (Best fit: Monod equation)

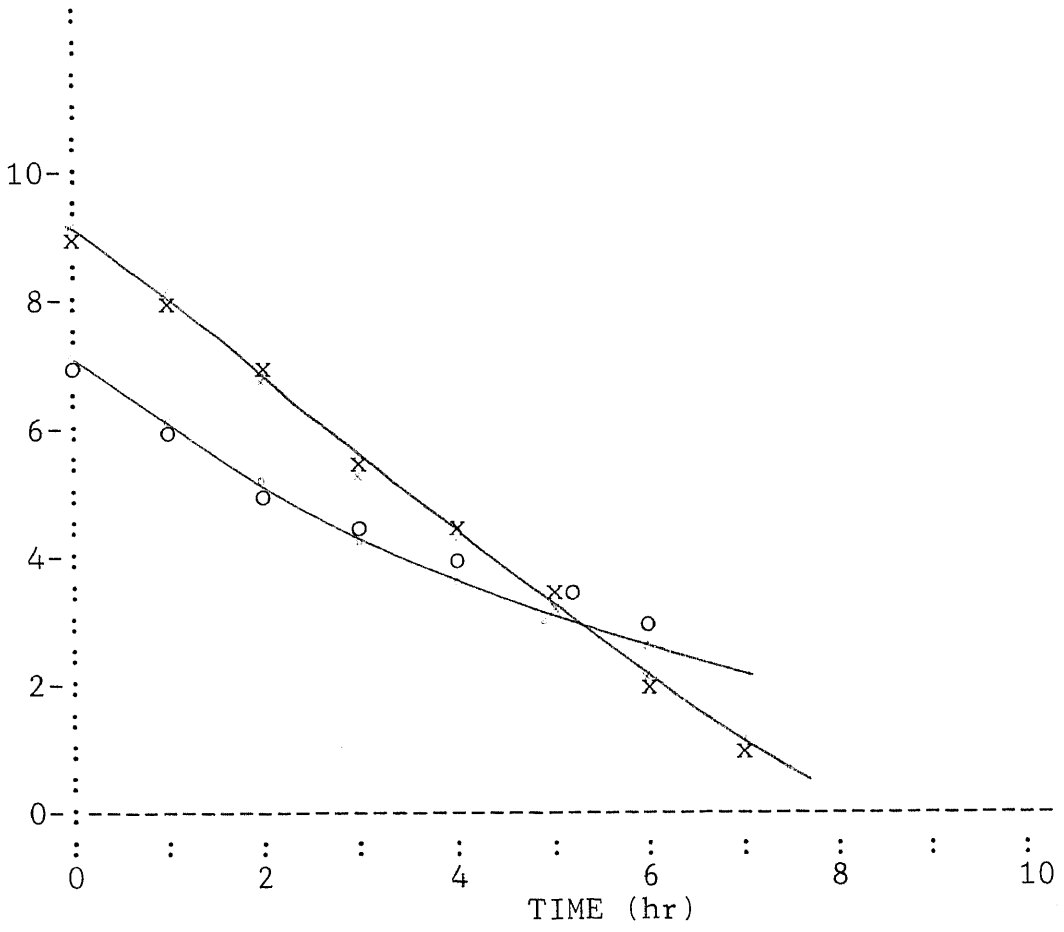


Figure 6-C

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 5

Data for 2,6-Dichlorophenol Concentration vs. Time

(Unacclimated sludge, Temp. 80 °F)

o ... Run 1 (Best fit: Zero-order equation)
x ... Run 2 (Best fit: Zero-order equation)

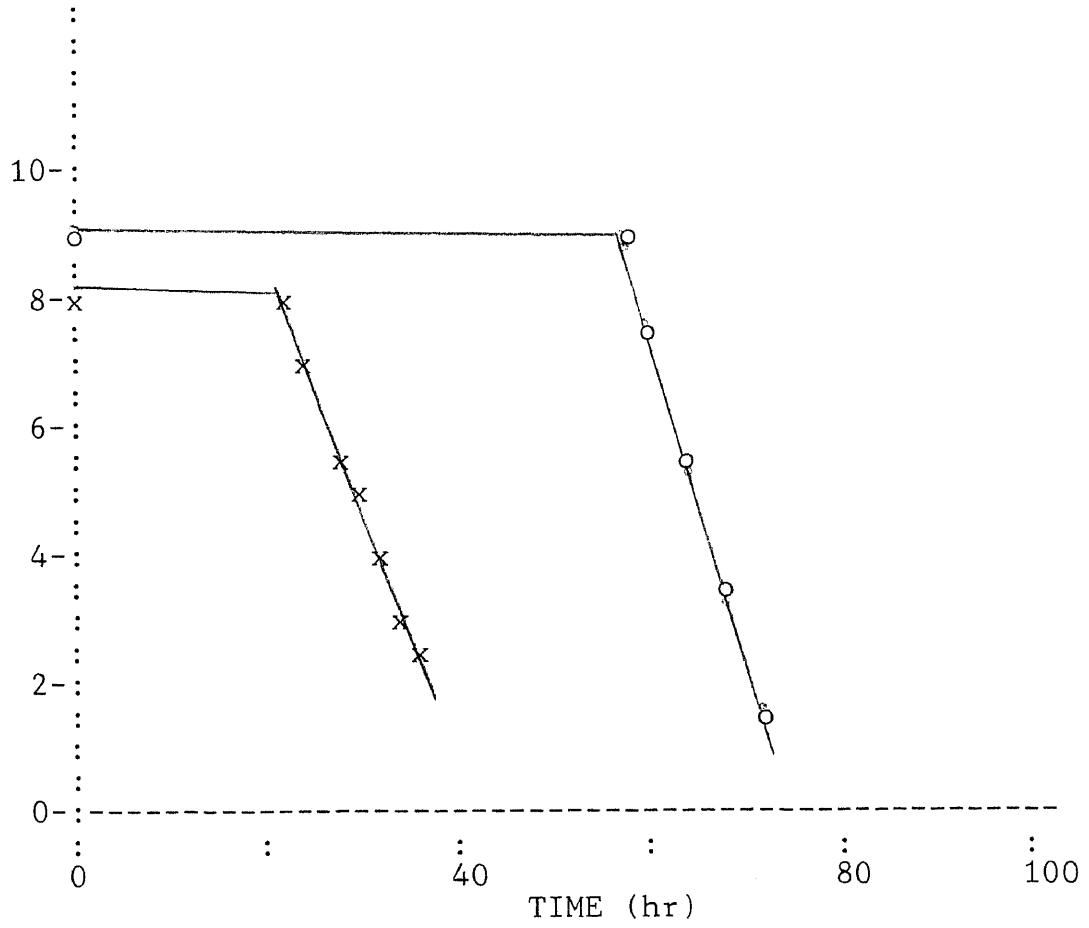


Figure 7-A

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 6

Data for 2-Chlorophenol Concentration vs. Time

(Unacclimated sludge, Temp. 80°F)

o ... Run 1 (Best fit: First-order equation)
x ... Run 2 (Best fit: Monod equation)

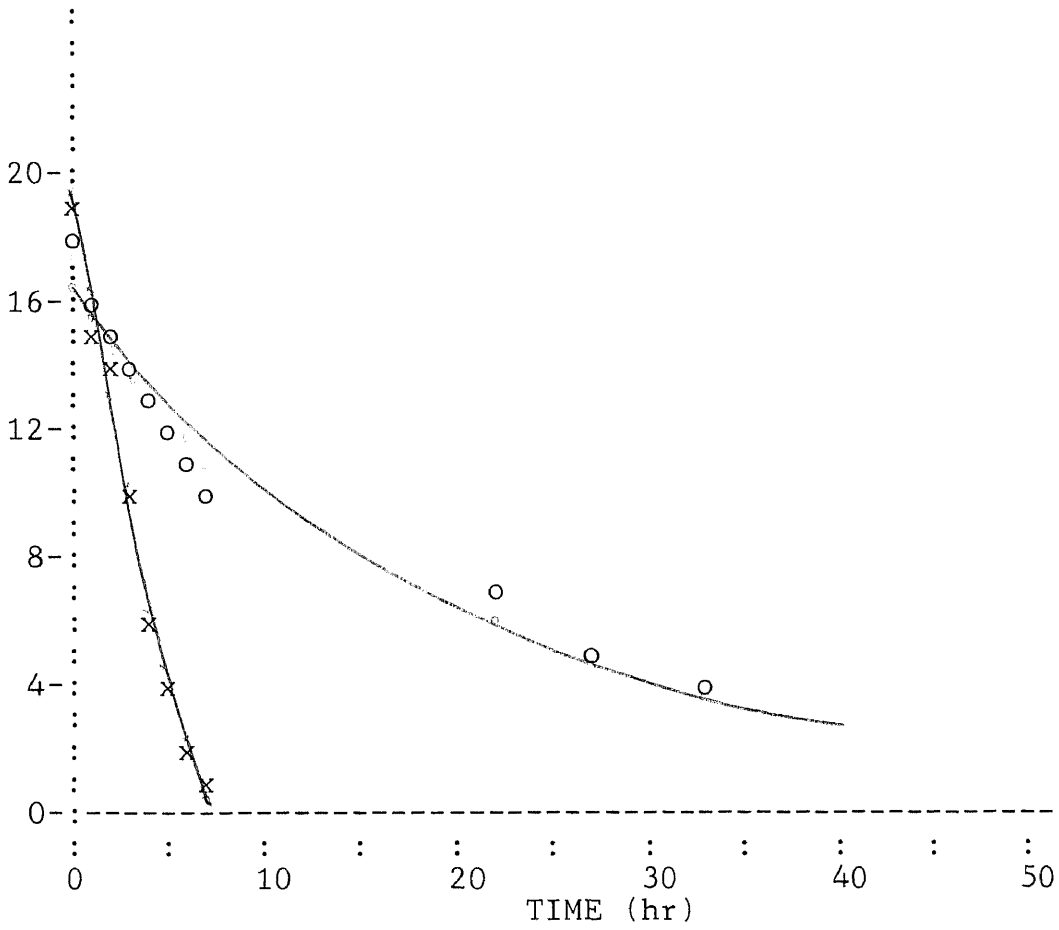


Figure 7-B

2-Chlorophenol+Nitorbenzene+2,6-Dichlorophenol, Experiment 6

Data for Nitrobenzene Concentration vs. Time

(Unacclimated sludge, Temp. 80°F)

o ... Run 1 (Best fit: Monod equation)
x ... Run 2 (Best fit: Monod equation)

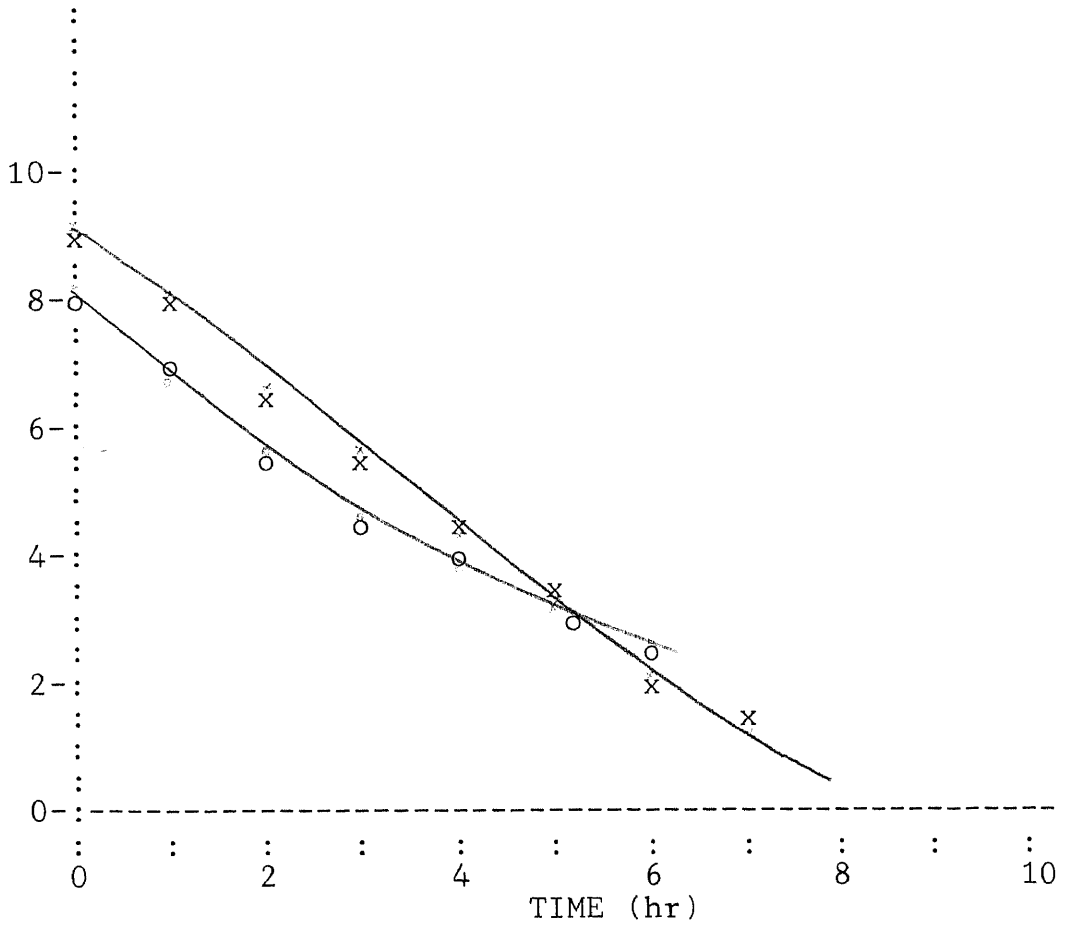


Figure 7-C

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 6

Data for 2,6-Dichlorophenol Concentration vs. Time

(Unacclimated sludge, Temp. 80°F)

o ... Run 1 (Best fit: Zero-order equation)
x ... Run 2 (Best fit: Zero-order equation)

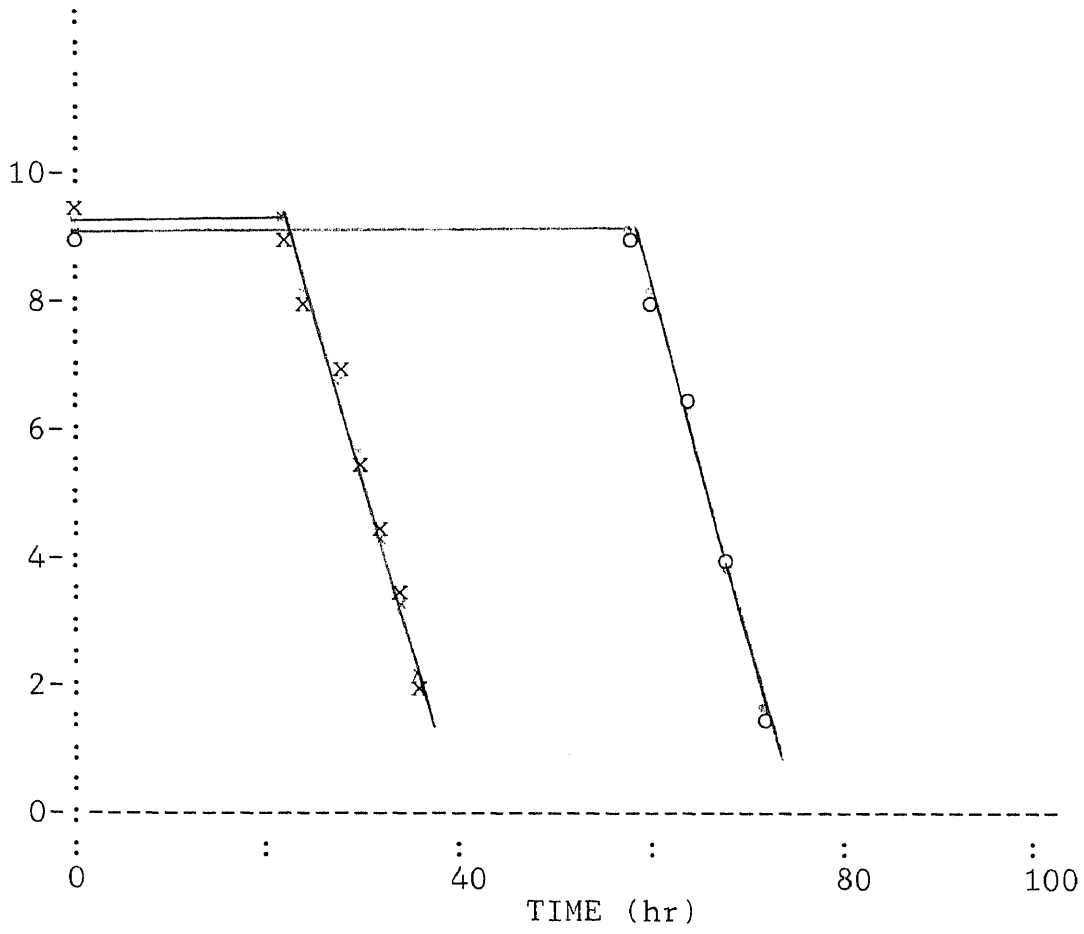


Figure 8-A

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 7

Data for 2-Chlorophenol Concentration vs. Time

(Phenol-acclimated sludge, Temp. 80°F)

o ... Run 1 (Best fit: Monod equation)

