

ION EXCHANGERS IN WASTEWATER RECLAMATION

by

Oscar Vicente Campos-Saravia

---

A Thesis Submitted to the Faculty of the  
DEPARTMENT OF CIVIL ENGINEERING AND ENGINEERING MECHANICS

In Partial Fulfillment of the Requirements  
For the Degree of

MASTER OF SCIENCE  
WITH A MAJOR IN CIVIL ENGINEERING

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 7 1

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: \_\_\_\_\_

*Godwin Kewer*

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

*Robert A. Phillips*

ROBERT A. PHILLIPS

Professor of Civil Engineering

*Aug 10 1971*

Date

## ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude to Dr. Robert A. Phillips for his advice and guidance in the preparation of this thesis. Professor Quentin M. Mees is to be thanked for his suggestions concerning the subject matter of this thesis. The Department of Civil Engineering and Engineering Mechanics, The University of Arizona, must be credited for providing the necessary facilities.

The author also wishes to thank the Nalco Chemical Company and the Rohm and Haas Company for providing the resins and their necessary information. Appreciation is extended to other members of the faculty, staff, and fellow students for their comments and suggestions.

Mrs. J. L. Cude is to be thanked for typing this thesis.

## TABLE OF CONTENTS

	Page
LIST OF ILLUSTRATIONS . . . . .	vi
LIST OF TABLES . . . . .	viii
ABSTRACT . . . . .	ix
CHAPTER	
I INTRODUCTION . . . . .	1
Purpose and Scope . . . . .	1
II REVIEW OF LITERATURE . . . . .	3
Characteristics of an Oxidation Pond Effluent . . .	3
Ion Exchange Process . . . . .	3
Ion Exchange Resins . . . . .	4
Resin Properties . . . . .	4
Capacity . . . . .	4
Regeneration . . . . .	5
Backwashing . . . . .	5
Other Operating Conditions . . . . .	5
Previous Investigations . . . . .	6
III EXPERIMENTAL TECHNIQUES AND ANALYSES . . . . .	9
Preliminary Waste Water Clarification . . . . .	9
Resin Techniques . . . . .	9
Experimental Apparatus . . . . .	9
Resin Characteristics . . . . .	11
Dowex HGR-W . . . . .	11
Amberlite XE-258 . . . . .	11
Dowex 11 . . . . .	13
Column Operation . . . . .	13
Analyses . . . . .	13
IV DATA PRESENTATION AND DISCUSSION . . . . .	15
Phase 1. Operation Without Organic Screen . . . . .	15
Phase 2. Operation With Organic Screen . . . . .	31
Application for Industrial Needs . . . . .	47
Operating Cost . . . . .	48

TABLE OF CONTENTS--Continued

CHAPTER	Page
V SUMMARY AND CONCLUSIONS . . . . .	53
APPENDIX A: SUGGESTED OPERATING CONDITIONS FOR RESINS USED . . .	55
APPENDIX B: RESULTS OF ANALYSES PERFORMED DURING PHASE 1 AND PHASE 2 . . . . .	59
REFERENCES . . . . .	70

## LIST OF ILLUSTRATIONS

Figure		Page
1.	Characteristics of the Filter Sand . . . . .	10
2.	Diagram of the Demineralizing System . . . . .	12
3.	pH Readings During Phase 1 . . . . .	18
4.	Specific Conductance Readings During Phase 1 . . . . .	19
5.	Alkalinity Results During Phase 1 . . . . .	20
6.	Total Hardness Results During Phase 1 . . . . .	21
7.	Turbidity Results During Phase 1 . . . . .	23
8.	Total Residue Analyses During Phase 1 . . . . .	24
9.	Total Filterable Residue Analyses During Phase 1 . . . . .	25
10.	Oxygen Absorption Results During Phase 1 . . . . .	26
11.	COD Results During Phase 1 . . . . .	27
12.	MBAS Results During Phase 1 . . . . .	28
13.	Calcium Results During Phase 1 . . . . .	29
14.	Chloride Results During Phase 1 . . . . .	30
15.	pH Readings During Phase 2 . . . . .	32
16.	Specific Conductance Readings During Phase 2 . . . . .	33
17.	Alkalinity Results During Phase 2 . . . . .	34
18.	Total Filterable Residue Analyses During Phase 2 . . . . .	35
19.	Oxygen Absorption Results During Phase 2 . . . . .	36
20.	COD Results During Phase 2 . . . . .	37
21.	MBAS Results During Phase 2 . . . . .	38

LIST OF ILLUSTRATIONS--Continued

Figure		Page
22.	Sodium Results During Phase 2 . . . . .	39
23.	Chloride Results During Phase 2 . . . . .	40
24.	pH Readings After Dowex 11 Resin . . . . .	41
25.	Specific Conductance Readings After Dowex 11 Resin . . . . .	42
26.	Alkalinity Results After Dowex 11 Resin . . . . .	43
27.	COD Results After Dowex 11 Resin . . . . .	44
28.	Chloride Results After Dowex 11 Resin . . . . .	45

LIST OF TABLES

Table		Page
1.	Quality of treated oxidation pond effluent for column loading (Phase 1) . . . . .	16
2.	Quality of treated oxidation pond effluent for column loading (Phase 2) . . . . .	17
3.	Comparison between the suggested limits of tolerance for boiler feed waters and the water obtained during this study . . . . .	49
4.	Comparison between the requirements for textile manufacture waters and the water obtained during this study . . . . .	50

## ABSTRACT

The effluent of a sewage oxidation pond owned and operated by Pima County, Arizona, and located near Tucson, Arizona, was used to evaluate the feasibility of the use of the ion exchange process for treatment of waters of this type. The oxidation pond effluent was pretreated with alum, settled, and filtered.

When Dowex HGR-W and Amberlite XE-258 resins were used in a conventional system, the quality of the effluent water decreased during subsequent cycles as did the original capacity of the system. With the installation of Dowex 11 anion resin ahead of the other two, better quality water was obtained and original capacity of the system retained during successive cycles.

## CHAPTER I

### INTRODUCTION

Over the last two decades new sources of water have been a subject of many conferences, meetings, investigations, etc. Undoubtedly, this subject is important especially in areas where shortages of water exist. It has been demonstrated in areas where the agricultural, industrial, commercial, and domestic water supply is by ground water that water levels of these sources are being depleted at high rates. Similar shortages are encountered with surface supplies as well.

One of the more promising sources of water is waste water from communities. This represents 55 to 75 percent of the total water used. Effluents from waste treatment plants and oxidation ponds can be improved with proper treatment, and high quality water can be obtained.

The easiest and most logical step for treatment of an effluent from an oxidation pond is a standard water treatment process, which involves chemical dosage, mixing, flocculation, sedimentation, and filtration, followed, perhaps, by a tertiary treatment. The choice for this last step would be the one or more steps required to produce a desired water depending on the quality requirements.

#### Purpose and Scope

In addition to standard water treatment, tertiary treatment by ion exchange process was selected for the purpose of this thesis. The

objective of this research was to evaluate the pond effluent after treatment by both processes, and ascertain its possible application for various industrial needs.

A modification in the ion exchange process was used to obtain better quality water, longer periods of time between regenerations, and consequently lower overall costs.

In order to accomplish the previously stated purposes, chemical dosage, mixing, flocculation, sedimentation, and filtration were used to remove algae and other particulate constituents from the oxidation pond effluent. Following this treatment, demineralizing ion exchange resins were employed. Laboratory analyses were conducted to evaluate the potential value of the new water.

## CHAPTER II

### REVIEW OF LITERATURE

Sewage oxidation ponds are shallow basins used for purifying waste water. These ponds are designed for detention periods of between three and four weeks, using a biochemical oxygen demand (BOD) loading in the vicinity of 45 lb/day/acre (1). Oxidation ponds are constructed between three and four feet deep and have free form.

#### Characteristics of an Oxidation Pond Effluent

Sewage effluent from an oxidation pond can be used successfully as irrigation water. It may increase crop yield and contributes nitrogen and other nutrients to the soil (2). For other purposes the degree of treatment of the effluent from an oxidation pond depends on its chemical composition and the potential use of the water.

