THE EFFECTS OF ORGANIC TOXIC COMPOUNDS ON THE PERFORMANCE OF A BATCH-OPERATED ACTIVATED SLUDGE PROCESS

By

GYE DAE WHANG

Bachelor of Engineering

Yonsei University

Seoul, Korea

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Thesis Approved:

D. F. Gaudy Jr.
Thesis Adviser

Don F Kincannon

Marcia H. Bates

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Rapid industrialization and increasing demand for products by modern society has been the cause of introduction of new chemicals into the environment at an ever increasing rate. In the past, the immediate benefits to society through the use of new chemical products has far outweighed considerations of the possible environmental deterioration they might cause. However, at the present time, society has become well aware of adverse environmental effects and has expressed its concern through the organization of new governmental agencies to regulate and control water pollution.

Fortunately, some of the industrial compounds are degraded in the biosphere, and there is growing investigative effort to determine which compounds are biodegradable and which may not be easily biodegradable. Some compounds may persist in the aqueous environment for some period of time before microorganisms with the genetic capability to metabolize them can acclimate to the compounds.

An important practical problem which arises because of the fairly recent passage of Public Law 92-500 is the effect of rather small concentrations of potentially toxic compounds on the metabolic efficiency of biological wastewater treatment processes. It is recalled that Public Law 92-500 provides for 75 percent or more of the financing of publicly owned treatment works (POTWs). Many of the newly designed and

constructed municipal sewage works employ biological treatment, and in particular, the activated sludge process. From a practical standpoint, the nation cannot afford to spend billions of dollars on the installation of activated sludge processes without concern over the effect that various chemicals in certain industrial wastes may have on the effectiveness of the treatment facility if these industrial wastes are sewered to the municipal sewerage system. There are some very important scientific questions which need to be answered for the purpose of establishing sound regulatory policies in regard to discharge of certain of these chemicals to municipal sewers. For example, which compounds should be removed prior to discharge, and which type of compounds can be discharged without causing harm? Also, are there limitations on the amounts and concentrations of these compounds which can be handled adequately by the municipal sewage treatment plant?

The work reported in this thesis forms a part of an overall effort being made in the bioenvironmental engineering laboratories to investigate this problem under the sponsorship of a research project from the Environmental Protection Agency (#805242). This report deals with the biological response to varying concentrations of the following priority (toxic) pollutants: benzene, hexachlorobenzene, anthracene, o-nitrophenol, chloroform, trichloroethylene.

CHAPTER II

LITERATURE REVIEW

The widespread use of synthetic chemicals has caused many pollution problems. Some of these compounds are readily degraded by microorganisms, but others are resistant to biological decomposition and tend to accumulate in the environment, resulting in a potential hazard to public health and general degradation of environmental quality (1). It is very important to evaluate bacterial toxicity before potentially toxic chemicals are discharged to the receiving stream or to municipal wastewater facilities. In addition to toxicity to animal and humans, certain compounds can inhibit the self-purification capabilities of receiving streams or can have damaging effects on the treatment process, particularly on activated sludge processes.

Pitter (2) classified organic substances into four groups based on biodegradability and toxicity: 1) biodegradable and nontoxic; 2) nonbiodegradable and toxic; 3) biodegradable and toxic; and 4) nonbiodegradable and toxic. He also listed four stages of degradation: primary, partial, acceptable, and total.

Alexander (1) reported that several conditions must be fulfilled in order that a particular substance can be degraded. First, microorganisms must be present in the environment. These organisms must have the ability to degrade the compound, and the compounds must be in proper molecular configuration to be degraded by the microorganisms;

that is, the structure of the compound could be modified by the environment in such a way as to hamper its attack by an organism which had the ability to metabolize the compound in its native form. Furthermore, there should be no substance present which would prevent induction of enzymes needed to initiate the metabolism of the compound. Also, there should be an environment generally favorable for microbial proliferation and enzyme production. He also reported 15 mechanisms of "recalcitrance." Much research has been done to find relationships between chemical structure of compounds and their biodegradability; such work has been accomplished using both pure culture and heterogeneous populations of microorganism (3)(4)(5)(6)(7)(8)(9). However, there has been no uniformity in the method of assessing the biodegradability of various compounds in the many studies which have been performed. It has been found that slight changes in the chemical structure of many molecules change their biodegradability (3)(4)(7), and the position of the functional groups on compounds also change the metabolic availability (5)(6)(8)(9). The ability of an activated sludge to degrade certain compounds has been tested by adapting the cells to analogs or parent compounds or related compounds (10)(11)(12). It has been found that the general mechanisms of response are that activated sludge may change predominant species or undergo induction of specific enzymes in the species already predominating so as to acclimate to the new chemical compounds. Acclimation may be needed even though the population may have been preadapted to other similar compounds. However, judicious selection of preadapting compounds can shorten the time required for acclimation or adaptation to new compounds in a wastewater; that is, if one wishes to develop an activated sludge on a specific

industrial waste containing one or more toxic pollutants, the sludge can be developed faster if is first acclimated to a compound (or to compounds) similar to those known to be in the industrial waste.

Eckenfelder et al. (13) found that influent wastewater strength, temperature, biodegradation rate, and total dissolved solids would influence the performance of biological treatment plants treating various organic chemical industry wastes. Some of the factors affecting biodegradability are (2): physical-chemical factors, temperature, solubility and degree of mixing of the compound in the medium, dissolved oxygen, and pH.

Biological factors include the source and condition of the microorganisms, adaptabilities, and resistance to toxic substances and specific metabolic control mechanisms which make the cells responsive to other substrates in the environment.

Chemical factors include the size of the molecule and the number, location, and the kinds of substituents as well as the general stereochemistry of the molecules.

Various methods have been used to measure the inhibition of microbial activity in the presence of toxic compounds or to measure the metabolic availability of a compounds as substrate for growth. Batch studies are ideal for the measurement of growth, and they can be used to test the substrate removal rate. Ludzack (14) discussed various methods for measuring biodegradability of organic pollutants in wastewaters. He discussed the advantages and limitations of bench scale tests as design guides. Although he concluded that bench scale studies will give a basis for predicting later behavior in the treatment plant, factors which effect the microbial responses and performance

should also be studied after the plant has been placed in full scale operation. Patterson (15) held that the BOD and COD tests were not adequate as standards for measurement of bio-mass and activity parameters of activated sludge undergoing toxic stress, since toxicity of the compounds may vary according to the nutrient supply and the physiological condition of the microorganisms. He recommended the use of such analyses as total dehydrogenase activity, oxygen uptake, and cellular ATP for assessment of toxic effects. However, it cannot be denied that substrate removal tests using the COD test for assessing the removal rate have advantages over other measurements because they are relatively quick and the results are rather reliable.

It is important to note that many organic chemicals found in wastewaters are of rather low solubility and some are subject to stripping during the biological treatment process (16). Gaudy (17)(18) found that stripping kinetics were dependent upon airflow rate, tank geometry, and temperature. He also found that independently determined stripping and biological kinetic coefficients could be used to predict the removal of volatile compounds by the dual process of biological metabolism and physical stripping. Bunch (19) determined the biodegradability of several compunds by analyzing the reaction liquor after seven days of incubation at room temperature under static aerobic conditions. He employed settled sewage as inoculum to BOD dilution water containing small amounts of yeast extract and known concentrations of test compounds. His results indicated that the degree of biodegradability of compounds during the test period provides an indication of the time required for adaption and is valuable for predicting the behavior of a compound in a wastewater treatment plant and in surface

water to some extent because this test shows biodegradation only under given conditions.

McKinney (10) studied the oxidation of several aromatic compounds using adapted activated sludges. He concluded that activated sludge can oxidize phenolic and related compounds. Ludzack (4) attempted to clarify relationships between chemical structure and microbial acclimation. He showed that activated sludge could be adapted to a wide variety of compounds. His methods of study included oxygen uptake and BOD. However, he found that the number of functional groups in a molecule, the size and solubility of the molecule, isomerism, etc. made it extremely difficult to outline very simple rules describing the metabolic availability of a material as a function of its structure. Chambers (11) studied 104 compounds, using phenol-acclimated sludge. His findings indicated that the position and type of groups in the aromatic ring, the number and type of substituents, and size and complexity of the substituents would effect the relationship between molecular structure and biodegradability.

Heidman et al. (20) studied the effect of sodium pentachlorophenol on activated sludge. It was found that this compound did not affect the treatment efficiency in concentrations up to 250 mg/l, but it was the cause of poor settling and brought about a change in predominating microorganisms. Also, it was noted that shock loading of rather small concentrations affected the treatment efficiency. Camisa (21) developed rapid and reproducible methods for analysis of tri-chloroethylene-bearing wastes. He found that considerable amounts of trichloroethylene are absorbed by activated sludge solids and the fact that TCE is strippable contributed to the efficiency of removal. Haller

(12) studied chloro,nitro substituted aromatic compounds to determine whether they could be degraded by soil and wastewater microorganisms and by organisms pre-adapted to the compounds. He found that the positions of the functional groups affected the biodegradability. Strackle and Baumann (22) studied problems associated with biological treatment of municipal wastewaters subjected to various industrial wastes including those containing substituted benzene ring compounds and phenol. They operated a trickling filter pilot plant and an activated sludge plant and observed that a fairly long period of time was required to adapt the microflora to these organic pollutants. The conclusion was that the activated sludge process was the best method to use for treatment because biomass concentration as well as the contact time with the organic material could be more readily controlled.

At the time of writing this thesis, the list of priority pollutants includes 129 toxic components, most of which are organic compounds. The six chosen for study here represent a broad spectrum of characteristics. Some pertinent facts about these compounds are given in Table I. The values listed for COD recovery are the percentage of the theoretical (calculated) COD which are recorded upon subjecting the compounds to the COD test.

TABLE I

SOME GENERAL CHARACTERISTICS OF PRIORITY POLLUTANTS STUDIED DURING THIS INVESTIGATION

	BENZENE	HEXACHLOROBENZENE	ANTHRACENE	O-NITROPHENOL	CHLOROFORM	TRICHLOROETHYLENE
Formula	C_6H_6	C_6Cl_6	$C_6H_4 = (CH)_2 = C_6H_4$	$NO_2C_6H_4OH$	$CHCl_3$	C_2HCl_3
Physical State (23)	colorless liquid	white needles solid	white solid	light yellow needles solid	colorless liquid	colorless liquid
Molecular Wt. (23)	78.11	284.80	178.22	139.11	119.38	131.5
Density (23)	0.8786	2.044	1.24	1657	1.489	1.46
Solubility (24)	1780 mg/l	nonsoluble	0.075 mg/l	2100 mg/l	8.000 mg/l	1.1 mg/l
Method of Production	fractional distillation of light oil	ultimate production from chlorinating benzene in the presence of ferric chloride	heat the crude benzole and tar	react nitrobenzene with sodium hydroxide, hydrolysis of O-nitrochlorobenzene, nitration of phenol	chlorinate the methane	chlorination of acetylene
Uses (24)	organic chemicals, pesticide plastics and resins, synthetic rubber, dye, pharmaceuticals, flavors and perfumes, paints and coatings, etc.	wood preservatives, fungicide, production of aromatic fluorocarbons	dye intermediate	synthesis of o-amino phenol, o-nitroanisole, and certain other dyestuff intermediates	intermediate in the manufacture of chlorofluoromethane, solvent, fire extinguisher	metal degreasing, solvent extraction, refrigerant and heat exchange liquid, organic synthesis
COD Recovery	95.3 percent	NO	85.4 percent	99.4 percent	15.7 percent	47.7 percent
Biodegradability	biodegradable (25) difficult to degrade	refractory (25)	biodegradable (26)	biodegradable (2)	refractory (25)	very difficult to degrade (25)

CHAPTER III

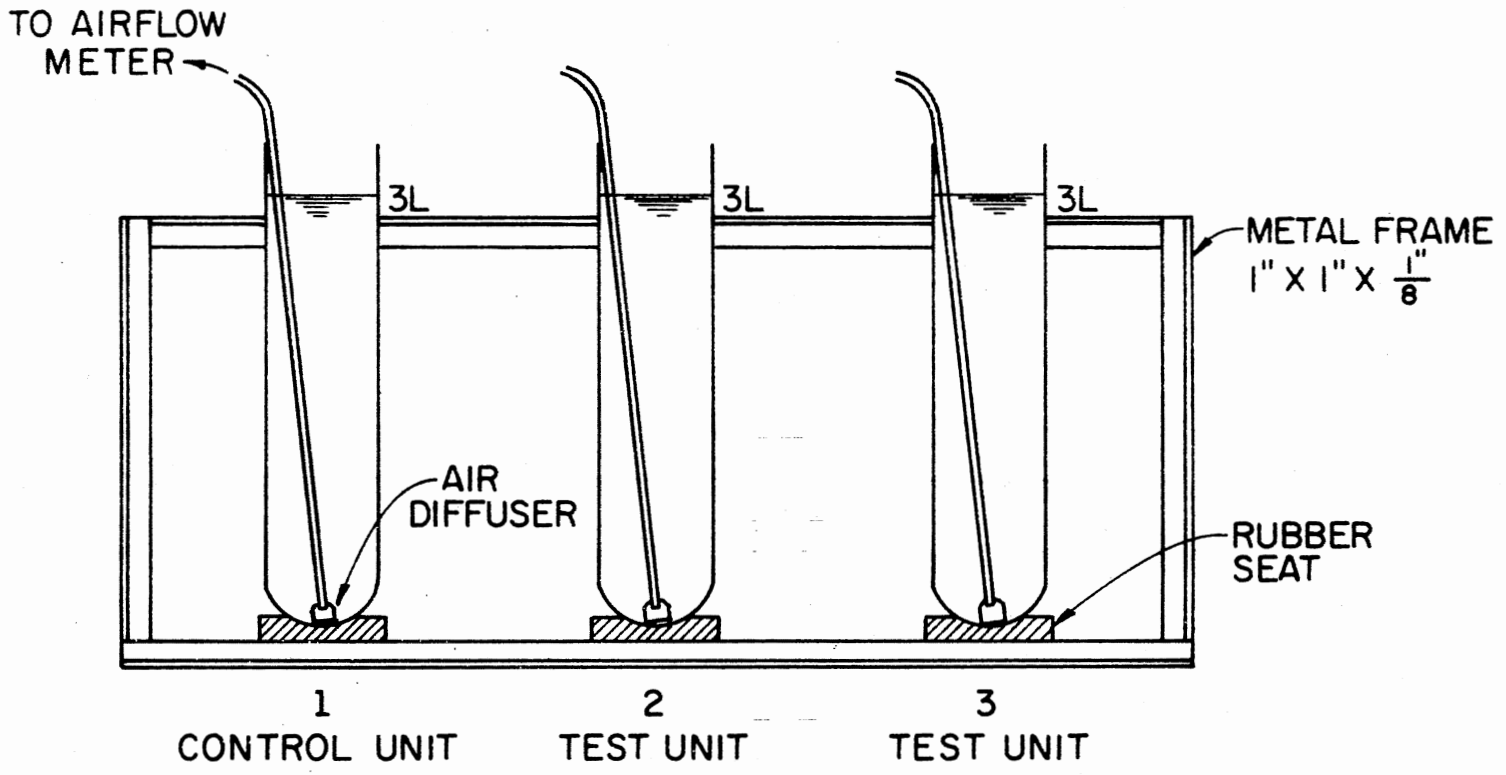
MATERIALS AND METHODS

Bench scale batch reactors were employed to study the effects of toxic organic compounds on activated sludges. Three 3.75-inch diameter batch reactors made of Pyrex glass were used, and each had a total volume of 3.5 liters (3.0 liter aeration liquor volume). The experimental apparatus used in these studies is shown in Figure 1.

To keep the units completely mixed and to provide sufficient oxygen to meet the respiration requirement of the microorganisms, diffused air was supplied through a carborundum diffuser; the airflow rate was two liters per hour. Dissolved oxygen concentration in the reactor was measured from time to time to ensure that the system was maintained under highly aerobic conditions. The temperature in the reactor was not controlled; thus, it varied somewhat during the study. The temperature variation was not severe, and was closely monitored.

Biomass was developed in a batch reactor using effluent from the primary settling tank of the Stillwater municipal sewage treatment plant as seed. After developing a sufficient concentration of biomass in the batch reactor, the biomass was divided into three equal portions. These portions of the sludge were used to start two units which were to receive normal wastes plus varying concentrations of the test compounds; a first unit was retained as a control unit. After studying the effects of two priority pollutants for an extended period

Figure 1. Schematic Diagram of Laboratory Scale Batch Reactors



BATCH REACTORS

of time, the units were rested by feeding the standard or normal waste material for several weeks and thereafter the units were used to study the effects of another pair of priority pollutants. The unit used as the control in the first set of experiments was also used as the control (undosed with toxicant) in studying succeeding pairs of priority pollutants.

Feed Preparation and Dosing Schedule

Sewage from the primary effluent of the Stillwater municipal sewage treatment plant was used as the normal feedstock. Stillwater is a rather small campus town, and the strength of the sewage is subject to periodic variation; it is extremely weak during periods between semesters. Average total COD during this study was 137 mg/l; average soluble COD was 74 mg/l, and average total BOD was 39 mg/l. Soluble BOD averaged 21 mg/l. In order to maintain adequate feeding strength, the municipal sewage was supplemented with 200 mg/l glucose and 75 mg/l ammonium sulfate. In general, the COD-to-nitrogen ratio was approximately 20:1. No other mineral salts or buffer were added since it was expected that the primary effluent would possess all of the trace nutrients required.

A total of six high priority pollutants were studied. Prior to dosing, the batch reactors were operated for a sufficient time to be sure that they had come to a relatively steady condition with regard to residual COD and biological solids production; that is, they were undosed until all three units were producing approximately the same residual COD and biological solids prior to the daily feeding.

Daily Feeding Procedure

The three reactors were fed once daily. The general feeding procedure was as follows: first, the sidewalls of the reactor above the liquid level were scraped down and mixed thoroughly in the reactor. One liter of mixed liquor was wasted from each unit; then the air diffusers were removed and the remaining two liters were allowed to settle for one hour. After one hour of settling, a second liter (supernatant) was wasted from each unit. Glucose and ammonium sulfate were added from stock solutions and the dosages of priority pollutants were added to the appropriate test reactors. All units were then returned to the 3-liter mark with primary effluent from the Stillwater municipal treatment plant. Occasionally, anti-foam spray was used to prevent foaming. The priority pollutants examined in this study were:

benzene

chloroform

trichloroethylene

o-nitrophenol

hexachlorobenzene

anthracene

During the study of any particular compound, dosage levels were increased as follows. There was a period in which the dosage was 5 mg/l. After examining the effect for a period of time, the dosage was increased to approximately 25 mg/l, and thereafter to approximately 50 mg/l. It is important to note that these dosage levels were based upon the two liters of daily feed material; thus, the initial concentration of these substances in the reaction liquor after bringing each unit to its

3-liter operational level was two-thirds of the feed dosage level. After obtaining information on the effects of repeated daily dosages at the same level, the dosage level was cycled to gain some idea of the system's ability to accommodate a fluctuating load with priority pollutants.

Sampling Procedure and Analyses

Samples were taken before each wasting and feeding period and immediately after feeding the reactors and bringing them to the 3-liter operating volume. In general, the samples were not taken daily, i.e., before and after every wasting and feeding. Usually, samples were taken on alternate days; however, during cyclic shocking of the units with toxic compounds, samples were taken daily.

Total suspended solids concentration was measured using the membrane filter technique (Millipore Filter Co., Bedford, Mass., H.A. 0.45 μm). Soluble substrate in the reaction liquor was measured as chemical oxygen demand according to procedures outlined in Standard Methods for the Examination of Water and Wastewater. pH was measured before and after each feeding; dissolved oxygen was measured periodically using a Weston-Stack dissolved oxygen analyzer, Model 330. Periodically, samples were taken for measurement of total COD, soluble TOC before feeding, total COD supernatant after one hour of settling, and total suspended solids of the supernatant after one hour of settling. Also, during each period at a specific toxic loading level, 1-liter samples of mixed liquor, supernatant, and feed were taken for analysis of the specific test compound, where such analyses were possible. These samples were taken to the chemistry department for analysis.

Auxiliary Studies

During the study of the effects of each compound it was advisable to gain information on the rate of purification during the 23-hour reaction time following each daily feeding. Also, since a significant number of priority pollutants are volatile, it was desirable to gain some idea of the strippability of each compound.

24-hour Batch Studies

Batch studies were usually conducted on the day the concentration of the priority pollutant was changed. Thus, after the feeding of the unit, soluble COD and suspended solids in the reactor were determined at frequent intervals during the ensuing 23-hour aeration period. Samples were taken frequently during the initial 2-hour period and thereafter the frequency of sampling was decreased.

Stripping Tests

Each of the six priority pollutants was tested for its batch stripping characteristics. Using similar batch reactors void of microbial cells, concentrations of 250, 500, and 1000 mg/l COD of test compound were aerated at the same airflow rate used in the batch aerator sludge units. These concentrations were made up in 2-liter volumes of tap water and placed in tightly sealed two 2-liter volumetric flasks. After ten minutes of mixing using a magnetic stirrer, this material was transferred to the batch reactor, bringing total volume to three liters, and the stripping tests were initiated. This procedure minimized error due to evaporative losses for highly strippable compounds.

CHAPTER IV

RESULTS AND DISCUSSION

Long-term Batch Studies

In Figures 2 through 7, the performance characteristics for control units and test units for the six high-priority pollutant compounds are presented. While these graphs are very helpful in showing comparative performance, the statistical analyses of these data during each period of operation provide a more quantitative numerical comparison. Values of the statistical parameters are given in Tables II, III, and IV; results of other analyses made periodically but not as often as those plotted in the figures are given in Table V. In Table VI, the results of analyses for specific compounds dosed to the units are listed. In the following discussion of effects of each compound, reference will be made to all three sets of information.

Benzene

Figure 2 shows little or no indication that benzene at 5, 20, or 50 mg/l feeding levels caused behavior any different than in the control system. Under cyclic loading (omitting the enormously high data point for soluble COD in the control), it would appear that benzene may cause a higher concentration of soluble COD, i.e., note the mean value of 33 vs. 45 mg/l. However, the short period of cyclic loading

Figure 2. Performance of Control Unit vs. Performance of Benzene Unit

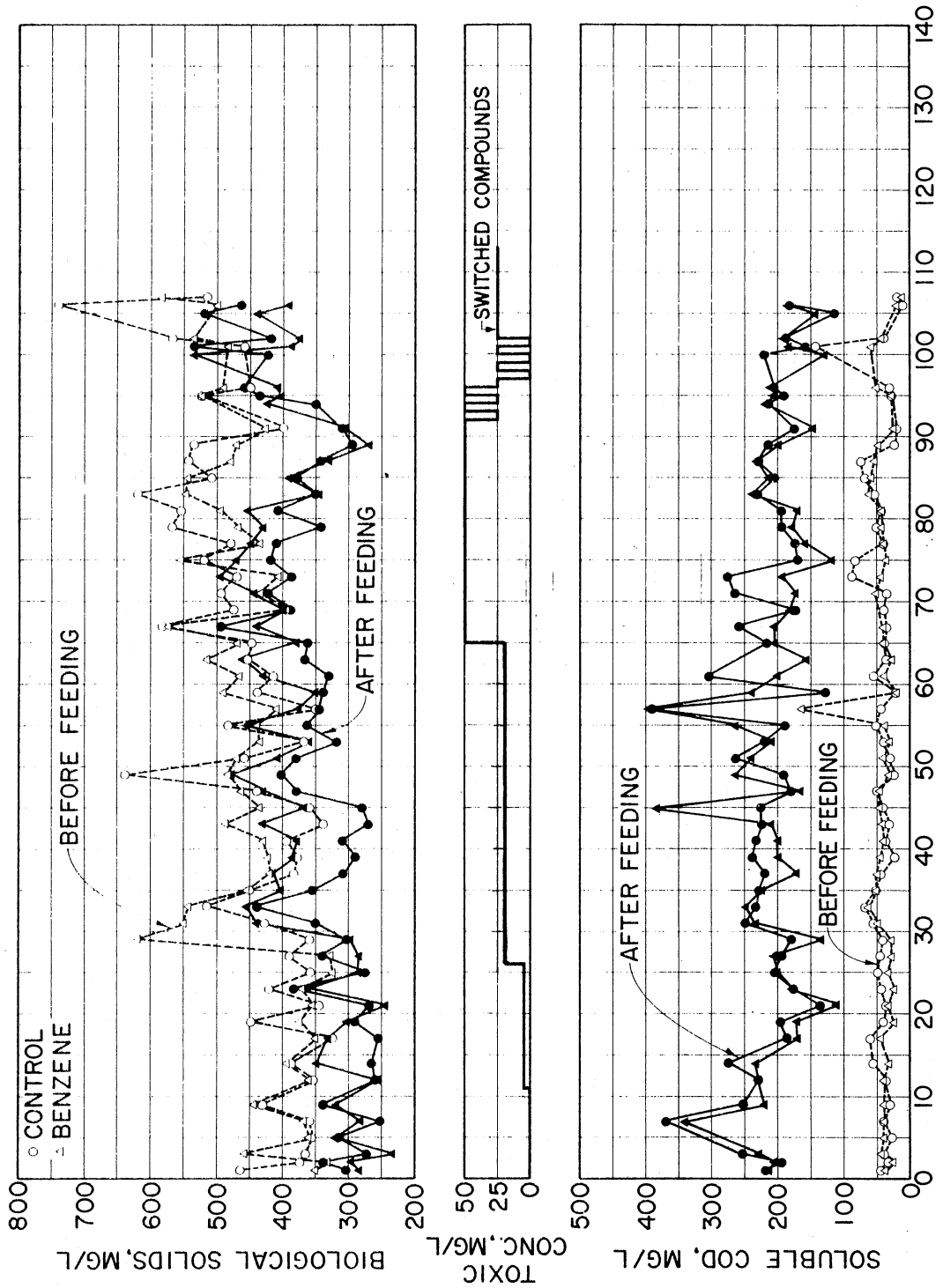

○ CONTROL
△ BENZENE
BEFORE FEEDING
AFTER FEEDING
BIOLOGICAL SOLIDS, MG/L
800
700
600
500
400
300
200
SWITCHED COMPOUNDS
TOXIC CONC., MG/L
50
25
0
AFTER FEEDING
BEFORE FEEDING
SOLUBLE COD, MG/L
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
TIME, DAYS

Figure 3. Performance of Control Unit vs. Performance of Hexachlorbenzene Unit

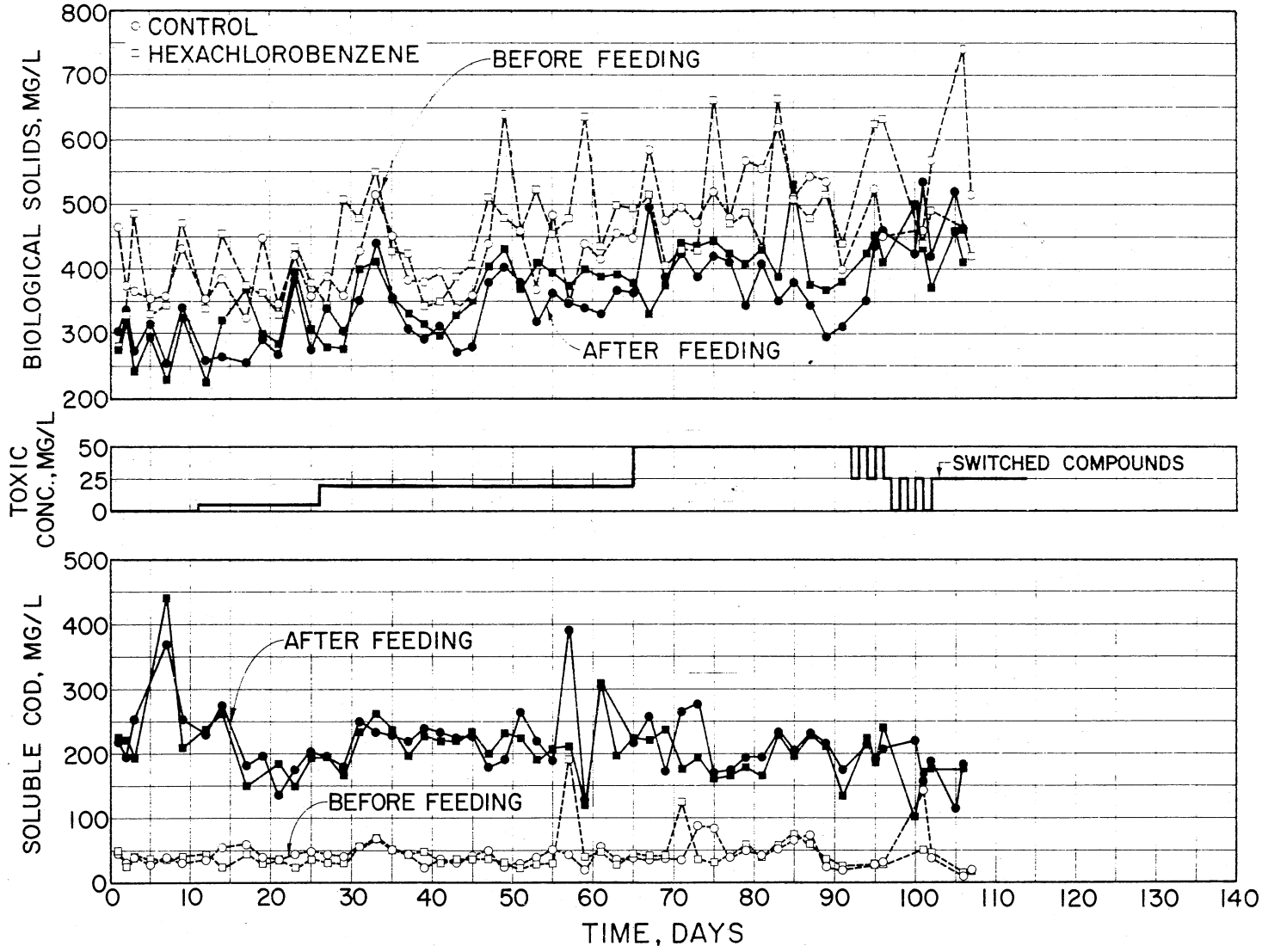

CONTROL
HEXACHLOROBENZENE
BEFORE FEEDING
AFTER FEEDING
BIOLOGICAL SOLIDS, MG/L
800
700
600
500
400
300
200
TOXIC CONC., MG/L
50
25
0
SWITCHED COMPOUNDS
SOLUBLE COD, MG/L
500
400
300
200
100
0
AFTER FEEDING
BEFORE FEEDING
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
TIME, DAYS