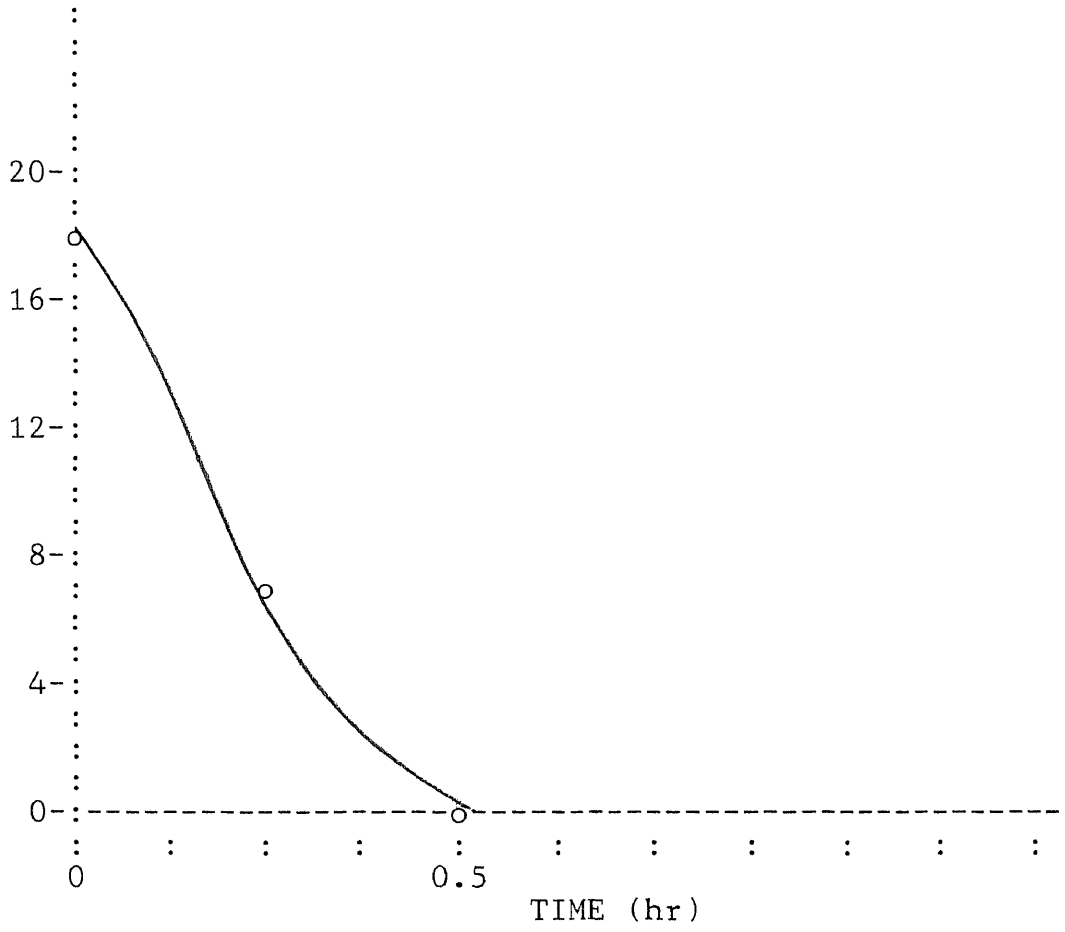


Figure 8-B

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 7

Data for Nitrobenzene Concentration vs. Time

(Phenol-acclimated sludge, Temp. 78°F)

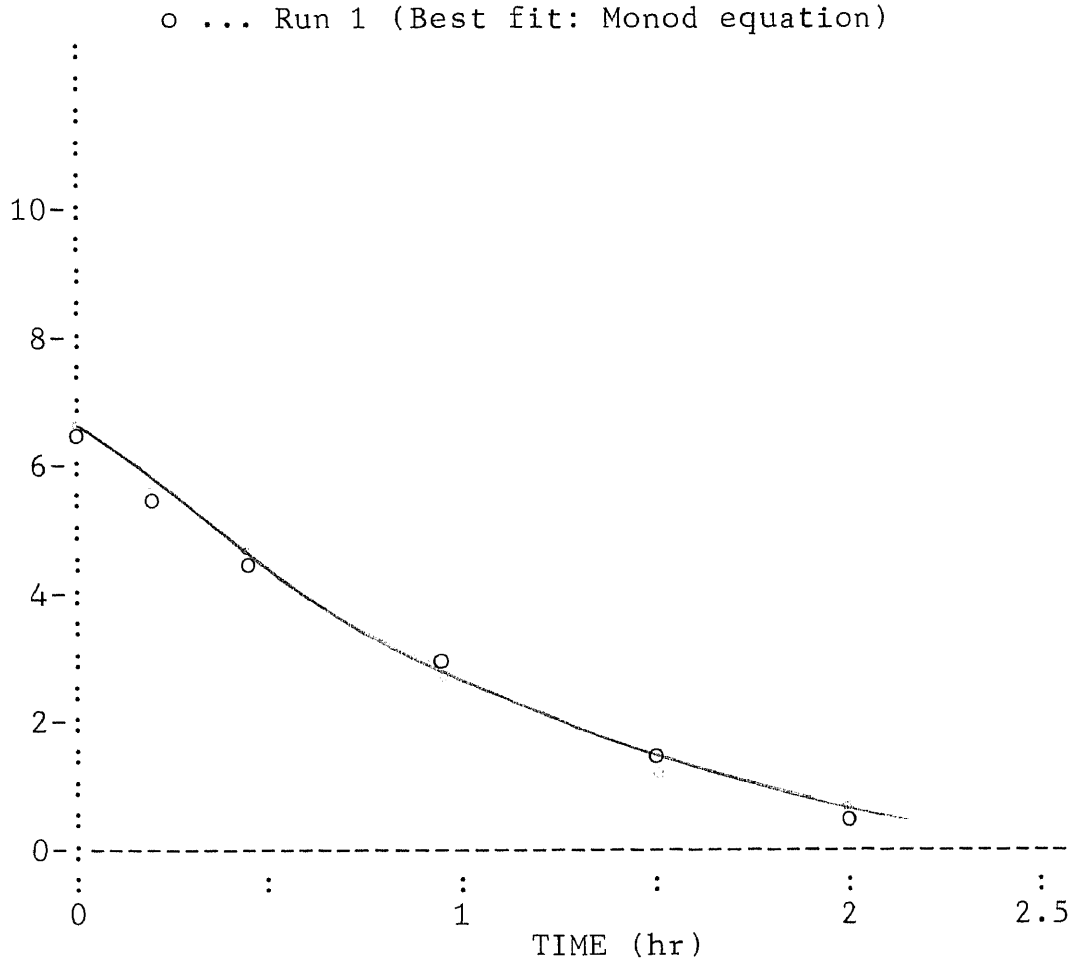


Figure 8-C

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 7

Data for 2,6-Dichlorophenol Concentration vs. Time

(Phenol-acclimated sludge, Temp. 80°F)

o ... Run 1 (Best fit: Zero-order equation)

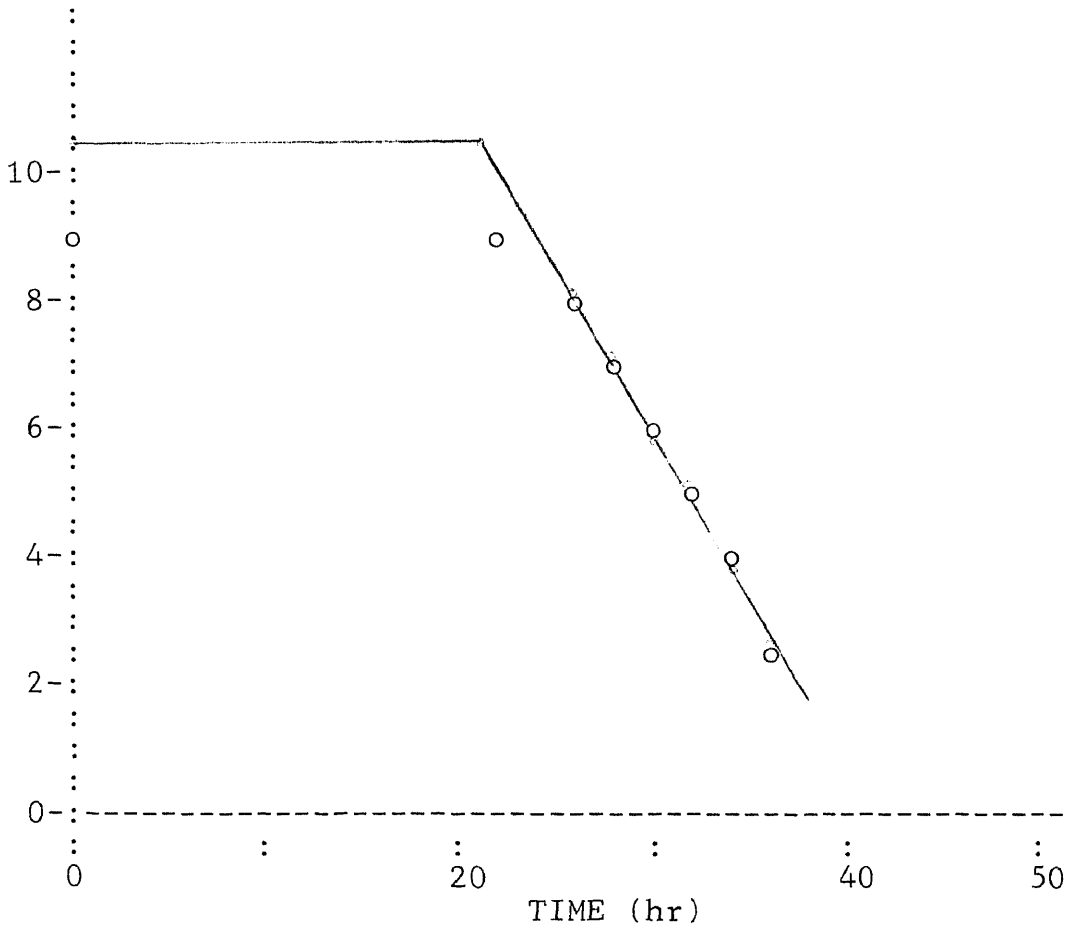


Figure 9-A

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 8

Data for 2-Chlorophenol Concentration vs. Time

(Phenol-acclimated sludge, Temp. 80°F)

o ... Run 1 (Best fit: Monod equation)

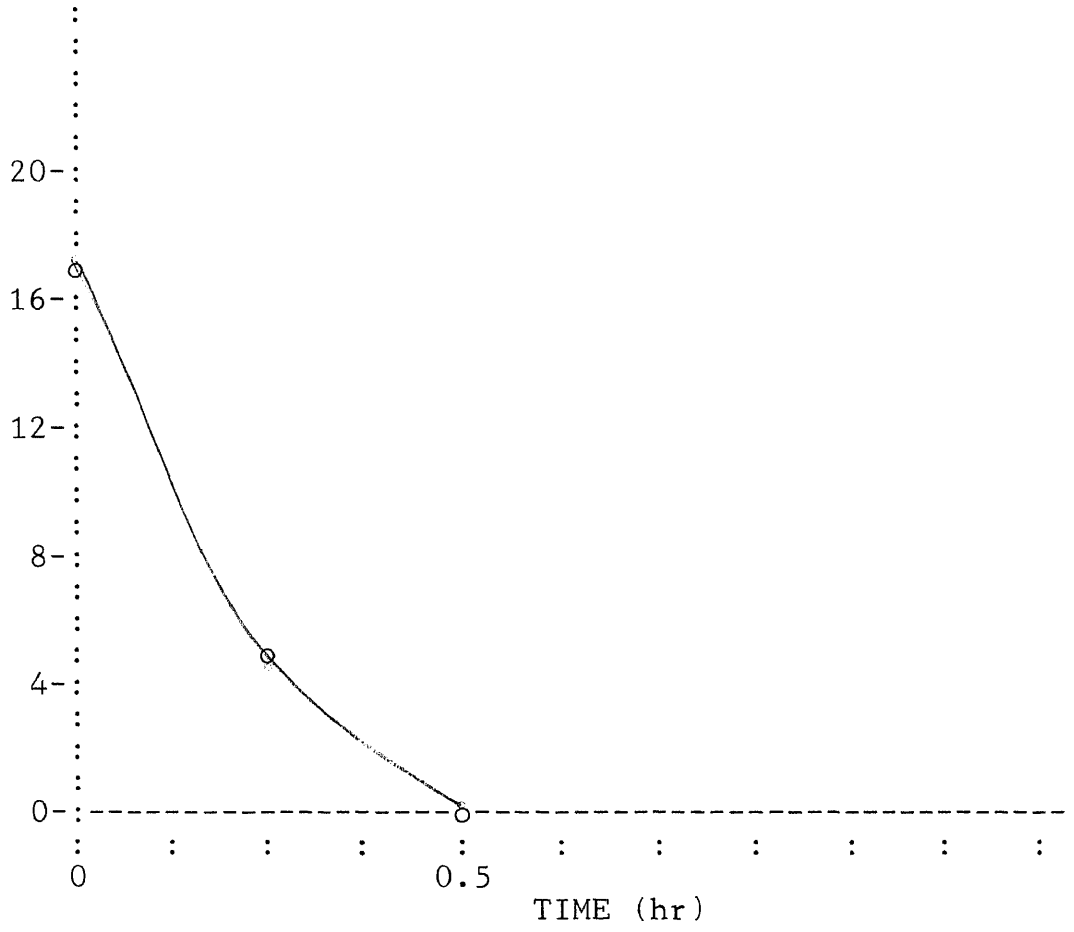


Figure 9-B

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 8

Data for Nitrobenzene Concentration vs. Time

(Phenol-acclimated sludge, Temp. 78°F)

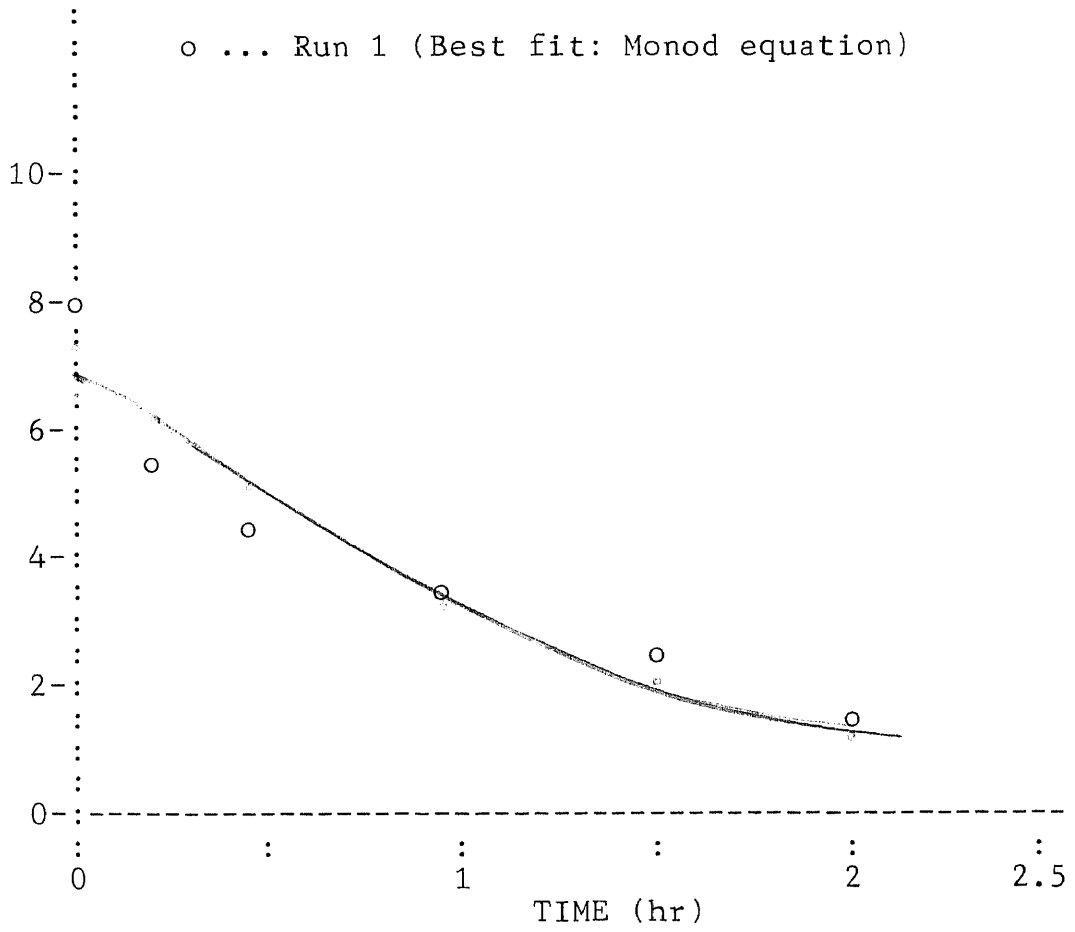


Figure 9-C

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 8

Data for 2,6-Dichlorophenol Concentration vs. Time

(Phenol-acclimated sludge, Temp. 80 °F)

o ... Run 1 (Best fit: Zero-order equation)