#### Ion Exchange Process

Ion exchange can be defined as a reversible exchange of ions between a solid and a liquid in which there is no substantial change in the structure of the solid. In this definition the "solid" is the ion exchange material or resin particle (3).

During the past ten years, ion exchange techniques have found wide application in the fields of water and waste water treatment. It now can be compared with processes such as distillation and

precipitation for the removal of only certain undesirable components or to produce extremely pure water.

### Ion Exchange Resins

The most important ion exchange resins produced and employed today are the synthetic organic resins. These synthetic ion exchange resins are actually a special type of polyelectrolyte. Cross-linked polyelectrolytes can be visualized as an elastic three-dimensional hydrocarbon network. The most useful hydrocarbon network developed to date is that formed by the copolymerization of styrene and divinylbenzene (3).

The chemical behavior of ion exchange resins is divided into two major classes: 1) cation resins, those capable of exchanging cations or positively charged ions; and 2) anion resins, those capable of exchanging anions or negatively charged ions 3).

The nature of the ionizable groups attached to the hydrocarbon network determines the chemical behavior of an ion exchange resin. There are four major types of ion exchange resins in commercial use at the present time: 1) strong acid (cation) resins, 2) weak acid (cation) resins, 3) strong base (anion) resins, and 4) weak base (anion) resins. The terms cation and anion refer to the charge on the ions which are removed or exchanged.

### Resin Properties

Capacity. The total capacity of an ion exchange resin is the number of ionic (or potentially ionic) sites per unit weight or volume

of resin. The exchange capacity of a bed is commonly expressed in the number of kilograins of substance removed from the liquid by passage through 1 cu ft of exchange medium. Because ion exchangers were first used for the softening of water, comparisons of exchange capacity are generally made by expressing the substance removed in terms of hardness as  $\text{CaCO}_3$ . A more useful unit of exchange capacity is the number of gram-equivalents of ions removed by a unit volume of exchanger. Gram-equivalents per kilogram or milliequivalents per gram may be used instead. Capacity curves for individual resins are provided by manufacturers.

Regeneration. When a bed is no longer capable of useful ion exchange, it is said to be exhausted and needs regeneration. The regenerating requirements of a bed are expressed in pounds of chemical per cubic foot of exchanger or per kilograin of substance removed from the liquid.

Backwashing. The backwashing process for ion exchange resins is based on the principle used for backwashing sand filters. The flow rate is expressed in gpm/sq ft. Another way for expressing flow rate is based on the backwash flow required for a desired percent expansion of the resin. Expression of flow rates varies according to the operating conditions suggested by the manufacturers. The flow is upward and washes off light insoluble contaminants. Backwashing also eliminates resin compaction.

Other Operating Conditions. The pH range, maximum temperature, minimum bed depth, service flow rate, rinse water requirements, and

other operating conditions for each resin are provided in guides from the manufacturers.

### Previous Investigations

Today in almost all ion exchange processes synthetic organic resins are being used. These synthetic organic resins at first were limited to the cationic type and were used extensively for water softening.

In about 1948, strong basic anion exchange resins were developed. These resins are more difficult to manufacture and have a lower chemical and thermal stability than the cation resins (4).

The largest and oldest application of ion exchange resins is in water treatment. Of the 680,000 cu ft of resins produced in 1961, it is estimated that 600,000 cu ft went to water treatment (5). Cation resins are used for the removal of hardness and partial alkalization of water, whereas both anion and cation resins are required for demineralization. Other special applications which use anion exchange resins include the removal of sulfates, hydrogen sulfides, and nitrates from water.

In 1960, it was estimated that there were 1500 technical articles published on ion exchange resins (6). Klumb (7) has referred to the biological fouling in which the resins are clumped together by bacteria and because of this clumping are not free to exchange their ions or to be regenerated. He also pointed out that experimental evidence indicates that cation exchangers are incapable in themselves of sustaining bacterial growth. Bacteria may grow in the softener material

because of the presence of filtered organic matter, especially during optimum temperature conditions (7).

Wirth (8) has reported that chlorine present in the water is primarily responsible for cation resin degradation. Iron and manganese cause inorganic fouling, principally to the cation resins, and periodic cleanup procedures are recommended to remove these fouling agents. Inorganic ions have also been reported as a source of fouling for anion resins but this is considered to be a minor cause (8).

The largest quantities of anion exchange resins are used in demineralization of water supplies. Associated with their use are problems of resin deterioration and fouling. Many researchers have attributed this deterioration and fouling to four main causes: 1) biological fouling, 2) chemical attack, 3) inorganic fouling, and 4) organic fouling. This fouling is so serious that 25 percent of the annual sales of anion resins are for the replacement of fouled or deteriorated resins (9).

One of the main reasons for organic fouling of anion exchange resins is due to the exchange of large amounts of organic acids. Accumulation of these acids on the resins gradually reduces the operating capacity of the column. The most important technique in prevention of fouling is the limiting of organic accumulation on the resins. The use of scavenger beds appears to be an effective means of fouling prevention (10).

Recent studies (11) have shown that special strong base anion exchange resins can be installed ahead of a demineralizing system to

screen out organics responsible for poisoning anionic resins. This allows for longer periods of time between regenerations and in increasing the lifetime of the resins.

## CHAPTER III

### EXPERIMENTAL TECHNIQUES AND ANALYSES

#### Preliminary Waste Water Clarification

Samples of waste water were obtained from the Ina Road oxidation pond, Pima County, Arizona. Solids were removed by batch clarification in 50-gal drums using a dosage to 450 mg/l alum [as  $\text{Al}_2(\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O}$ ] followed by an adjustment to  $\text{pH } 6 \pm 0.1$ . The optimum pH range for coagulation with alum is between 5.0 to 7.0. Below pH 5.0 the alkalinity is insufficient to precipitate  $\text{Al}^{3+}$  completely, and above pH 7.0 the tendency is for aluminate ions to be formed which will dissolve (12).

Times of 60 sec, 30 min, and 2 hr were used for rapid mixing, flocculation, and sedimentation, respectively. The clarified supernatant was withdrawn by a siphon and filtered through a 2.5-ft, gravel-supported sand filter at a rate of 3 gpm/sq ft. The effective size of the sand was 0.49 mm, with a uniformity coefficient of 1.59, as shown in Figure 1.

#### Resin Techniques

##### Experimental Apparatus

In the first phase of this study, a strong acid cation exchange resin (Dowex HGR-W), followed by a strongly basic anion exchange resin (Amberlite XE-258), was employed. The second phase of the study