Figure 4. Performance of Control Unit vs. Performance of Anthracene Unit

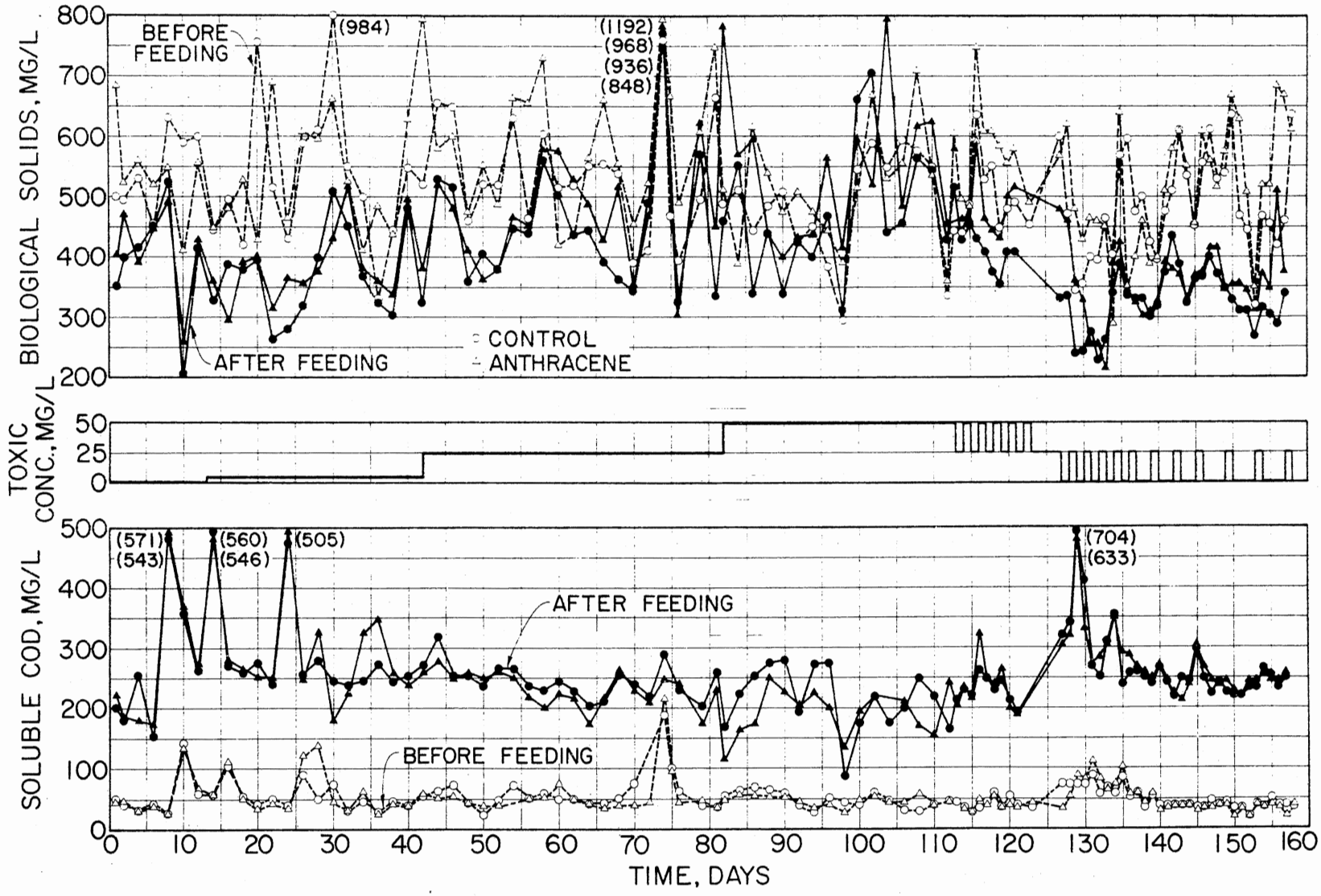

BIOLOGICAL SOLIDS, MG/L
800
700
600
500
400
300
200
BEFORE FEEDING
(984)
(1192)
(968)
(936)
(848)
AFTER FEEDING
CONTROL
ANTHRACENE
TOXIC CONC., MG/L
50
25
0
SOLUBLE COD, MG/L
500
400
300
200
100
0
(571)
(543)
(560)
(546)
(505)
(704)
(633)
AFTER FEEDING
BEFORE FEEDING
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
TIME, DAYS

Figure 5. Performance of Control Unit vs. Performance of O-nitrophenol Unit

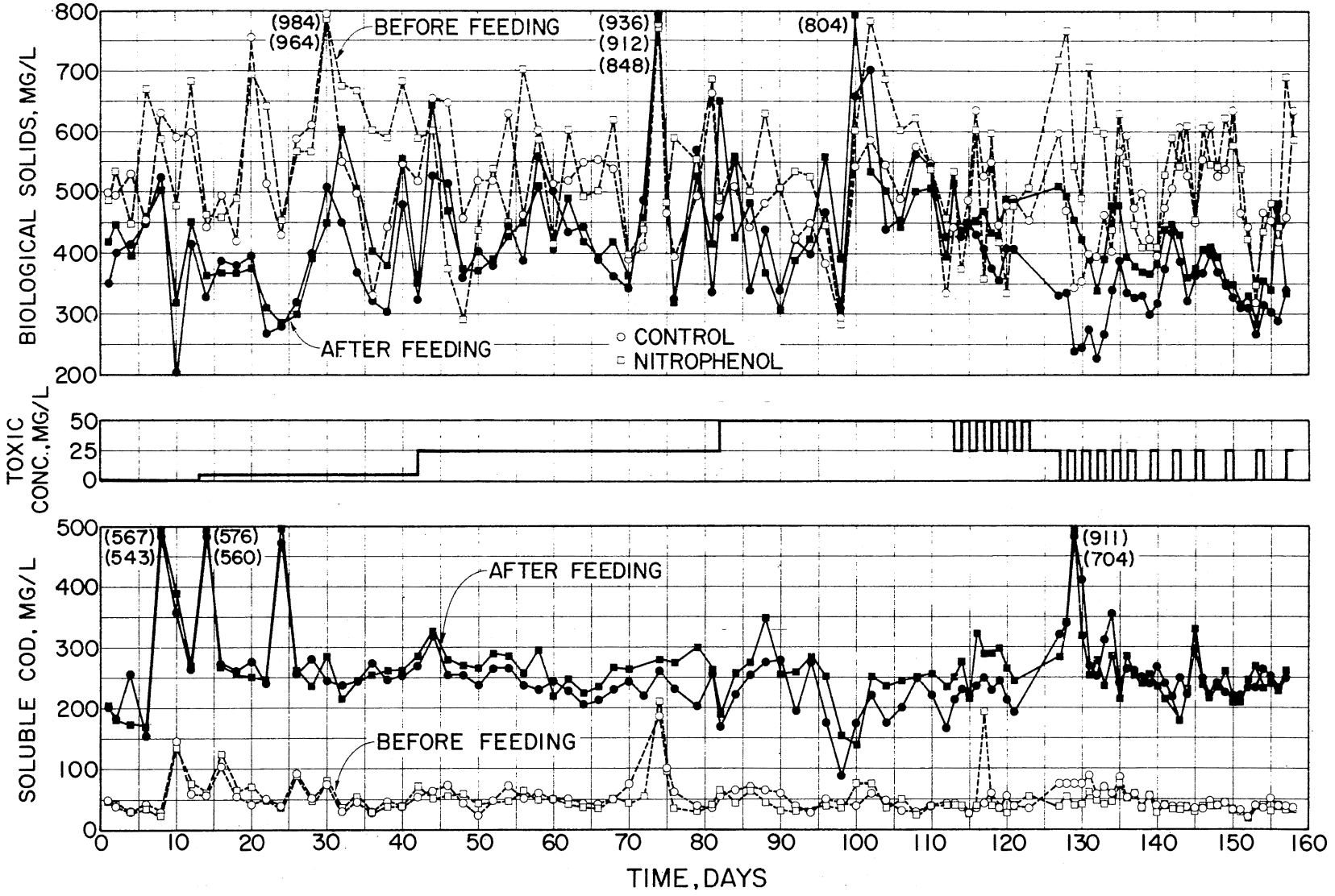

BIOLOGICAL SOLIDS, MG/L
800
700
600
500
400
300
200
(984)
(964)
BEFORE FEEDING
(936)
(912)
(848)
(804)
AFTER FEEDING
CONTROL
NITROPHENOL
TOXIC CONC., MG/L
50
25
0
SOLUBLE COD, MG/L
500
400
300
200
100
0
(567)
(543)
(576)
(560)
AFTER FEEDING
(911)
(704)
BEFORE FEEDING
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
TIME, DAYS

Figure 6. Performance of Control Unit vs. Performance of Chloroform Unit

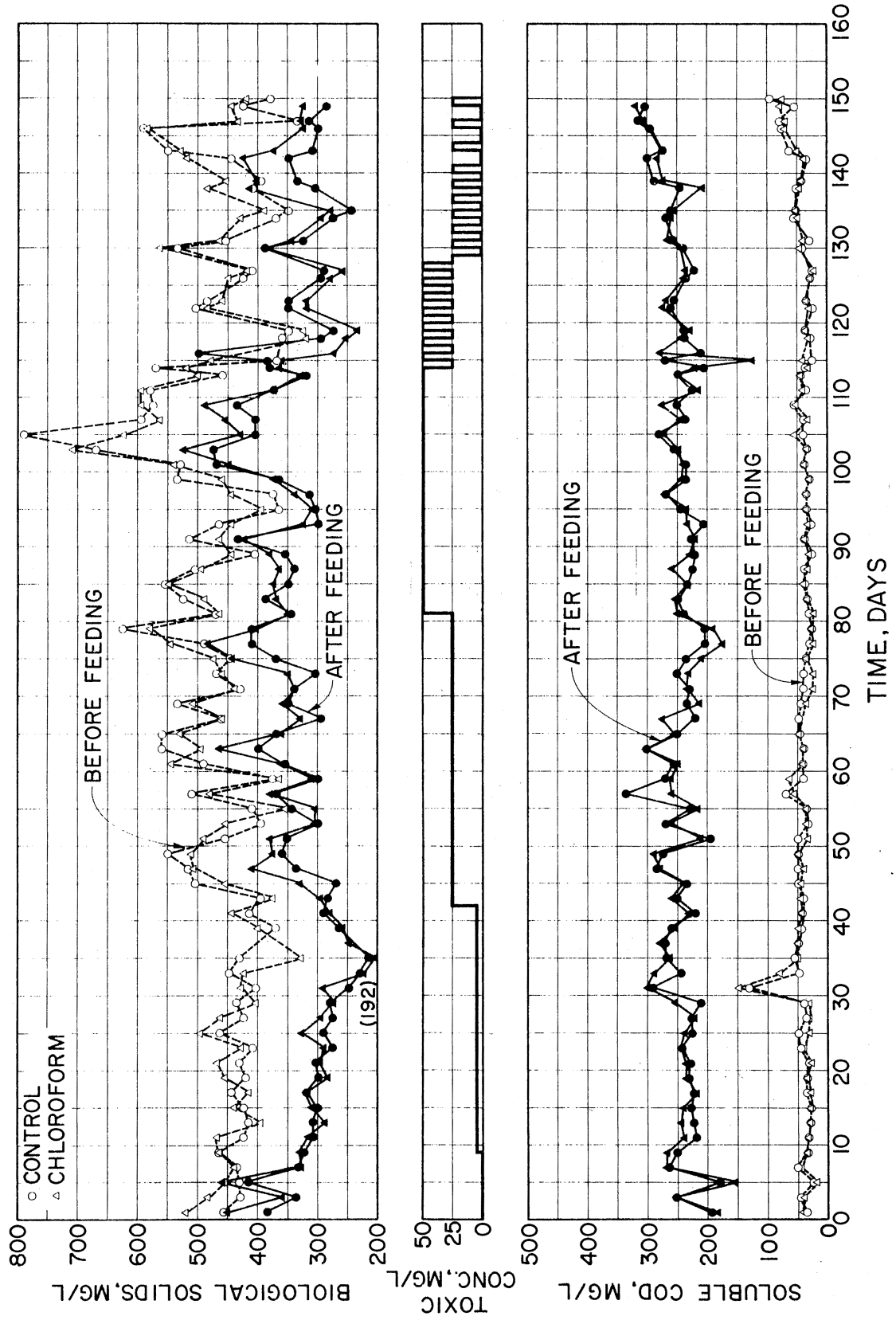

○ CONTROL
△ CHLOROFORM
BEFORE FEEDING
AFTER FEEDING
(192)
BIOLOGICAL SOLIDS, MG/L
800
700
600
500
400
300
200
TOXIC CONC., MG/L
50
25
0
SOLUBLE COD, MG/L
500
400
300
200
100
0
AFTER FEEDING
BEFORE FEEDING
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
TIME, DAYS

Figure 7. Performance of Control Unit vs. Performance of Trichloroethylene Unit

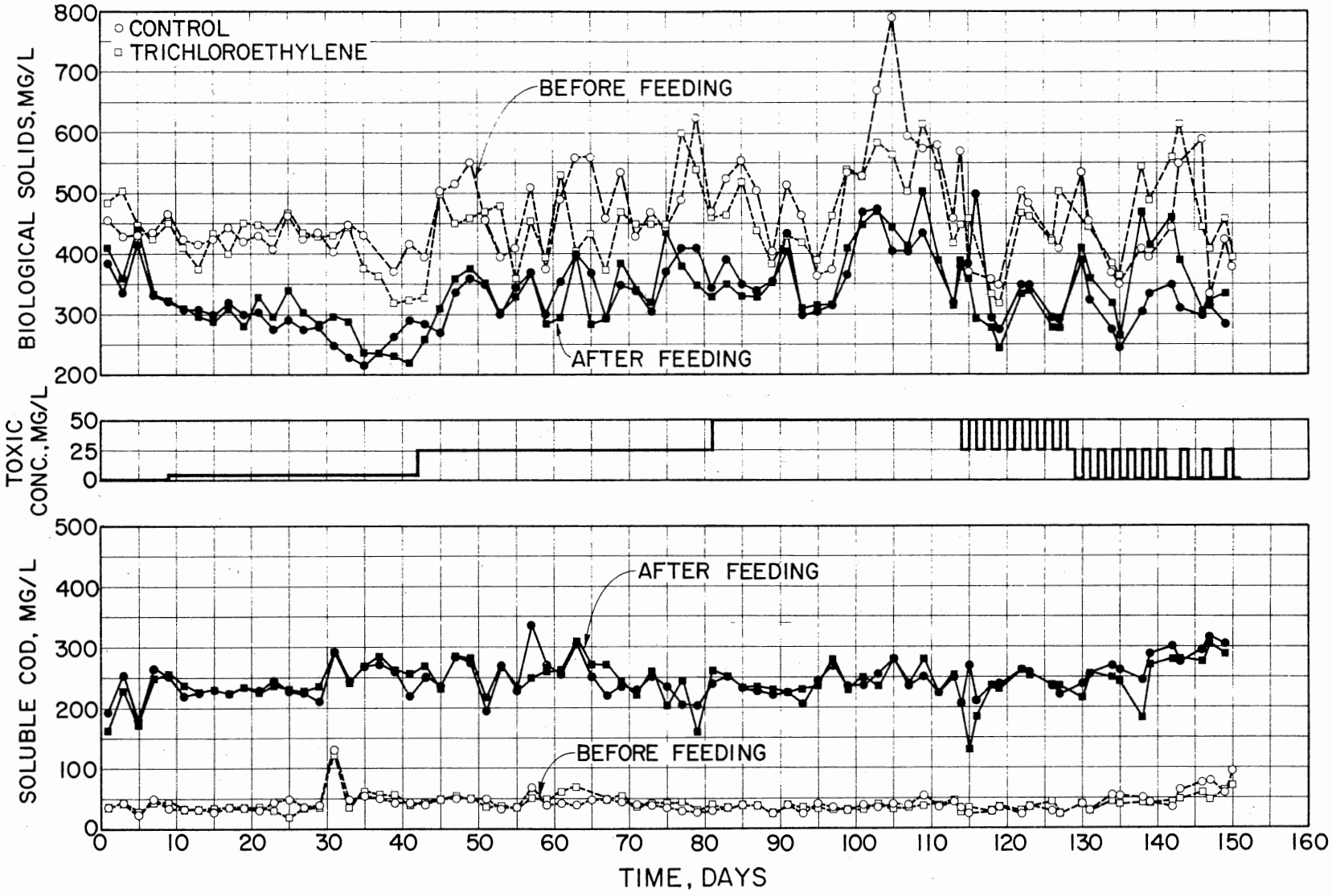

CONTROL
TRICHLOROETHYLENE
BEFORE FEEDING
AFTER FEEDING
BIOLOGICAL SOLIDS, MG/L
800
700
600
500
400
300
200
TOXIC CONC., MG/L
50
25
0
SOLUBLE COD, MG/L
500
400
300
200
100
0
AFTER FEEDING
BEFORE FEEDING
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
TIME, DAYS

TABLE II

STATISTICAL ANALYSIS COMPARISON OF CONTROL AND TEST UNITS DOSED WITH BENZENE AND HEXACHLOROBENZENE

Date 1977	Parameter	CONTROL				BENZENE				HEXACHLOROBENZENE				Remarks
		COD		SOLIDS		COD		SOLIDS		COD		SOLIDS		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
9-13	N	6	5	6	6	6	5	6	6	6	5	6	6	No toxic
	(Mean)	36.7	257.4	391.3	304.3	38.0	242.0	386.3	289.3	38.0	258.4	374.0	281.7	
	σ	6.5	67.2	45.6	34.6	6.2	55.9	51.6	31.8	7.8	103.4	84.4	40.0	
	R	28-46	194-369	354-464	254-340	26-44	206-341	334-458	234-320	26-50	193-442	280-486	230-326	
	C.V	17.7	26.1	11.6	11.4	16.3	23.1	13.4	11.0	20.5	40.0	22.6	14.2	
9-24	N	7	7	7	7	7	7	7	7	7	6	7	7	5 mg/l toxic
10- 8	(Mean)	45.9	199.4	376.9	286.1	33	184.7	362.3	305.4	33.9	195.7	382.6	315.1	
	σ	9.5	43.5	44.4	44.7	7.5	41.2	21.4	44.8	8.7	46.1	46.6	55.6	
	R	36-60	136-274	324-448	256-384	24-44	112-233	326-394	246-362	24-44	148-262	330-456	226-396	
	C.V	20.7	21.8	11.8	15.6	22.6	22.3	5.9	14.7	25.5	23.5	12.2	17.6	
10- 9	N	19	18	20	20	19	19	18	19	19	18	19	19	20 mg/l toxic
11-16	(Mean)	42.6	232.4	422.9	345.6	40.0	219.4	461.1	405.0	39.6	221.3	457.8	369.5	
	σ	11.4	50.5	73.2	41.2	10.3	55.3	51.9	47.5	11.1	30.5	74.6	42.3	
	R	23-68	179-392	304-640	272-440	20-64	134-396	328-552	284-484	24-68	167-308	342-638	280-432	
	C.V	26.8	21.7	17.3	11.9	25.8	25.2	11.2	11.7	28.0	13.8	16.3	11.4	
11- 7	N	13	13	13	13	12	13	13	11	13	13	13	10	50 mg/l toxic
12-12	(Mean)	50.5	212.5	520.0	381.8	46.2	185.0	480.2	390.9	51.7	192.3	496.0	392.8	
	σ	21.7	37.3	57.4	53.2	10.7	33.5	59.8	66.8	26.2	31.6	81.7	34.0	
	R	20-88	170-265	400-620	296-496	24-61	118-238	408-576	272-472	24-126	135-237	408-660	332-444	
	C.V	43.0	17.6	11.0	13.9	23.2	18.1	12.4	17.1	50.7	16.4	16.5	8.7	
12-13	N	3	6	4	5	4	6	4	6	4	6	4	6	cyclic shock toxic
12-24	(Mean)	33	196.3	501	418.4	45.5	191.7	509	422.7	38.5	183	547	432	
	σ	5.6	22.0	55.1	40.3	13.4	34.6	25.0	57.9	12.2	48	96	42.6	
	R	28-39	157-220	452.568	352-460	28-59	129-223	484-536	376-536	28-51	102-239	440-632	372-500	
	C.V	16.9	11.2	11.0	9.6	29.4	18.1	4.9	13.7	31.7	26.2	17.6	9.9	
9-13	N	48	49	50	51	48	50	48	49	49	48	49	48	Total
12-28	(Mean)	44.23	216	452.2	353.6	41.9	206.3	453.4	379.2	43.6	206.6	454.8	370.2	
	σ	20.8	50.3	88.1	64.7	20.7	54.8	71.7	70.0	27.1	50.9	87.8	65.7	
	R	23-88	136-392	304-640	256-496	20-64	112-396	326-576	234-536	24-126	102-442	280-660	226-500	
	C.V	47.1	23.3	19.5	18.3	49.4	26.6	15.8	18.5	62.1	24.6	19.3	17.8	
	N													

TABLE III

STATISTICAL ANALYSIS COMPARISON OF CONTROL AND TEST UNITS DOSED WITH ANTHRACENE AND O-NITROPHENOL

Date 1978	Parameter	CONTROL				ANTHRACENE				O-NITROPHENOL				Remarks
		COD		SOLIDS		COD		SOLIDS		COD		SOLIDS		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
1-10	N	7	7	7	7	7	7	7	7	7	7	7	7	No toxic
	(Mean)	56.3	275.3	544.0	394.3	55.7	282.3	543.4	413.7	55.9	278.9	556.6	428.6	
	σ	40.7	131.7	65.0	98.9	37.1	145.0	80.0	76.5	38.3	149.2	94.3	58.5	
	R	26-145	154-543	456-632	204-524	26-134	173-571	412-684	260-472	24-134	169-389	448-684	320-504	
	C.V	72.3	47.8	12.0	25.1	66.6	51.4	14.7	18.5	68.5	53.5	16.9	13.6	
1-23 2-20	N	15	15	15	15	15	15	15	15	15	15	15	15	5 mg/l toxic
	(Mean)	54.5	292.6	542.9	368.0	60.1	300.8	545.3	384.0	59.0	293.4	608.3	402.9	
	σ	20.8	93.4	156.7	71.3	35.0	100.8	112.8	59.6	25.0	101.4	129.2	91.7	
	R	30-104	238-560	456-964	268-508	26-138	180-546	412-796	296-516	30-124	214-576	456-964	284-604	
	C.V	38.2	31.9	28.9	19.4	58.2	33.5	20.7	15.5	42.4	34.6	21.2	22.6	
2-21 3-31	N	19	19	20	19	18	19	20	19	19	18	20	19	25 mg/l toxic
	(Mean)	62.1	245.5	543.2	459.2	58.3	231.0	606.6	492.4	58.2	269.2	528.4	462.1	
	σ	34.8	28.1	109.6	138.7	41.8	28.8	165.4	141.1	39.6	26.6	120.8	130.8	
	R	24-187	203-318	392-848	324-936	35-215	173-278	420-1192	304-968	31-211	220-326	292-772	320-912	
	C.V	56.0	11.5	20.2	30.2	71.7	12.5	27.3	28.7	68.0	9.9	22.9	28.3	
4-1 5-1	N	16	16	16	16	16	15	16	16	15	16	16	16	50 mg/l toxic
	(Mean)	48.4	208.9	476.5	470.8	46.9	193.3	514.3	545.8	47.1	244.4	549.8	481.3	
	σ	13.1	51.3	83.7	110.0	8.5	39.3	95.7	122.0	16.1	45.9	112.3	120.7	
	R	28-69	88-279	296-588	312-704	28-58	117-251	360-708	400-796	26-76	154-348	284-784	308-804	
	C.V	27.1	24.5	17.6	23.4	18.2	20.3	18.6	22.4	34.2	18.8	20.4	25.1	
5- 2 5-12	N	10	9	10	9	9	9	10	9	10	9	10	9	25 mg/l - 50 mg/l
	(Mean)	41.9	228.9	496.4	420.4	40.11	236.3	576	494.7	54	272.3	466.8	464	
	σ	10.0	22.2	61.3	46.0	8.4	40.9	78.0	57.9	49.8	31.9	95.8	29.5	
	R	28-61	193-266	440-636	356-516	28-56	189-323	484-748	432-592	28-194	216-323	336-604	432-516	
	C.V	23.9	9.7	12.4	10.9	20.9	17.3	13.5	11.7	92.3	11.7	20.5	6.4	
5-13 5-25	N	10	10	10	10	10	10	10	10	10	10	10	10	0 mg/l - 25 mg/l
	(Mean)	71.9	347.5	460	298.8	75.7	339.2	475	351.2	50.7	341.4	616	436.8	
	σ	11.6	136.1	97.2	54.2	23.0	105.9	110.7	89.5	11.8	203.5	96.5	56.2	
	R	53-89	240-704	344-600	228-388	35-112	274-633	228-640	216-480	39-77	215-911	440-768	340-512	
	C.V	16.2	39.2	21.1	18.1	30.4	31.2	23.3	25.5	23.4	59.6	15.7	12.9	
5-20 6- 3	N	9	9	9	9	9	9	9	9	9	9	9	9	0 mg/l, 0 mg/l, 25 mg/l
	(Mean)	42.4	250	486.2	352	42	254.7	483.6	345.8	40	239.4	491.1	395.6	
	σ	9.0	24.3	62.6	42.7	10.8	27.5	82.5	32.3	11	41.1	79.9	34.3	
	R	36-60	218-297	396-608	300-436	32-60	214-305	388-608	304-392	28-60	178-329	412-612	360-448	
	C.V	21.2	9.72	12.9	12.1	25.8	10.8	17.1	9.3	27.4	17.2	16.3	8.7	
6- 4 6-16	N	13	12	13	12	13	12	13	12	13	12	13	12	0, 0, 0 mg/l, 25 mg/l
	(Mean)	38.2	237.3	503.4	329.7	33.8	245.3	570.8	378.3	34.5	237.3	527.7	365.7	
	σ	7.6	14.5	92.4	37.7	7.8	12.7	90.5	51.2	7.3	19.8	95.9	52.6	
	R	21-52	221-265	320-636	268-400	21-40	221-269	352-684	312-512	17-44	209-269	348-692	284-484	
	C.V	20.0	6.1	18.4	11.4	22.9	5.2	15.8	13.5	21.0	8.3	18.2	14.4	
5- 2 6-16	N	42	40	42	40	41	40	42	40	42	40	42	40	cyclic shock toxic
	(Mean)	48	266.8	487.6	347.4	47.2	268.9	530.5	390.4	44.2	271.7	526.4	412.3	
	σ	16.4	83.0	80.2	61.9	21.0	69.7	100.0	83.1	26.1	109.9	105.3	58.6	
	R	21-89	193-704	320-636	228-516	21-112	189-633	288-748	216-592	17-194	178-911	336-768	284-516	
	C.V	34.3	31.2	16.4	17.8	44.5	25.9	18.9	21.3	59.1	40.4	20.0	14.2	
1-10 6-16	N	99	97	100	97	97	16	100	97	98	96	100	97	Total
	(Mean)	52.3	257.5	509.2	396.2	51.9	255.5	546.3	430.7	50.5	270.6	544.9	432.9	
	σ	23.6	80.2	103.1	106.0	28.4	79.9	118.2	117.1	29	92.4	114.1	96.0	
	R	21-187	88-704	296-964	204-936	21-215	117-633	288-1192	216-968	17-211	169-911	284-964	284-912	
	C.V	45.1	31.2	20.2	26.8	54.7	31.3	21.6	26.8	57.4	34.2	20.9	22.2	