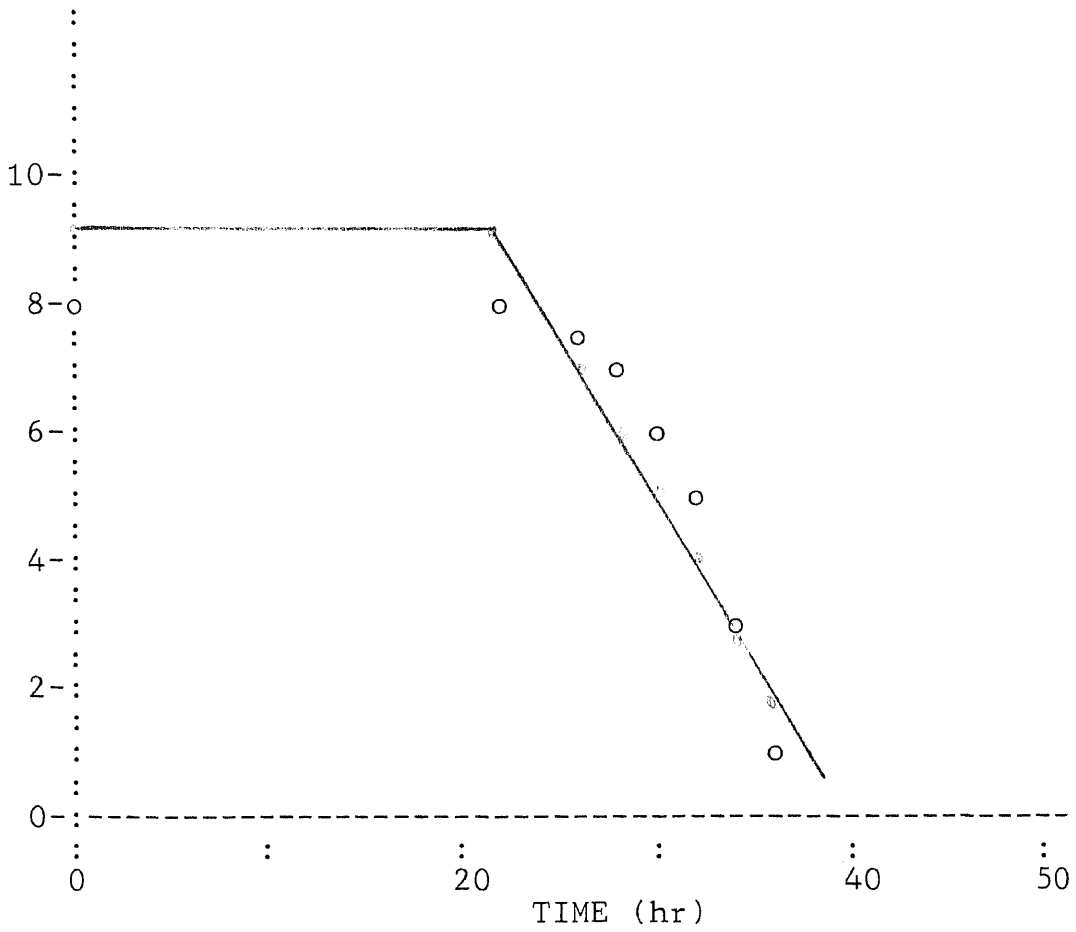


Figure 10

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 1

Time Versus MLSS

(Unacclimated sludge, Temp. 78°F)

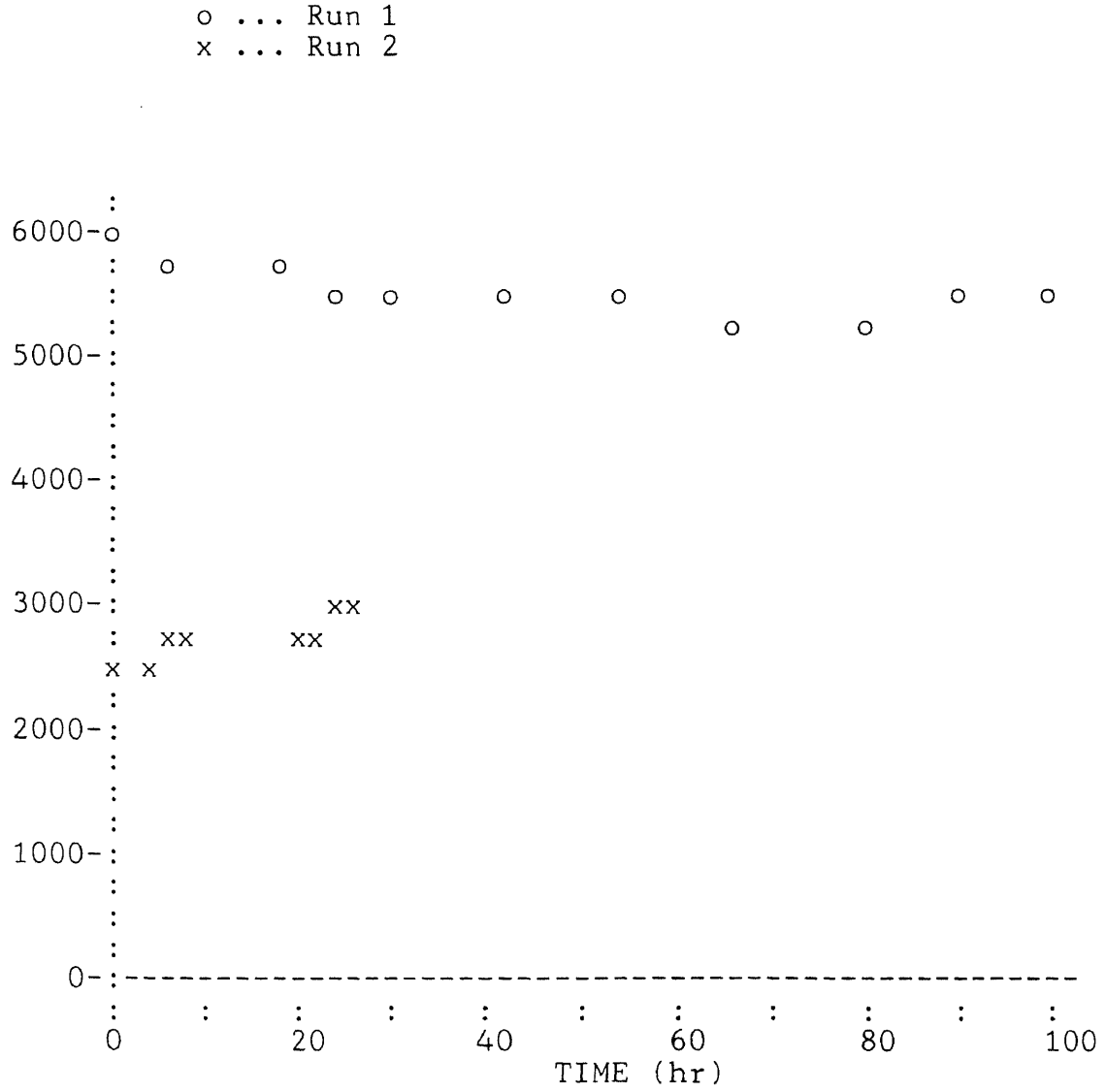


Figure 11

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 2

Time Versus MLSS

(Unacclimated sludge, Temp. 78°F)

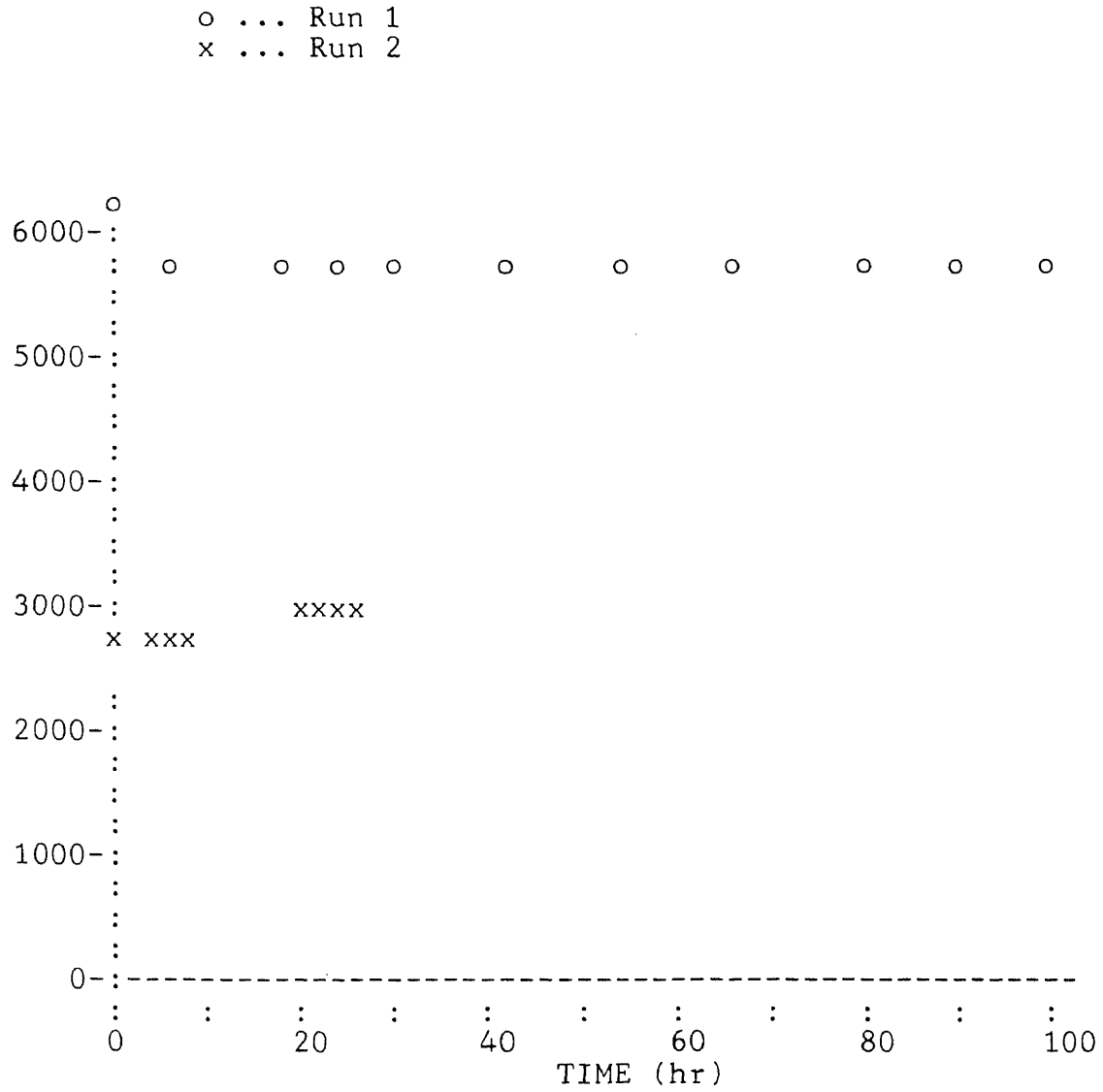


Figure 12

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 3

Time Versus MLSS

(Phenol-acclimated sludge, Temp. 78°F)

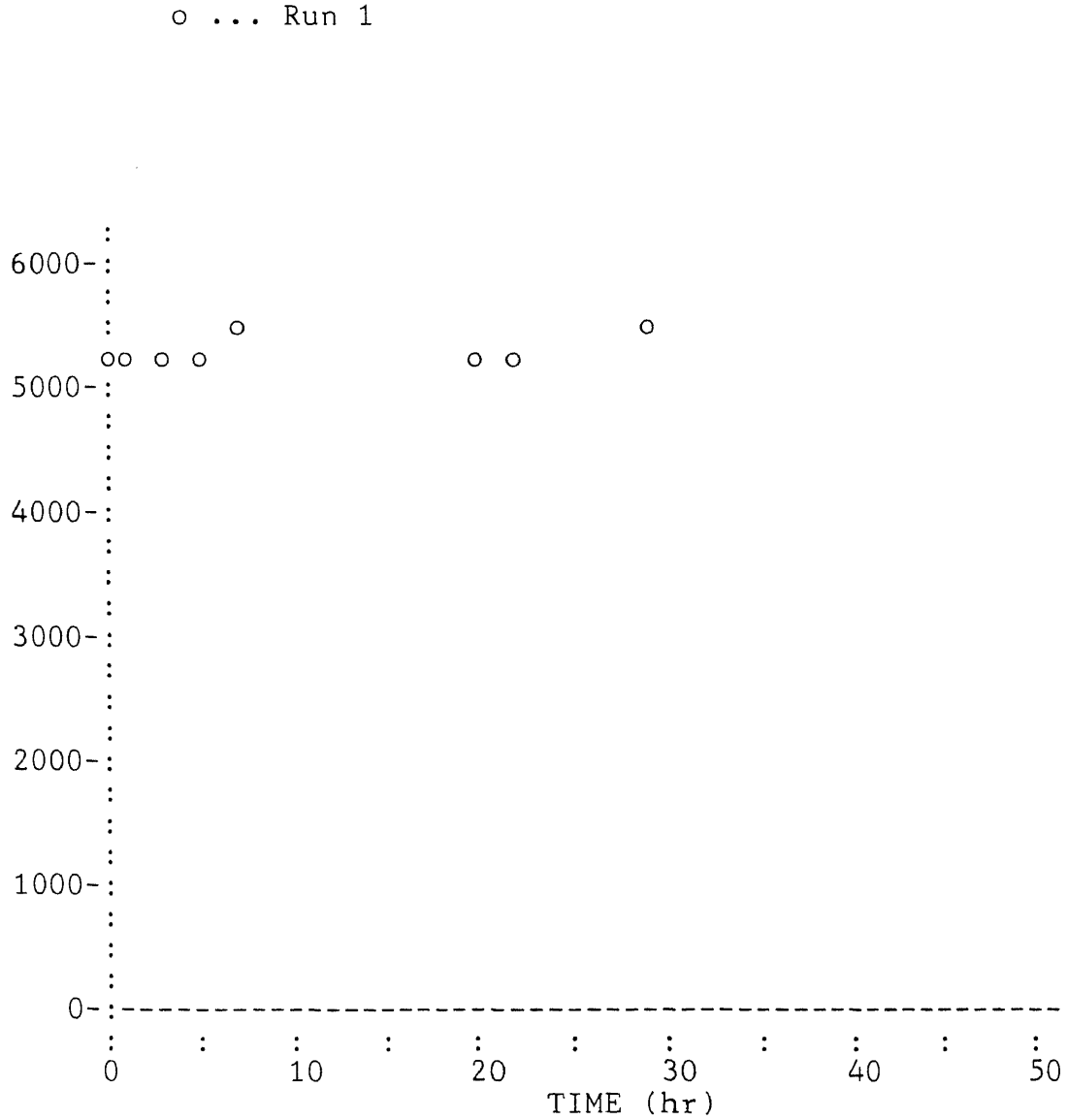


Figure 13

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 4

Time Versus MLSS

(Phenol-acclimated sludge, Temp. 78°F)