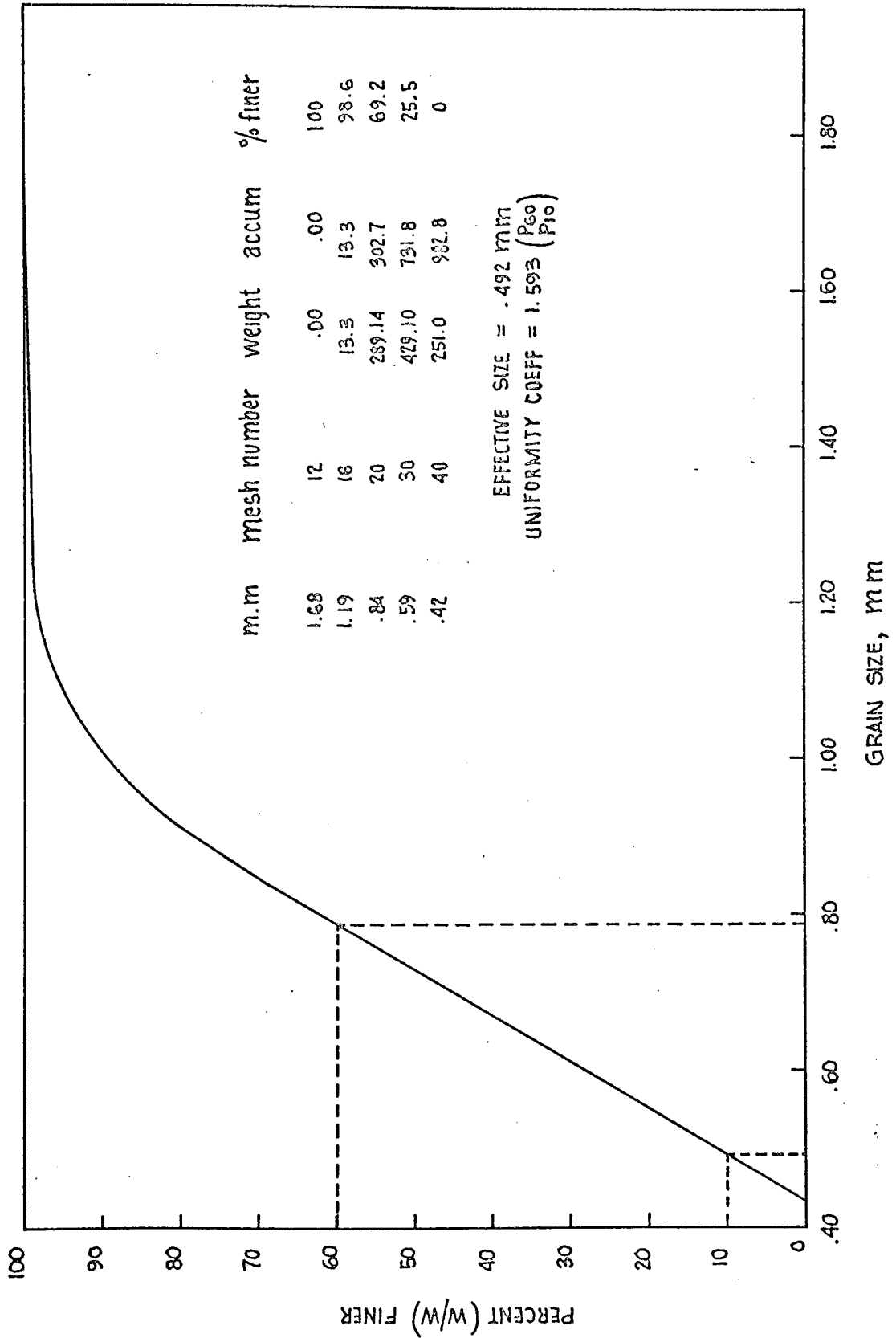


Figure 1. Characteristics of the Filter Sand.

involved the use of a second strongly basic anion exchange resin (Dowex 11), which was installed ahead of the two previously mentioned resins, as shown in Figure 2.

Lucite columns of 1.25-in. diameter and 18-in. height were filled with the resin material to a depth of 12 in., giving a volume of 0.00836 cu ft. Backwashing of the resin was done by attaching a second column to the top of the resin columns in order to provide needed expansion height.

### Resin Characteristics

Dowex HGR-W. This cation exchange resin is produced from a sulfonated copolymer of styrene and 10 percent divinylbenzene. For deionization Dowex HGR-W in combination with strong base resins can provide extremely high purity water. Suggested operating conditions in the hydrogen cycle (13), as provided by the manufacturer, are presented in Appendix A.

Amberlite XE-258. This anion exchange resin derives its exchange activity from quaternary ammonium groups. The difference between this resin and the styrene-divinylbenzene resins is that the acrylic-based structure is more hydrophilic. Laboratory tests have suggested that Amberlite XE-258 resin can be used as an organic scavenger in the treatment of waters (10), and in the hydroxide form can be used as the anion exchanger component of a conventional deionization system. Suggested operating conditions for Amberlite XE-258 (Rohm and Haas Company, Philadelphia, Pennsylvania) in the hydroxyl form are presented in Appendix A.

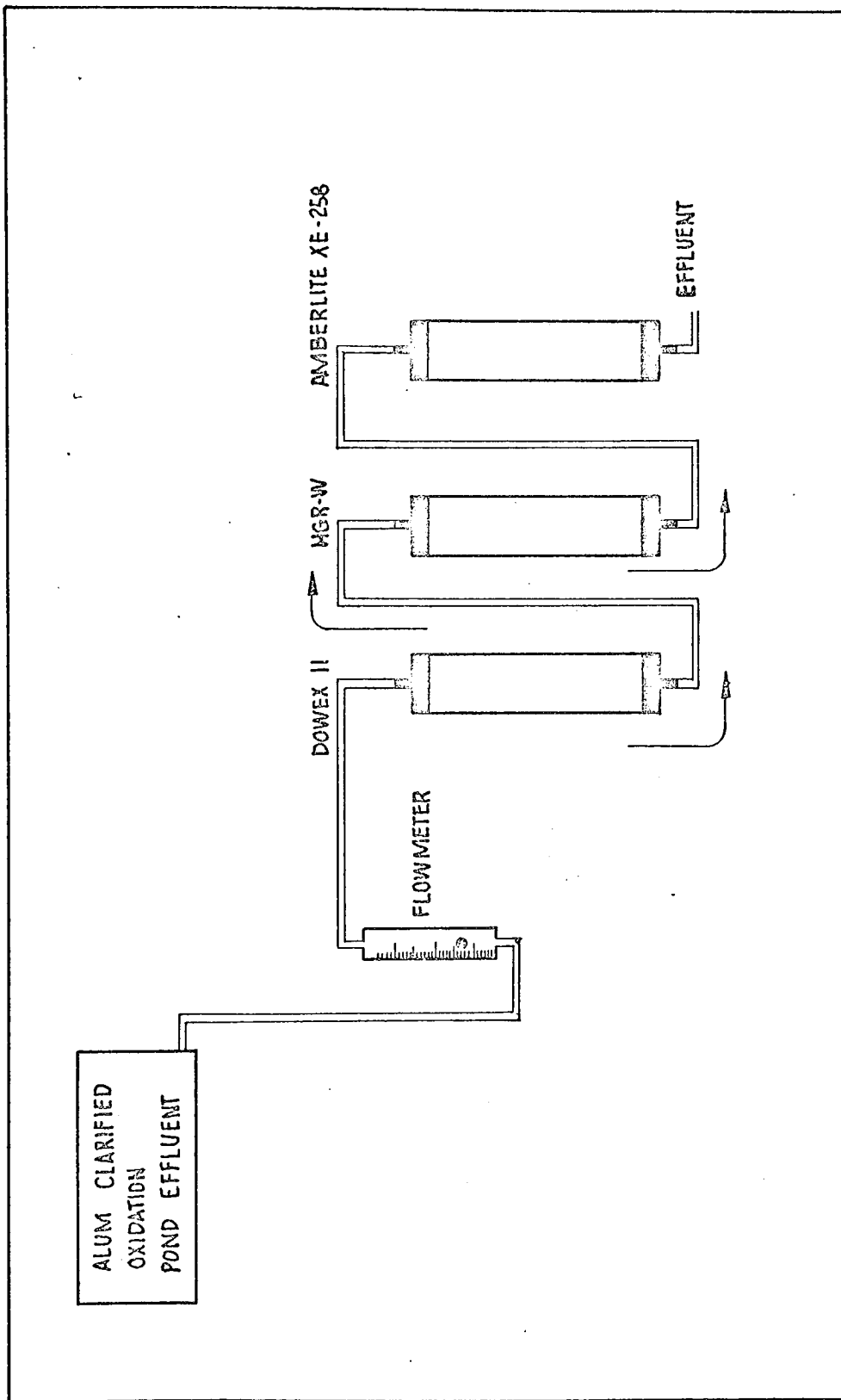


Figure 2. Diagram of the Demineralizing System.

Dowex 11. This is a high porosity strong base anion exchange resin. Its porous structure offers advantages in treating waters which contain organic matter and color. Suggested operating conditions in the hydroxyl form (13) are presented in Appendix A.

#### Column Operation

Regeneration levels of 9.5 lb NaOH/cu ft and concentrations of 4 percent NaOH were used to provide a capacity of 18 Kgr/cu ft as  $\text{CaCO}_3$  in the anion exchangers (13). For the cation exchanger a regenerant level of 9 lb  $\text{H}_2\text{SO}_4$ /cu ft and a concentration of 96 percent  $\text{H}_2\text{SO}_4$  was used to provide it with a capacity of 20 Kgr/cu ft as  $\text{CaCO}_3$  (13).