TABLE IV

STATISTICAL ANALYSIS COMPARISON OF CONTROL AND TEST UNITS DOSED WITH CHLOROFORM AND TRICHLOROETHYLENE

Date 1978	Parameter	CONTROL				CHLOROFORM				TRICHLOROETHYLENE				Remarks
		COD		SOLIDS		COD		SOLIDS		COD		SOLIDS		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
7-24	N	5	5	5	5	5	5	5	5	5	5	5	5	No toxic
8- 1	(Mean)	38.8	228.4	440.0	358.4	36.4	226.0	472.8	384.4	39.6	213.4	462.4	375.2	
	σ	10.5	38.8	17.2	39.9	9.6	52.1	30.8	64.8	7.2	43.2	31.6	52.5	
	R	24-52	180-264	428-468	324-416	20- 44	156-268	440-520	328-460	24- 45	163-256	424-504	320-440	
	C.V	23.5	17.0	3.9	11.1	26.4	23.1	6.5	16.9	18.2	20.2	6.8	14.0	
8-2	N	16	16	15	15	16	16	15	16	16	16	16	16	5 mg/l toxic
9-3	(Mean)	46.4	238.8	424.3	280.8	47.19	249.8	430.7	281.4	44	244.3	409.6	284	
	σ	24.1	22.8	21.3	30.4	29.9	22.9	40.3	36.0	23	22.2	45.15	35.3	
	R	28-132	211-292	372-464	216-320	28-148	220-300	328-496	192-328	20-120	224-296	320-468	220-340	
	C.V	51.9	9.6	5.0	10.8	63.3	9.2	9.4	12.8	52.2	9.1	11.0	12.4	
9- 4	N	20	20	20	20	19	20	20	20	19	20	20	20	25 mg/l toxic
10-12	(Mean)	42.4	248.8	482.5	360.1	38.7	244.2	475.2	378.6	45.7	249.5	453.4	338.2	
	σ	9.1	34.6	64.9	65.7	11.2	33.3	59.4	64.8	9.9	33.1	62.9	44.9	
	R	28-68	195-336	375-625	270-410	24-64	176-304	355-580	296-485	28-70	160-309	328-600	260-400	
	C.V	21.5	13.9	13.4	18.2	28.9	13.6	12.5	17.1	21.7	13.3	13.9	13.3	
10-13	N	16	16	16	15	16	16	16	16	16	16	16	16	50 mg/l toxic
11-13	(Mean)	37.6	240.5	527.8	377.7	38.9	245.8	520.	395	35.2	243.9	488.8	381.9	
	σ	7.1	18.6	107.51	58.3	7.2	17.5	82.8	61.6	4.4	20.3	71.5	63.1	
	R	26-56	206-280	365-790	300-475	31-56	217-276	395-710	310-525	26-45	221-280	385-615	310-503	
	C.V	18.9	7.7	20.4	15.4	18.5	7.1	15.9	15.6	12.6	8.3	14.6	16.5	
11-14	N	8	9	8	9	8	9	8	9	8	9	8	9	25 mg/l - 50 mg/l
11-27	(Mean)	30	237.6	434.4	346.7	33	235.2	432.5	296.7	32.2	219.6	428.8	311.7	
	σ	4.9	22.0	78.8	70.5	5.3	45.4	73.8	46.6	6.0	40.7	66.4	46.8	
	R	24-36	207-270	350-570	275-500	24-42	127-278	320-520	235-365	24-45	131-262	320-505	245-390	
	C.V	16.3	9.24	18.1	20.3	16.1	19.3	17.1	15.7	18.7	18.5	15.5	15.0	
11-28	N	6	6	6	6	6	6	6	6	6	6	6	6	0 mg/l - 25 mg/l
12-10	(Mean)	46.2	260.2	419.2	312.5	46.3	252.3	465	354.2	40.5	237.8	461.7	373.3	
	σ	9.7	17.3	67.2	50.4	4.2	23.1	58.9	56.9	5.5	32.4	76.7	73.7	
	R	30-57	240-269	370-535	245-390	41-53	209-273	390-565	280-415	30-45	184-272	365-545	265-470	
	C.V	21.0	6.7	16.0	16.1	9.0	9.2	12.7	16.1	13.5	13.6	16.6	19.8	
12-11	N	6	5	6	5	6	5	6	5	6	5	6	5	0 mg/l, 0 mg/l - 25 mg/l
12-20	(Mean)	68.3	298.4	454.2	312.0	65	296.8	489.2	356	56	285.6	480.8	363	
	σ	20.3	14.6	98.3	24.1	15.6	17.8	65.5	43.9	11.0	11.2	87.6	62.7	
	R	36-96	276-316	335-590	285-350	40-80	276-320	420-585	325-425	44-72	276-304	395-615	305-460	
	C.V	29.7	4.9	21.6	7.7	24.0	6.0	13.4	12.3	19.7	19.9	18.2	17.3	
11-14	N	20	20	20	20	20	20	20	20	20	20	20	20	cyclic shock toxic
12-20	(Mean)	46.4	259.6	435.8	327.8	46.6	255.8	459.2	328.5	41.9	241.6	454.3	343	
	σ	20.2	30.9	78.8	56.5	16.2	41.5	68.1	55.3	12.6	15.9	75.5	63.6	
	R	24-96	207-316	335-590	245-500	24-80	127-320	320-585	236-425	24-72	131-304	320-615	245-470	
	C.V	43.5	11.9	18.1	17.2	34.8	16.2	14.8	16.8	30.2	6.6	16.6	18.5	
7- 4	N	77	77	76	76	76	77	76	77	76	77	77	77	Total
12-20	(Mean)	43.0	246.5	465.7	334.6	42.5	247.5	471.5	346.4	41.9	242.9	452.4	399.7	
	σ	16.3	29.6	81.0	56.4	17.6	32.7	68.4	66.2	13.9	32.5	67.5	61.7	
	R	24-132	180-336	335-590	216-500	20-148	127-320	320-710	192-525	20-120	131-309	320-615	220-505	
	C.V	37.9	12.0	17.4	16.9	41.4	13.2	14.5	19.1	33.1	13.4	14.9	18.2	

TABLE V

COMPARISON OF SETTLEABILITY AND TOC VALUES BETWEEN CONTROL UNIT AND TEST UNITS DOSED WITH BENZENE, HEXACHLOROBENZENE, ANTHRACENE, O-NITROPHENOL, CHLOROFORM, AND TRICHLOROETHYLENE

DATE (1977)	ANALYSIS	CONTROL (mg/l)	BENZENE (mg/l)	HEXACHLORO-BENZENE (mg/l)	REMARKS
12- ?	1-hr Settled Susp. Sol.	60	56	6	50 mg/l toxic dosage Day 81, Fig. 2-3
12-10		42	70	20	50 mg/l toxid dosage Day 89, Fig. 2-3
(1978)			ANTHRA-CENE	O-NITRO-PHENOL	
2-20	TOC	18	23	25	25 mg/l toxid dosage Day 42, Fig. 4-5
	Mixed Liquid Total COD	653	658	628	
	1-hr Settled Susp. Sol.	8	18	8	
3-30	Mixed Liquid Total COD	625	690	738	25 mg/l toxic dosage Day 80, Fig. 4-5
	1-hr Settled Susp. Sol.	40	44	56	
3-31	TOC	18	32	25	25 mg/l toxic dosage Day 81, Fig.
5- 1	TOC	33	19	52	50 mg/l toxic dosage Day 112, Fig. 4-5
	Mixed Liquor Total COD	620	596	612	
	1-hr Settled Total COD	38	38	42	
5- 2	TOC	56	30	46	50 mg/l toxic dosage Day 113, Fig. 4-5
	Mixed Liquor Total COD	636	697	570	
	1-hr Settled Total COD	53	66	66	
	1-hr Settled Susp. Sol.	28	26	22	
5-17	TOC	38	56	38	0 toxic dosage Day 128, Fig. 4-5
	Mixed Liquor Total COD	624	729	757	
	1-hr Settled Total COD	100	59	47	
	1-hr Settled Susp. Sol.	62	20	20	
			CHLORO-FORM	TRICHOLORO-ETHYLENE	
8- 1	TOC	26	11	14	No toxic dosage Day 9, Fig. 6-7
	Mixed Liquor Total COD	516	576	516	
	1-hr Settled Total COD	44	44	48	
	1-hr Settled Susp. Sol.	6	6	6	
8- 7	1-hr Settled Susp. Sol.	10	14	9	5 mg/l toxic dosage Day 15, Fig. 6-7
8-17	1-hr Settled Susp. Sol.	10	12	14	5 mg/l toxic dosage Day 25, Fig. 6-7
8-29	TOC	-	33	45	5 mg/l toxic dosage Day 37, Fig. 6-7
	1-hr Settled Susp. Sol.	19	7	47	
9- 3	1-hr Settled Susp. Sol	6	6	14	5 mg/l toxic dosage Day 42, Fig. 6-7
9- 4	1-hr Settled Susp. Sol.	5	9	14	25 mg/l toxic dosage Day 43, Fig. 6-7
9-12	1-hr Settled Susp. Sol.	26	37	28	25 mg/l toxic dosage Day 51, Fig. 6-7
9-20	1-hr Settled Susp. Sol.	14	28	15	25 mg/l toxic dosage Day 59, Fig. 6-7

TABLE V (Continued)

DATE (1978)	ANALYSIS	CONTROL (mg/l)	CHLORO-FORM (mg/l)	TRICHOLORO-ETHYLENE (mg/l)	REMARKS
10- 2	1-hr Settled Susp. Sol.	19	22	12	25 mg/l toxic dosage Day 71, Fig. 6-7
10-12	TOC	43	10	10	25 mg/l toxic dosage Day 81, Fig. 6-7
	Mixed Liquor Total COD	584	580	564	
	1-hr Settled Susp. Sol.	12	12	13	
10-13	1-hr Settled Susp. Sol.	26	22	25	50 mg/l toxic dosage Day 82, Fig. 6-7
10-22	TOC	9.2	8	9	50 mg/l toxic dosage Day 91, Fig. 6-7
	1-hr Settled Susp. Sol.	14	16	15	
10-26	1-hr Settled Susp. Sol.	26	19	19	50 mg/l toxic dosage Day 95, Fig.
11- 9	TOC	-	10	7	50 mg/l toxic dosage Day 109, Fig. 6-7
	1-hr Settled Susp. Sol.	13	17	15	
11-14	TOC	5	3	9	50 mg/l toxic dosage Day 114, Fig. 6-7
	Mixed Liquor Total COD	582	598	537	
	1-hr Settled Susp. Sol.	15	19	29	
11-15	TOC	11	12	12	25 mg/l toxic dosage Day 115, Fig. 6-7
	Mixed Liquor Total COD	577	611	604	
	1-hr Settled Susp. Sol.	22	18	20	
11-30	TOC	20	22	19	0 mg/l toxic dosage Day 130, Fig. 6-7
	1-hr Settled Susp. Sol.	16	9	19	
11-31	TOC	21	22	17	25 mg/l toxic dosage Day 131, Fig. 6-7
	Mixed Liquor Total COD	575	565	575	
	1-hr Settled Susp. Sol.	20	6	13	
12-13	TOC	12	5	9	0 mg/l toxic dosage Day 143, Fig. 6-7
	1-hr Settled Susp. Sol.	18	24	48	

TABLE VI

QUANTITATIVE ANALYSIS FOR REMOVAL OF TEST COMPOUNDS, ANTHRACENE, O-NITROPHENOL, CHLOROFORM, AND TRICHLOROETHYLENE IN TEST UNITS

Date (1978)	Sample Name	Amount of Dosage (mg/l)	Quantitative Analysis of Compound in Sample (mg/l)
		Anthracene	
2-12	feed sample	5	1.9
2-13	mixed liquor	5	2.8
2-13	1-hr settled effluent	5	0.006
2-18	feed sample	5	2.0
2-19	mixed liquor	5	6.5
2-19	1-hr settled effluent	5	<0.003
3-29	feed sample	25	9.6
3-30	mixed liquor	25	10.8
3-30	1-hr settled effluent	25	<0.002
4-23	feed sample	50	26.0
4-24	mixed liquor	50	31.6
4-24	1-hr settled effluent	50	0.08
4-28	mixed liquor	50	47.0
4-28	1-hr settled effluent	50	0.17
6-15	feed sample	25	13.2
6-16	mixed liquor	25	22.0
		Nitrophenol	
2-12	feed sample	5	3.8
2-13	mixed liquor	5	<0.06
2-13	1-hr settled effluent	5	<0.06
2-18	feed sample	5	3.6
2-19	mixed liquor	5	<0.02
2-19	1-hr settled effluent	5	<0.02
3-29	feed sample	25	23.1
3-30	mixed liquor	25	<0.04
3-30	1-hr settled effluent	25	<0.06
4-23	feed sample	50	37.5
4-24	mixed liquor	50	<0.04
4-24	1-hr settled effluent	50	<0.06
4-28	mixed liquor	50	<0.06
4-28	1-hr settled effluent	50	<0.04
6-15	feed sample	25	20.9
6-16	mixed liquor	25	<0.06

TABLE VI (Continued)

Date (1978)	Sample Name	Amount of Dosage (mg/l)	Quantitative Analysis of Compound in Sample (mg/l)
		Chloroform ($CHCl_3$)	
8-25	feed sample	5	<0.2
8-26	mixed liquor	5	<0.2
8-26	1-hr settled effluent	5	<0.2
10-11	feed sample	25	14.2
10-12	mixed liquor	25	<0.2
10-12	1-hr settled effluent	25	<0.2
10-21	feed sample	50	27.0
10-22	mixed liquor	50	<0.15
10-22	1-hr settled effluent	50	4.2
11- 8	feed sample	50	14.4
11- 9	mixed liquor	50	<0.15
11- 9	1-hr settled effluent	50	<0.2
12- 1	1-hr settled effluent	25	<0.2
12-13	feed sample	25	27.5
12-14	mixed liquor	25	<0.2
12-14	1-hr settled effluent	25	<0.2
		Trichloroethylene (C_2HCl_3)	
8-25	feed sample	5	3.1
8-26	mixed liquor	5	<0.01
8-26	1-hr settled effluent	5	<0.01
10-11	feed sample	25	12.2
10-12	mixed liquor	25	<0.01
10-12	1-hr settled effluent	25	<0.01
10-21	feed sample	50	50.0
10-22	mixed liquor	50	<0.005
10-22	1-hr settled effluent	50	<0.005
11- 8	feed sample	50	7.0
11- 9	mixed liquor	50	<0.005
11- 9	1-hr settled effluent	50	<0.01
12- 1	1-hr settled effluent	25	<0.01
12-13	feed sample	25	9.6
12-14	mixed liquor	25	<0.01
12-14	1-hr settled effluent	25	<0.01

and the small number of samples obtained during this period are not really adequate for statistical analysis. Two samples taken for analysis of suspended solids during operation at the 50 mg/l dosing level (see Table V) indicate little difference between supernatant suspended solids values on day 81, whereas for the sample taken on day 89 there was a very noticeable increased suspended solids concentration in the supernatant of the benzene unit.

Hexachlorobenzene

At the concentrations fed, hexachlorobenzene did not appear to cause any significant increase in soluble COD (Figure 3). When all data points on soluble COD were lumped to determine overall average, it can be seen (Table II) that the mean values for soluble COD in the control and in the hexachlorobenzene units were the same. However, the coefficient of variation for the hexachlorobenzene unit was noticeably higher than for the control (47.1 vs. 62.1). The supernatant suspended solids concentration was much lower in the hexachlorobenzene units than in the controls on days 81 and 89 (Table V).

Anthracene

The second study period included comparative assessment of the effects of anthracene and o-nitrophenol. During this study period, the municipal sewage occasionally exhibited a foamy character. At the beginning of the period, there were wide fluctuations in the concentration of municipal sewage, as can be seen in Figure 4, which shows the results for dosage with anthracene. Also, an abnormally high feed COD was manifested on day 129. The highly soluble COD before feeding

on day 74 corresponded with the occurrence of a large amount of foaming in the unit. The addition of 5 mg/l of anthracene did not appear to affect behavior of the unit adversely, except for a period of significantly higher leakage than in the control between days 25 and 30. This result did not greatly affect the mean COD values during this period (see 55 vs. 60 for control and anthracene system, Table III) but it did cause quite some change in the standard deviation and coefficient of variation. When the dosage was increased to 25 mg/l, there was little difference in the soluble COD in the control and anthracene units, but the unit receiving the toxic compound exhibited a somewhat higher biological solids concentration. Increasing the dosage to 50 mg/l did not seriously affect the effluent quality with respect to soluble COD. On the contrary, the average COD in the test unit was slightly lower than in the control. Fluctuating the loading between 25 and 50 mg/l from days 113 to 123 did not cause any difference in the soluble COD in the control and test units. Cycling the loading from 0 to 25 mg/l did not appear to cause any significant differences in the soluble COD. During this period, there was a considerable dropoff in the biological solids concentration in both the control and the anthracene units. Increasing the time of zero concentration beginning on day 137 did not lead to any change in behavior; that is, the control unit and the anthracene test unit exhibited essentially the same COD concentration. The results shown in Table VI provide some indication that anthracene was removed during the aeration period.

O-Nitrophenol

It is seen from Figure 5 that addition of 5 mg/l o-nitrophenol had

little effect on the behavior of the system. The statistical analyses shown in Table III for this period indicate a slightly higher mean soluble COD and higher coefficient of variation due to the dosage of 5 mg/l of o-nitrophenol. It is interesting to note that this dosage level of o-nitrophenol caused a soluble color of the reaction liquor; the reaction liquor turned slightly yellow. The color persisted until the second day of feeding. However, there was a slight reduction in its intensity by this time. This provided some indication that the o-nitrophenol was partially removed or partially converted to some other intermediate which did not exhibit any color. This condition prevailed for eight days. From day 8 on, even though there was a slight yellow color immediately after feeding, no color was observed by the time for the next day's feeding. This indicates that the biomass may have acclimated to the compound. It is also possible that this period may have been one of adaptation wherein a few species capable of using the o-nitrophenol increased in relative numbers in the sludge; that is, this may have been a period of adaptation rather than acclimation. When the dosage was increased to 25 mg/l on day 42, the yellow color increased after feeding. In response to this dosing level, there was a decrease in biomass concentration; however, the biomass level recovered after the first four days at this dosing level. The color due to the presence of o-nitrophenol was removed during the first day of dosage. When the dosage was increased to 50 mg/l, the yellow color of o-nitrophenol was not removed on the first day; however, after three days of such feeding, o-nitrophenol was removed during the daily feeding period, as evidenced by the absence of color when compared to the control. During the period of feeding 50 mg/l, the suspended solids

concentration in the unit receiving o-nitrophenol became higher than that in the control. The fact that the residual COD at the end of the feeding period was essentially the same as in the control whereas the higher COD due to the feeding of o-nitrophenol was evident in the sample taken immediately after feeding coupled with the fact that the biological solids concentration was somewhat higher during this feeding period can be taken as rather good evidence that the compound was metabolized by the sludge. When the loading was fluctuated between 25 and 50 mg/l between days 113 and 123, the biomass concentration in the o-nitrophenol unit fluctuated considerably and the coefficient of variation was twice as high as in the control. Also, the coefficient of variation for the residual soluble COD was considerably higher than for the control (92.3 for the o-nitrophenol system compared to 23.9 for the control, see Table III). When the cyclic loading was changed to 0-25-0 mg/l, the suspended solids concentration in the o-nitrophenol unit remained somewhat higher than in the control. The settling characteristics of the o-nitrophenol unit compared very favorably throughout the experimental period with those of the control. The results shown in Table VI indicate that o-nitrophenol was removed during the aeration period.

Chloroform

It is seen from Figure 6 and from Table IV that chloroform had little or no effect on the system under any of the loading conditions examined. Chloroform is only slightly soluble in water, and although it was partially emulsified by the agitation caused by the vigorous aeration supplied, there would appear to be no adverse effects.

Trichloroethylene

It can be seen from Figure 7 and from Tables IV and V that trichloroethylene which is only very slightly soluble had little or no adverse effect on the behavior of the batch activated sludge. It does seem significant to note, however, that a considerable number of samples were taken of supernatant suspended solids after the 1-hour settling period and when there were differences in the suspended solids concentration in the supernatant, the trichloroethylene unit exhibited a higher solids leakage than the control, i.e., settling effectiveness in the trichloroethylene unit was not as good as in the control. For example, see the 1-hour supernatant solids concentrations for days 37, 114, and 143 (Table V).

24-hour Batch Studies

All 24-hour batch studies conducted during this investigation to compare the effect of various concentrations of priority compounds on the rate of removal of soluble COD are shown in Figures 8 through 37. For the experiments conducted with benzene and with hexachlorobenzene, the biomass in the control unit was taken from units which had received and had been adapted to concentrations of 5 to 20 mg/l. However, in all other cases, anthracene, o-nitrophenol, chloroform, and trichloroethylene, the biomass in the control unit is that in the control unit for the main line of study; that is, these undosed control units were those which had at no time received any dosage of the test compounds.

It is seen from the results for benzene (Figures 8 and 9), that dosages of 20 mg/l and 50 mg/l did not have any effect on the removal

Figure 8. Performance of Control Unit vs. Performance of Benzene Unit During 24-hour Batch Study. On Day 57, Unit was fed 20 mg/l Benzene

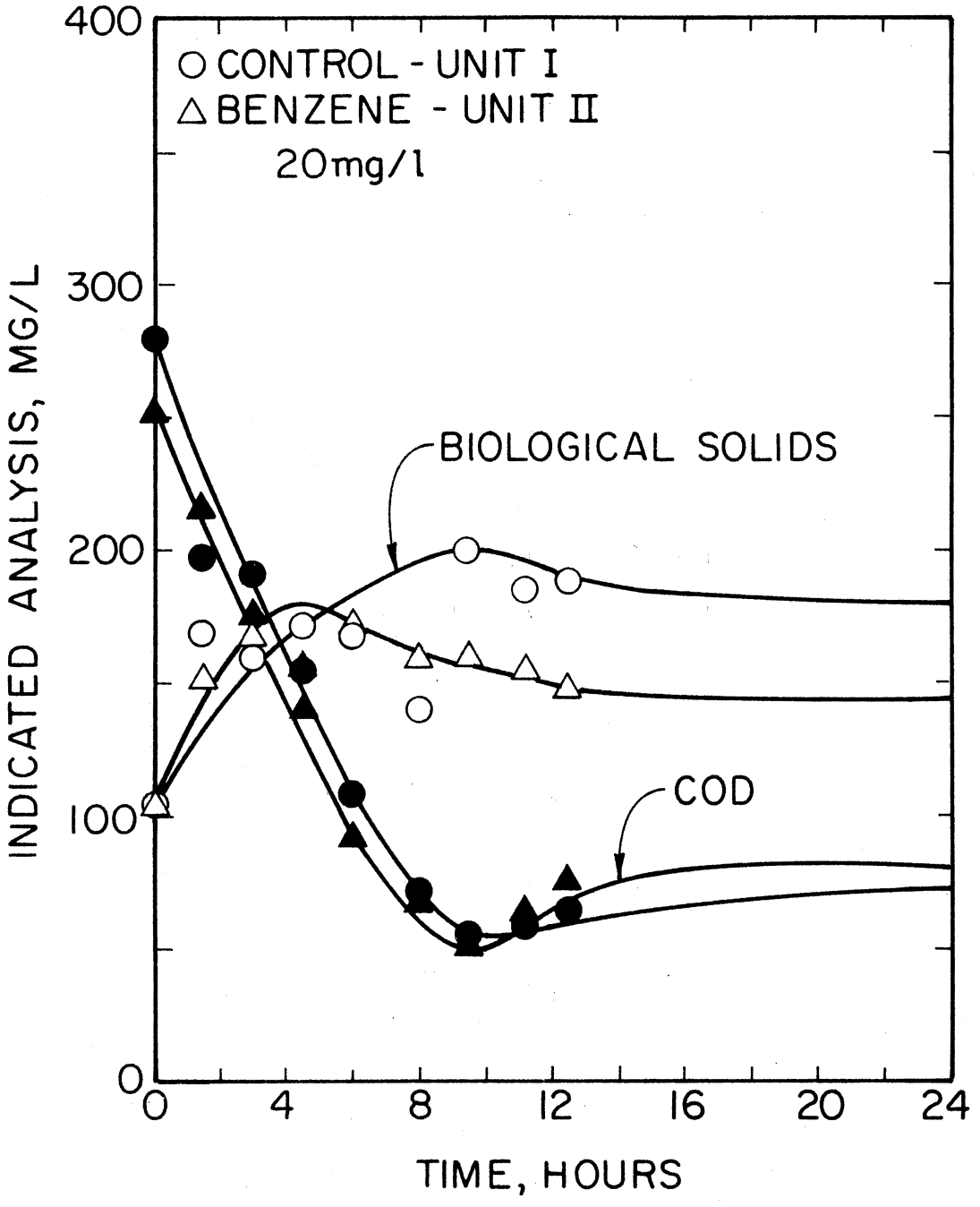

400
300
200
100
0
○ CONTROL - UNIT I
△ BENZENE - UNIT II
20mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 9. Performance of Control Unit vs. Performance of Benzene Unit During 24-hour Batch Study. On Day 86, Unit was fed 50 mg/l Benzene

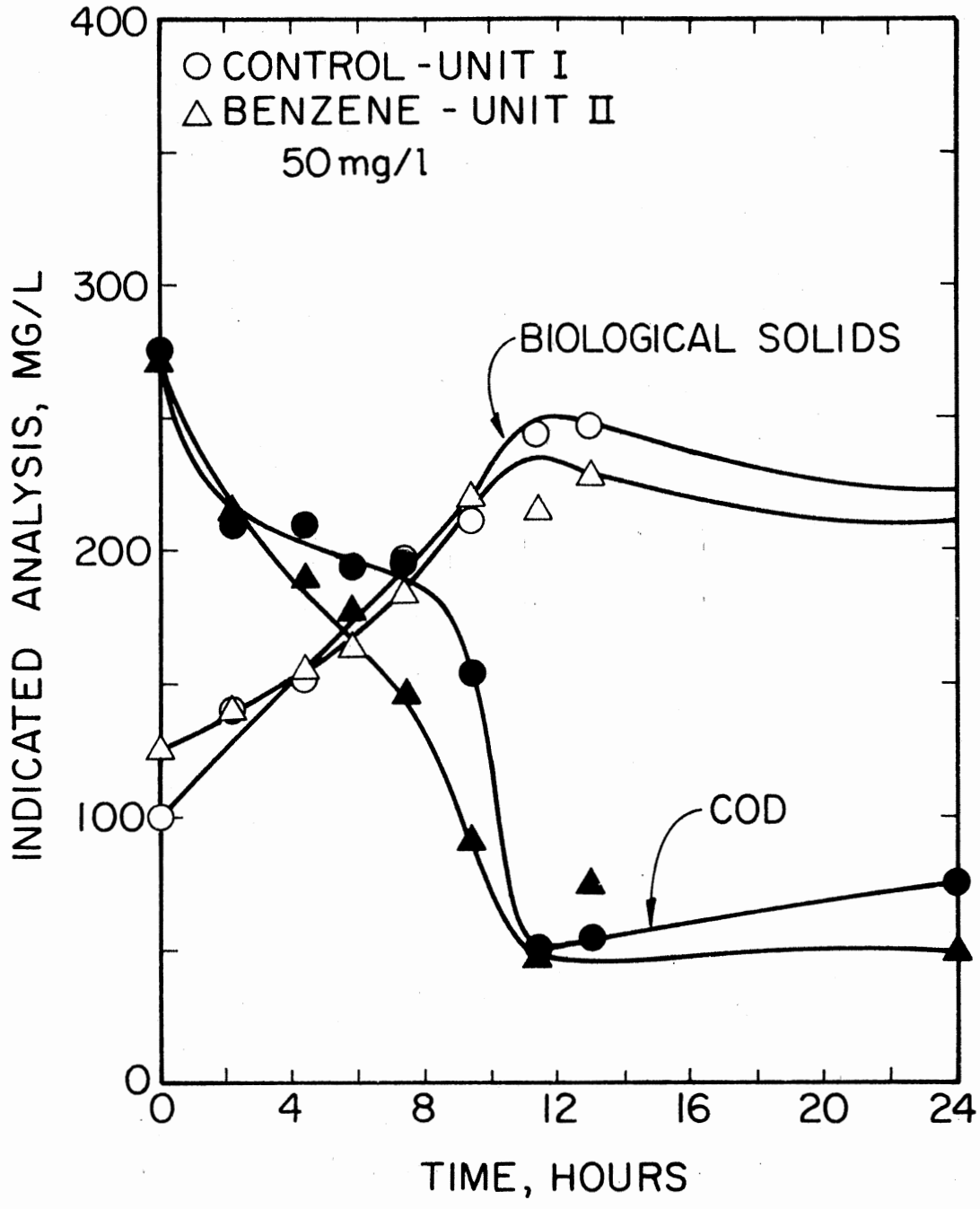

400
300
200
100
0
○ CONTROL - UNIT I
△ BENZENE - UNIT II
50 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 10. Performance of Control Unit vs. Performance of Hexachlorobenzene Unit During 24-hour Batch Study. On Day 57, Unit was fed 20 mg/l Hexachlorobenzene

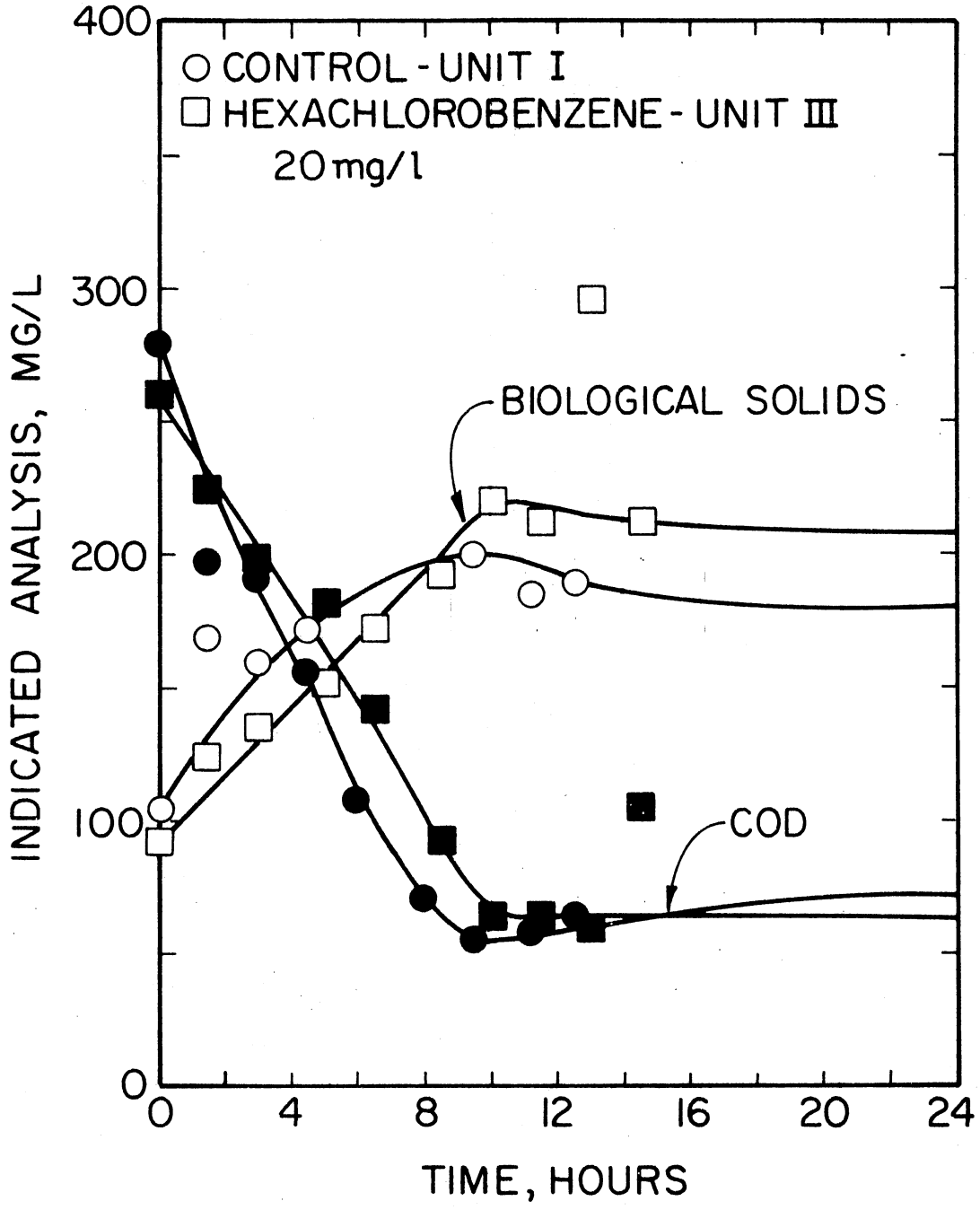

400
300
200
100
0
○ CONTROL - UNIT I
□ HEXACHLOROBENZENE - UNIT III
20 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 11. Performance of Control Unit vs. Performance of Hexachlorobenzene Unit During 24-hour Batch Study. On Day 86, Unit was fed 50 mg/l Hexachlorobenzene