o ... Run 1

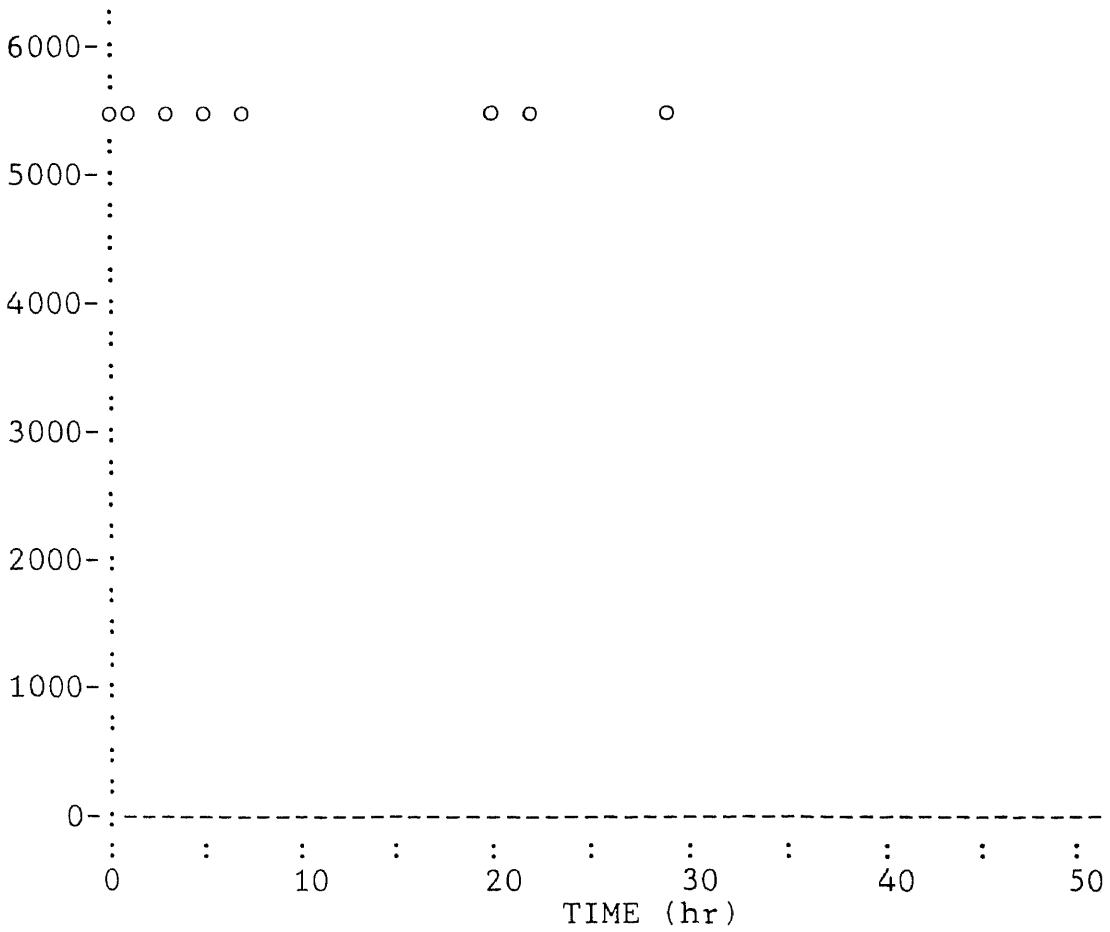


Figure 14

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 5

Time Versus MLSS

(Unacclimated sludge, Temp. 80 °F)

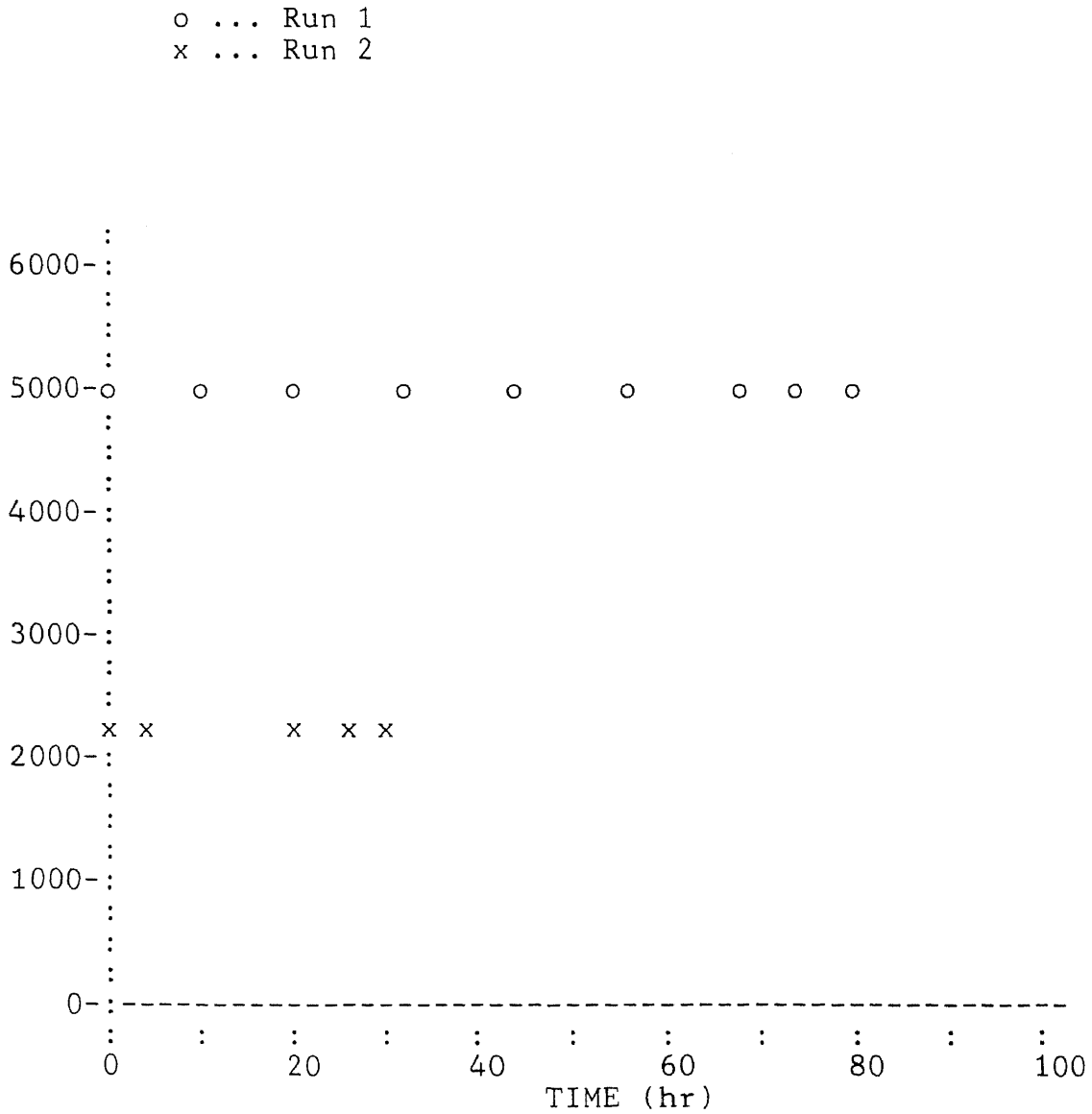


Figure 15

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 6

Time Versus MLSS

(Unacclimated sludge, Temp. 80°F)

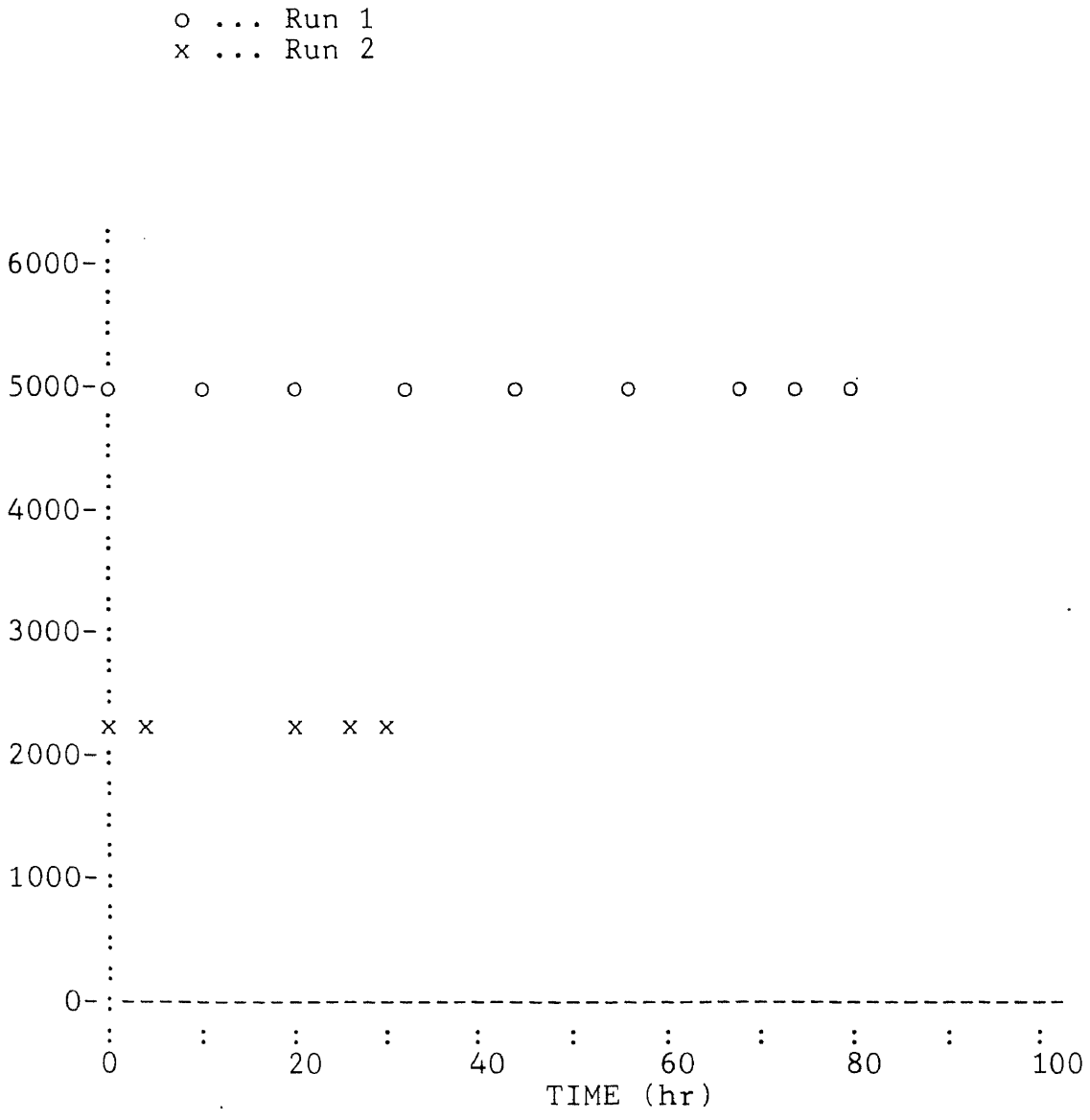


Figure 16

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 7

Time Versus MLSS

(Phenol-acclimated sludge, Temp. 80°F)

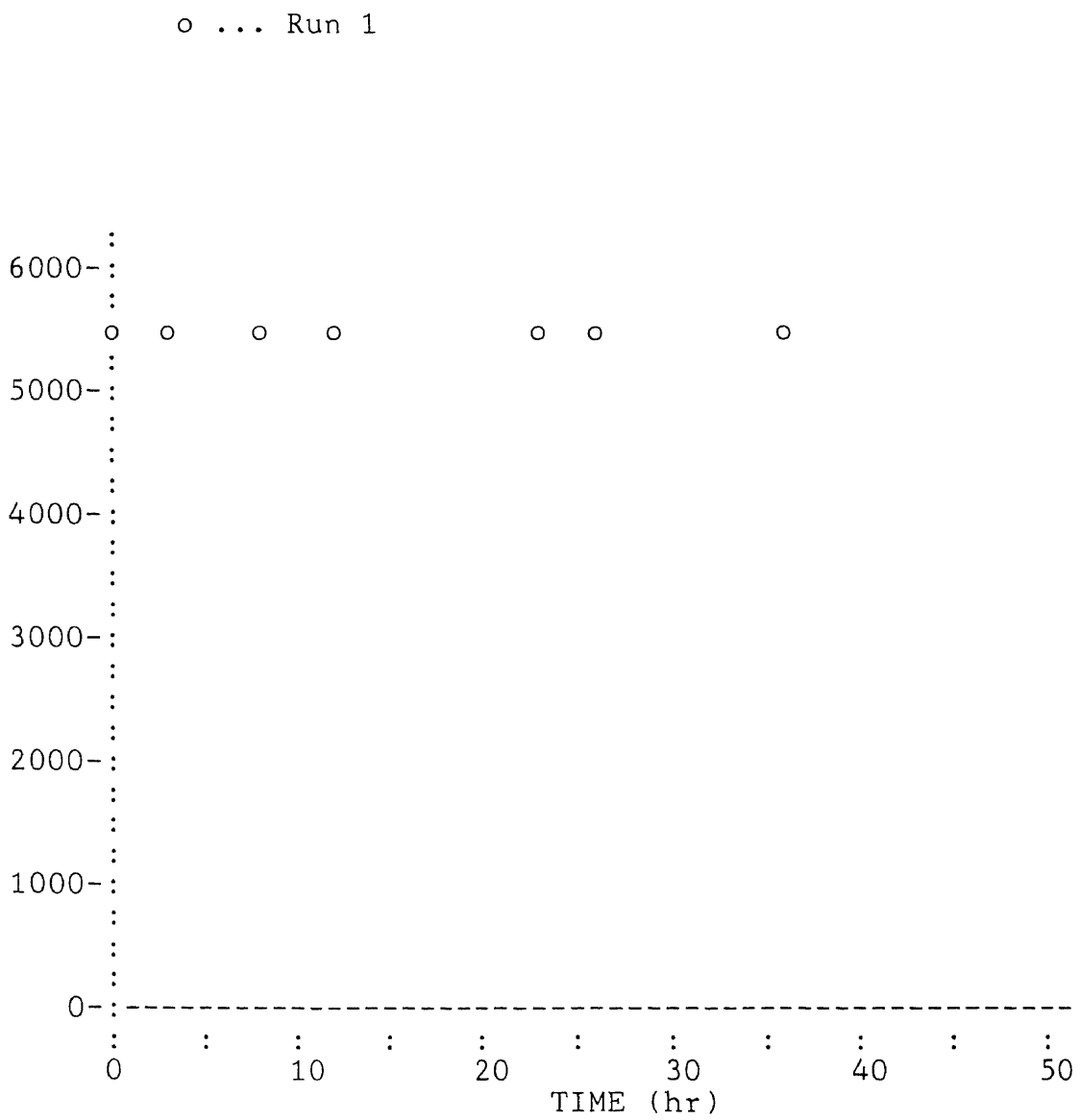


Figure 17

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 8

Time Versus MLSS

(Phenol-acclimated sludge, Temp. 80°F)

o ... Run 1

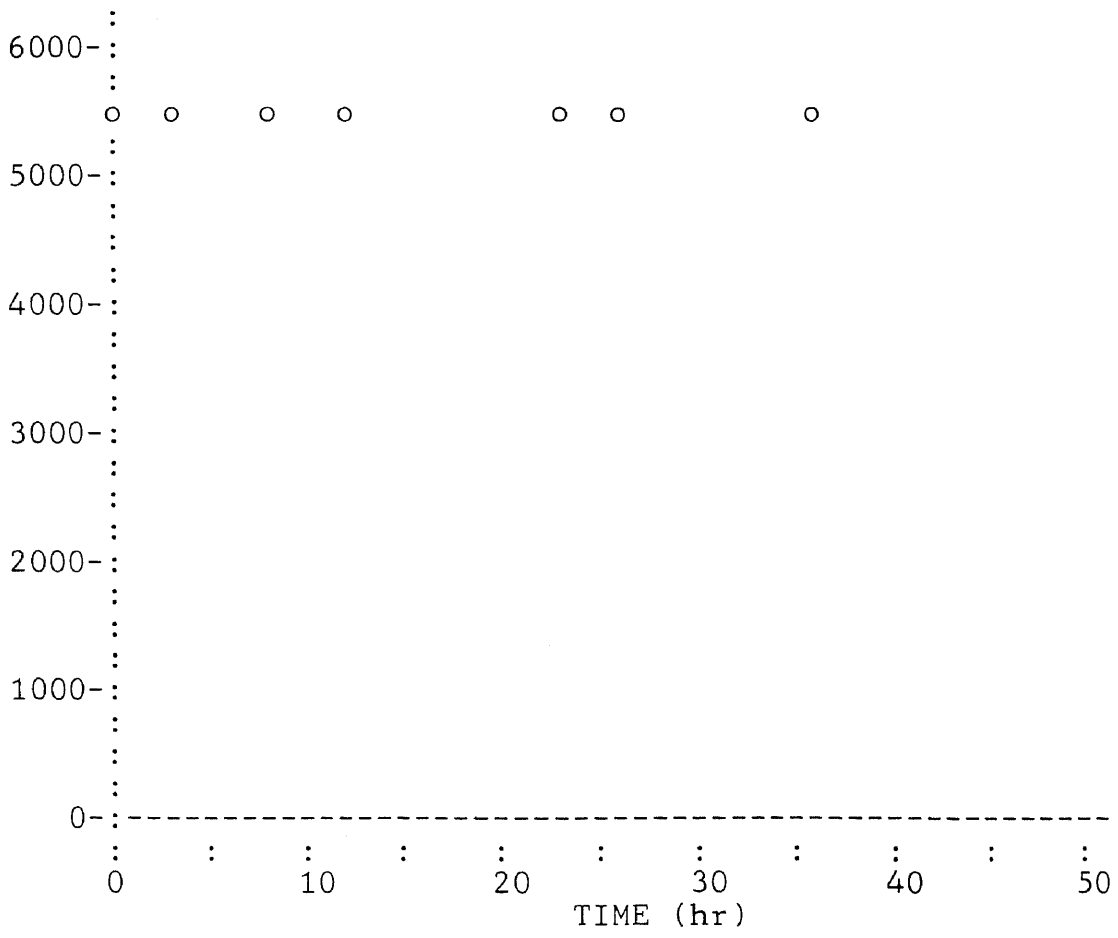


Figure 18

Phenol+Nitrobenzene+2,6-Dichloropheno, Experiment 1

Time Versus Ammonia Concentration

(Unacclimated sludge, Temp. 78 °F)