Backwash, regeneration, and rinse steps were carried out at equivalent rates and volumes as recommended by the resin manufacturers and are presented in Appendix A.

#### Analyses

Water quality tests used in evaluating resin performance were carried out according to "Standard Methods" (14) with the exception of the oxygen absorption test (3). This test was used as a mean of evaluating the organic matter at levels below the lower limits of sensitivity for the chemical oxygen demand (COD) test.

Oxygen absorption (OA) values are expressed as mg/l of oxygen just as in the COD test. The OA values do not necessarily have a constant relationship to values obtained by means of the COD test. The OA method uses the weaker oxidizing agent potassium permanganate rather than potassium dichromate and was carried out for 4 hr at 27°C.

The following analyses were conducted for evaluating raw water quality and resin performance:

<u>Analysis</u>	<u>Method</u>
Hydrogen ion concentration (pH)	Glass electrode pH meter
Specific conductance	Conductivity meter
Turbidity	Jackson candle turbidimeter and spectrophotometer
Alkalinity	Potentiometric titration method
Residue (total and filterable)	Residue on evaporation
Total hardness	EDTA titration method
Oxygen absorption (OA)	Acid permanganate method
Chemical oxygen demand (COD)	Dichromate reflux method
Methylene blue active substance (MBAS)	Chloroform extraction

## CHAPTER IV

### DATA PRESENTATION AND DISCUSSION

As stated in Chapter III, Phase 1 of this study dealt with the use of a cation exchange resin (Dowex HGR-W) and an anion exchange resin (Amberlite XE-258) installed in series. Phase 2 involved the use of a second anion exchange resin (Dowex 11) acting as an organic screen and installed ahead of the above two resins.

The effluent of the stabilization lagoon was treated as previously described. Tables 1 and 2 show the characteristics of the influent water used during Phase 1 and Phase 2 of this study, respectively.

#### Phase 1. Operation Without Organic Screen

The procedure in this phase was to submit the two resins to four operating cycles. Following exhaustion, backwashing, regeneration, and rinse, each cycle was repeated. Samples for analyses were taken every 30 min (except for total residue and total filtrable residue which were taken every 60 min) after the cycle started and until the system was not able to remove any ions, or the concentration of these ions in the effluent increased considerably (exhaustion symptoms).

Figures 3, 4, 5, and 6 show the variations in pH, specific conductance, total alkalinity, and total hardness for the four consecutive operating cycles. During these cycles, pH, specific conductance, and total alkalinity values were nearly constant during the first 270 min,

Table 1. Quality of treated oxidation pond effluent for column loading (Phase 1).

Analyses	Oxidation Pond Effluent	Effluent After Alum Coagulation	Effluent After Filtration
pH	7.6	6.0	6.5
Temperature, °C	16	18	20
Turbidity, JTU	163	26	15
Specific conductance, umhos	660	880	900
Total residue, mg/l	774	843	872
Filterable residue, mg/l	645	804	835
Alkalinity, mg/l as CaCO <sub>3</sub>	375	146	146
Total hardness, mg/l as CaCO <sub>3</sub>	168	168	160
Calcium, mg/l	-	-	58
Chloride, mg/l	-	-	157
Oxygen-absorption, mg/l	5.72	5.0	4.7
COD, mg/l	247	53.6	39.5
MBAS, mg/l	435	2.00	1.72

Table 2. Quality of treated oxidation pond effluent for column loading (Phase 2).

Analyses	Oxidation Pond Effluent	Effluent After Coagulation	Effluent After Filtration	
			a	b
pH	7.5	6.0	6.3	7.05
Temperature, °C	16	27	24	14
Turbidity, JTU	145	33	19	17
Specific conductance, umhos	780	900	970	780
Total residue, mg/l	629	629	620	-
Filterable residue, mg/l	529	594	603	534
Alkalinity, mg/l as CaCO <sub>3</sub>	315	116	115	130
Total hardness, mg/l as CaCO <sub>3</sub>	126	128	146	167.2
Calcium, mg/l	-	-	48	53
Chloride, mg/l	-	-	124	127.1
Sodium, mg/l	-	-	190	185
Oxygen absorption, mg/l	6.32	5.4	5.0	-
COD, mg/l	294	59.8	51.2	45.1
MBAS, mg/l	7.5	4.15	3.0	-

a. Average quality of influent during first cycle.

b. Average quality of influent during second cycle.

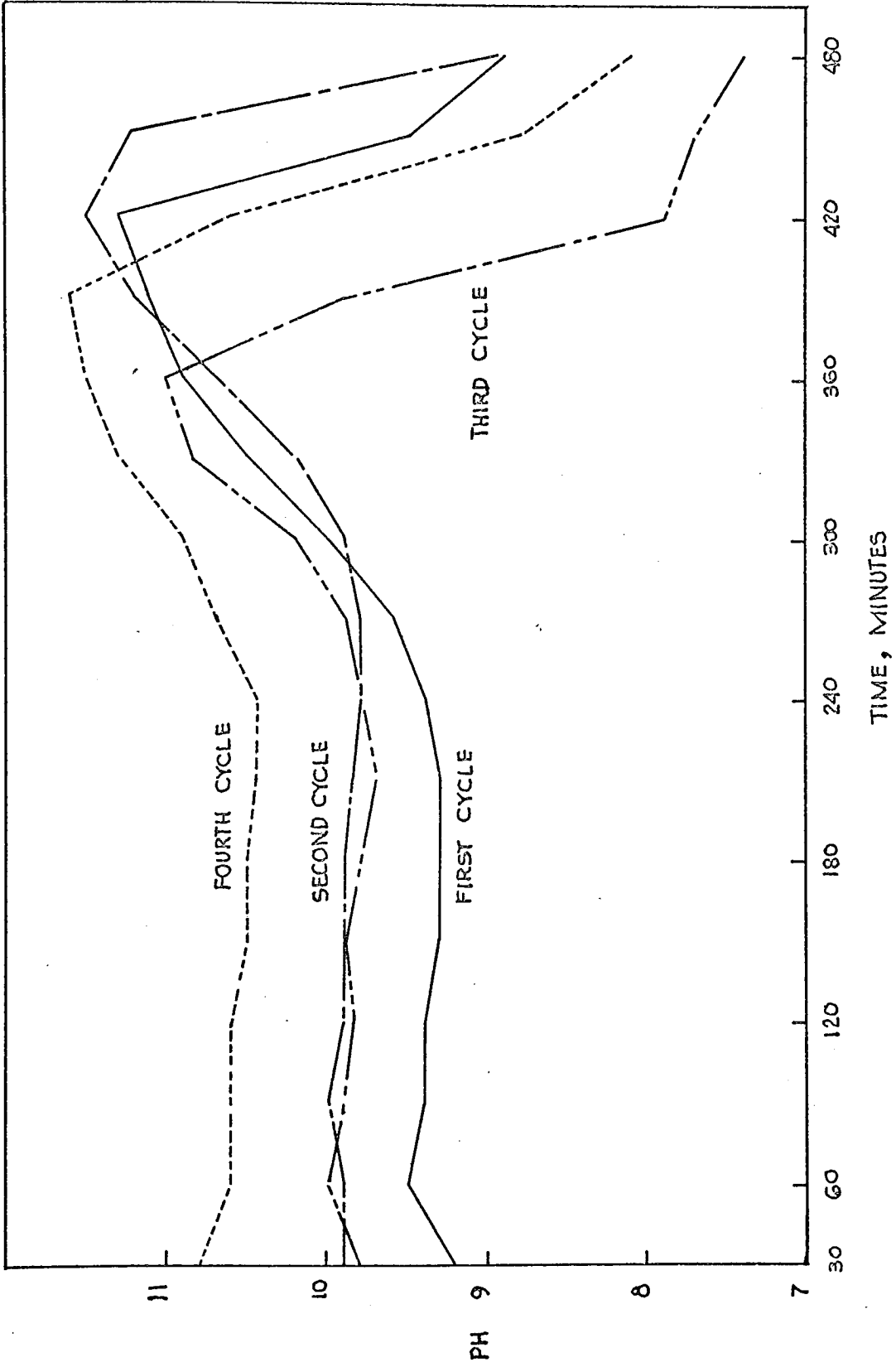


Figure 3. pH Readings During Phase 1.