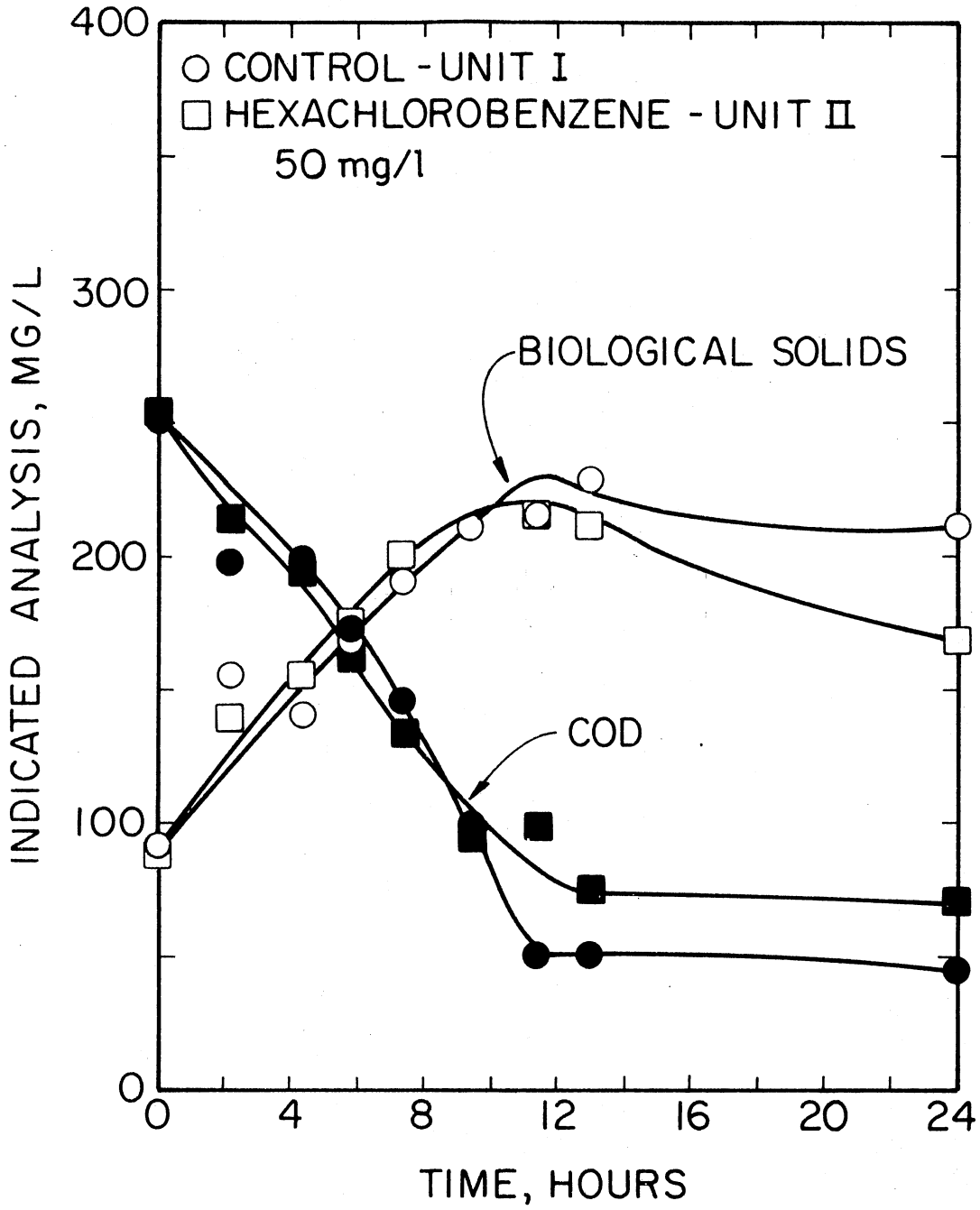

400
300
200
100
0
CONTROL - UNIT I
HEXACHLOROBENZENE - UNIT II
50 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 12. Performance of Control Unit vs. Performance of Anthracene Unit During 24-hour Batch Study. On Day 13, Unit was fed 5 mg/l Anthracene

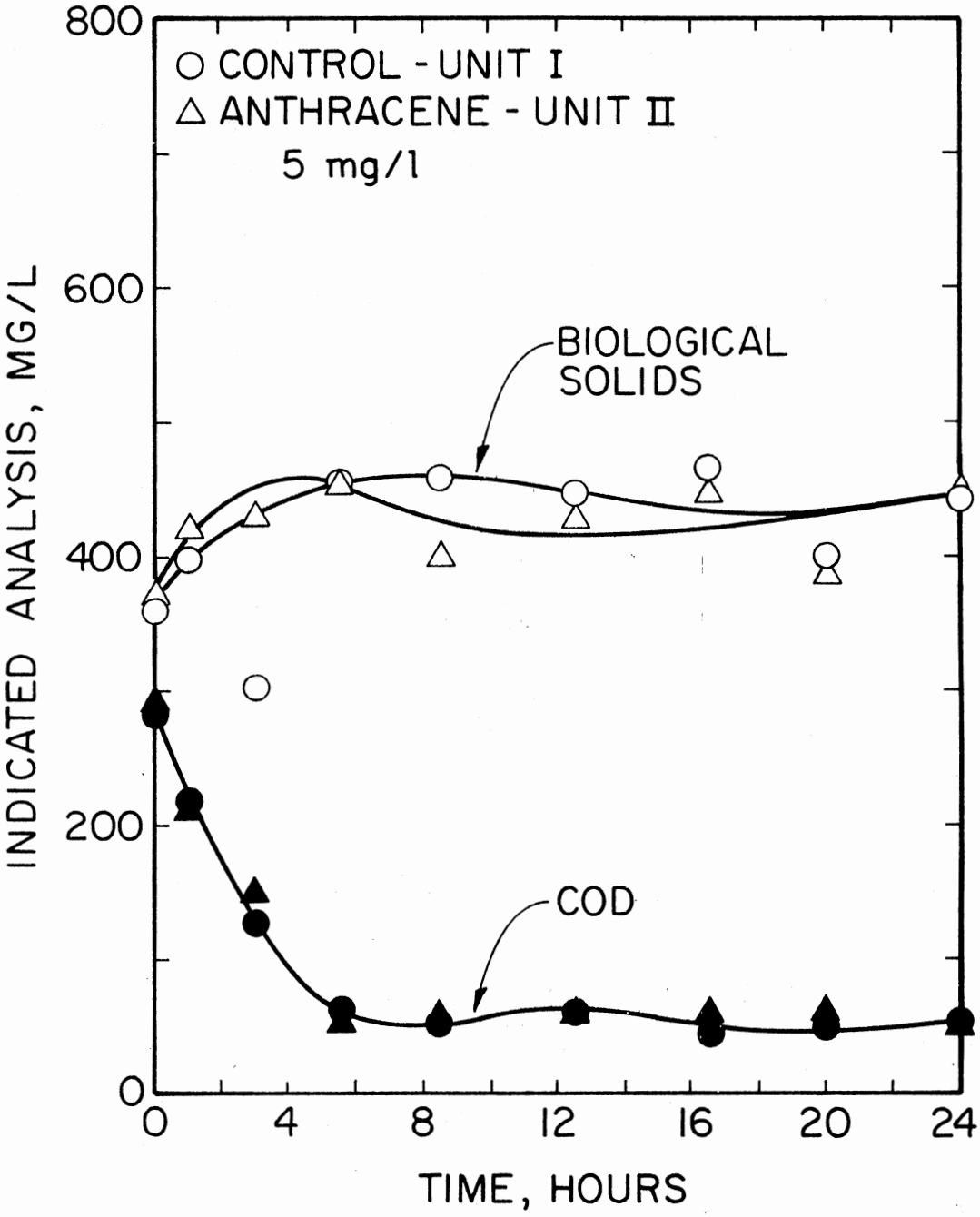

800
600
400
200
0
○ CONTROL - UNIT I
△ ANTHRACENE - UNIT II
5 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 13. Performance of Control Unit vs. Performance of Anthracene Unit During 24-hour Batch Study. On Day 42, Unit was fed 25 mg/l Anthracene

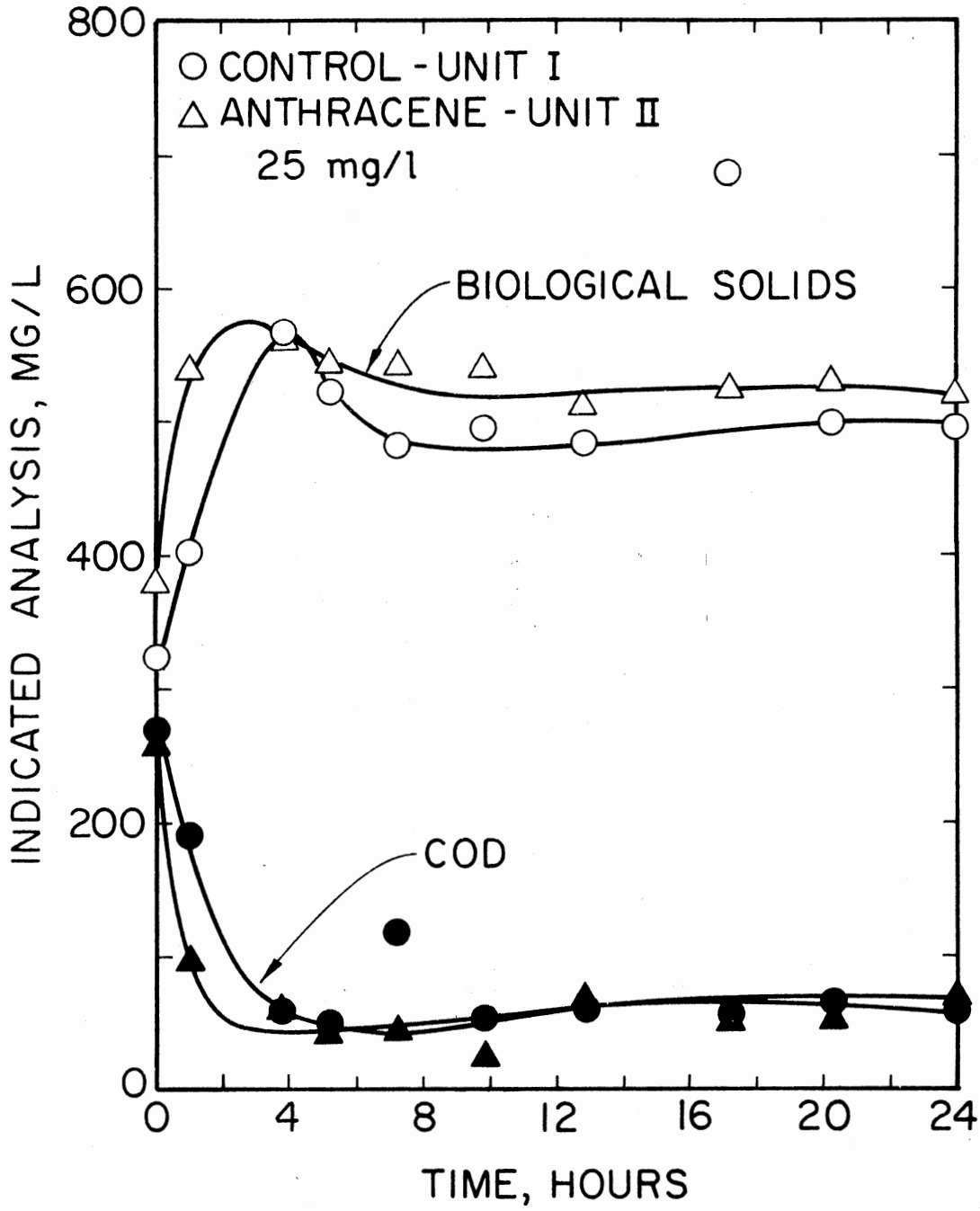

800
600
400
200
0
○ CONTROL - UNIT I
△ ANTHRACENE - UNIT II
25 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 14. Performance of Control Unit vs. Performance of Anthracene Unit During 24-hour Batch Study. On Day 81, Unit was fed 50 mg/l Anthracene

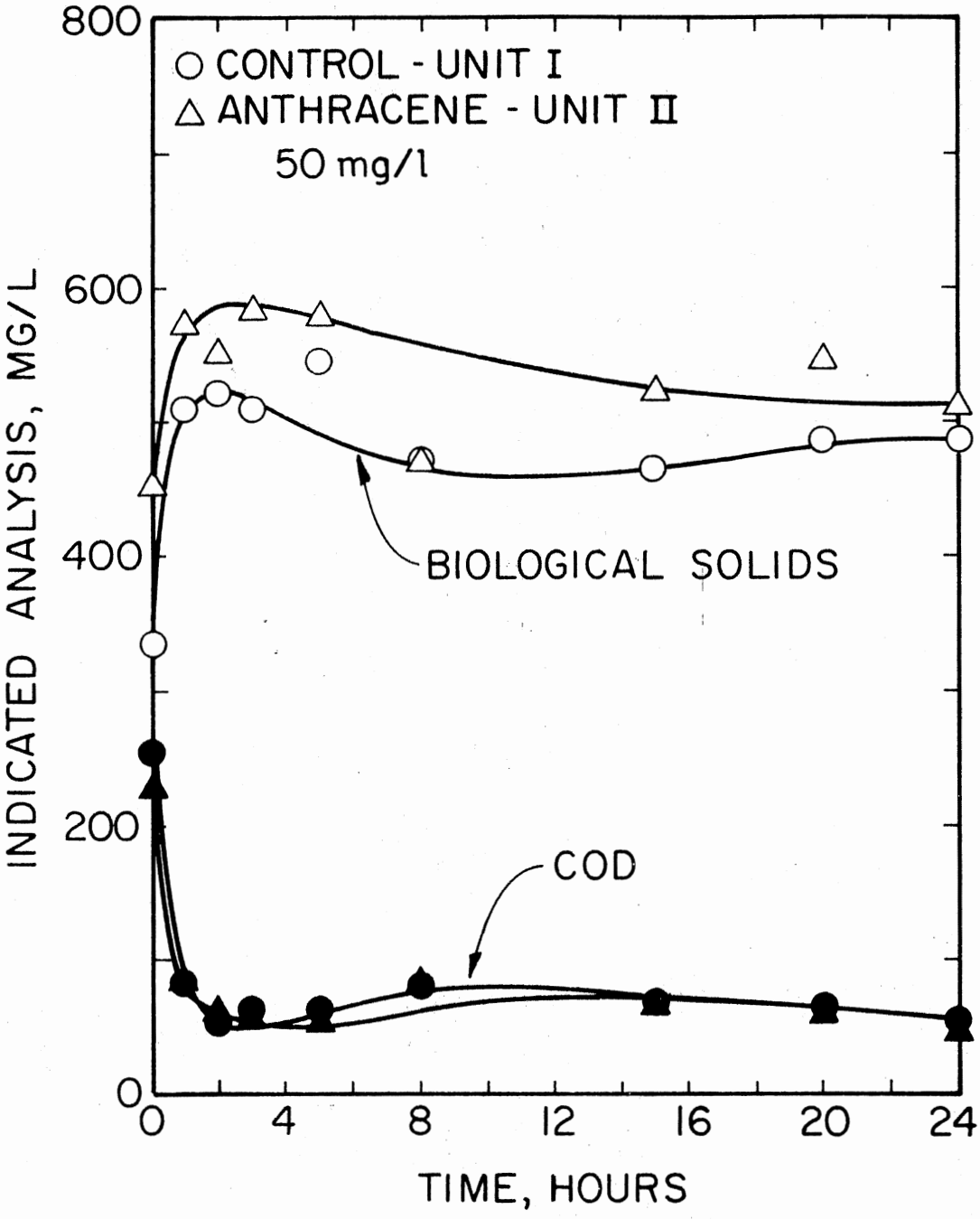

800
600
400
200
0
○ CONTROL - UNIT I
△ ANTHRACENE - UNIT II
50 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 15. Performance of Control Unit vs. Performance of Anthracene Unit During 24-hour Batch Study. On Day 114, at Beginning of Daily Switching of Anthracene Dosage From 50 mg/l to 25 mg/l, Unit was fed 50 mg/l Anthracene

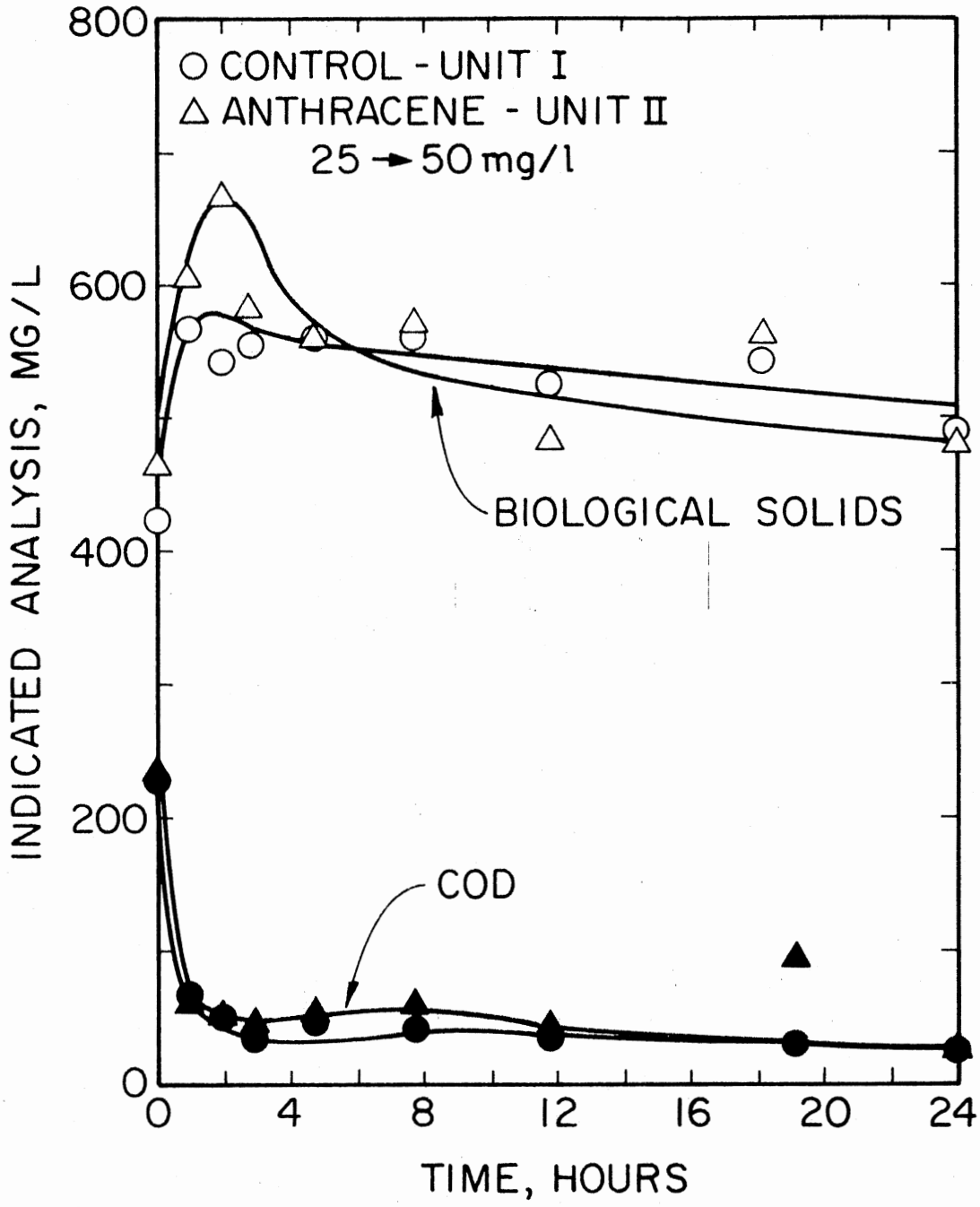

800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
ANTHRACENE - UNIT II
25 → 50 mg/l
BIOLOGICAL SOLIDS
COD
0
4
8
12
16
20
24
TIME, HOURS

Figure 16. Performance of Control Unit vs. Performance of Anthracene Unit During 24-hour Batch Study. On Day 122, at End of Daily Switching of Anthracene Dosage From 50 mg/l to 25 mg/l, Unit was fed 50 mg/l Anthracene

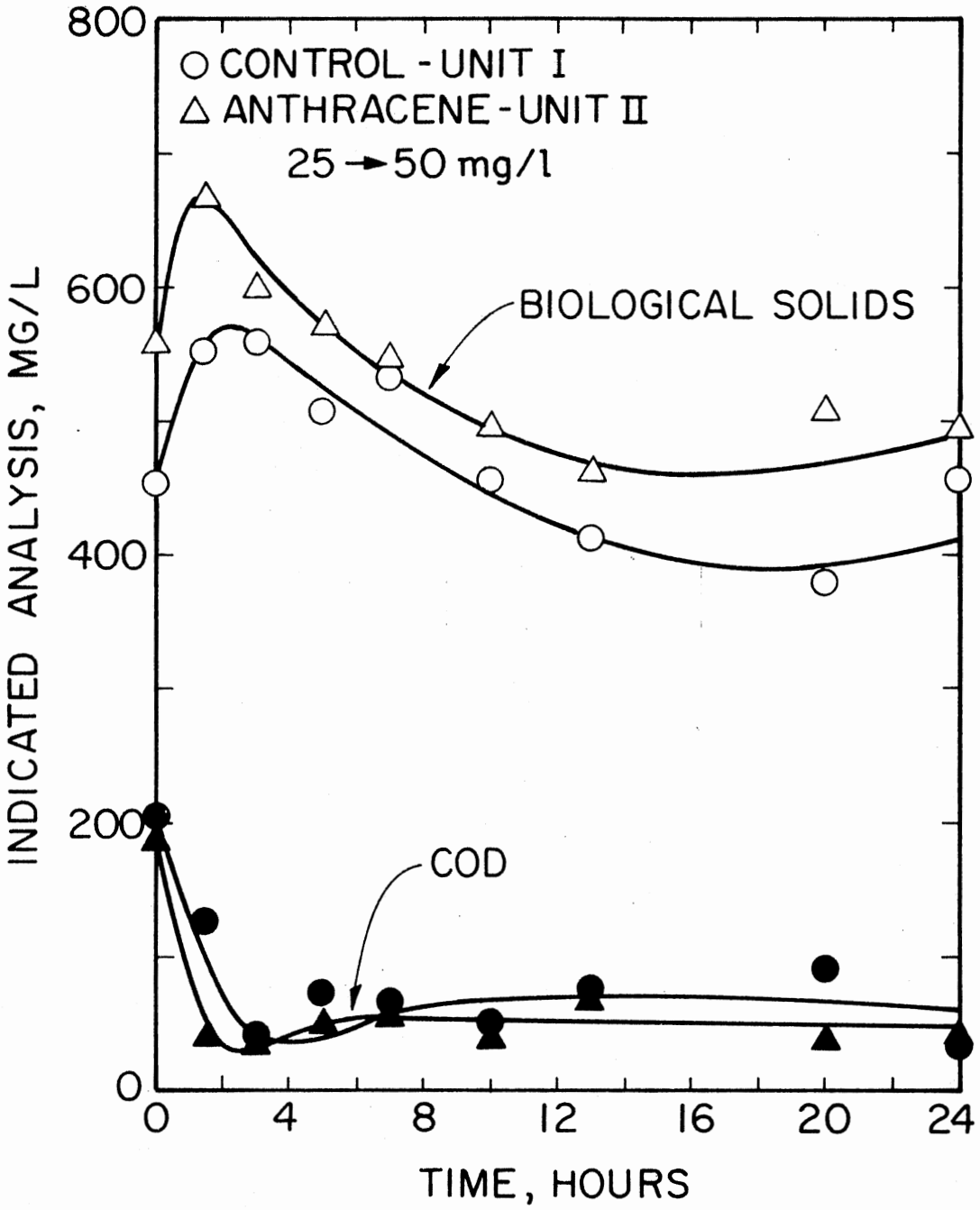

800
600
400
200
0
○ CONTROL - UNIT I
△ ANTHRACENE - UNIT II
25 → 50 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 17. Performance of Control Unit vs. Performance of Anthracene Unit During 24-hour Batch Study. On Day 128, at Beginning of Daily Switching of Anthracene Dosage From 25 mg/l to 0 mg/l, Unit was fed 25 mg/l Anthracene

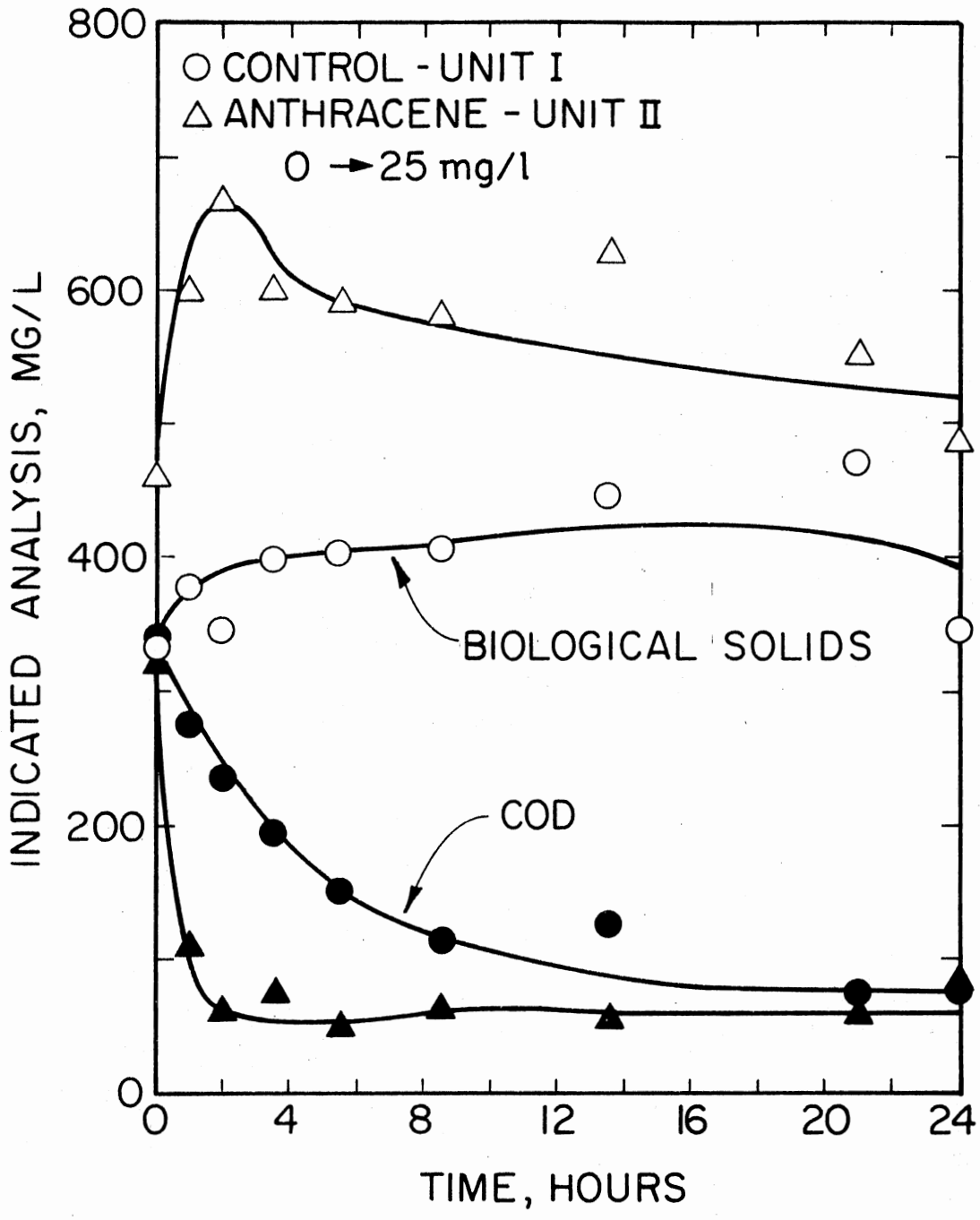

800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
ANTHRACENE - UNIT II
0 → 25 mg/l
BIOLOGICAL SOLIDS
COD
0
4
8
12
16
20
24
TIME, HOURS

Figure 18. Performance of Control Unit vs. Performance of Anthracene Unit During 24-hour Batch Study. On Day 136, at End of Daily Switching of Anthracene Dosage From 25 to 0 mg/l, Unit was fed 25 mg/l Anthracene