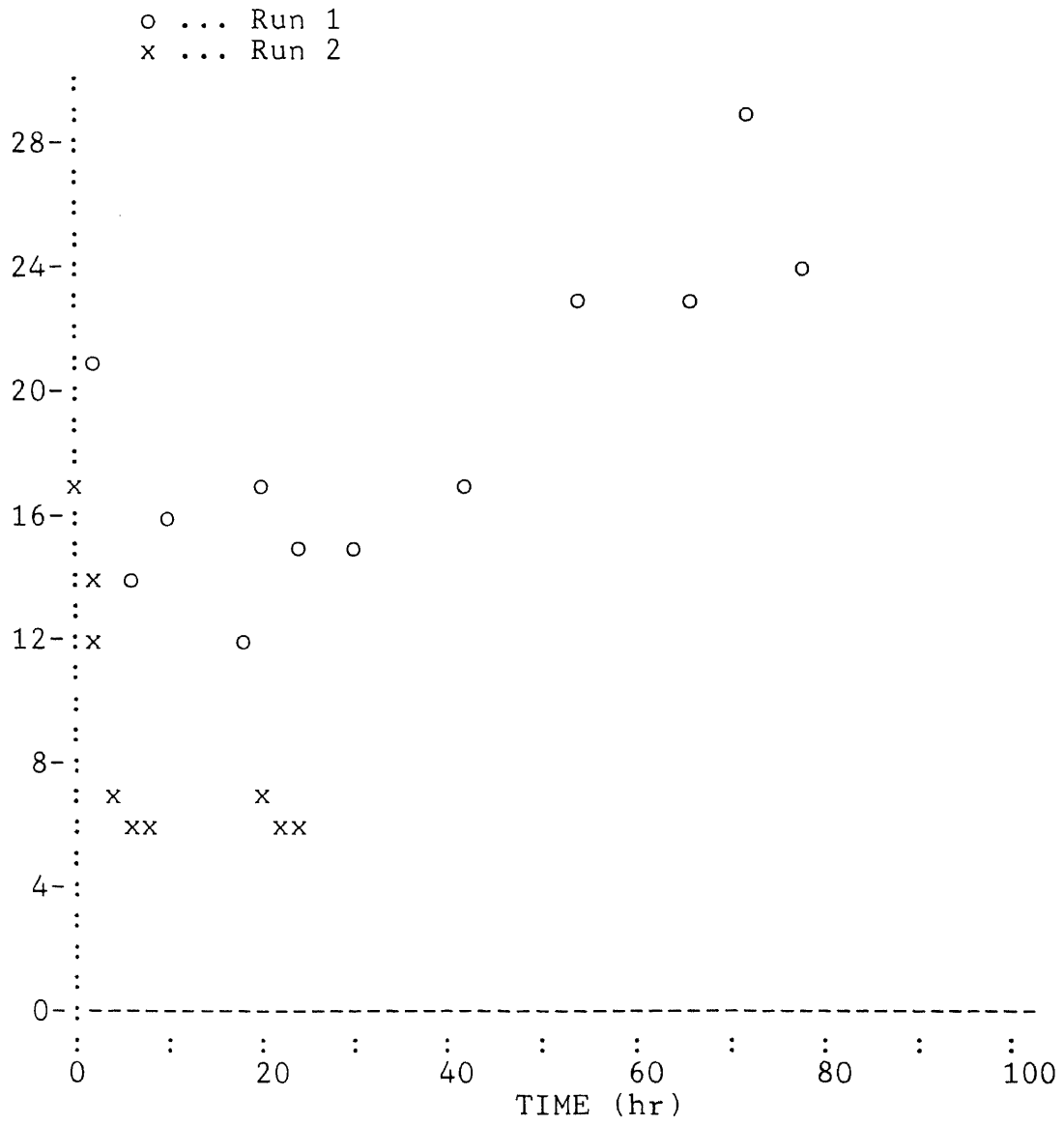


Figure 19

Phenol+Nitrobenzene+2,6-Dichloropheno, Experiment 2

Time Versus Ammonia Concentration

(Unacclimated sludge, Temp. 78 °F)

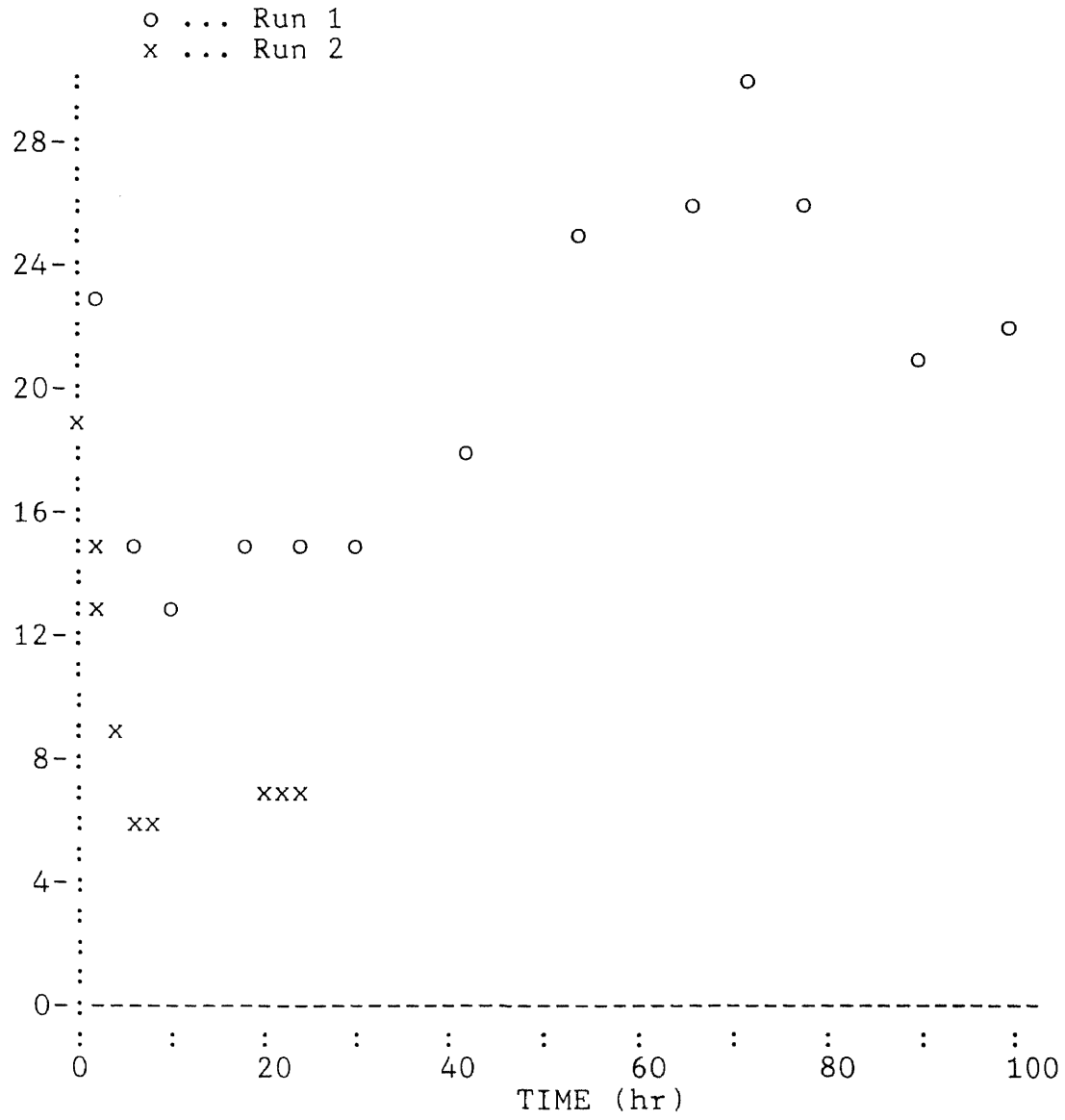


Figure 20

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 3

Time Versus Ammonia Concentration

(Phenol-acclimated sludge, Temp. 78°F)

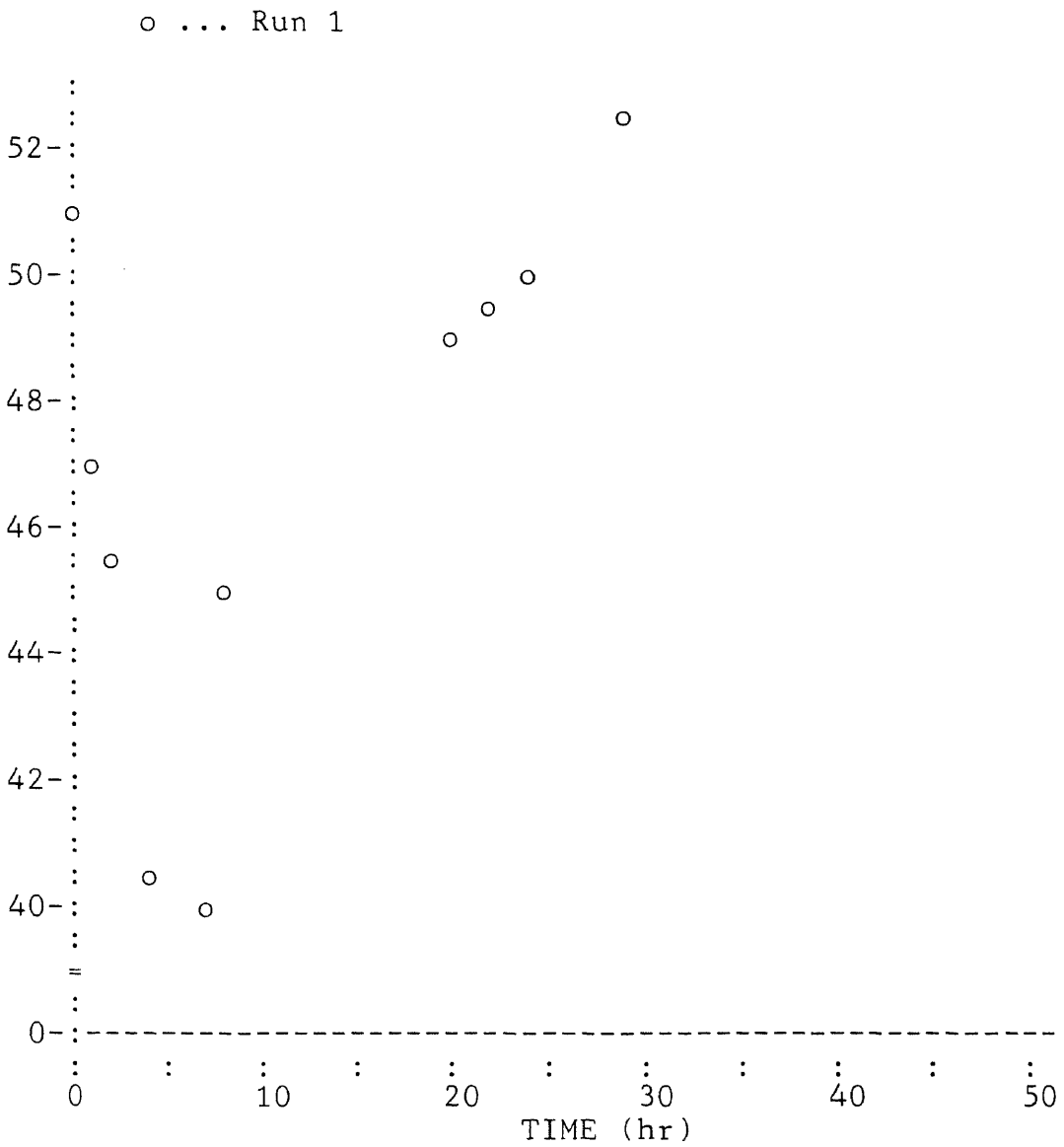


Figure 21

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 4

Time Versus Ammonia Concentration

(Phenol-acclimated sludge, Temp. 78 °F)

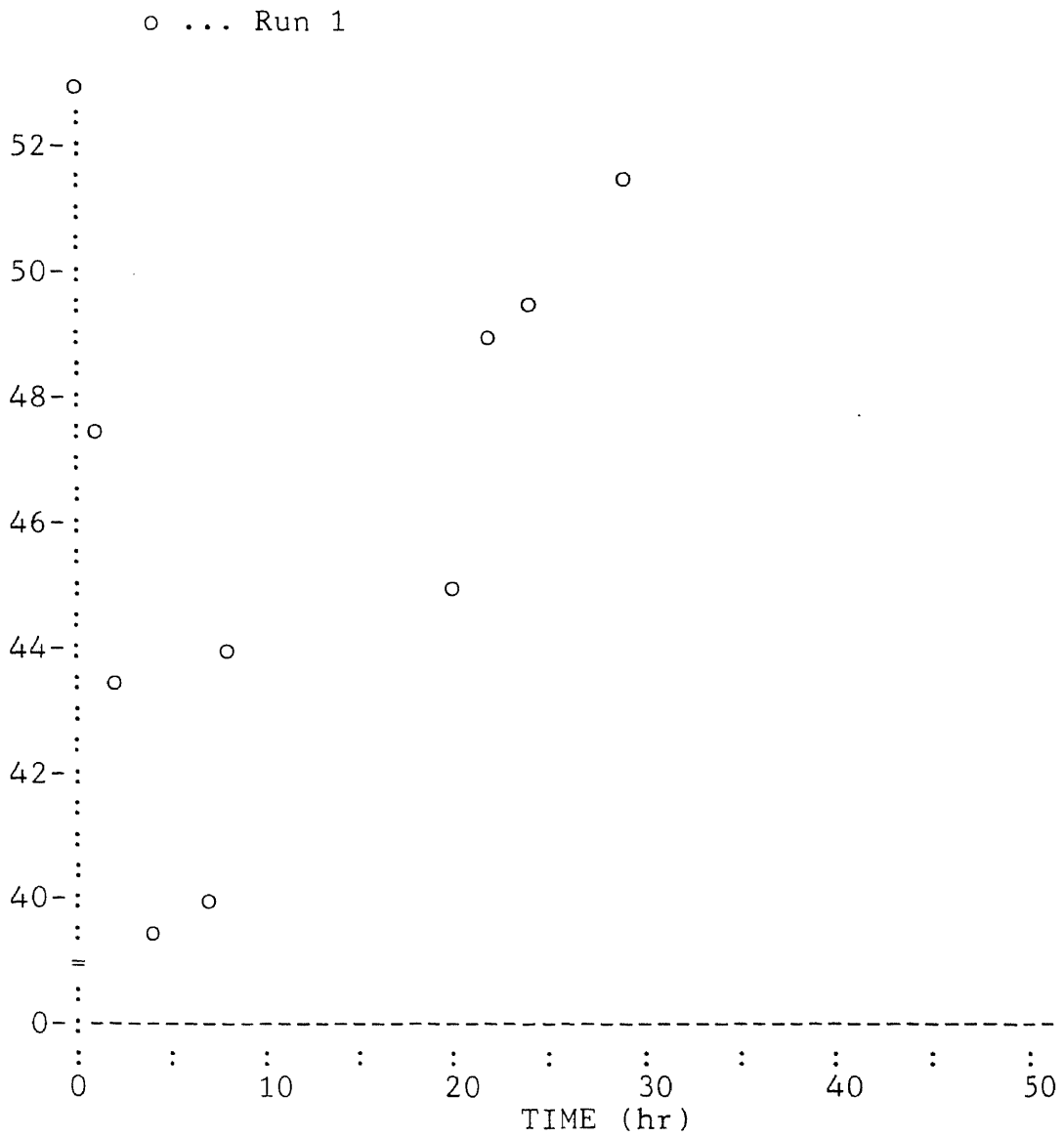


Figure 22

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 5

Time Versus Ammonia Concentration

(Unacclimated sludge, Temp. 80°F)