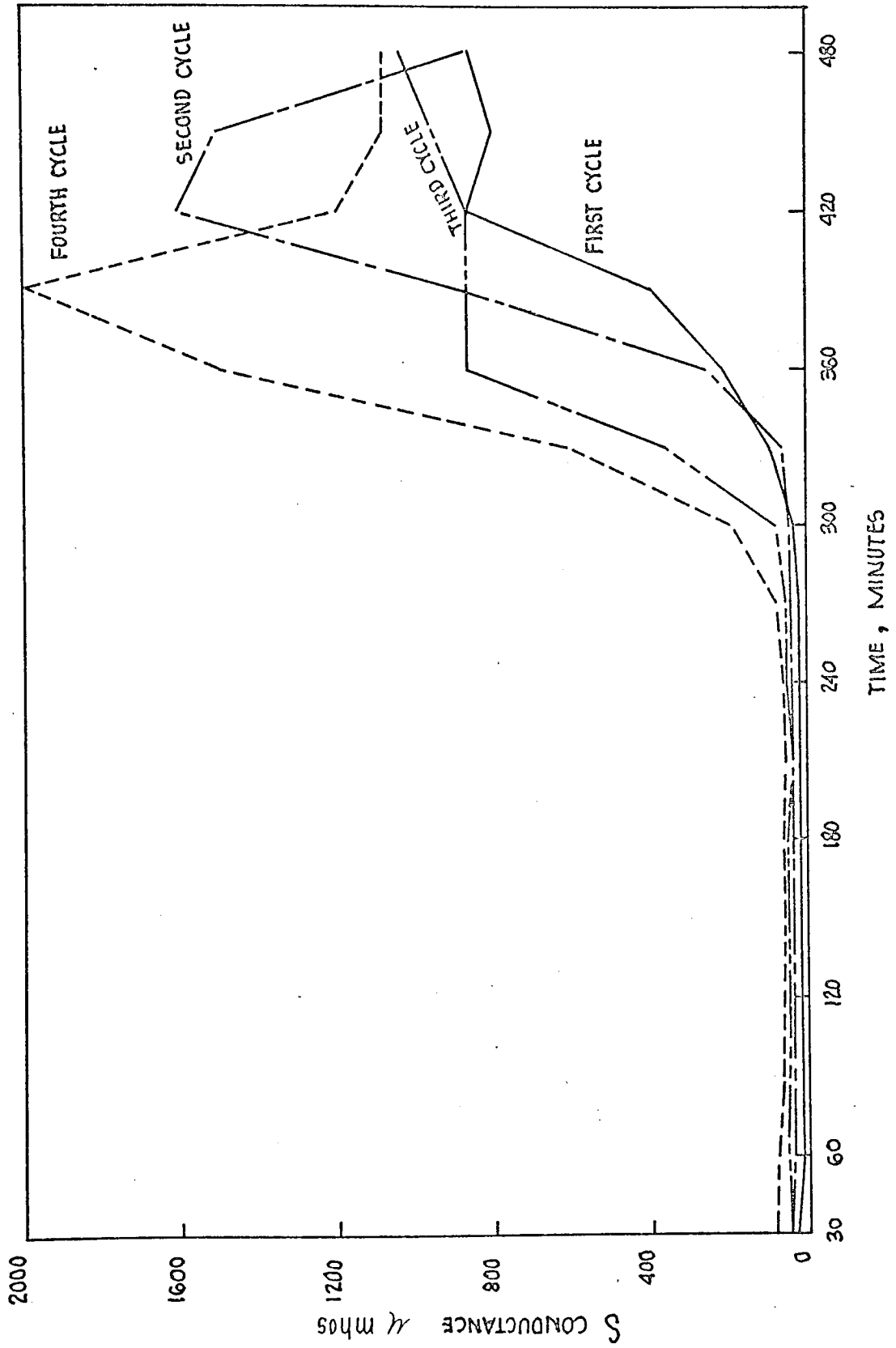


Figure 4. Specific Conductance Readings During Phase 1.

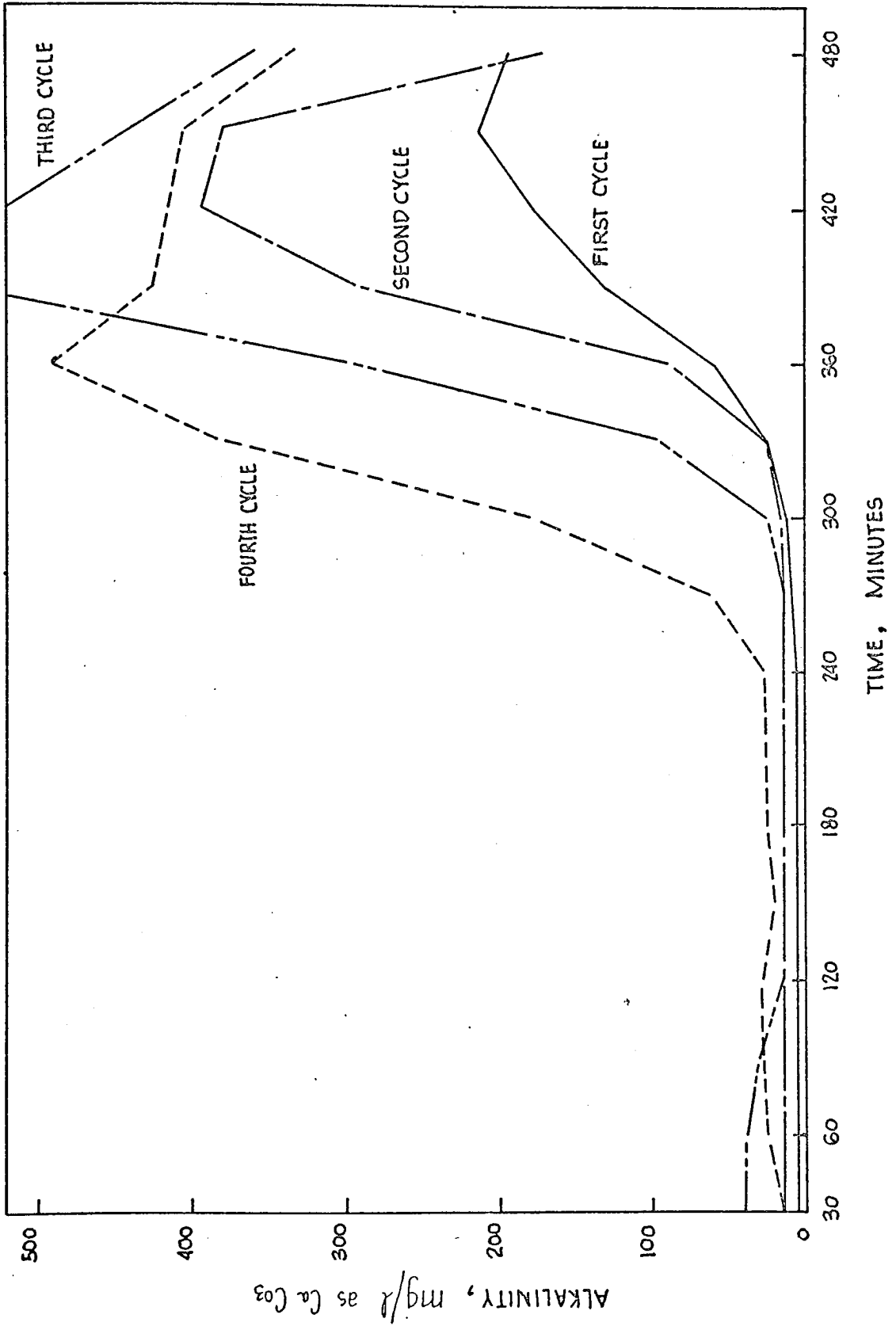


Figure 5. Alkalinity Results During Phase 1.