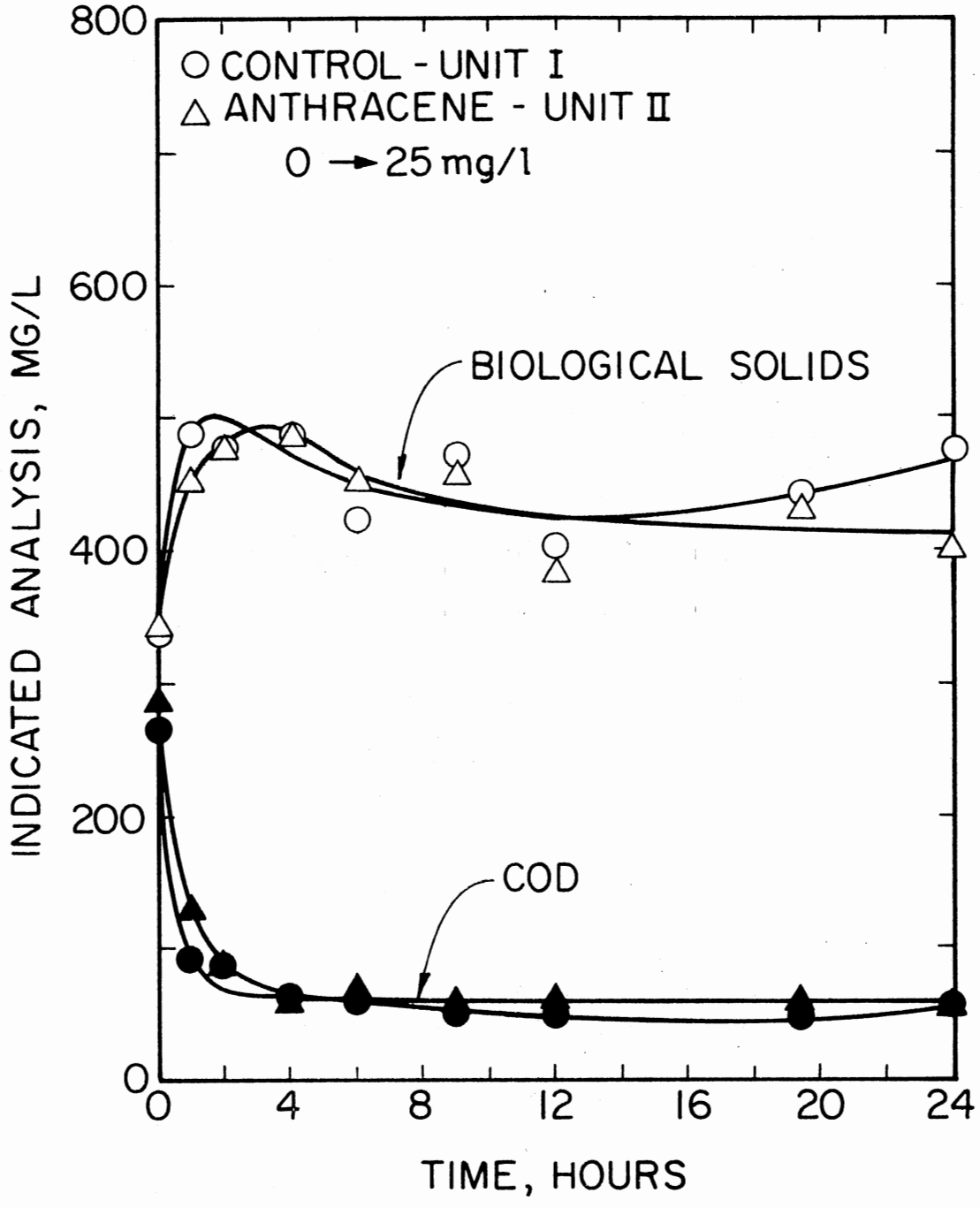

800
600
400
200
0
CONTROL - UNIT I
ANTHRACENE - UNIT II
0 → 25 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 19. Performance of Control Unit vs. Performance of O-nitrophenol Unit During 24-hour Batch Study. On Day 13, Unit was fed 5 mg/l O-nitrophenol

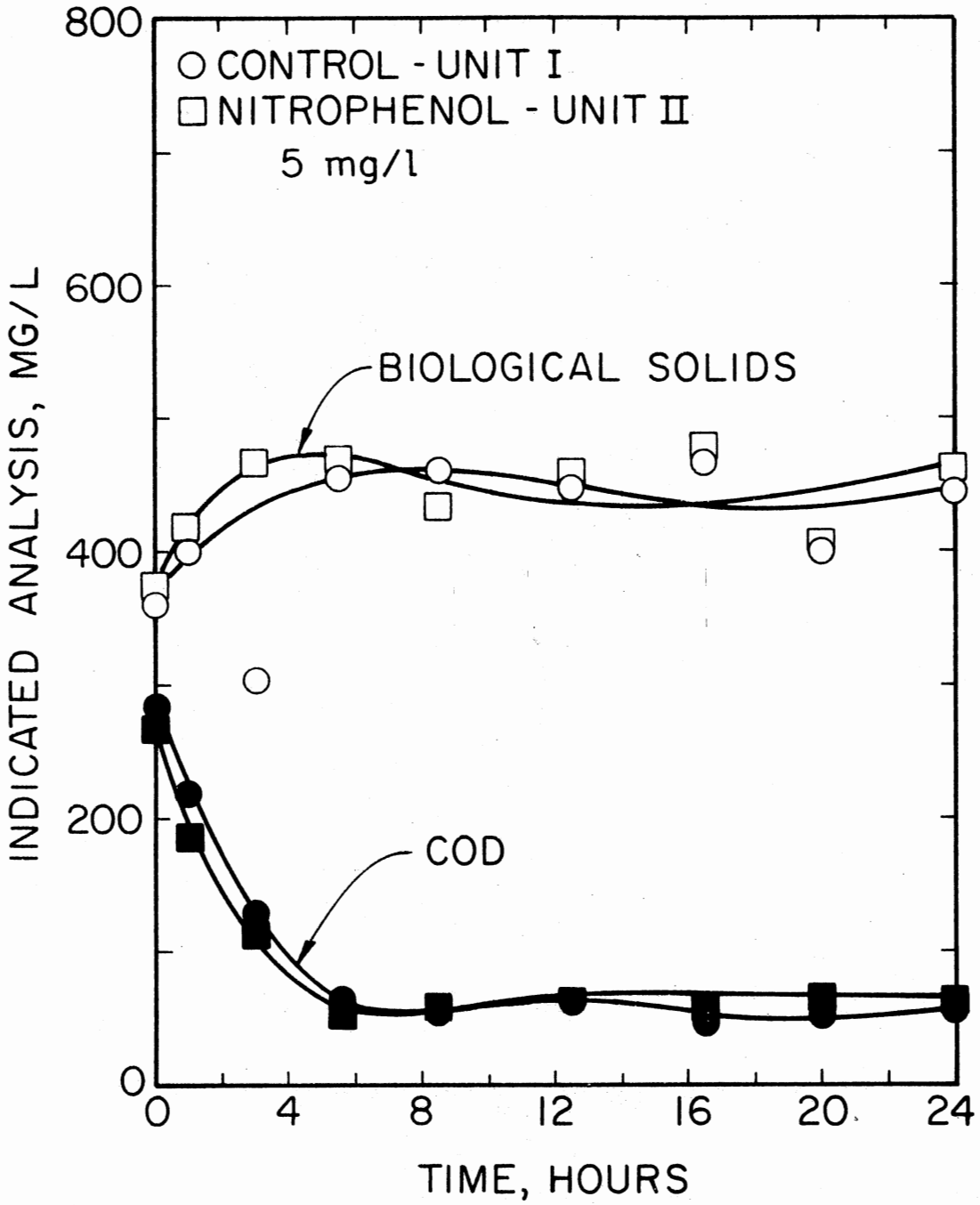

800
600
400
200
0
CONTROL - UNIT I
NITROPHENOL - UNIT II
5 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 20. Performance of Control Unit vs. Performance of O-nitrophenol Unit During 24-hour Batch Study. On Day 42, Unit was fed 25 mg/l O-nitrophenol

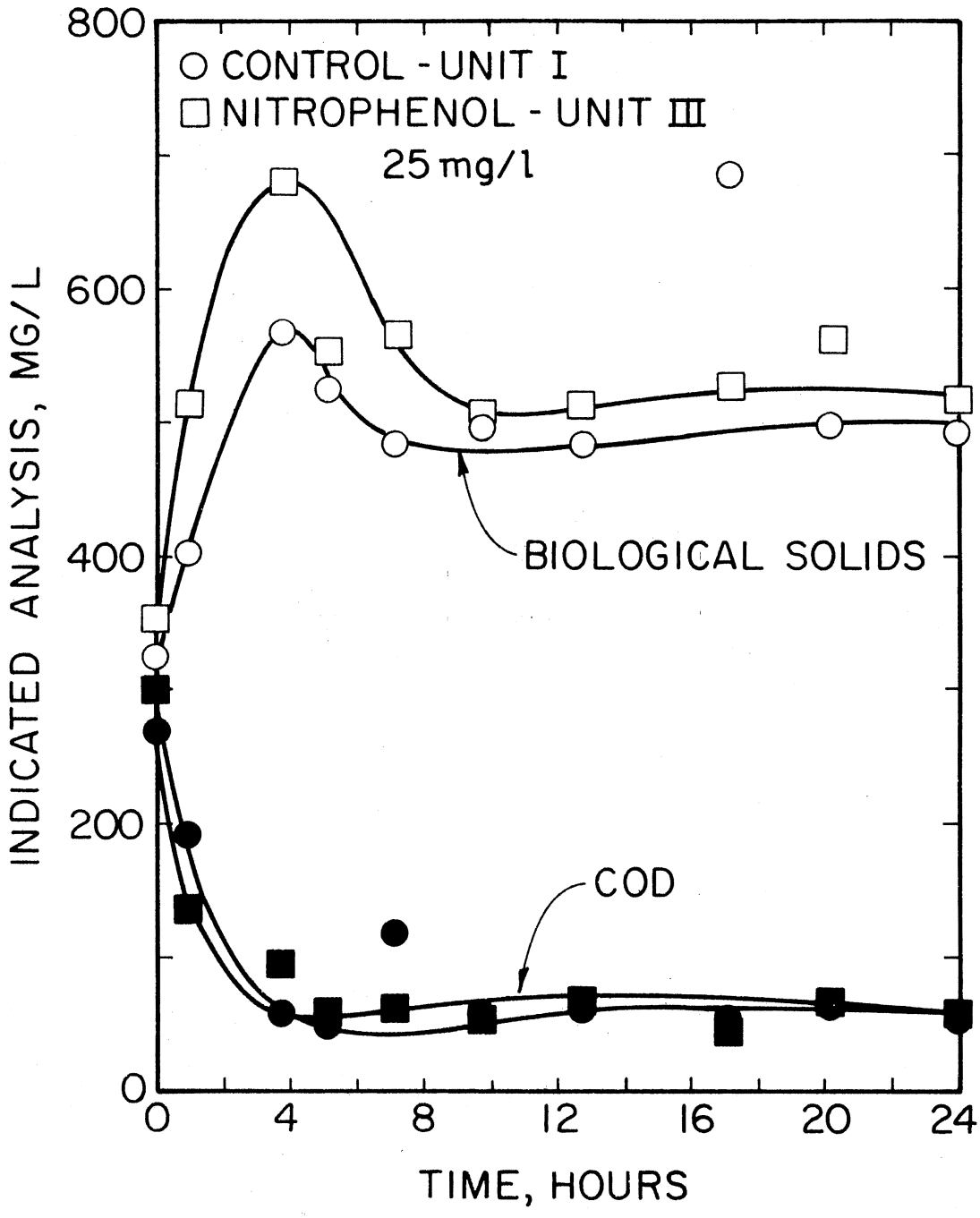

800
600
400
200
0
CONTROL - UNIT I
NITROPHENOL - UNIT III
25 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 21. Performance of Control Unit vs. Performance of O-nitrophenol Unit During 24-hour Batch Study. On Day 81, Unit was fed 50 mg/l O-nitrophenol

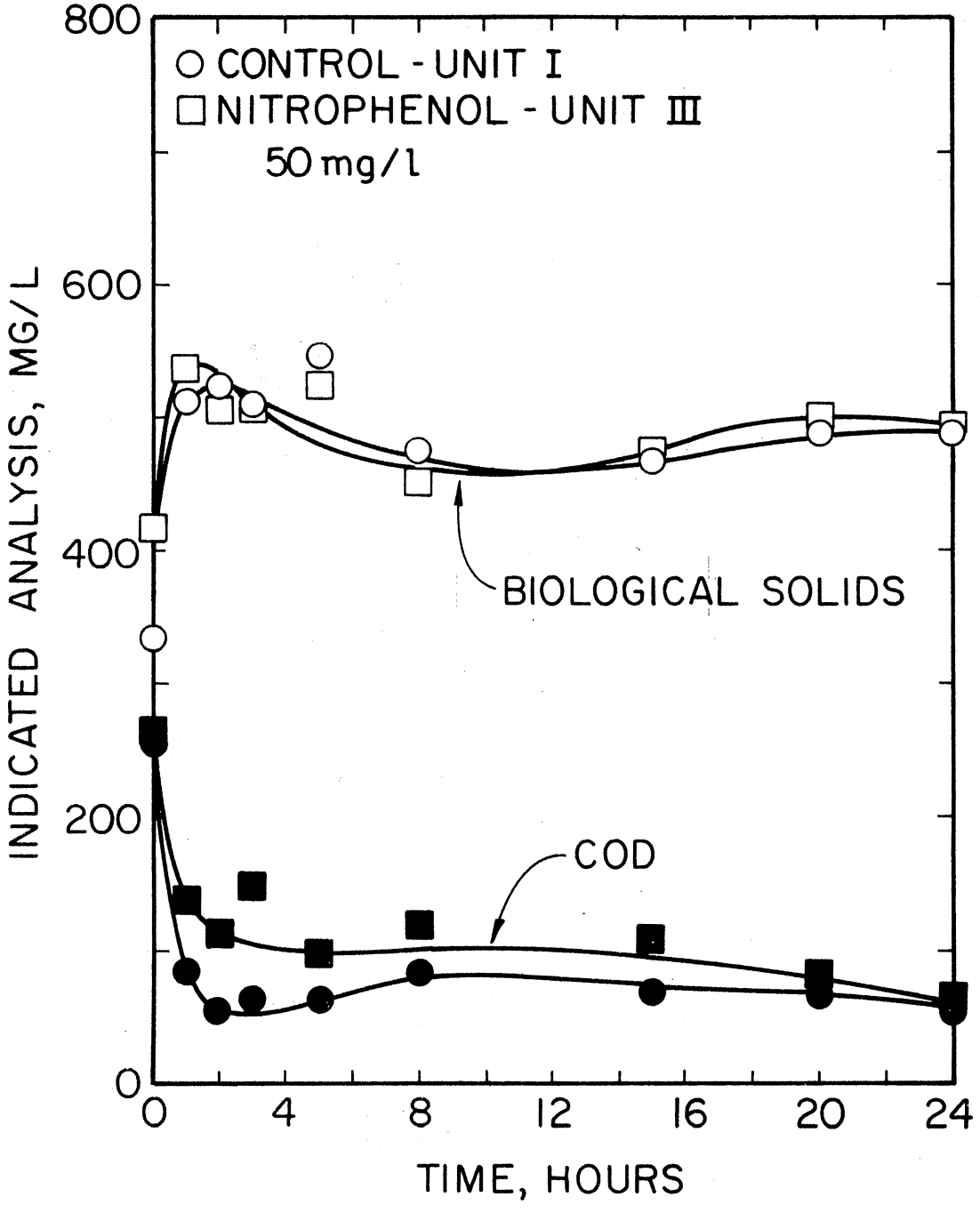

800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
NITROPHENOL - UNIT III
50 mg/l
BIOLOGICAL SOLIDS
COD
0
4
8
12
16
20
24
TIME, HOURS

Figure 22. Performance of Control Unit vs. Performance of O-nitrophenol Unit During 24-hour Batch Study. On Day 114, at Beginning of Daily Switching of O-nitrophenol Dosage From 50 mg/l to 25 mg/l, Unit was fed 50 mg/l O-nitrophenol

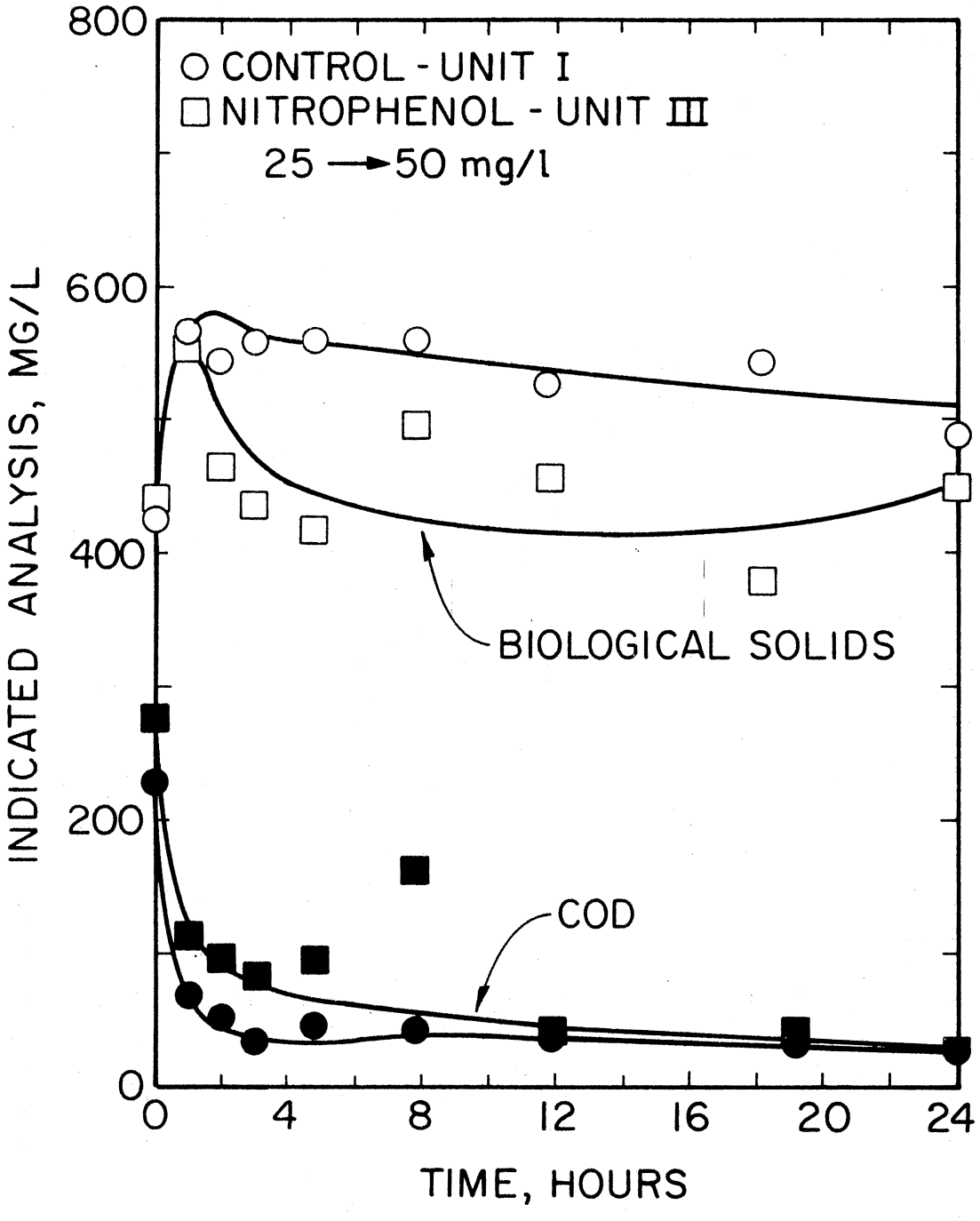

800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
NITROPHENOL - UNIT III
25 → 50 mg/l
BIOLOGICAL SOLIDS
COD
0
4
8
12
16
20
24
TIME, HOURS

Figure 23. Performance of Control Unit vs. Performance of O-nitrophenol Unit During 24-hour Batch Study. On Day 122, at End of Daily Switching of O-nitrophenol Dosage From 50 mg/l to 25 mg/l, Unit was fed 50 mg/l O-nitrophenol

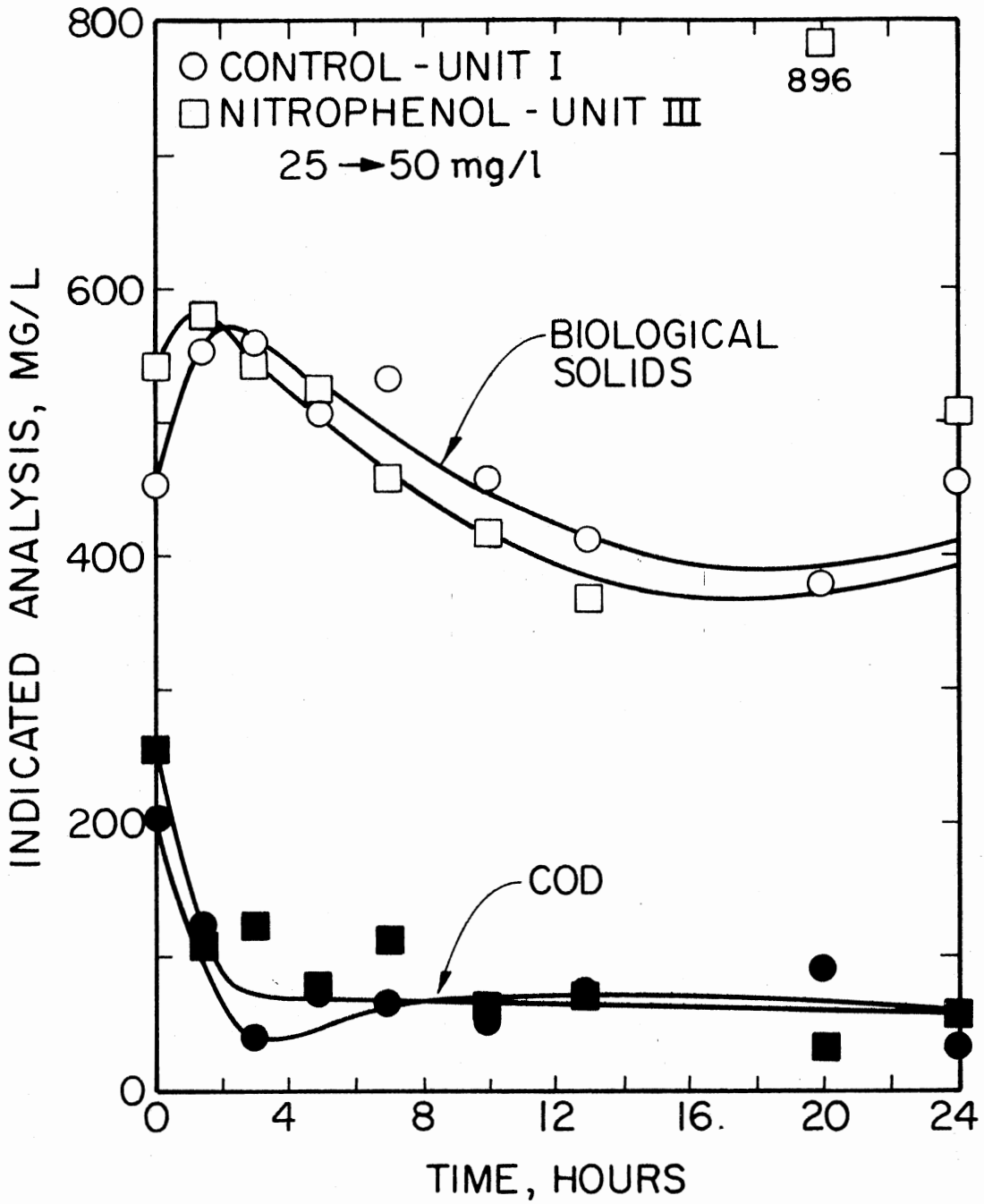

800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
NITROPHENOL - UNIT III
25 → 50 mg/l
896
BIOLOGICAL SOLIDS
COD
0
4
8
12
16.
20
24
TIME, HOURS

Figure 24. Performance of Control Unit vs. Performance of O-nitrophenol Unit During 24-hour Batch Study. On Day 128, at Beginning of Daily Switching of O-nitrophenol Dosage From 25 mg/l to 0 mg/l, Unit was fed 25 mg/l O-nitrophenol

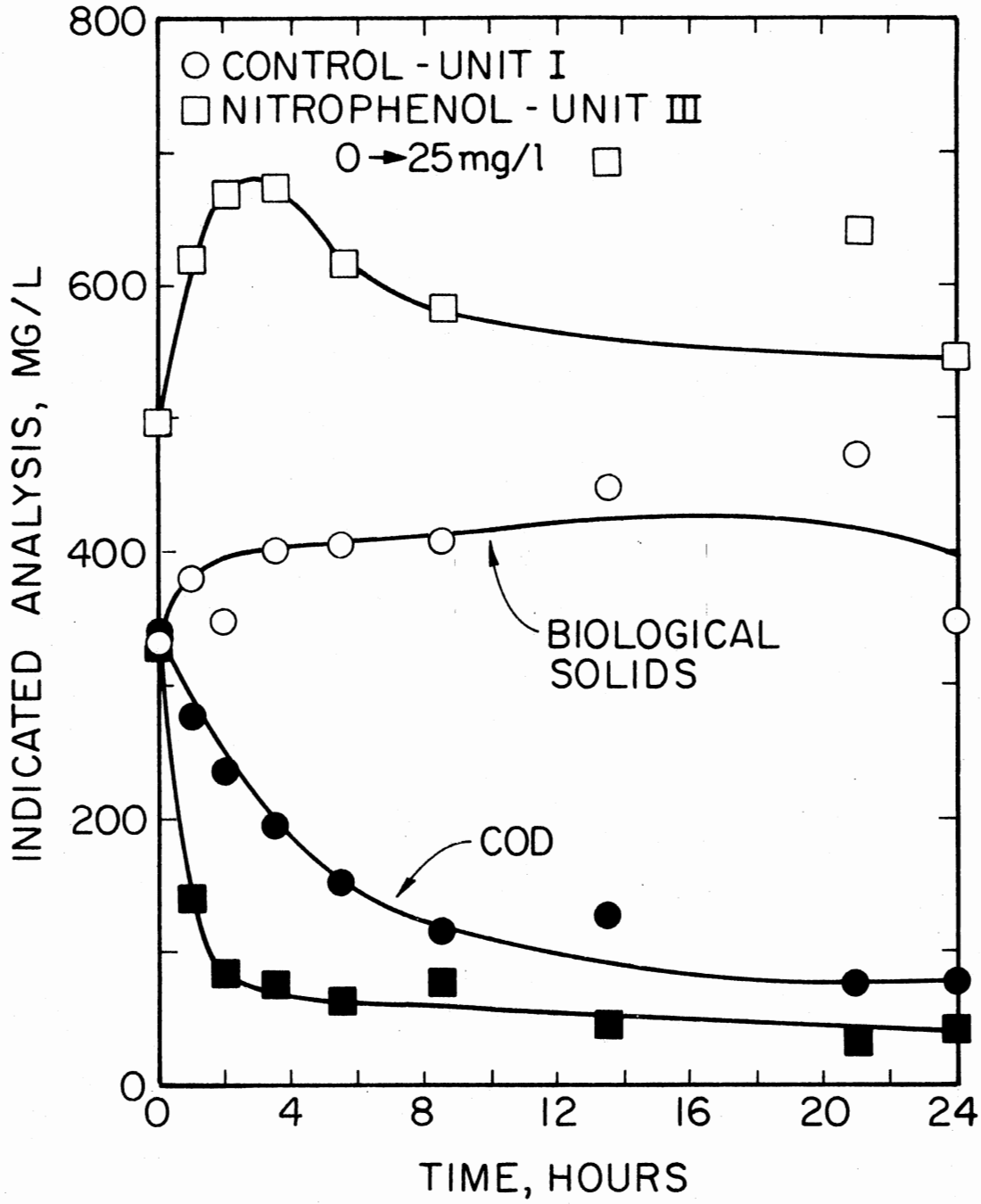

800
600
400
200
0
0
4
8
12
16
20
24
INDICATED ANALYSIS, MG/L
TIME, HOURS
CONTROL - UNIT I
NITROPHENOL - UNIT III
0 → 25 mg/l
BIOLOGICAL SOLIDS
COD

Figure 25. Performance of Control Unit vs. Performance of O-nitrophenol Unit During 24-hour Batch Study. On Day 136, at End of Daily Switching of O-nitrophenol Dosage From 25 mg/l to 0 mg/l, Unit was fed 25 mg/l O-nitrophenol