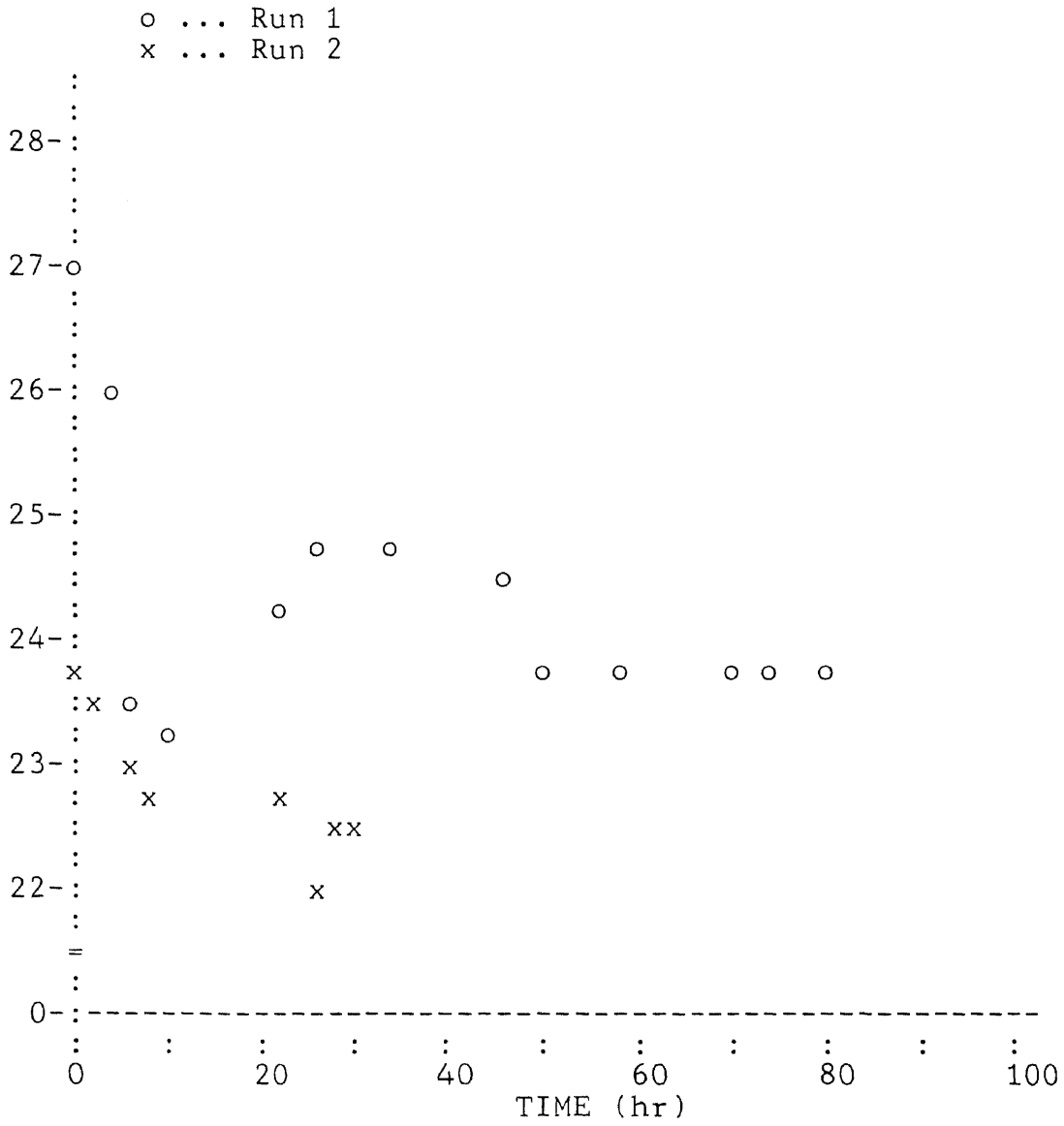


Figure 23

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 6

Time Versus Ammonia Concentration

(Unacclimated sludge, Temp. 80°F)

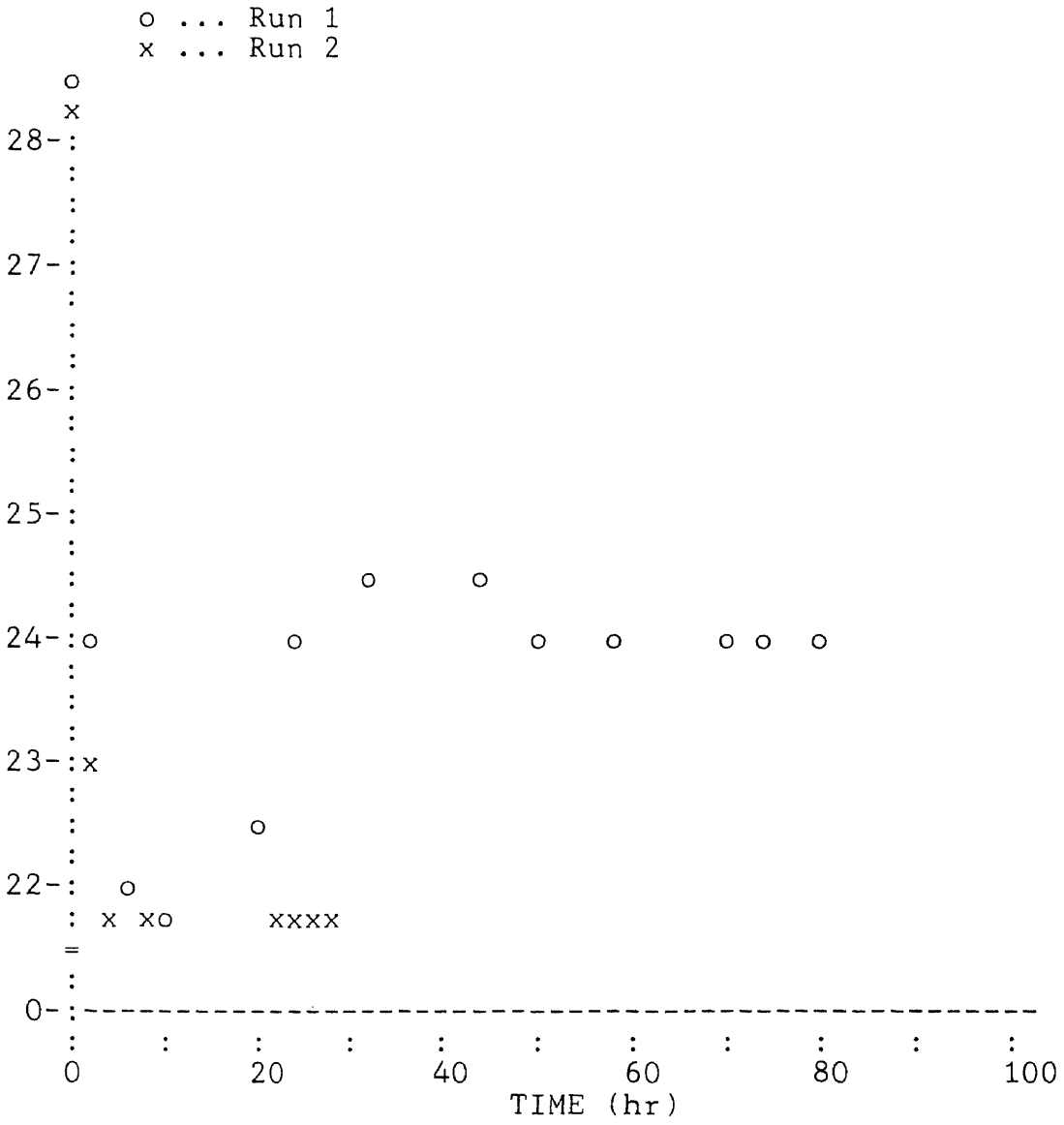


Figure 24

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 7

Time Versus Ammonia Concentration

(Phenol-acclimated sludge, Temp. 80 °F)

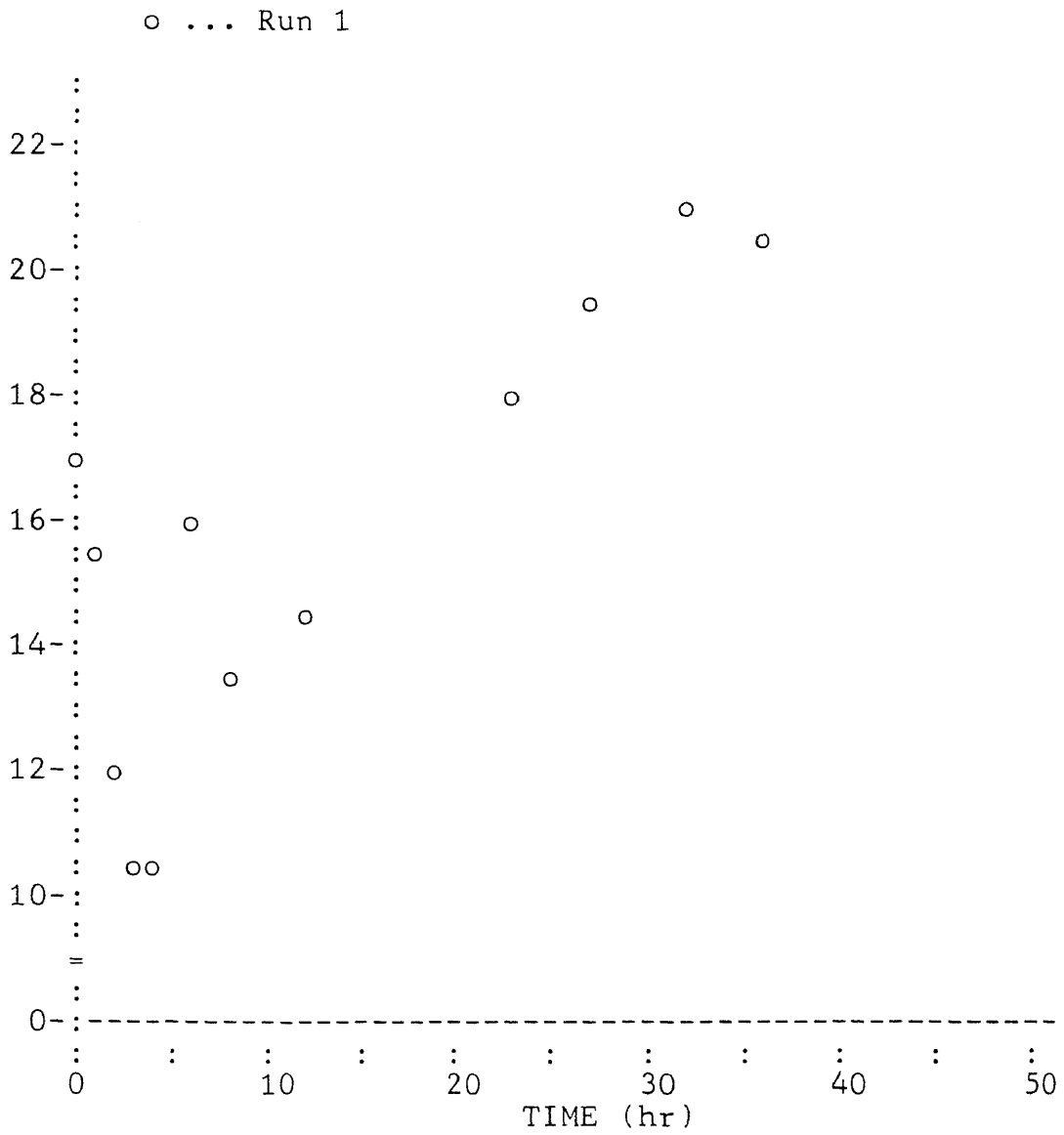


Figure 25

2-Chlorophenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 8

Time Versus Ammonia Concentration

(Phenol-acclimated sludge, Temp. 80 °F)

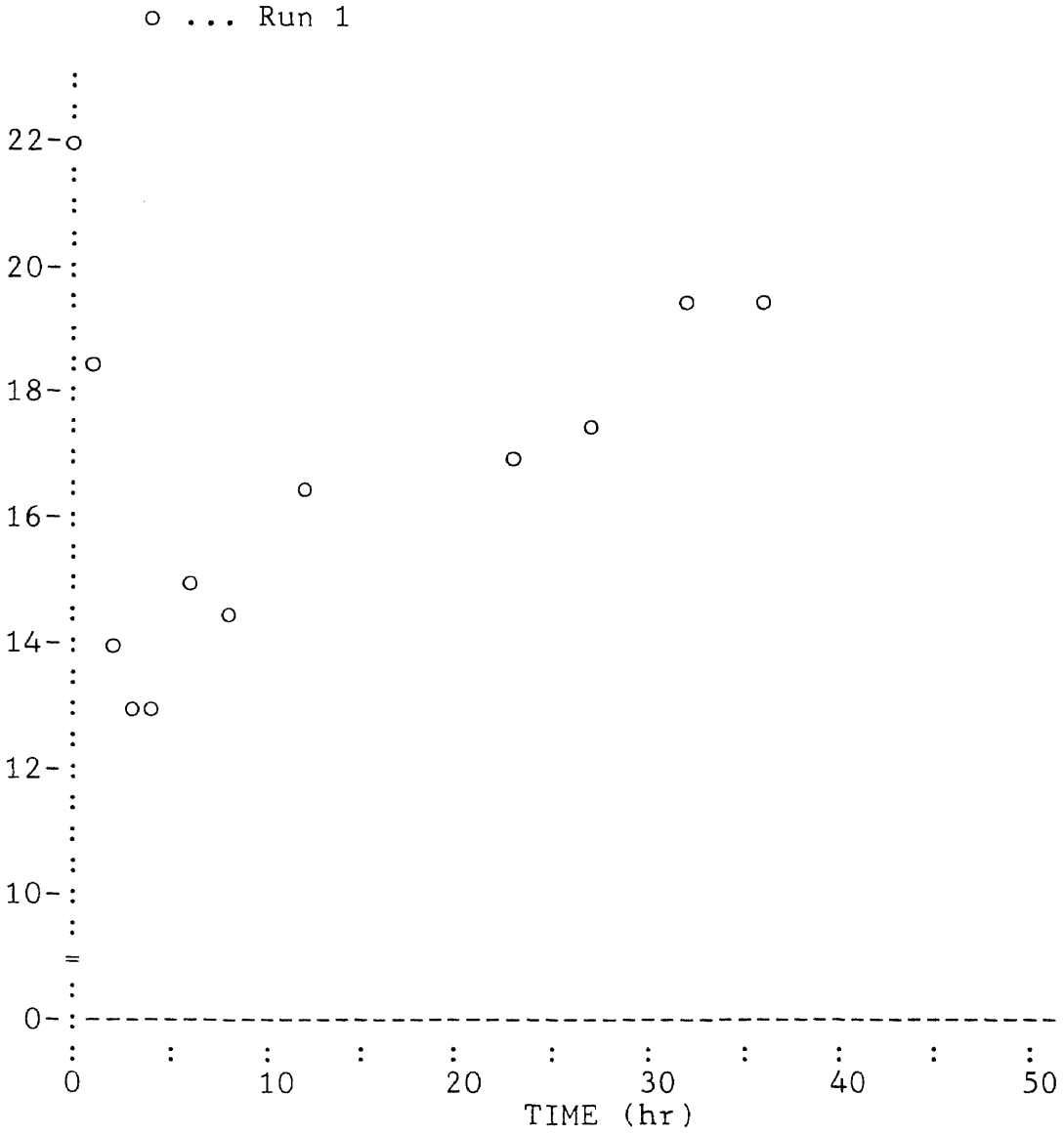


Figure 26

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 1

Time versus COD

(Unacclimated sludge, Temp. 78°F)