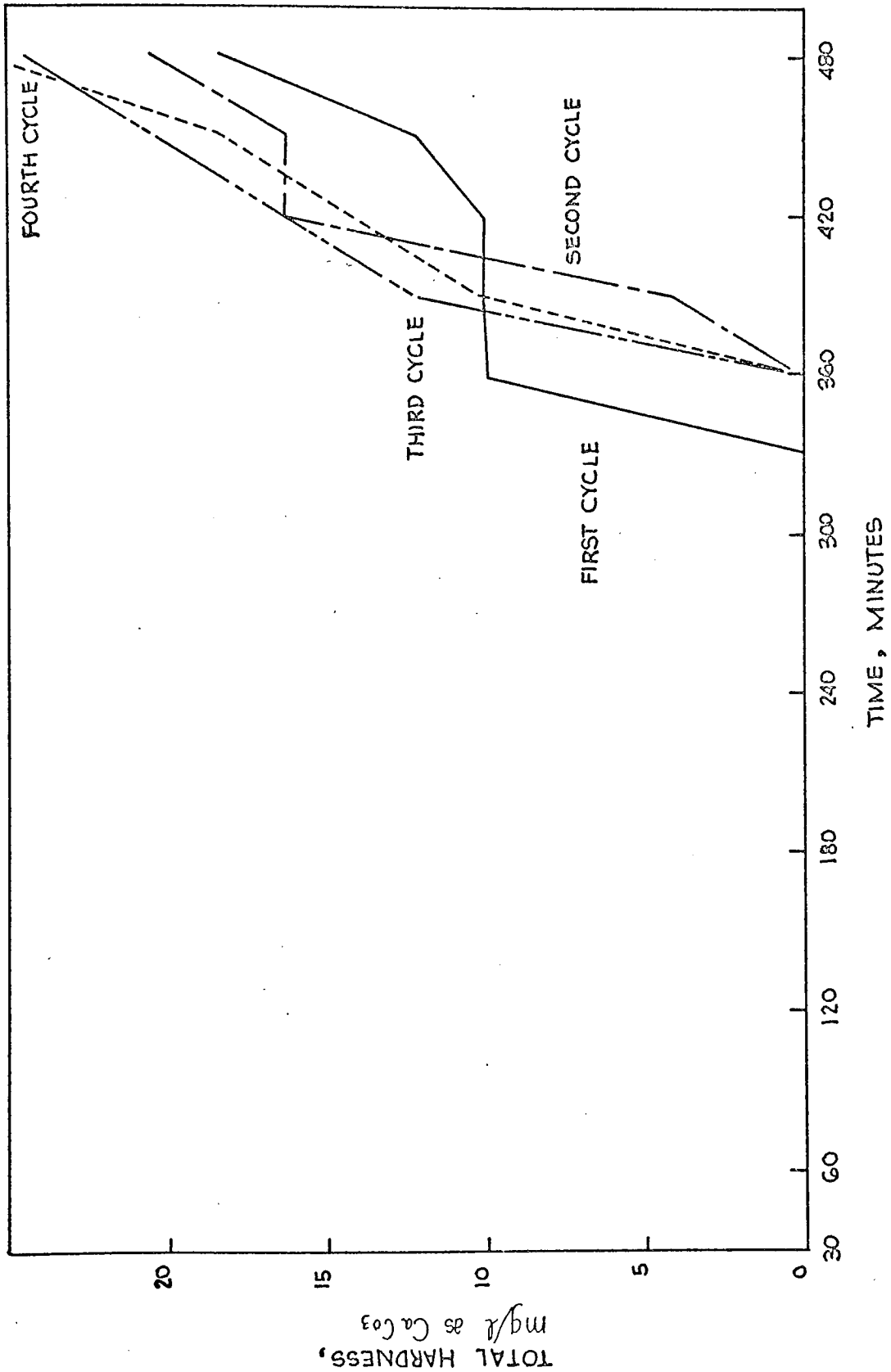


Figure 6. Total Hardness Results During Phase I.

after which they rose to a maximum value at around 390 min. Thereafter they decreased sharply with a tendency to reach values for the alum clarified effluent. Total hardness ions, which were absent before 360 min during the first three cycles, appeared at about 330 min during the fourth cycle.

Figures 7, 8, and 9 show the variations in turbidity, total residue, and total filterable residue analyses during Phase 1. These values which also remained nearly constant during the first 270 min increased after this time and almost reached values for the influent water.

Organic matter, as expressed by OA and COD tests, was low during the first 270 min of Phase 1, increasing sharply after this period of time, as shown in Figures 10 and 11. Methylene blue active substance (MBAS) was not detectable before 390 min during the first cycle; however, during the successive cycles it was detected sooner as can be seen in Figure 12. Calcium and chloride analyses (Figures 13 and 14) were conducted during the third and fourth cycles as indicators of exhaustion.

Analyses performed during this phase show that exhaustion started to occur at approximately 270 min after the cycle started. Results of these analyses increased or were detected sooner during the successive cycles (Figures 3 through 12) indicating a decrease in the original capacity of the system and possible shorter periods of time between regenerations.

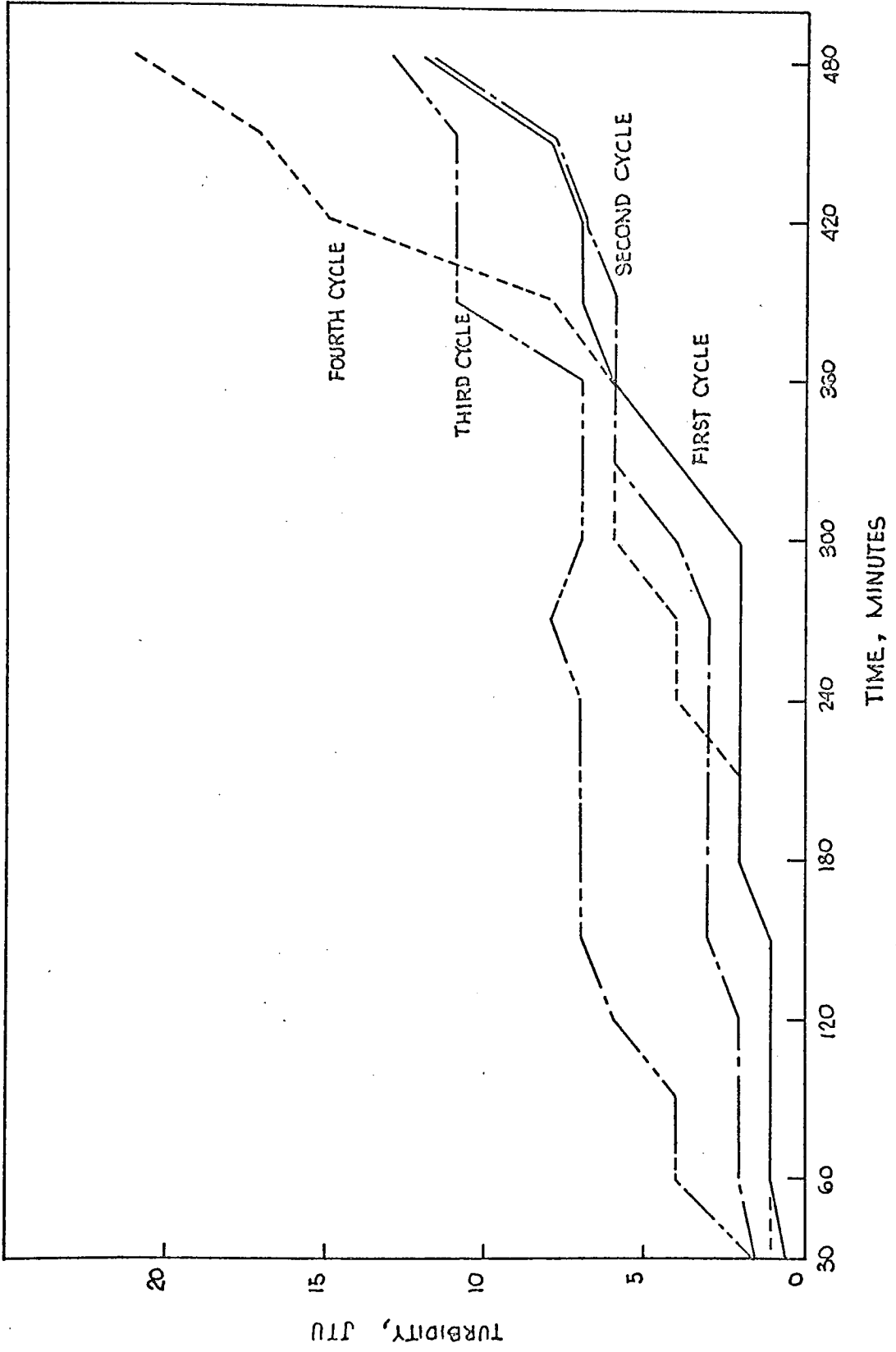


Figure 7. Turbidity Results During Phase 1.