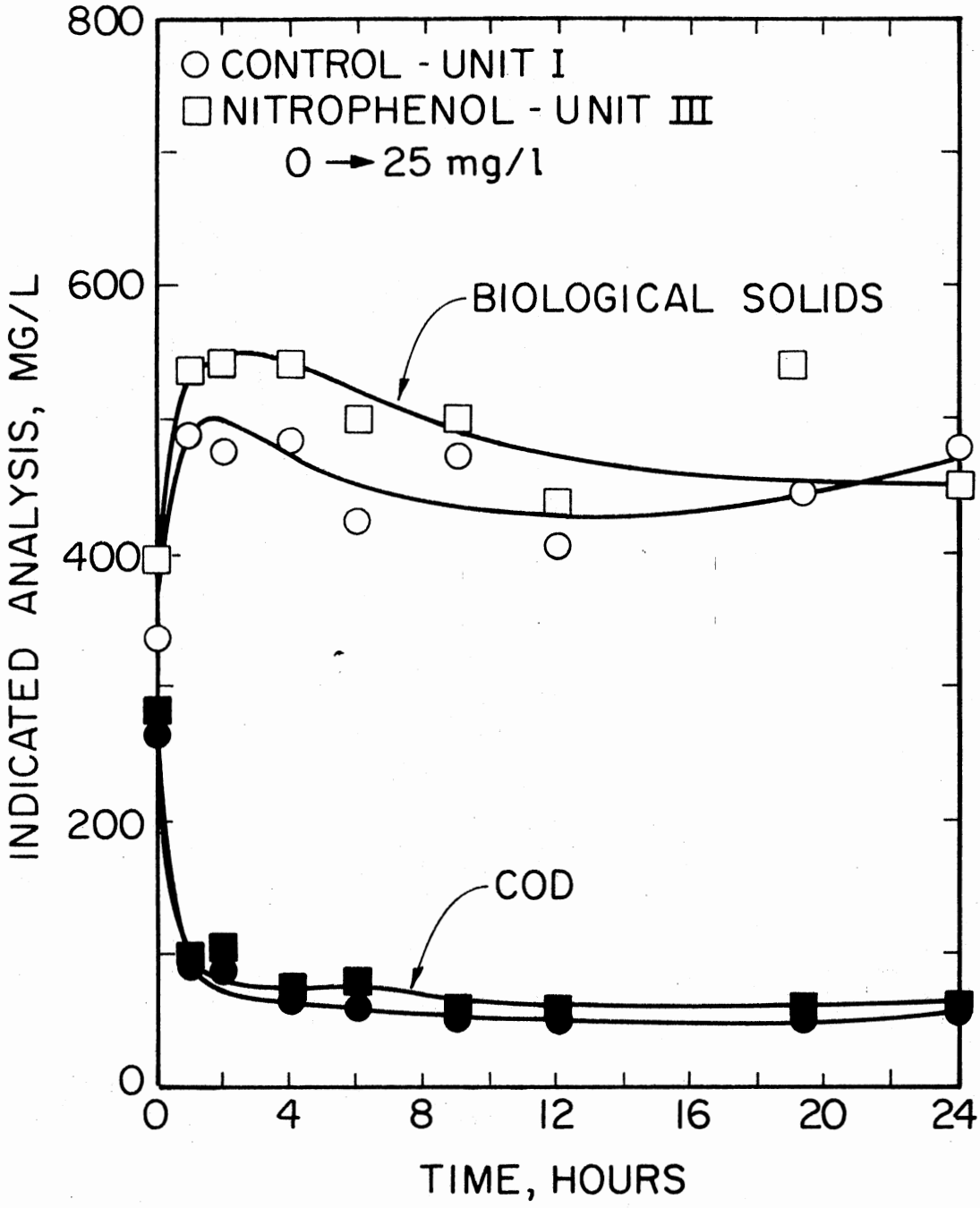

800
600
400
200
0
CONTROL - UNIT I
NITROPHENOL - UNIT III
0 → 25 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 26. Performance of Control Unit vs. Performance of Chloroform Unit During 24-hour Batch Study. On Day 9, Unit was fed 5 mg/l Chloroform

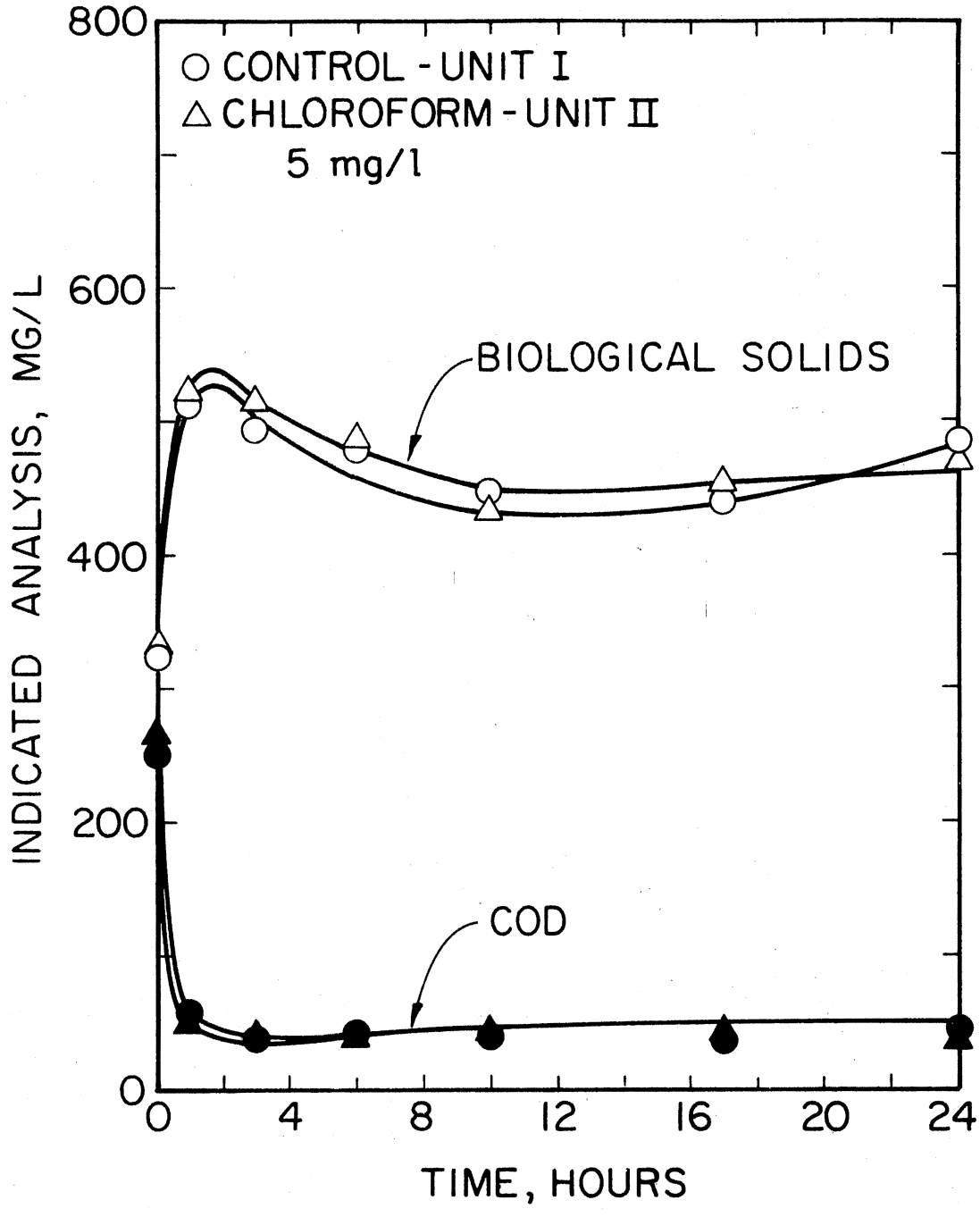

800
600
400
200
0
○ CONTROL - UNIT I
△ CHLOROFORM - UNIT II
5 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 27. Performance of Control Unit vs. Performance of Chloroform Unit During 24-hour Batch Study. On Day 42, Unit was fed 25 mg/l Chloroform

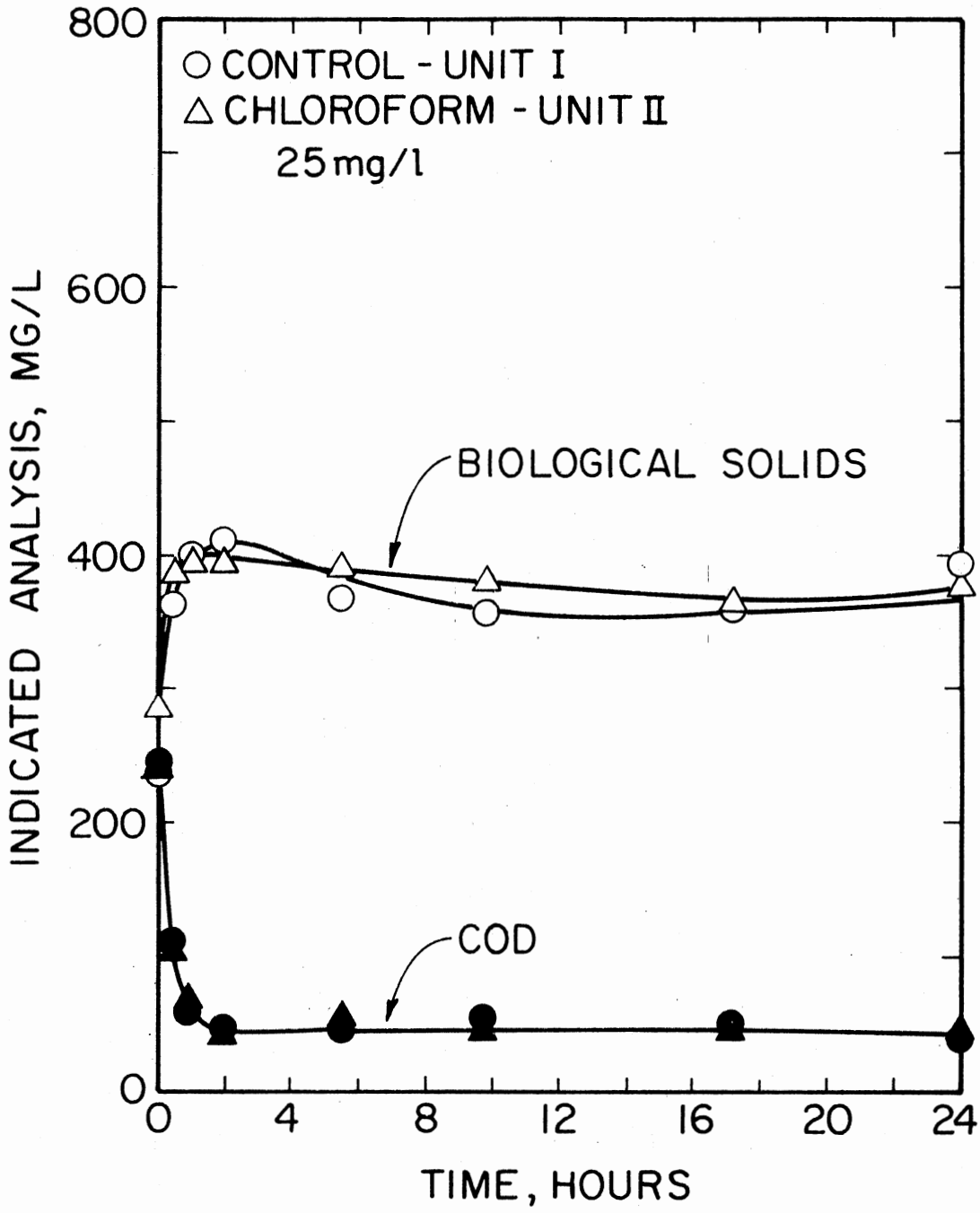

800
600
400
200
0
○ CONTROL - UNIT I
△ CHLOROFORM - UNIT II
25 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 28. Performance of Control Unit vs. Performance of Chloroform Unit During 24-hour Batch Study. On Day 81, Unit was fed 50 mg/l Chloroform

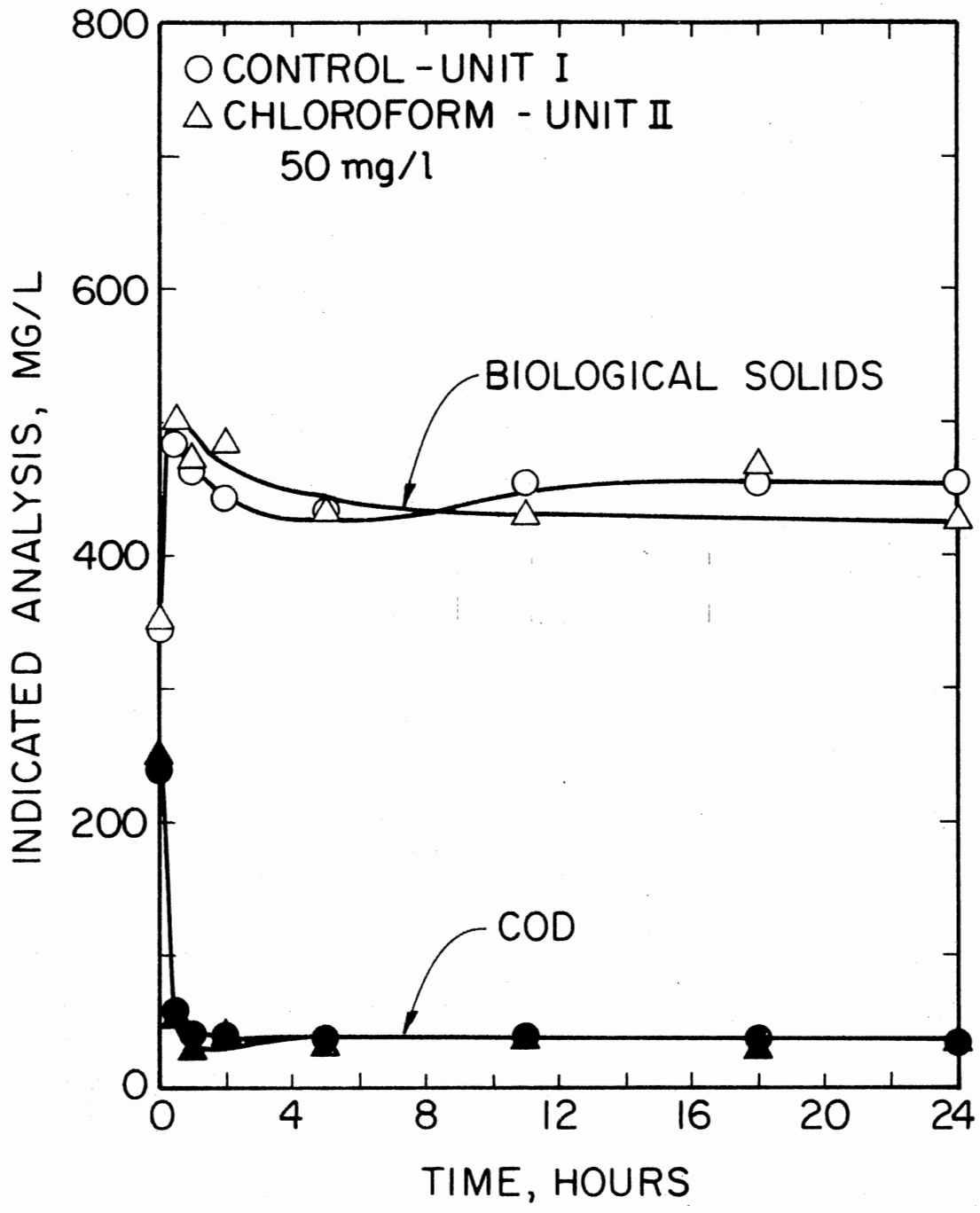

800
600
400
200
0
○ CONTROL - UNIT I
△ CHLOROFORM - UNIT II
50 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 29. Performance of Control Unit vs. Performance of Chloroform Unit During 24-hour Batch Study. On Day 115, at Beginning of Daily Switching of Chloroform Dosage From 50 mg/l to 25 mg/l, Unit was fed 50 mg/l Chloroform

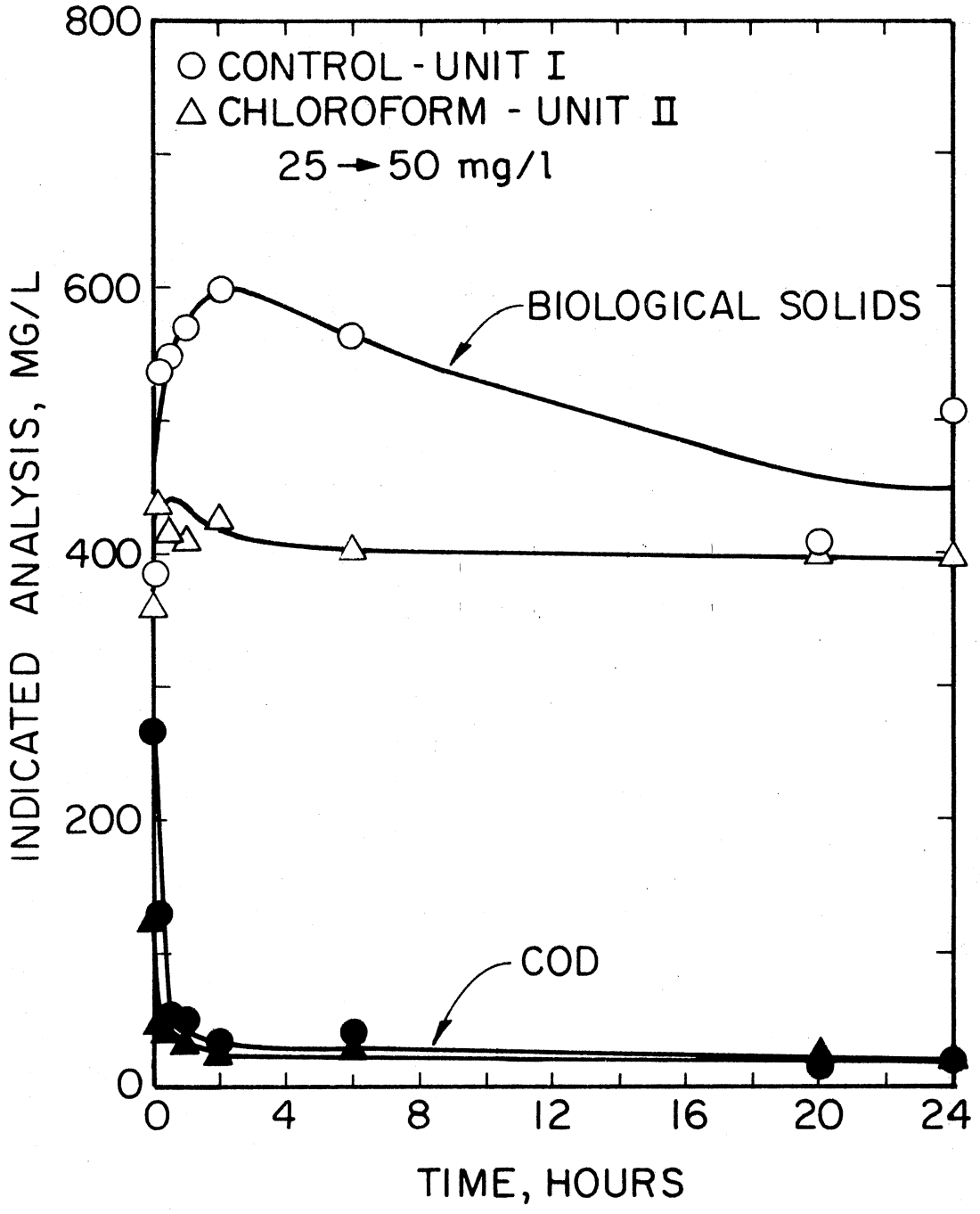

800
600
400
200
0
○ CONTROL - UNIT I
△ CHLOROFORM - UNIT II
25 → 50 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 30. Performance of Control Unit vs. Performance of Chloroform Unit During 24-hour Batch Study. On Day 130, at Beginning of Daily Switching of Chloroform Dosage From 25 mg/l to 0 mg/l, Unit was fed 25 mg/l Chloroform

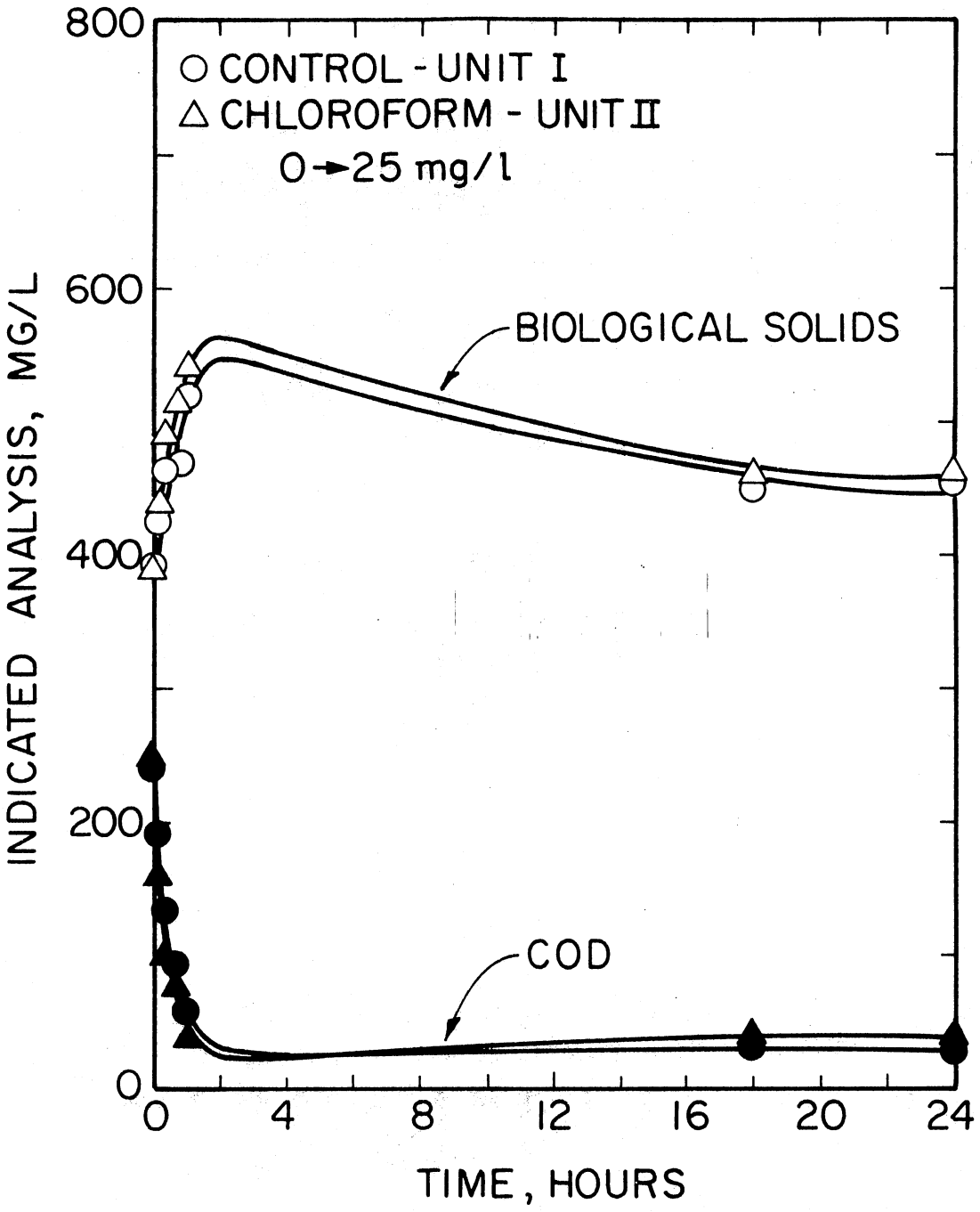

800
600
400
200
0
○ CONTROL - UNIT I
△ CHLOROFORM - UNIT II
0→25 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 31. Performance of Control Unit vs. Performance of Chloroform Unit During 24-hour Batch Study on Day 143, at Beginning of Cyclic Shock Load, 0 mg/l, 48 hrs., 25 mg/l, 24 hrs.

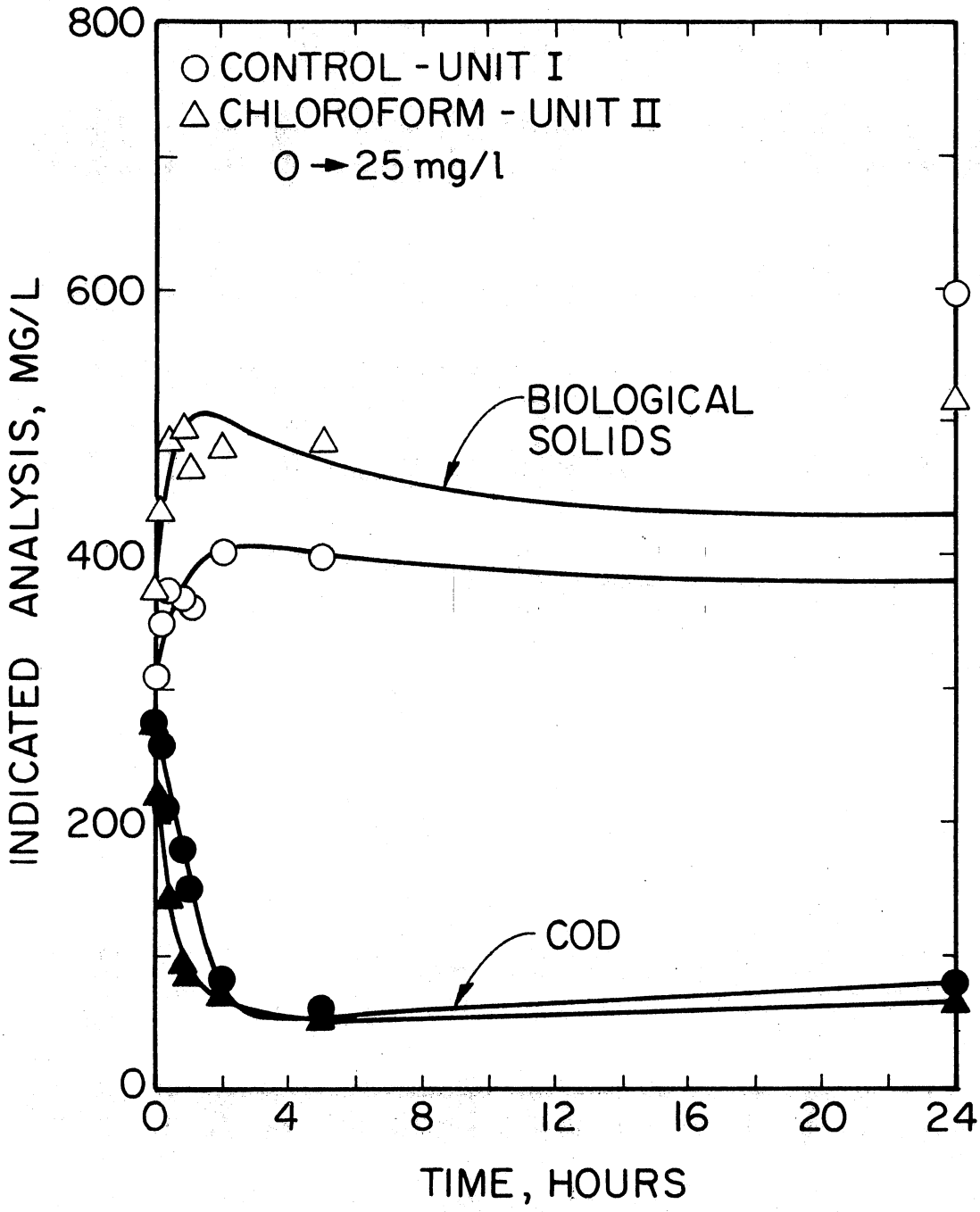

800
600
400
200
0
○ CONTROL - UNIT I
△ CHLOROFORM - UNIT II
0 → 25 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 32. Performance of Control Unit vs. Performance of Trichloroethylene Unit During 24-hour Batch Study. On Day 9, Unit was fed 5 mg/l Trichloroethylene

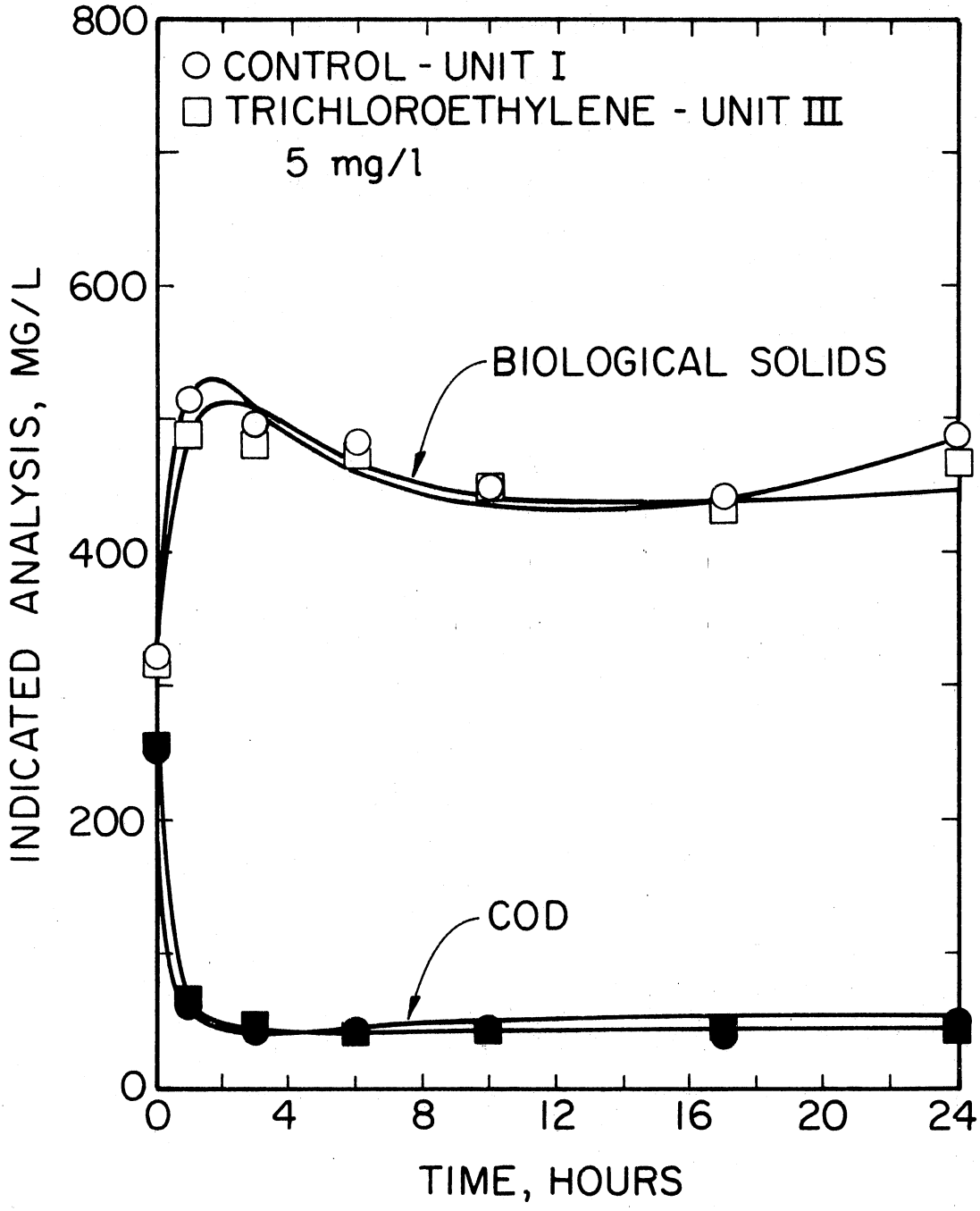

800
600
400
200
0
○ CONTROL - UNIT I
□ TRICHLOROETHYLENE - UNIT III
5 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 33. Performance of Control Unit vs. Performance of Trichloroethylene Unit During 24-hour Batch Study. On Day 42, Unit was fed 25 mg/l Trichloroethylene