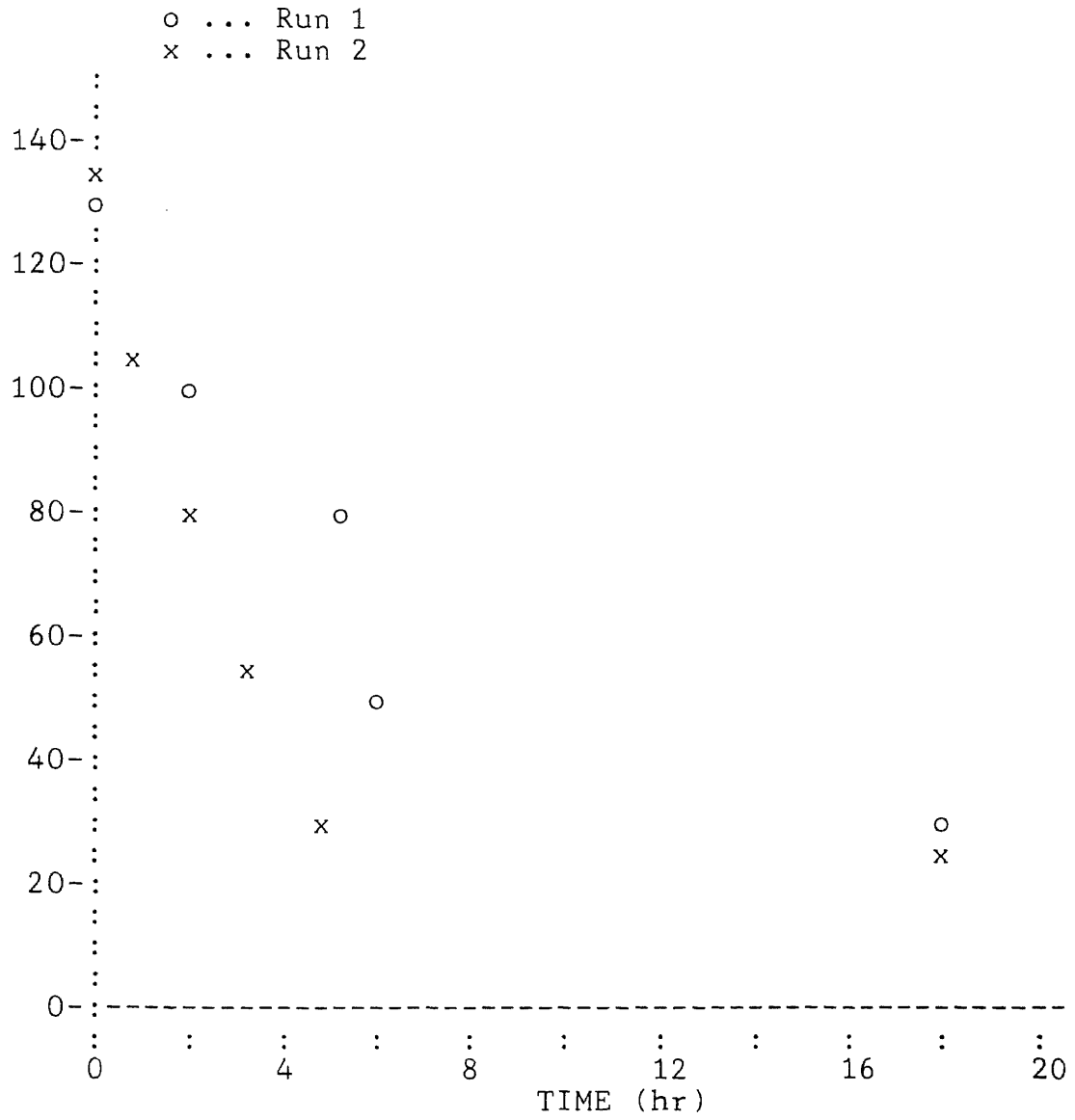


Figure 27

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 2

Time versus COD

(Unacclimated sludge, Temp. 78°F)

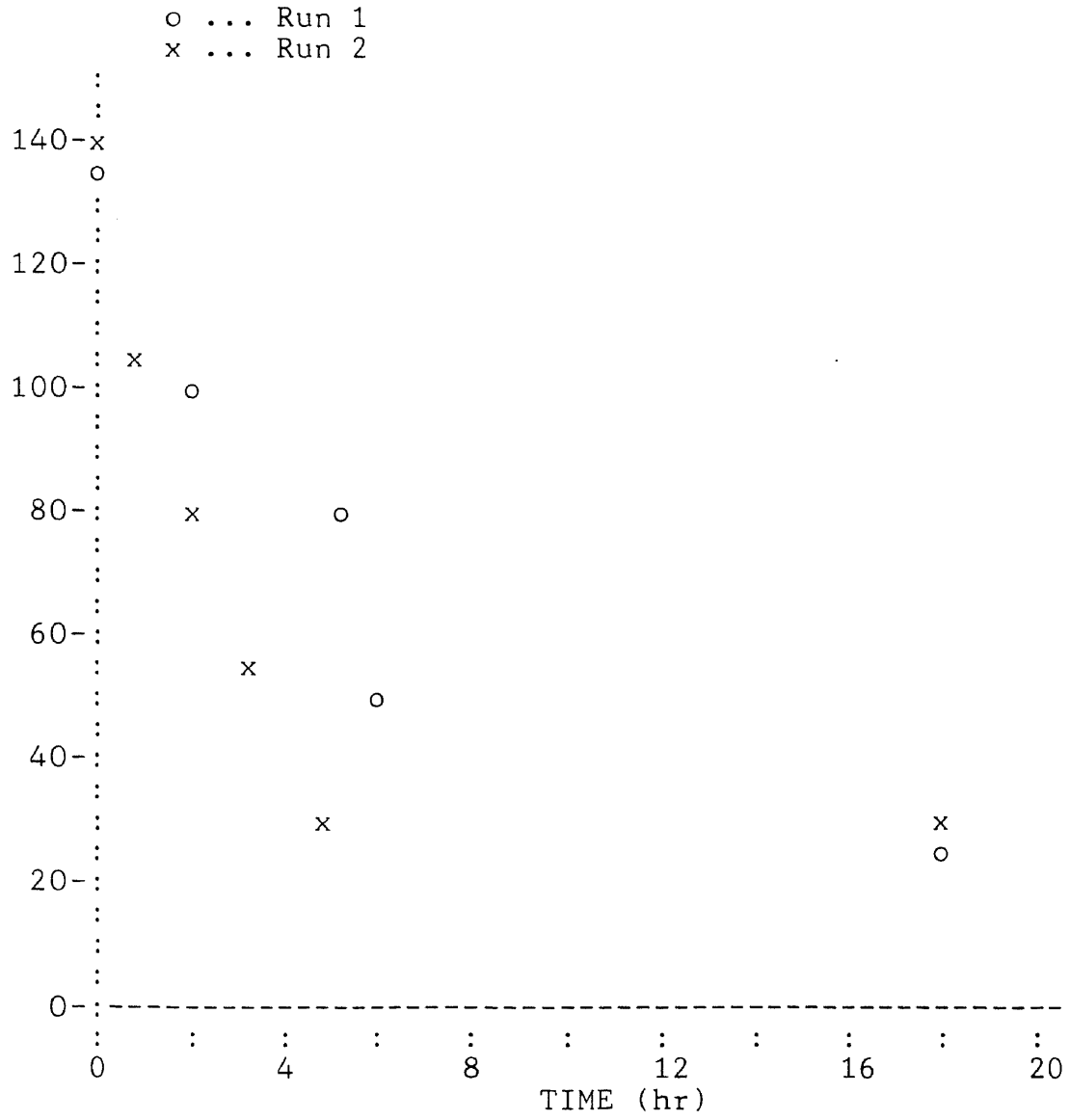


Figure 28

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 3

Time Versus COD

(Phenol-acclimated sludge, Temp. 78°F)

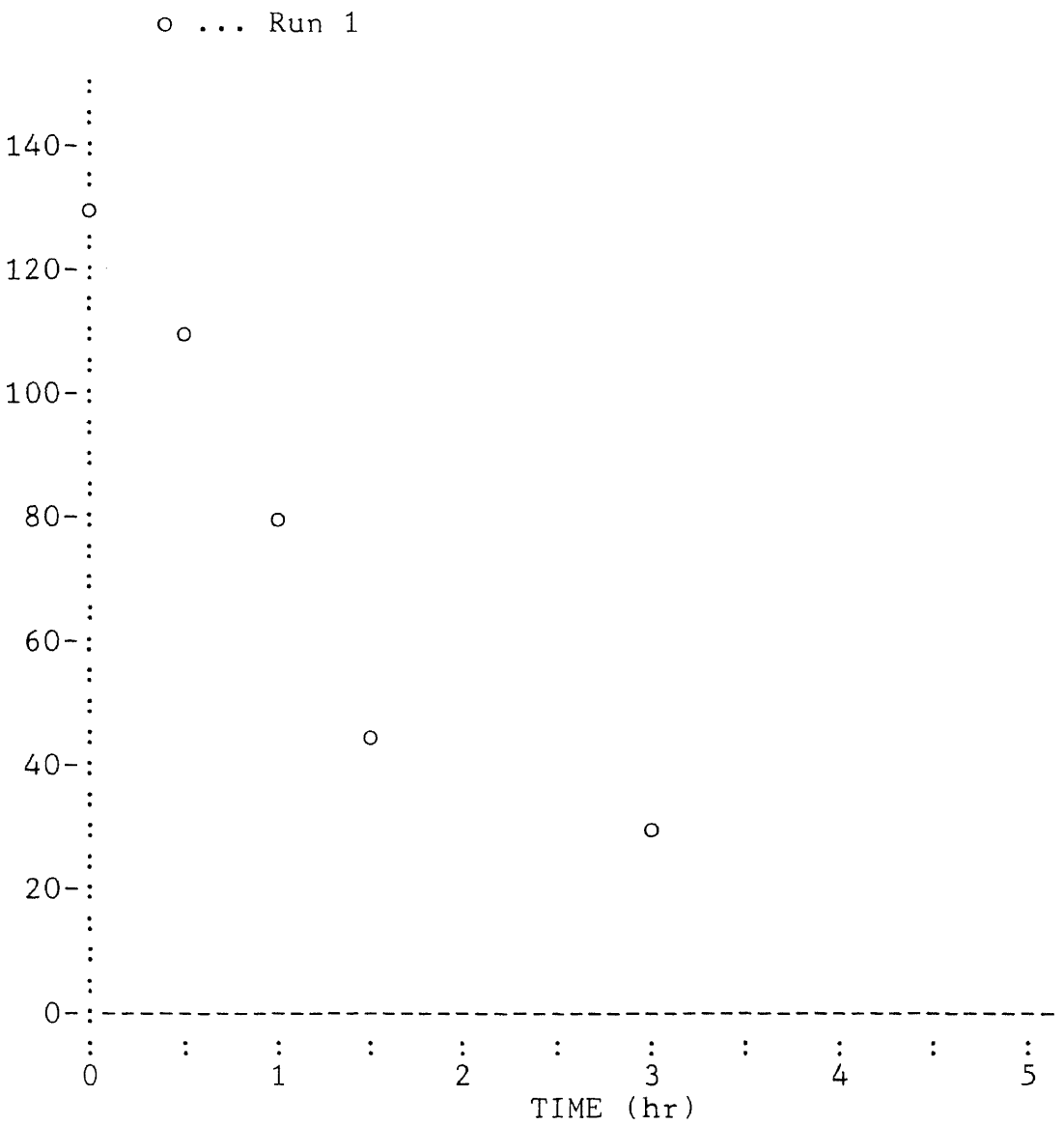


Figure 29

Phenol+Nitrobenzene+2,6-Dichlorophenol, Experiment 4

Time Versus COD

(Phenol-acclimated sludge, Temp. 78°F)

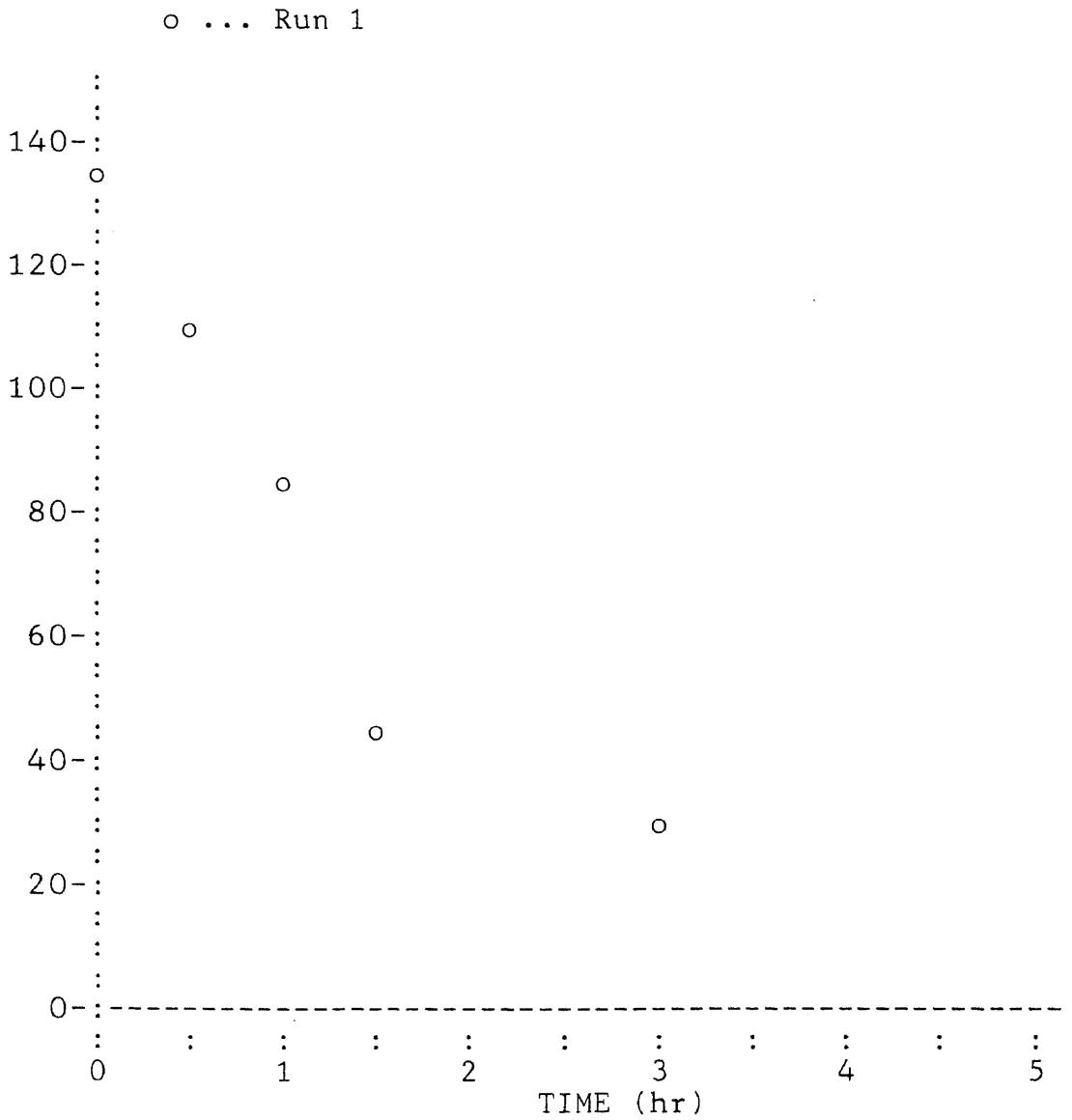
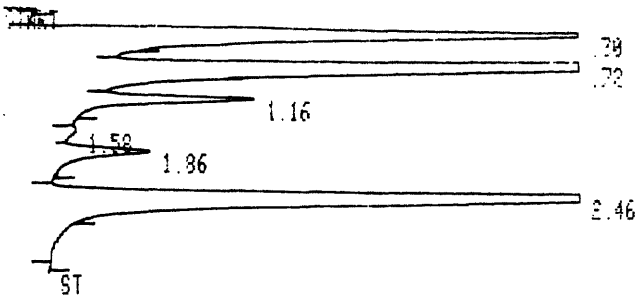


Figure 30

Integrator Output



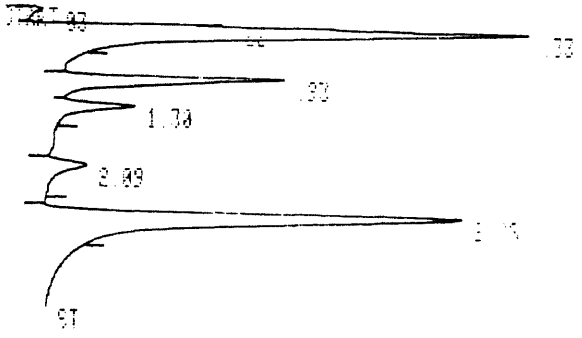
Ret. Time	Compound
.72	Phenol
1.16	Nitrobenzene
1.86	2,6-Dichlorophenol
2.46	Thymol (internal stnd.)