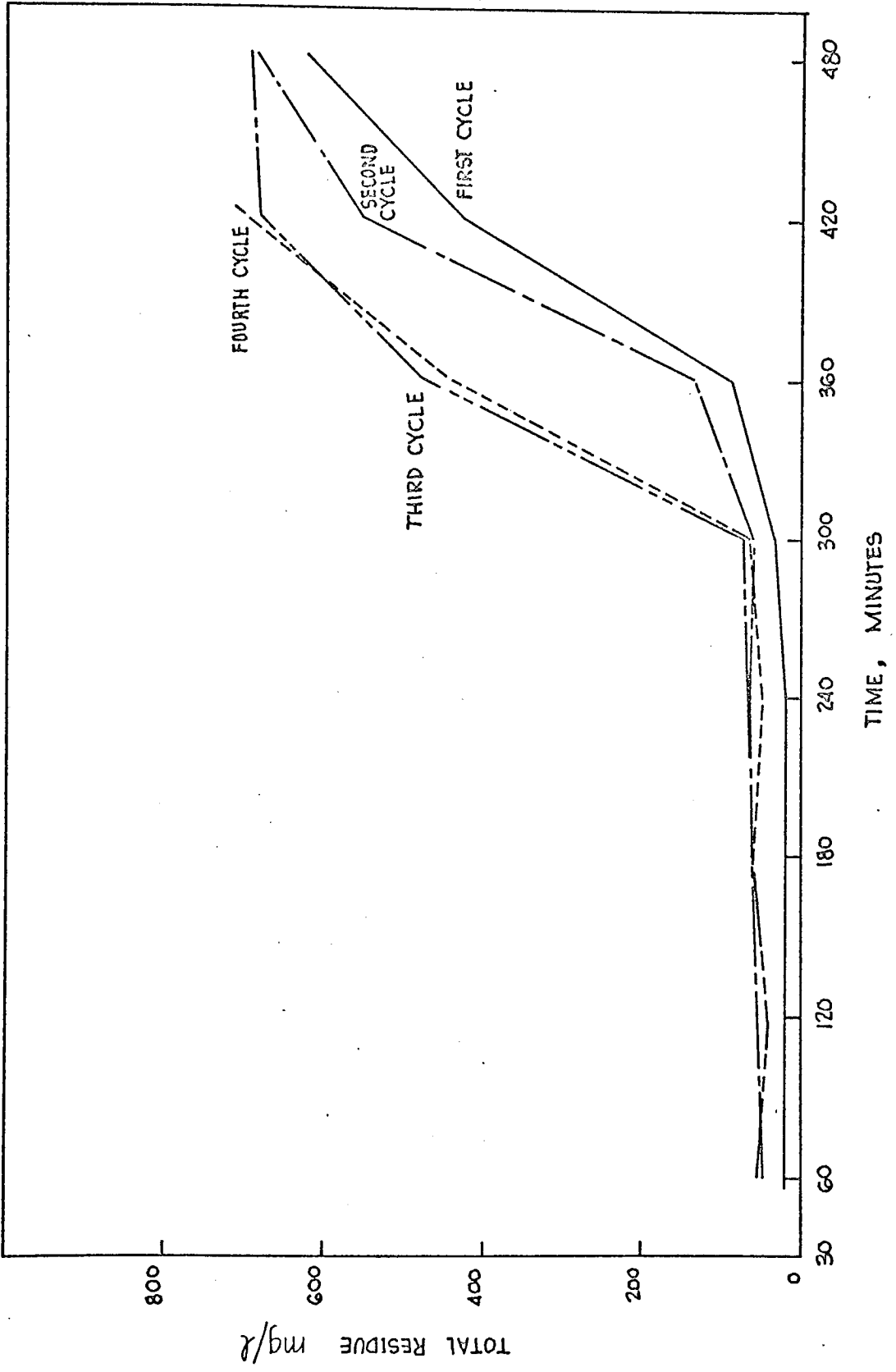


Figure 8. Total Residue Analyses During Phase 1.

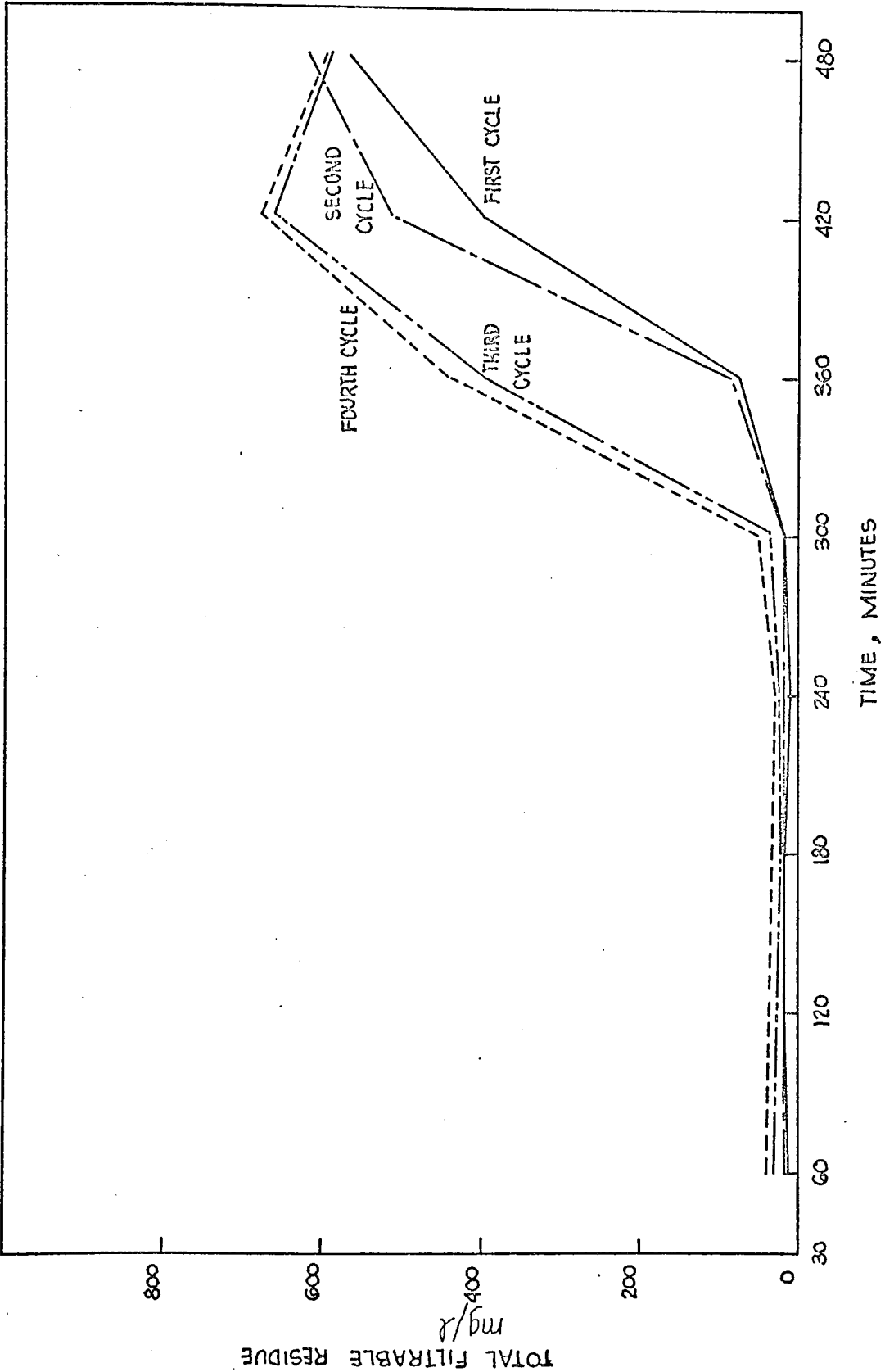


Figure 9. Total Filtrable Residue Analyses During Phase 1.