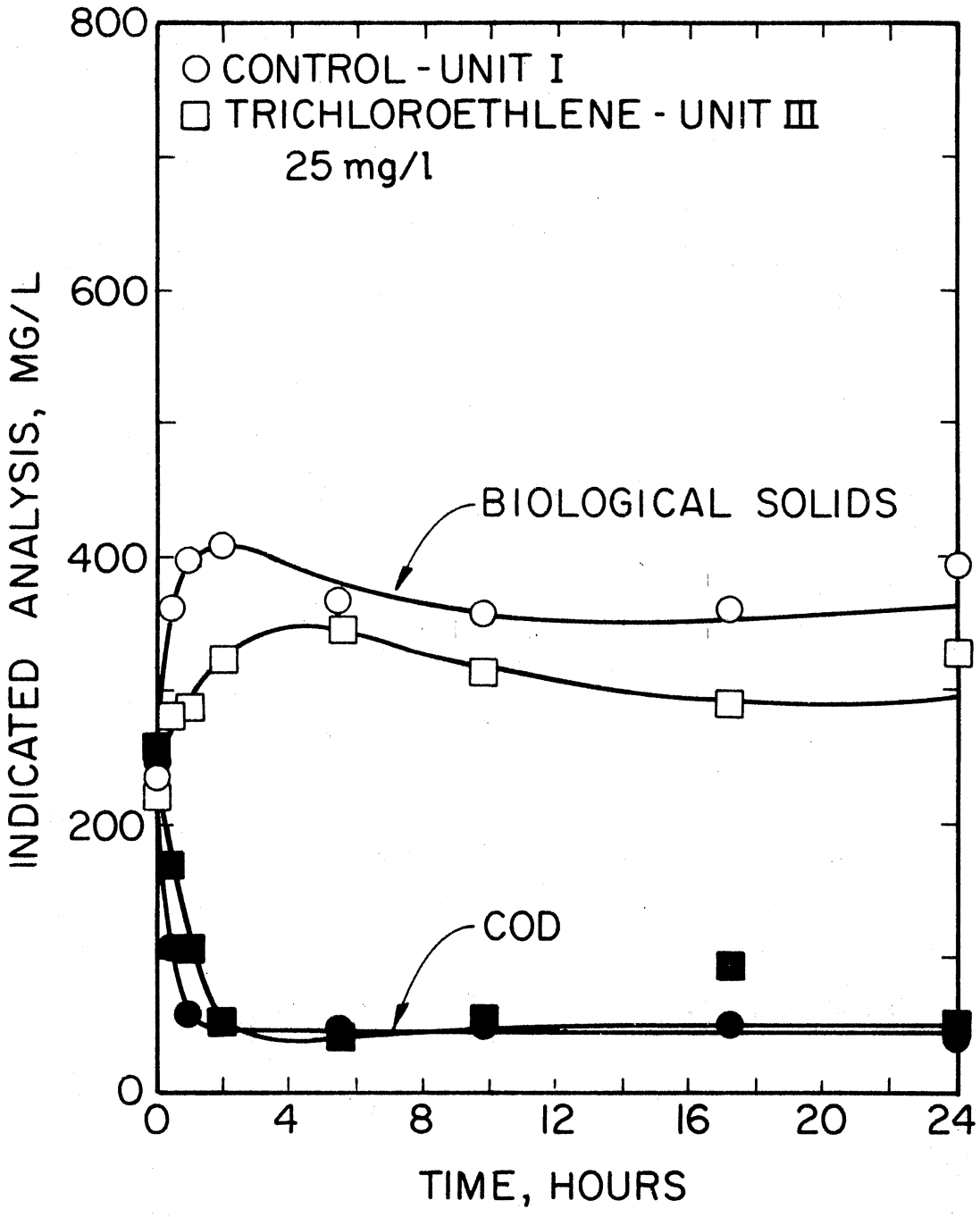

800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
TRICHLOROETHLENE - UNIT III
25 mg/l
BIOLOGICAL SOLIDS
COD
0
4
8
12
16
20
24
TIME, HOURS

Figure 34. Performance of Control Unit vs. Performance of Trichloroethylene Unit During 24-hour Batch Study. On Day 81, Unit was fed 50 mg/l Trichloroethylene

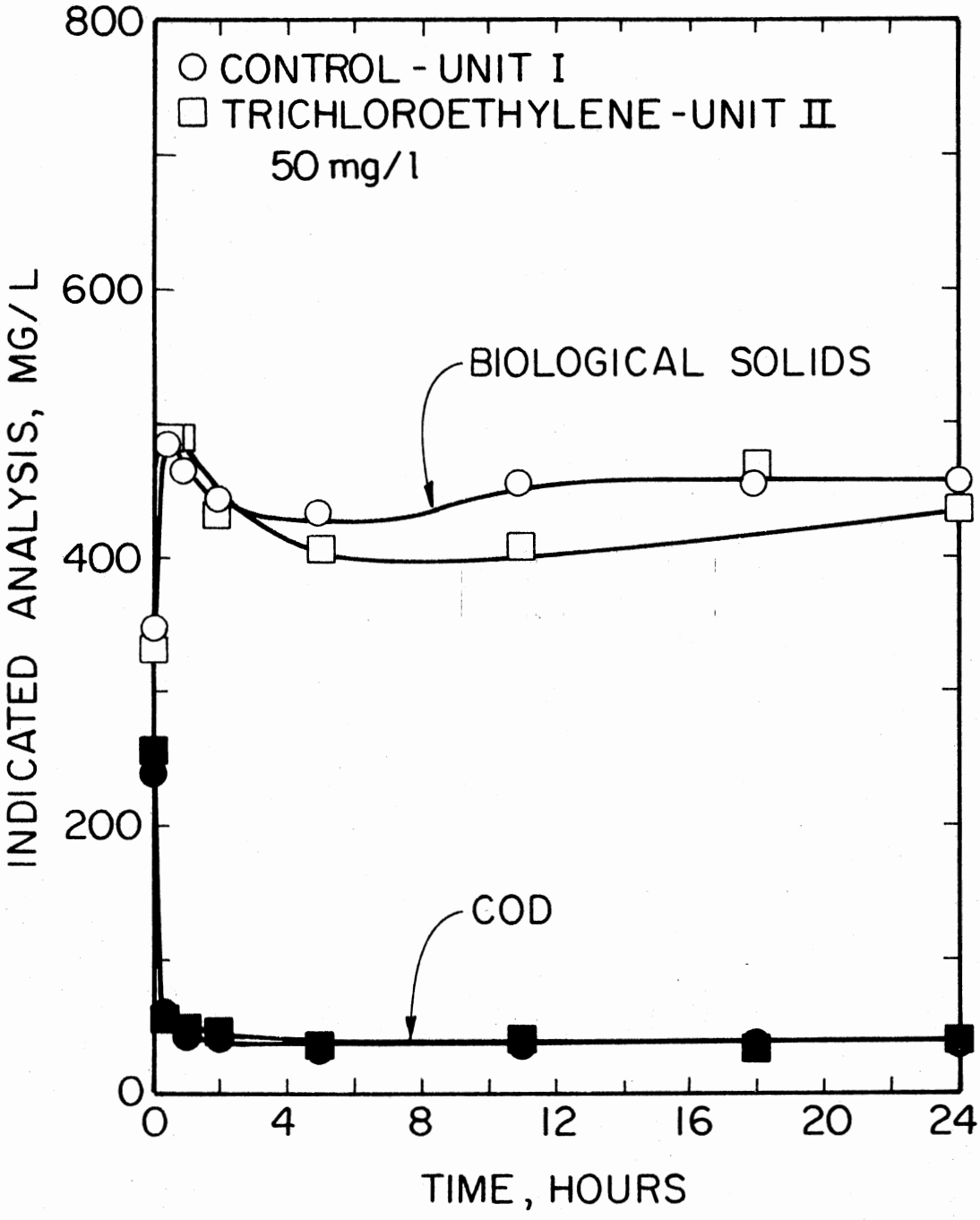

800
600
400
200
0
○ CONTROL - UNIT I
□ TRICHLOROETHYLENE - UNIT II
50 mg/l
BIOLOGICAL SOLIDS
COD
INDICATED ANALYSIS, MG/L
0
4
8
12
16
20
24
TIME, HOURS

Figure 35. Performance of Control Unit vs. Performance of Trichloroethylene Unit During 24-hour Batch Study. On Day 115, at Beginning of Daily Switching of Trichloroethylene Dosage From 50 mg/l to 25 mg/l, Unit was fed 50 mg/l Trichloroethylene

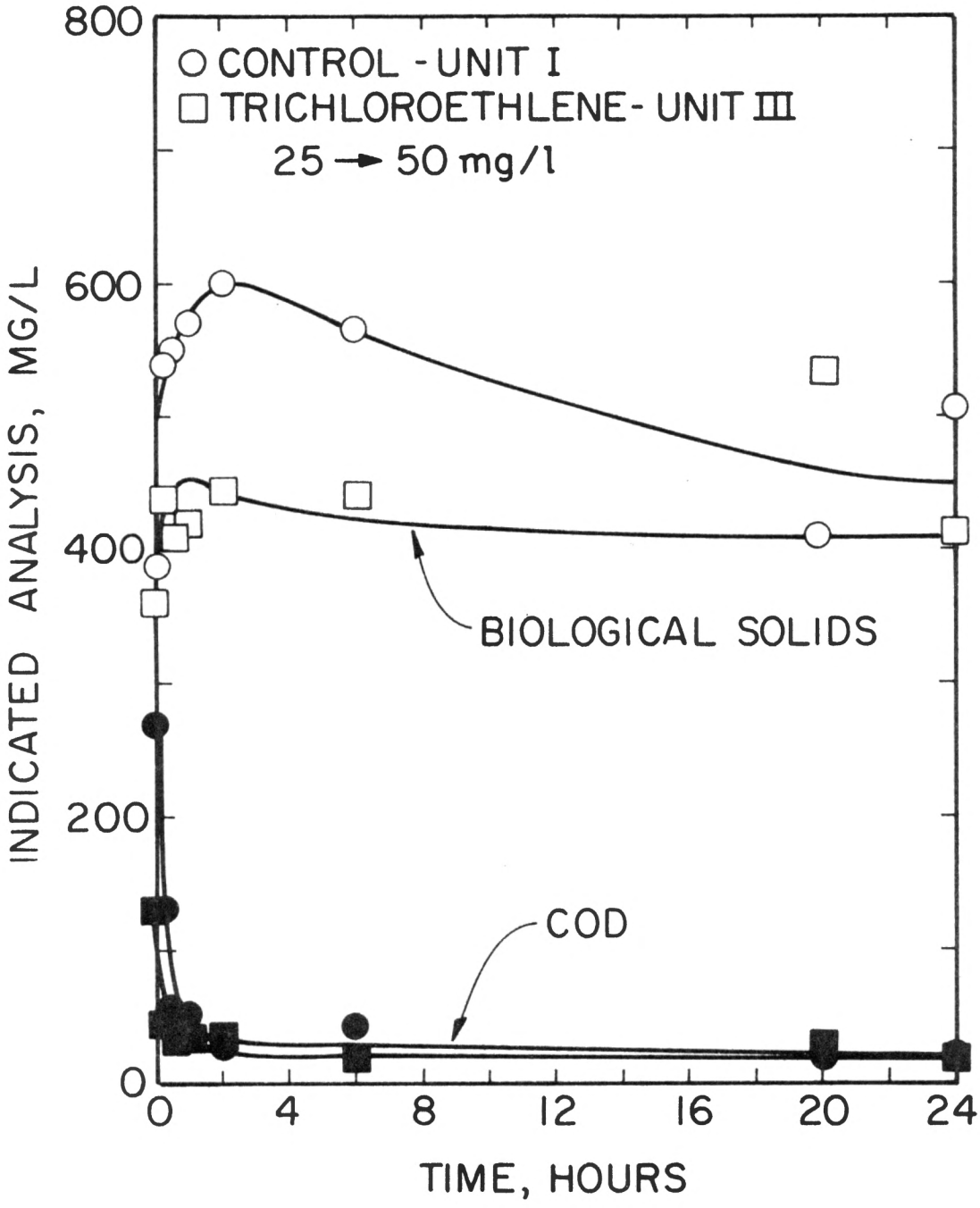

800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
TRICHLOROETHLENE- UNIT III
25 → 50 mg/l
BIOLOGICAL SOLIDS
COD
0
4
8
12
16
20
24
TIME, HOURS

Figure 36. Performance of Control Unit vs. Performance of Trichloroethylene Unit During 24-hour Batch Study. On Day 130, at Beginning of Daily Switching of Chloroform Dosage from 25 mg/l to 0 mg/l, Unit was fed 25 mg/l Trichloroethylene

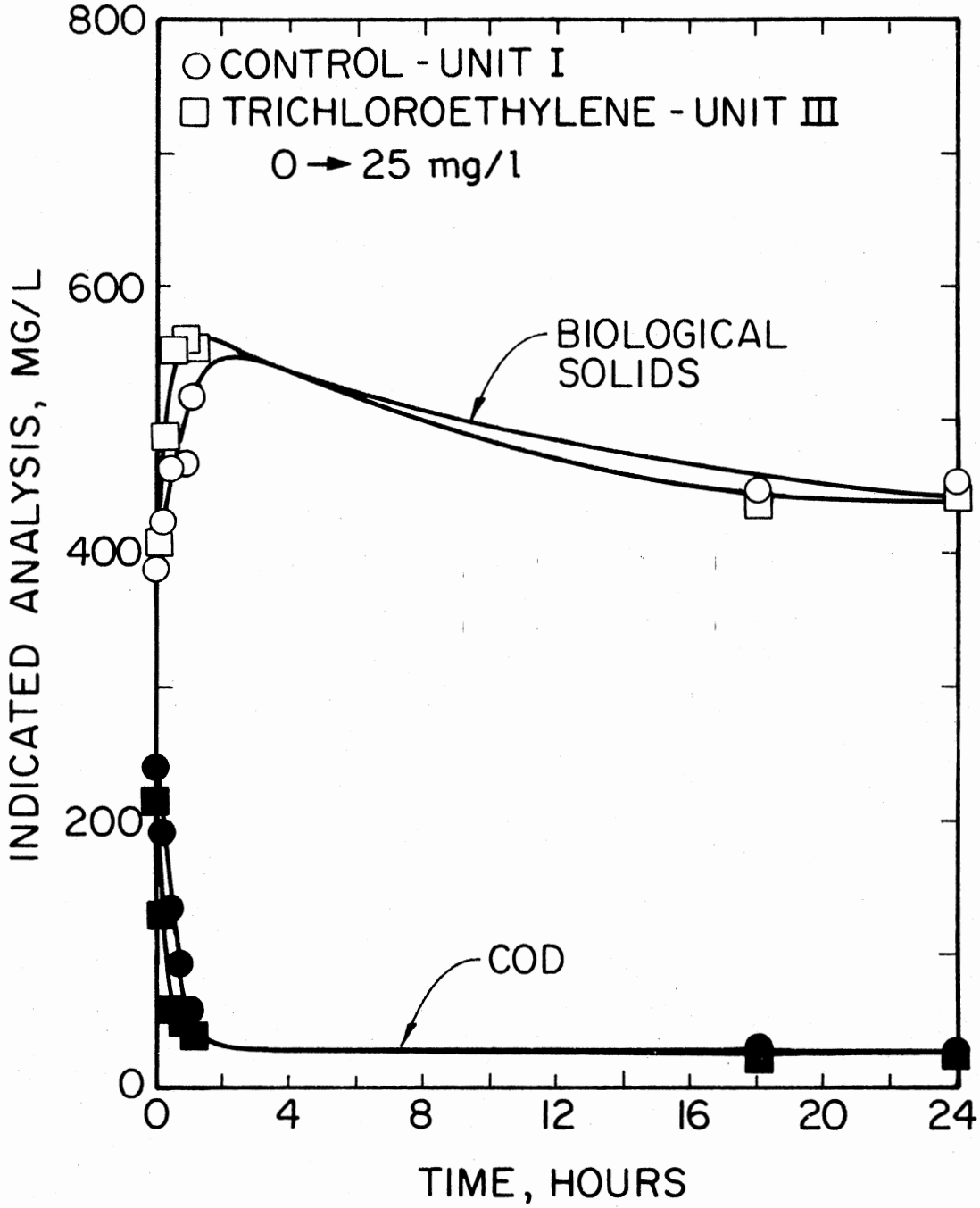
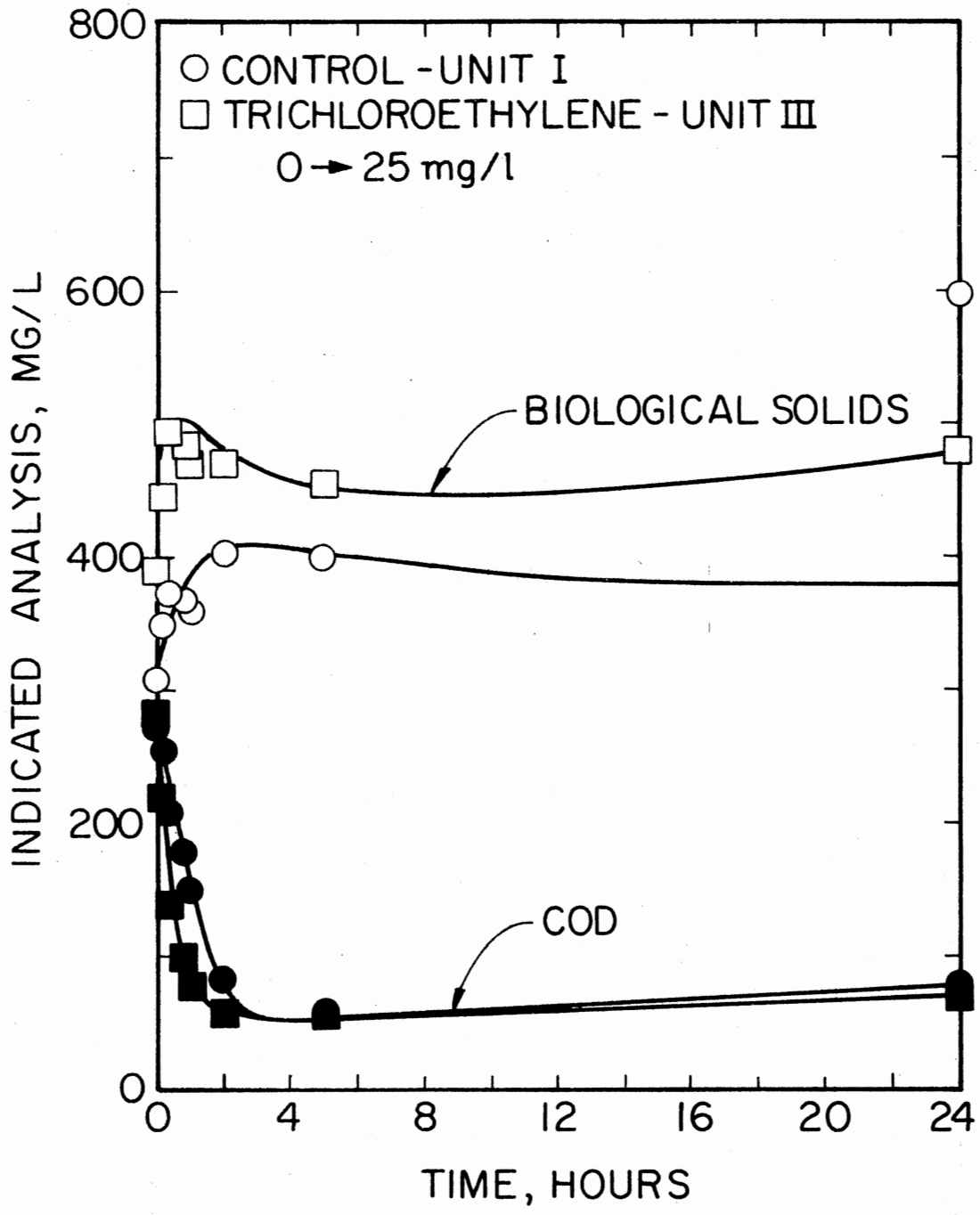

800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
TRICHLOROETHYLENE - UNIT III
0 → 25 mg/l
BIOLOGICAL SOLIDS
COD
0
4
8
12
16
20
24
TIME, HOURS

Figure 37. Performance of Control Unit vs Performance of Trichloroethylene Unit During 24-hour Batch Study on Day 143, at Beginning of Cyclic Trichloroethylene Shock Load 0 mg/l, 48 hrs - 25 mg/l, 24 hrs


800
600
400
200
0
INDICATED ANALYSIS, MG/L
CONTROL - UNIT I
TRICHLOROETHYLENE - UNIT III
0 → 25 mg/l
BIOLOGICAL SOLIDS
COD
0
4
8
12
16
20
24
TIME, HOURS

rate. The same can be said for the two figures showing results of dosage of hexachlorobenzene at 20 mg/l and 50 mg/l. It should be understood that in Figures 10 and 11, each control unit, although undosed in these experiments, had previously received 5 mg/l and 20 mg/l, respectively, before running the shock experiments. Thus, the biomasses in the control and the test reactors for these two compounds (Figures 8-11) was the same except that in the four experiments shown, the controls received no dosage of priority compounds as the dosage was increased from 5 to 20 mg/l in one case and 20 to 50 mg/l in the other case for the test compounds. From the results shown in these four figures, it must be concluded that neither benzene nor hexachlorobenzene at the dosage levels applied had any effect on substrate removal rate. Beginning with the experiments on anthracene, the control sludge was one which had never been dosed with test compound. These later comparisons may provide a somewhat more conservative or cautious comparison in regard to assessment of the effect of priority pollutants on municipal activated sludge. All batch results using varying concentrations of anthracene (Figures 12 through 18) indicate that the substrate removal rate was unaffected by this compound. However, for 25 and 50 mg/l dosing levels, the net increase in biomass concentration was lower than in the control system.

Regarding o-nitrophenol, there was no apparent difference in the COD removal curves for control and dose systems for o-nitrophenol feeding levels of 5 and 25 mg/l (Figures 19 and 20). However, at a dosage of 50 mg/l (Figure 21), there was a noticeable retardation in COD removal. This retardation was also evident when the o-nitrophenol unit dosage was changed from 25 to 50 mg/l (Figures 22 and 23); however,

when the dosage was cycled from 0 to 25 mg/l o-nitrophenol did not appear to have any adverse effect on substrate removal rate (Figure 24). However, the growth and substrate removal response for the control in this experiment seems abnormally slow.

Chloroform did not affect the substrate removal rate, nor did trichloroethylene.

Stripping Tests

Figures 38 through 45 show the results of stripping tests run by the feeding levels of 250, 500, and 1000 mg/l theoretical (calculated) feed COD. These figures show that anthracene is not stripped, and that o-nitrophenol is stripped only slightly during the 24-hour reaction period. Benzene, chloroform, and trichloroethylene are stripped at very rapid rates.

Semilogarithmic plots of the results (Figures 43-45) indicated that benzene followed a first-order decreasing rate kinetic mode of removal, but that chloroform and trichloroethylene did not follow first-order removal kinetics. These experiments were repeated, and the results were essentially identical. It can be seen from these results that metabolism of such compounds as benzene, chloroform, and trichloroethylene would have to be very rapid in order for these compounds to be removed biologically at a municipal activated sludge treatment plant. In any event, the compounds would have to be taken up very rapidly by the cells before they would be stripped, unless the stripping characteristics were decidedly slowed down by the presence of the biomass suspended solids. None of the compounds studied is stripped so rapidly,

Figure 38. Stripping Test of Benzene at Concentrations of 250, 500, and 1000 mg/l COD

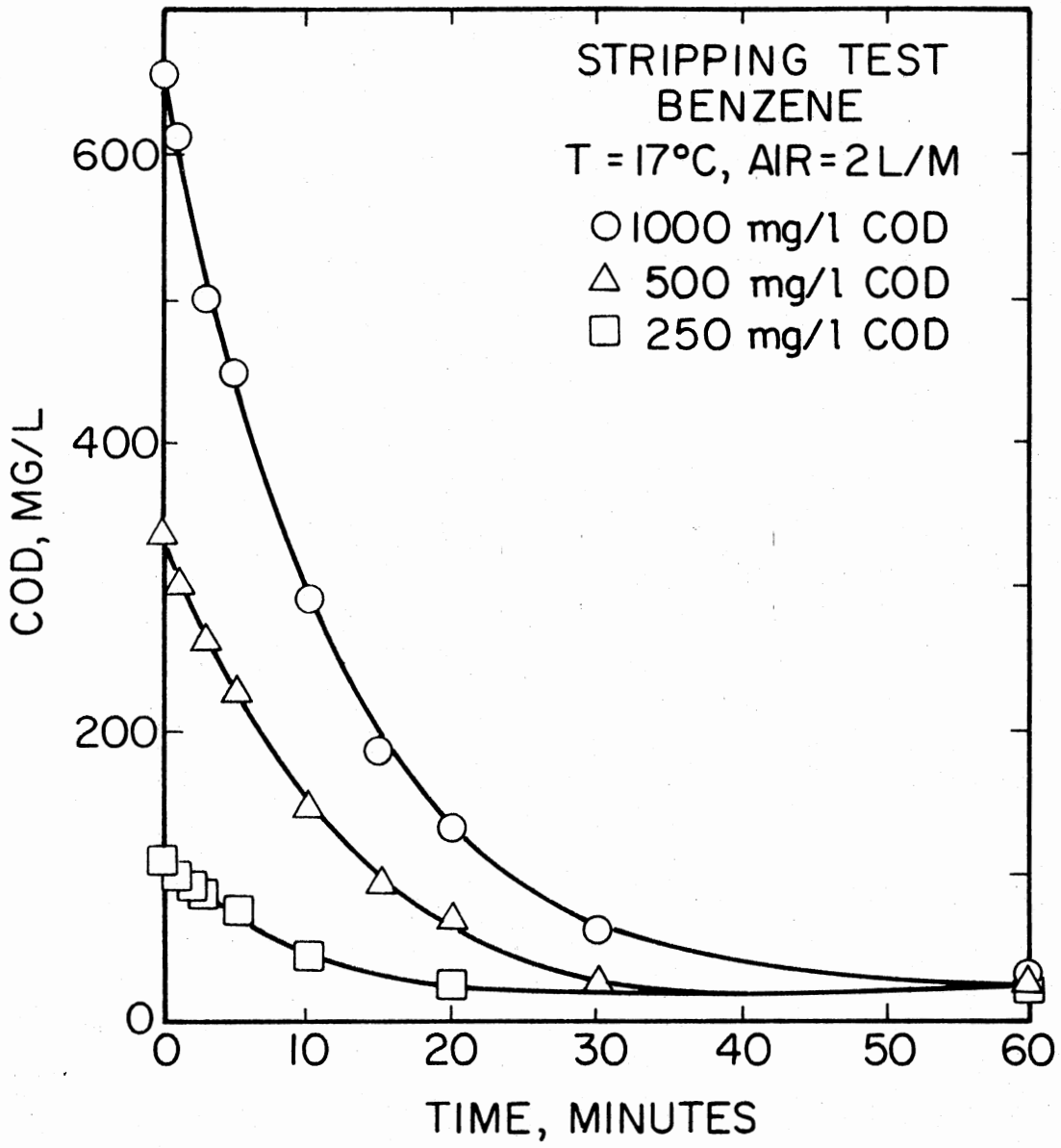

STRIPPING TEST
BENZENE
T = 17°C, AIR = 2 L/M
○ 1000 mg/l COD
△ 500 mg/l COD
□ 250 mg/l COD
COD, MG/L
0
200
400
600
0
10
20
30
40
50
60
TIME, MINUTES

Figure 39. Stripping Test of Anthracene at Concentrations of 250, 500, and 1000 mg/l COD

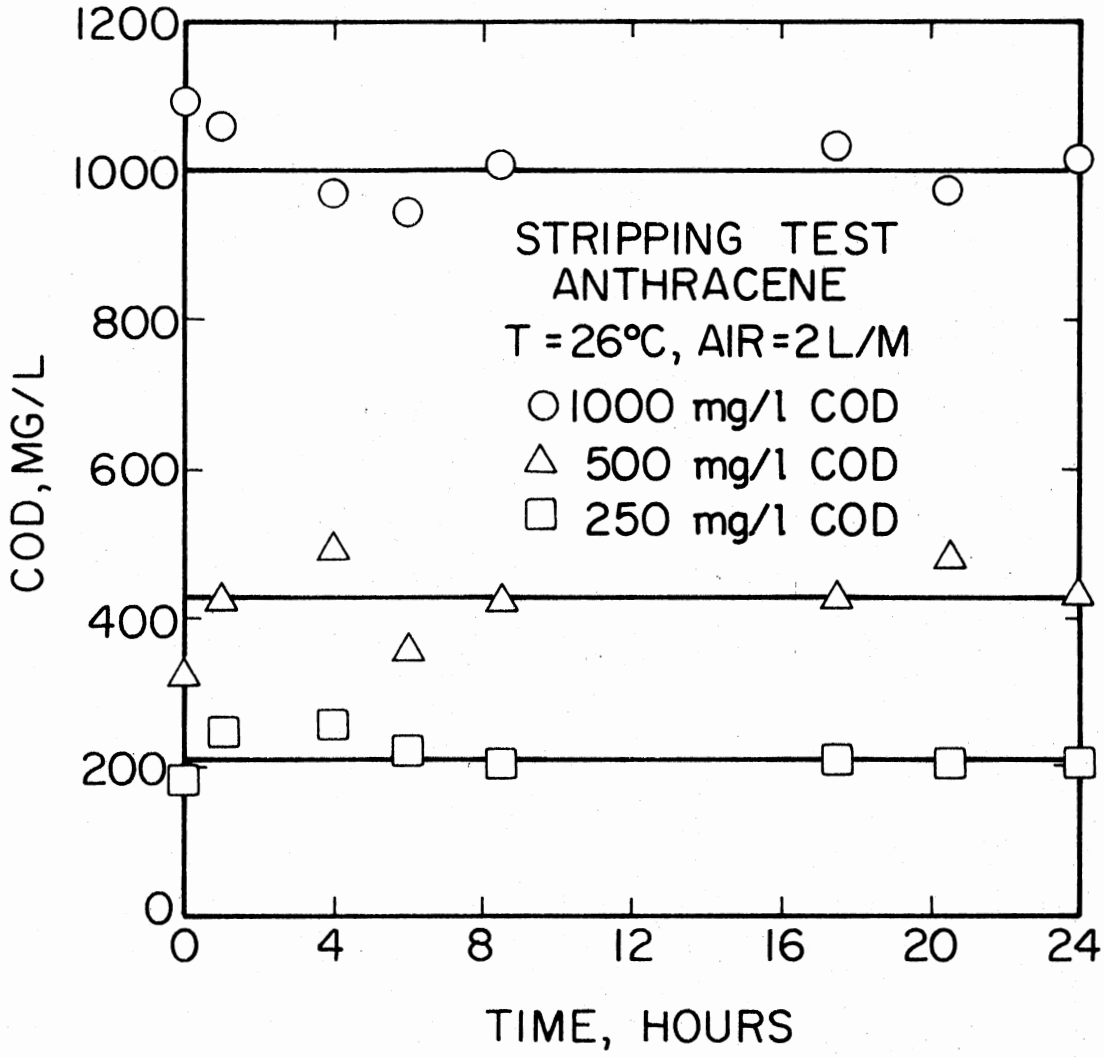

1200
1000
800
600
400
200
0
COD, MG/L
0
4
8
12
16
20
24
TIME, HOURS
STRIPPING TEST
ANTHRACENE
T = 26°C, AIR = 2 L/M
○ 1000 mg/l COD
△ 500 mg/l COD
□ 250 mg/l COD