RUN # 189

ISTD

RT	AREA	TYPE	CAL #	AMOUNT
0.72	1718100	PB	1	36.681
1.16	108790	BB	2	8.624
1.86	82180	PB	3	9.238
2.46	917300	PB	4&	45.450

TOTAL AREA= 2826400
ISTD AMT= 4.5450E+01
MUL FACTOR= 1.0000E+00



Ret. Time	Compound
.93	2-Chlorophenol
1.30	Nitrobenzene
2.09	2,6-Dichlorophenol
2.78	Thymol (internal stnd.)

RUN # 1800

ISTD

RT	AREA	TYPE	CAL#	AMOUNT
0.93	175870	BV	1	20.219
1.30	60978	VB	2	8.775
2.09	42314	BB	3	9.937
2.78	467810	PB	4&	45.450

TOTAL AREA= 746970
ISTD AMT= 4.5450E+01
MUL FACTOR= 1.0000E+00

APPENDIX

```
10 REM     ****************************
20 REM     *                          *
30 REM     *       ZERO-ORDER         *
40 REM     *                          *
50 REM     *     FIRST-ORDER          *
60 REM     *                          *
70 REM     ****************************
80 REM
90 REM WRITTEN BY:  NILESH NAIK
100 REM
110 REM PURPOSE:  CALCULTE CONSTANTS TO FIT TIME VERSUS
120 REM           CONC. DATA TO ZERO-ORDER AND FIRST-
130 REM           ORDER MODEL.
140 REM
150 REM ZERO-ORDER MODEL:
160 REM
170 REM      -DS/DT = K
180 REM
190 REM FIRST-ORDER MODEL:
200 REM
210 REM      -DS/DT = K*S
220 REM
230 REM INPUT: NUMBER OF DATA POINTS
240 REM          TIME 1
250 REM          CONCENTRATION 1
260 REM          TIME 2
270 REM          CONCENTRATION 2
280 REM
290 REM THIS PROGRAM USES LINEAR REGRESSION
300 REM TO SOLVE FOR CONSTANTS
310 REM
320 REM
330 REM
340 REM
350 DIM S(30)
360 DIM T(30)
370 REM DEFINE DATA
380 INPUT N
390 FOR I=1 TO N
400 INPUT T(I), S(I)
410 NEXT I
420 E1=0
430 E2=0
440 E3=0
450 E4=0
460 E5=0
470 E6=0
480 E7=0
490 E8=0
500 FOR J=1 TO N
510 E1=E1+S(J)
520 E2=E2+S(J)*S(J)
```

```
530 E3=E3+T(J)
540 E4=E4+T(J)*T(J)
550 E5=E5+S(J)*T(J)
560 E6=E6+(LOG(S(J)))
570 E7=E7+(LOG(S(J)))*(LOG(S(J)))
580 E8=E8+T(J)*(LOG(S(J)))
590 NEXT J
600 NXX=E4-(E3*E3)/N
610 NLX=E7-(E6*E6)/N
620 YYY=E2-(E1*E1)/N
630 XYX=E5-(E1*E3)/N
640 XLY=E8-(E6*E3)/N
650 XAVG=E3/N
660 LAVG=E6/N
670 YAVG=E1/N
680 SLOPE=XYX/NXX
690 FIRST=XLY/NXX
700 OEPT=YAVG-SLOPE*XAVG
710 FOEPT=LAVG-FIRST*XAVG
720 FSO=EXP(FOEPT)
730 PRINT"ZERO-ORDER CONSTANT: K0=",SLOPE
740 PRINT"FIRST-ORDER CONSTANT: K1=",FIRST
750 PRINT"TIME      S(EXP)      S(ZERO)      S(FIRST)"
760 EZ=0
770 EF=0
780 FOR K=1 TO N
790 SZ=SLOPE*T(K)-OEPT
800 SF=FSO*EXP(FIRST*T(K))
810 PRINT T(K), S(K), SZ, SF
820 EZ=EZ+(SZ-S(K))*(SZ-S(K))
830 EF=EF+(SF-S(K))*(SF-S(K))
840 NEXT K
850 AZ=EZ/(N-1)
860 AF=EF/(N-1)
870 PRINT"ABSOLUTE AVERAGE RESIDUAL: ZERO-ORDER",AZ
880 PRINT"ABSOLUTE AVERAGE RESIDUAL: FIRST-ORDER",AF
890 END

READY.
```

```
10 REM
20 REM ********************************
30 REM *                              *
40 REM *           MONOD              *
50 REM *                              *
60 REM ********************************
70 REM
80 REM WRITTEN BY:  NILESH NAIK
90 REM
100 REM PURPOSE:    CALCULATE CONSTANTS TO FIT TIME VERSUS CONCENTRATIO
110 REM DATA TO MONOD MODEL.
120 REM
130 REM MONOD MODEL
140 REM
150 REM -DS/DT = K1*S/(K2+S)
160 REM
170 REM INPUT: NUMBER OF DATA POINTS
180 REM        TIME 1
190 REM        CONCENTRATION 1
200 REM        TIME 2
210 REM        CONCENTRATION 2
220 REM
230 REM THIS PROGRAM USES MATRIX TO SOLVE CONSTANTS
240 REM
250 REM THIS PROGRAM USES NEWTON'S METHOD FOR TRIAL AND ERROR CALCULATIO
260 REM
270 REM
280 REM
290 REM
300 REM
310 DIM S(30)
315 DIM TC(30)
316 DIM SY(30)
320 DIM T(30)
330 DIM A1(9)
340 DIM A2(9)
350 DIM A3(9)
370 DIM B1(9)
380 DIM B2(9)
390 DIM B3(9)
410 DIM C1(9)
420 DIM C2(9)
430 DIM C3(9)
450 DIM D1(9)
460 DIM D2(9)
470 DIM D3(9)
530 REM        READING TIME AND CONC.
540 INPUT N
550 FOR I=1 TO N
560 INPUT T(I), S(I)
570 NEXT I
580 E1=0
590 E2=0
600 E3=0
610 E4=0
620 E5=0
630 E6=0
```

```
640 E7=0
650 E8=0
695 ED13=0
700 FOR J=1 TO N
710 E1=E1+S(J)
720 E2=E2+S(J)*S(J)
730 E3=E3+(LOG(S(J)))
740 E4=E4+(LOG(S(J)))*(LOG(S(J)))
750 E5=E5+S(J)*(LOG(S(J)))
760 E6=E6+T(J)
770 E7=E7+T(J)*(LOG(S(J)))
780 E8=E8+T(J)*S(J)
830 NEXT J
840 A1(1)=-N
850 B1(1)=E3
860 C1(1)=E1
870 D1(1)=E6
890 A2(1)=-E3
900 B2(1)=E4
910 C2(1)=E5
920 D2(1)=E7
940 A3(1)=-E1
950 B3(1)=E5
960 C3(1)=E2
970 D3(1)=E8
1040 B1(2)=B1(1)/A1(1)
1050 D1(2)=B1(1)/A1(1)
1060 C1(2)=C1(1)/A1(1)
1080 A1(2)=A1(1)/A1(1)
1090 B2(2)=B2(1)/A2(1)
1100 C2(2)=C2(1)/A2(1)
1110 D2(2)=D2(1)/A2(1)
1130 A2(2)=A2(1)/A2(1)
1140 B3(2)=B3(1)/A3(1)
1150 C3(2)=C3(1)/A3(1)
1160 D3(2)=D3(1)/A3(1)
1180 A3(2)=A3(1)/A3(1)
1230 A2(3)=A1(2)-A2(2)
1240 B2(3)=B1(2)-B2(2)
1250 C2(3)=C1(2)-C2(2)
1260 D2(3)=D1(2)-D2(2)
1270 A3(3)=A1(2)-A3(2)
1280 B3(3)=B1(2)-B3(2)
1290 C3(3)=C1(2)-C3(2)
1300 D3(3)=D1(2)-D3(2)
1360 C2(4)=C2(3)/B2(3)
1370 D2(4)=D2(3)/B2(3)
1390 B2(4)=B2(3)/B2(3)
1400 C3(4)=C3(3)/B3(3)
1410 B3(4)=B3(3)/B3(3)
1430 D3(4)=B3(3)/B3(3)
1480 B3(5)=B2(4)-B3(4)
1500 C3(5)=C2(4)-C3(4)
1520 D3(5)=B2(4)-B3(4)
1560 D3(6)=D3(5)/C3(5)
1580 C3(6)=C3(5)/C3(5)
1670 C=-D3(6)
```

```
1680 B=-C2(4)*C-D2(4)
1690 A=-E1(2)*B-C1(2)*C-D1(2)
1710 K1=1/C
1720 K2=K1*B
1740 PRINT"K1=",K1
1750 PRINT"K2=",K2
1765 PRINT"TIME          S(EXP)       S(CAL)"
1770 FOR K=1 TO N
1780 SO=S(K)
1790 SN=SO
1800 FS=B*(LOG(SN))+C*SN-A+T(K)
1820 DS=B/SN+C
1830 SO=SO-FS/DS
1840 IF ABS(SN-SO) > 0.0001 THEN 1790
1850 PRINT T(K), S(K), SO
1860 ED13=ED13+(SO-S(K))*(SO-S(K))
1870 NEXT K
1875 AAR=ED13/(N-1)
1880 PRINT"ABSOLUTE AVERAGE RESIDUAL =",AAR
1890 END

READY.
```

```
10 REM
20 REM ********************************
30 REM *                              *
40 REM *          HALDANE             *
50 REM *                              *
60 REM ********************************
70 REM
80 REM WRITTEN BY:  NILESH NAIK
90 REM
100 REM PURPOSE:    CALCULATE CONSTANTS TO FIT TIME VERSUS CONCENTRATION
110 REM DATA TO HALDANE MODEL.
120 REM
130 REM HALDANE MODEL
140 REM
150 REM -DS/DT = K1*S/(K2 + S + S /K3)
160 REM
170 REM INPUT: NUMBER OF DATA POINTS
180 REM        TIME 1
190 REM        CONCENTRATION 1
200 REM        TIME 2
210 REM        CONCENTRATION 2
220 REM
230 REM THIS PROGRAM USES MATRIX TO SOLVE CONSTANTS
240 REM
250 REM THIS PROGRAM USES NEWTON'S METHOD FOR TRIAL AND ERROR CALCULATION
260 REM
270 REM
280 REM
290 REM
300 REM
310 DIM S(30)
315 DIM SN(30)
320 DIM T(30)
330 DIM A(9)
340 DIM A2(9)
350 DIM A3(9)
360 DIM A4(9)
370 DIM B(9)
380 DIM B2(9)
390 DIM B3(9)
400 DIM B4(9)
410 DIM C(9)
420 DIM C2(9)
430 DIM C3(9)
440 DIM C4(9)
450 DIM D(9)
460 DIM D2(9)
470 DIM D3(9)
480 DIM D4(9)
490 DIM F(9)
500 DIM F2(9)
510 DIM F3(9)
520 DIM F4(9)
```

```
530 REM         READING TIME AND CONC.
540 INPUT N
550 FOR I=1 TO N
560 INPUT T(I), S(I)
570 NEXT I
580 E1=0
590 E2=0
600 E3=0
610 E4=0
620 E5=0
630 E6=0
640 E7=0
650 E8=0
660 E9=0
670 EA10=0
680 EB11=0
690 EC12=0
695 ED13=0
700 FOR J=1 TO N
710 E1=E1+S(J)
720 E2=E2+S(J)*S(J)
730 E3=E3+(LOG(S(J)))
740 E4=E4+(LOG(S(J)))*(LOG(S(J)))
750 E5=E5+S(J)*(LOG(S(J)))
760 E6=E6+T(J)
770 E7=E7+T(J)*(LOG(S(J)))
780 E8=E8+T(J)*S(J)
790 E9=E9+S(J)*S(J)*S(J)
800 EA10=EA10+S(J)*S(J)*S(J)*S(J)
810 EB11=EB11+S(J)*S(J)*(LOG(S(J)))
820 EC12=EC12+S(J)*S(J)*T(J)
830 NEXT J
840 A(1)=N
850 B(1)=E3
860 C(1)=E1
870 D(1)=E2
880 F(1)=E6
890 A2(1)=-E3
900 B2(1)=E4
910 C2(1)=E5
920 D2(1)=EB11
930 F2(1)=E7
940 A3(1)=-E1
950 B3(1)=E5
960 C3(1)=E2
970 D3(1)=E9
980 F3(1)=E8
990 A4(1)=-E2
1000 B4(1)=EB11
1010 C4(1)=E9
1020 D4(1)=EA10
1030 F4(1)=EC12
1040 B(2)=B(1)/A(1)
1050 C(2)=C(1)/A(1)
```

```
1060 D(2)=D(1)/A(1)
1070 F(2)=F(1)/A(1)
1080 A(2)=A(1)/A(1)
1090 B2(2)=B2(1)/A2(1)
1100 C2(2)=C2(1)/A2(1)
1110 D2(2)=D2(1)/A2(1)
1120 F2(2)=F2(1)/A2(1)
1130 A2(2)=A2(1)/A2(1)
1140 B3(2)=B3(1)/A3(1)
1150 C3(2)=C3(1)/A3(1)
1160 D3(2)=D3(1)/A3(1)
1170 F3(2)=F3(1)/A3(1)
1180 A3(2)=A3(1)/A3(1)
1190 B4(2)=B4(1)/A4(1)
1200 C4(2)=C4(1)/A4(1)
1210 D4(2)=D4(1)/A4(1)
1220 F4(2)=F4(1)/A4(1)
1230 A4(2)=A4(1)/A4(1)
1240 B2(3)=B(2)-B2(2)
1250 C2(3)=C(2)-C2(2)
1260 D2(3)=D(2)-D2(2)
1270 F2(3)=F(2)-F2(2)
1280 B3(3)=B(2)-B3(2)
1290 C3(3)=C(2)-C3(2)
1300 D3(3)=D(2)-D3(2)
1310 F3(3)=F(2)-F3(2)
1320 B4(3)=B(2)-B4(2)
1330 C4(3)=C(2)-C4(2)
1340 D4(3)=D(2)-D4(2)
1350 F4(3)=F(2)-F4(2)
1360 C2(4)=C2(3)/B2(3)
1370 D2(4)=D2(3)/B2(3)
1380 F2(4)=F2(3)/B2(3)
1390 B2(4)=B2(3)/B2(3)
1400 C3(4)=C3(3)/B3(3)
1410 D3(4)=D3(3)/B3(3)
1420 F3(4)=F3(3)/B3(3)
1430 B3(4)=B3(3)/B3(3)
1440 C4(4)=C4(3)/B4(3)
1450 D4(4)=D4(3)/B4(3)
1460 F4(4)=F4(3)/B4(3)
1470 B4(4)=B4(3)/B4(3)
1480 D3(5)=D2(4)-D3(4)
1490 B4(5)=D2(4)-B4(4)
1500 C3(5)=C2(4)-C3(4)
1510 C4(5)=C2(4)-C4(4)
1520 B3(5)=B2(4)-B3(4)
1530 D4(5)=D2(4)-D4(4)
1540 F3(5)=F2(4)-F3(4)
1550 F4(5)=F2(4)-F4(4)
1560 D3(6)=D3(5)/C3(5)
1570 F3(6)=F3(5)/C3(5)
1580 C3(6)=C3(5)/C3(5)
1590 D4(6)=D4(5)/C4(5)
1600 F4(6)=F4(5)/C4(5)
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1610 C4(6)=C4(5)/C4(5)
1620 C4(7)=C3(6)-C4(6)
1630 D4(7)=D3(6)-D4(6)
1640 F4(7)=F3(6)-F4(6)
1650 F4(8)=F4(7)/D4(7)
1660 D4(8)=D4(7)/D4(7)
1670 Z=-F4(8)
1680 Y=-Z*D3(6)-F3(6)
1690 X=-Y*C2(4)-Z*D2(4)-F2(4)
1700 W=-X*B(2)-Y*C(2)-Z*D(2)-F(2)
1710 K1=1/Y
1720 K2=X*K1
1730 K3=1/(2*K1*Z)
1740 PRINT"K1=",K1
1750 PRINT"K2=",K2
1760 PRINT"K3=",K3
1765 PRINT"TIME        S(EXP)        S(CAL)"
1770 FOR K=1 TO N
1780 SN(K)=S(K)
1790 SN=SN(K)
1800 FS=X*(LOG(SN))+Y*SN+Z*SN*SN-W+T(K)
1810 DS=K/SN+Y+Z*SN
1820 SN(K)=SN(K)-FS/DS
1830 IF ABS(SN-SN(K)) > 0.0001 THEN 1790
1840 PRINT T(K), S(K), SN(K)
1850 ED13=ED13+(SN(K)-S(K))*(SN(K)-S(K))
1860 NEXT K
1870 AAR=ED13/(N-1)
1880 PRINT"ABSOLUTE AVERAGE RESIDUAL =",AAR
1890 END

READY.
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