Figure 40. Stripping Test of O-nitrophenol at Concentrations of 250, 500, and 1000 mg/l COD

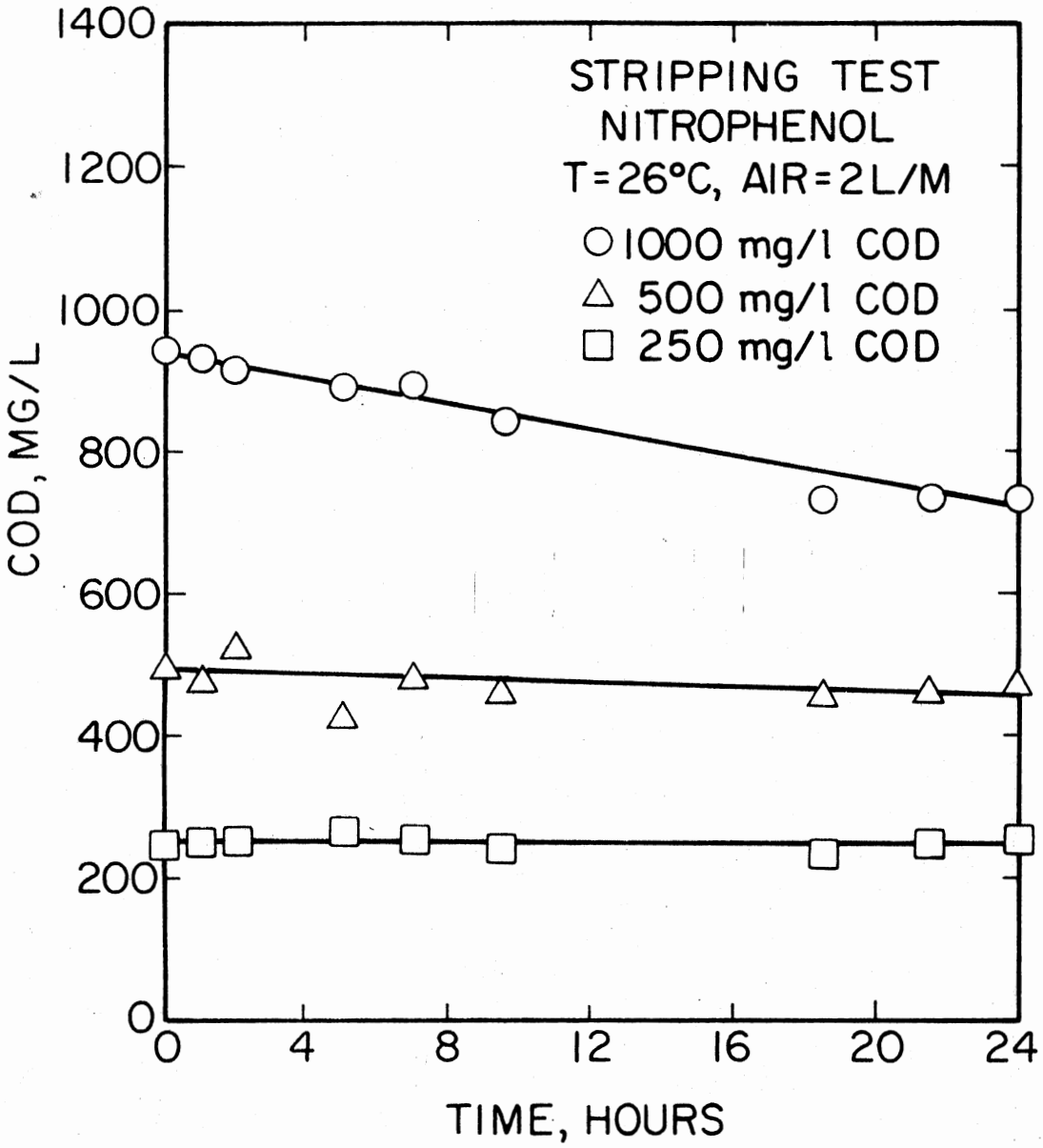

STRIPPING TEST
NITROPHENOL
T=26°C, AIR=2L/M
○ 1000 mg/l COD
△ 500 mg/l COD
□ 250 mg/l COD
COD, MG/L
1400
1200
1000
800
600
400
200
0
0
4
8
12
16
20
24
TIME, HOURS

Figure 41. Stripping Test of Chloroform at Concentrations of 250, 500, and 1000 mg/l COD

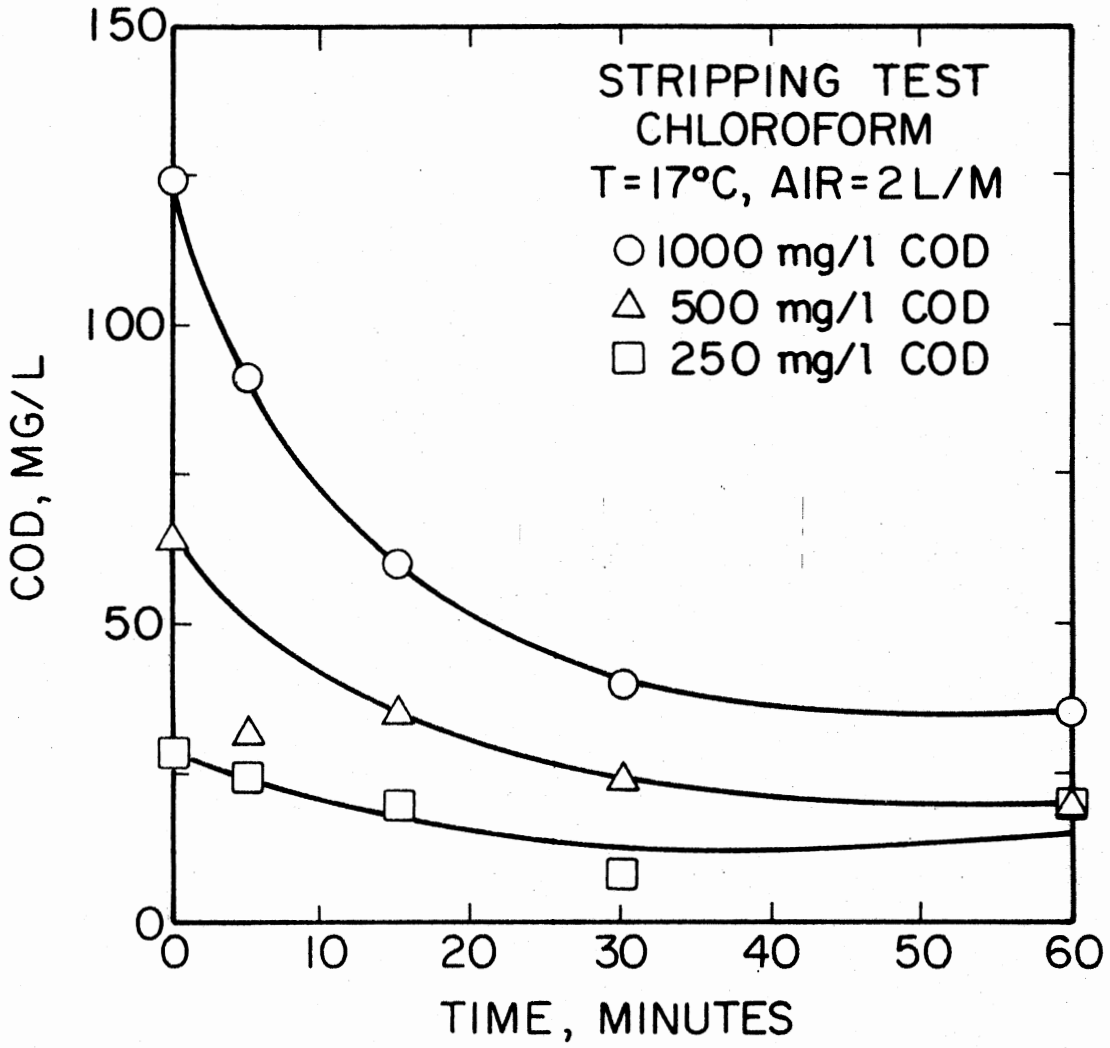

STRIPPING TEST
CHLOROFORM
T=17°C, AIR=2 L/M
○ 1000 mg/l COD
△ 500 mg/l COD
□ 250 mg/l COD
COD, MG/L
150
100
50
0
0
10
20
30
40
50
60
TIME, MINUTES

Figure 42. Stripping Test of Trichloroethylene at Concentrations of 250, 500, and 1000 mg/l COD

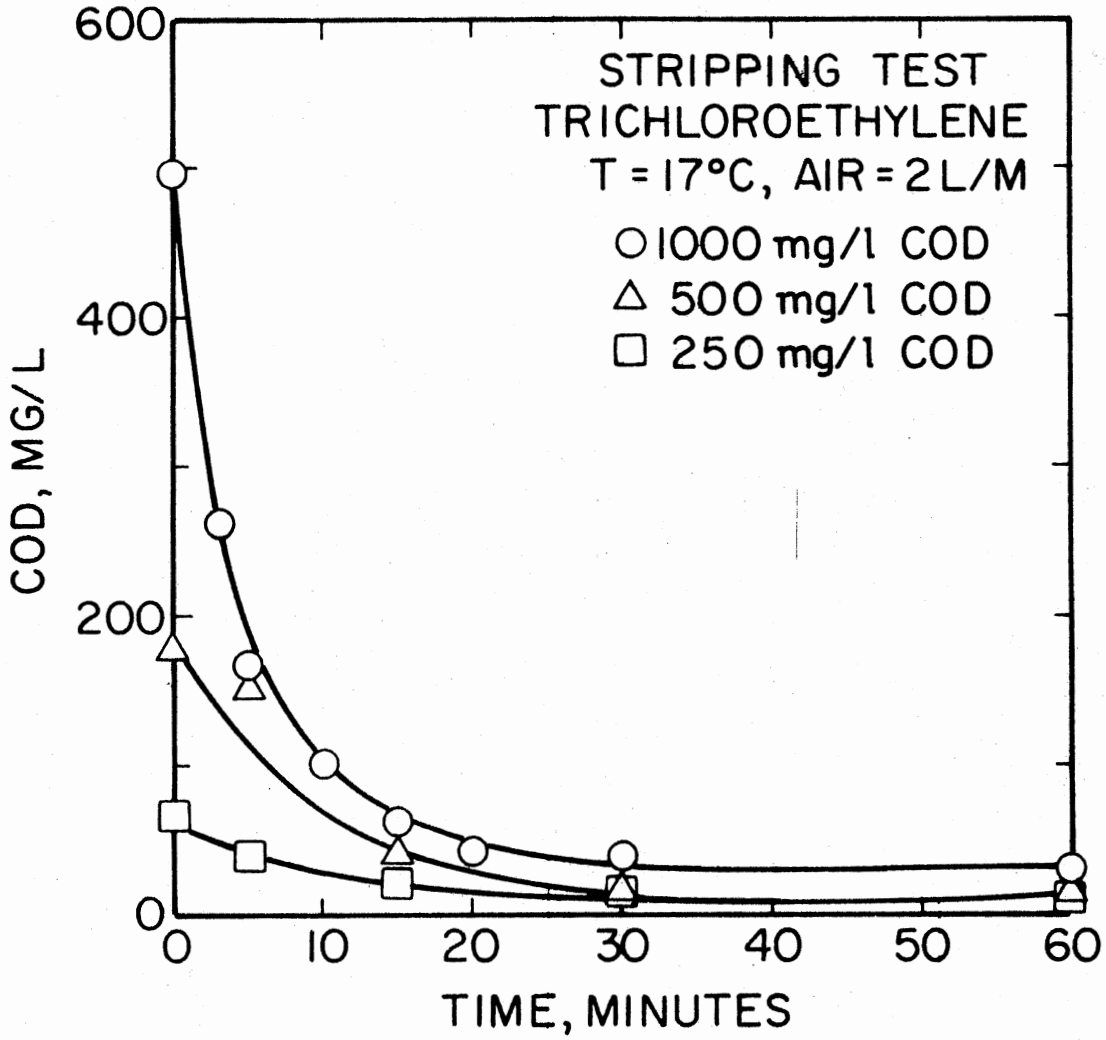

STRIPPING TEST
TRICHLOROETHYLENE
T = 17°C, AIR = 2 L/M
○ 1000 mg/l COD
△ 500 mg/l COD
□ 250 mg/l COD
COD, MG/L
600
400
200
0
0
10
20
30
40
50
60
TIME, MINUTES

Figure 43. Semilogarithmic Plot of Benzene Stripping Test at Concentrations of 250, 500, and 1000 mg/l COD

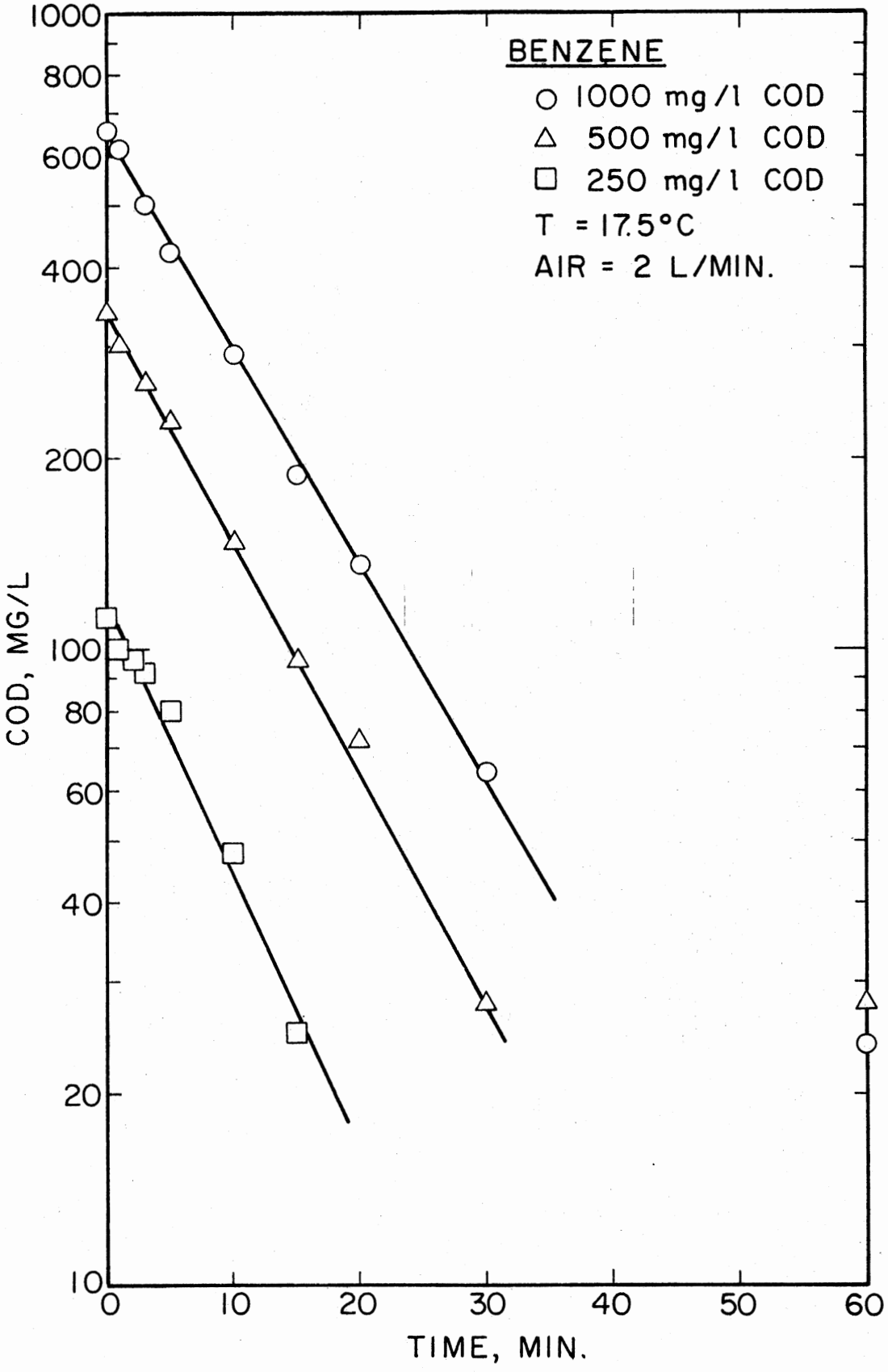

BENZENE
○ 1000 mg/l COD
△ 500 mg/l COD
□ 250 mg/l COD
T = 17.5°C
AIR = 2 L/MIN.
COD, MG/L
1000
800
600
400
200
100
80
60
40
20
10
0
10
20
30
40
50
60
TIME, MIN.

Figure 44. Semilogarithmic Plot of Chloroform Stripping Test at Concentrations of 250, 500, and 1000 mg/l COD

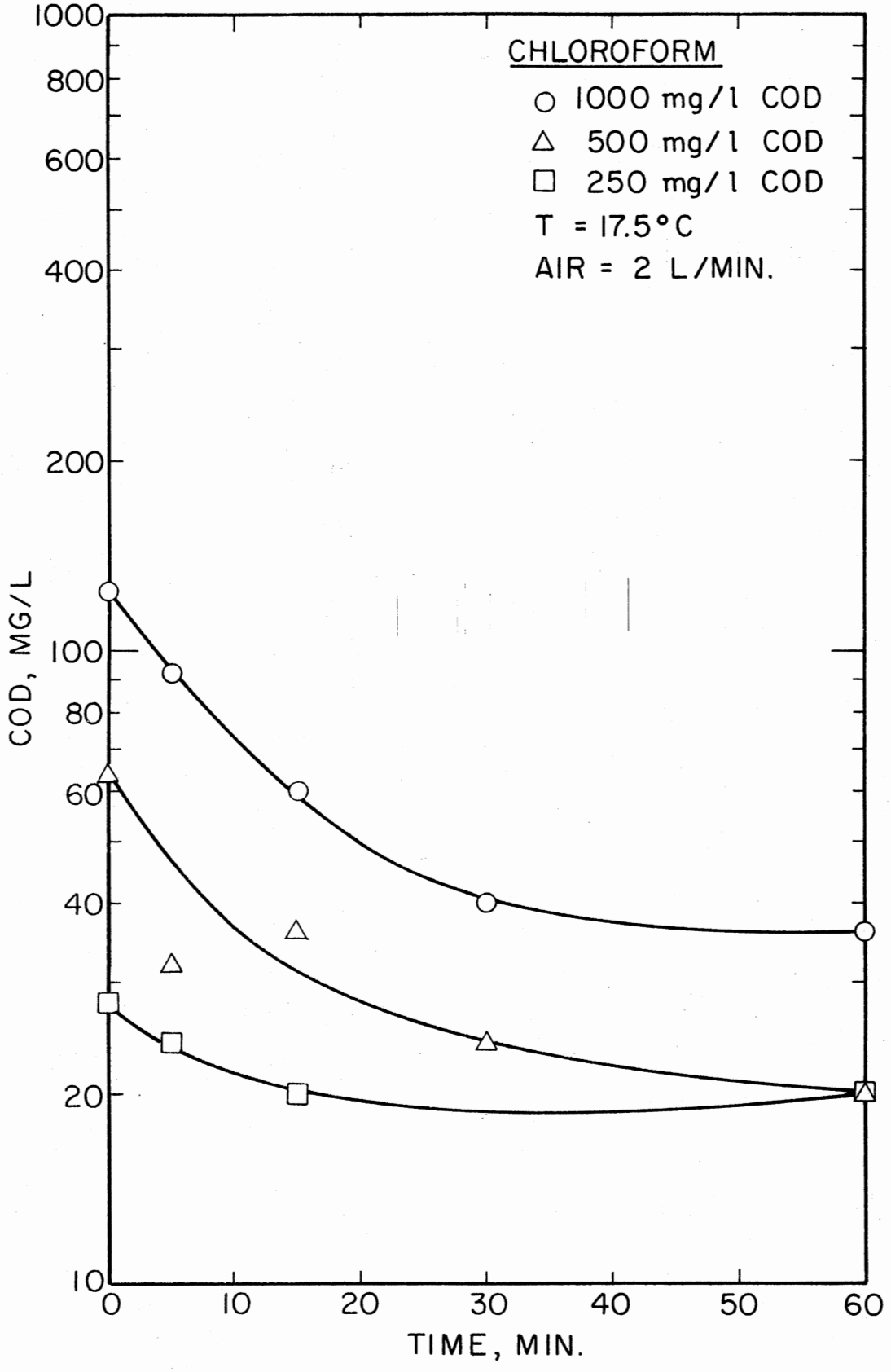
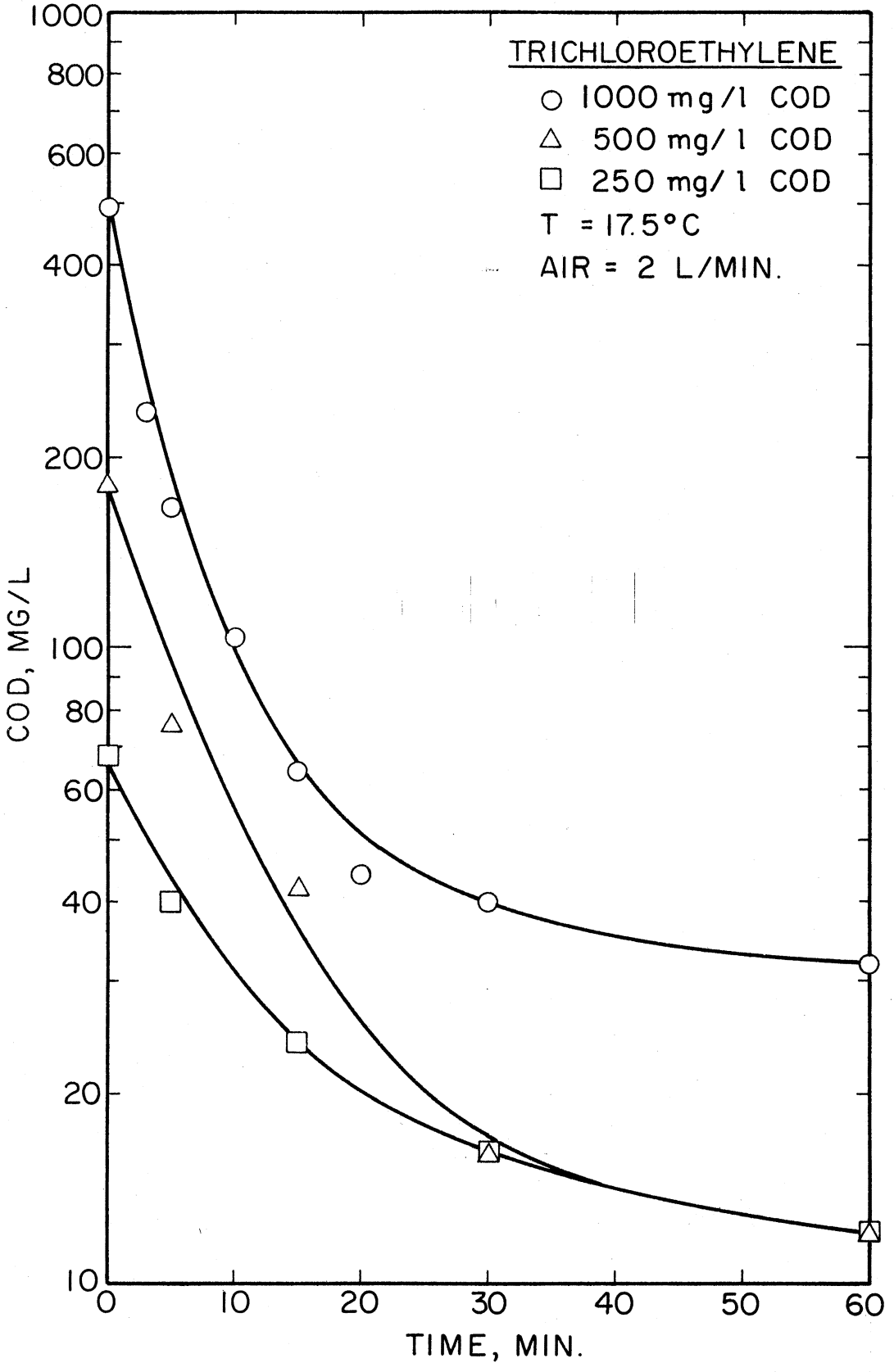

CHLOROFORM
○ 1000 mg/l COD
△ 500 mg/l COD
□ 250 mg/l COD
T = 17.5°C
AIR = 2 L/MIN.
COD, MG/L
1000
800
600
400
200
100
80
60
40
20
10
0
10
20
30
40
50
60
TIME, MIN.

Figure 45. Semilogarithmic Plot of Trichloroethylene Stripping Test at Concentrations of 250, 500, and 1000 mg/l COD


TRICHLOROETHYLENE
○ 1000 mg/l COD
△ 500 mg/l COD
□ 250 mg/l COD
T = 17.5°C
AIR = 2 L/MIN.
COD, MG/L
1000
800
600
400
200
100
80
60
40
20
10
0
10
20
30
40
50
60
TIME, MIN.

however, that the effect of its presence in a municipal wastewater can be neglected because of its possible removal by stripping pior to contact with the microorganisms in the activated sludge.

CHAPTER V

CONCLUSIONS

In general, one may conclude from these batch studies that rather high concentrations of the test compounds (5 to 50 mg/l) will have little or no effect on the substrate removal characteristics of an activated sludge process treating municipal sewage. However, it is as yet unclear whether such batch studies can be readily used to make conclusions in regard to behavior of activated sludge. Although batch fed units are subjected to rather severe shock loading conditions at each daily feeding, the 23-hour aeration period allows time for recovery which would not normally be available for a continuous flow activated sludge process unless it was one which employed an extended aeration period. The separate batch studies revealed for o-nitrophenol at rather high dosages (Figures 21, 22, and 23) that there was a decided retardation in removal rate. Such a finding is not noticeable in the normal daily feeding log of results, because after 23 hours of aeration, the control and the dosed systems are essentially the same regarding soluble COD.

There was some evidence, as can be seen from Table V, that hexachlorobenzene and anthracene affected the settleability of the sludge. At the time of completing this thesis, it is not possible to include in the analyses of these data the general findings of other experiments going on concurrently using other compounds, and in some instances, the

study of the same compounds used here in continuous flow activated sludge pilot plants. However, from the results thus far available, it appears that batch studies (which are more easily facilitated than are continuous flow operations) can be used to gain an overall insight regarding gross effects but are not a particularly good indicator of the magnitude and type of problem which may be encountered in an activated sludge. However, in regard to the six compounds herein tested, the dosed concentrations were purposely made higher than those anticipated at a publicly owned treatment works and it seems safe to conclude that in concentrations of a few milligrams per liter these compounds would not adversely affect the operation of a treatment plant or its sludge treatment and disposal facility. Also, for the compounds which were subjected to specific quantitative analysis, it does not appear that significant concentrations would pass through the treatment works.

CHAPTER VI

SUGGESTIONS FOR FUTURE WORK

A significant number of the priority pollutants are essentially not soluble in water. It may be a worthwhile expenditure of experimental effort to determine if changes in the chemical composition of the wastes could affect the solubility of some of these compounds.

Also, it would be well to extend the study to higher concentrations of some of the compounds; that is, it would be well to study biological pretreatment aspects with regard to certain of the priority pollutants.

In regard to pretreatment studies as well as to studies at low dosage concentrations to POTWs, the effect of addition of mixtures of compounds rather than single compounds would make an interesting subject for investigation.

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VITA

Gye Dae Whang

Candidate for the Degree of

Master of Science

Thesis: THE EFFECTS OF ORGANIC TOXIC COMPOUNDS ON THE PERFORMANCE OF A BATCH-OPERATED ACTIVATED SLUDGE PROCESS

Major Field: Bioenvironmental Engineering

Biographical:

Personal Data: Born April 12, 1950, in Seoul, Korea, the son of Young Ha and Kyung Sek Whang.

Education: Graduated from PoSung High School, Seoul, Korea, in February, 1968; received the Bachelor of Engineering degree from Yonsei University, Seoul, February, 1972; the Master of Science degree from Yonsei University, Seoul, in September, 1976; completed requirements for the Master of Science degree in Bioenvironmental Engineering at Oklahoma State University in July, 1979.

Professional Experience: Graduate research assistant, Bioenvironmental Department, Oklahoma State University, 1977-1979; field technician, Environmental Engineering Consultants, Stillwater, Oklahoma, 1979.

Membership in Professional Societies: Water Pollution Control Federation; National Society of Professional Engineers.