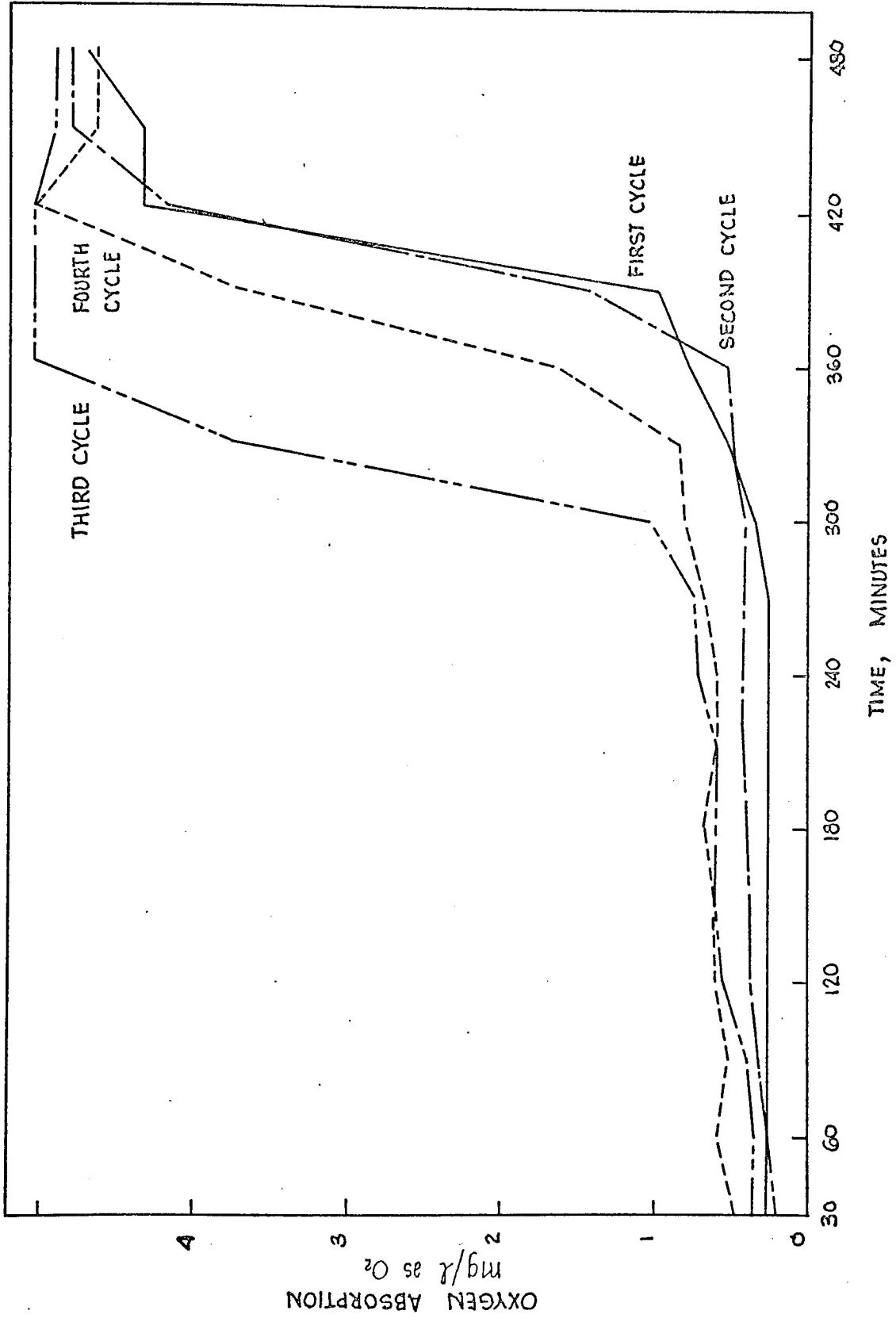


Figure 10. Oxygen Absorption Results During Phase I.

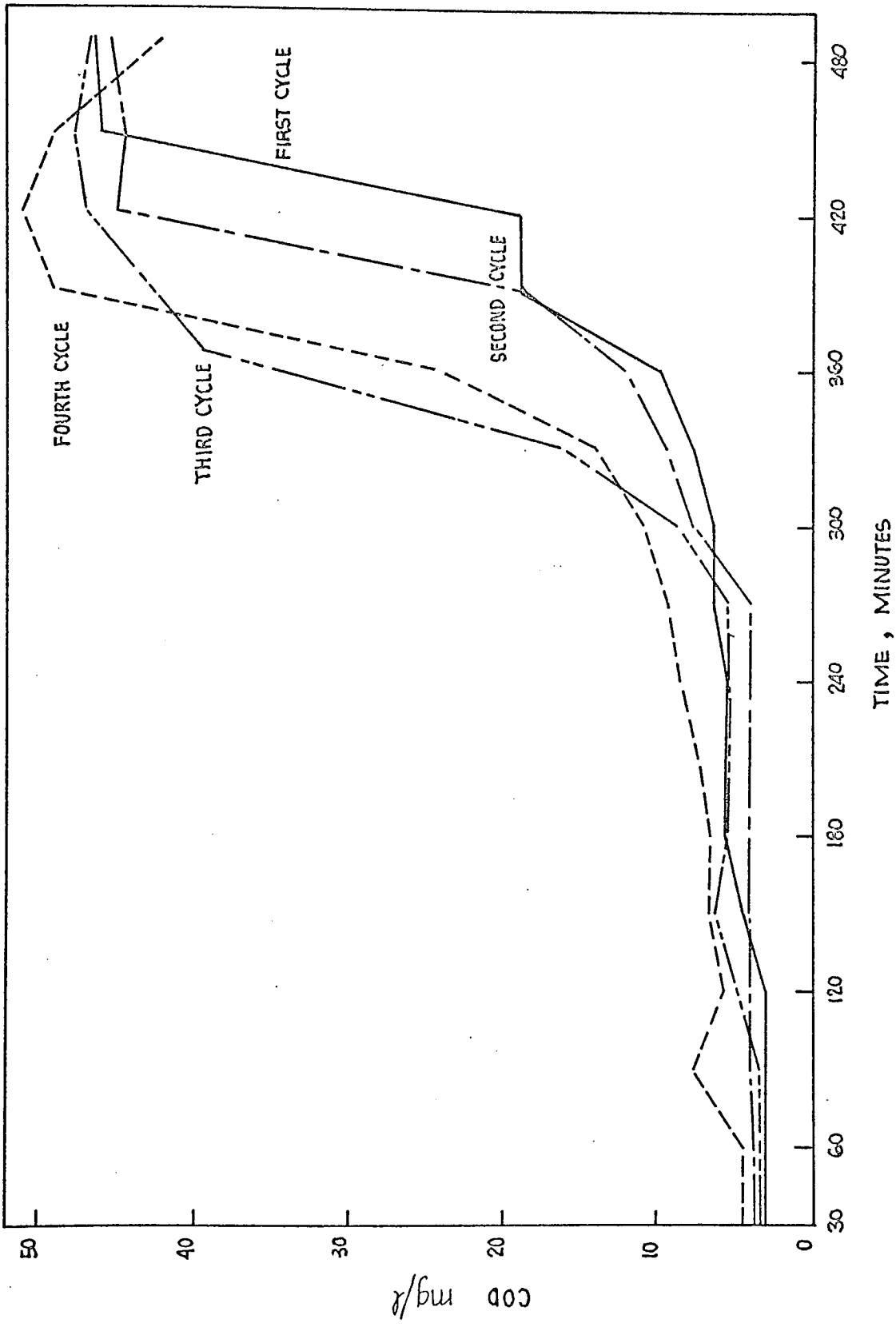


Figure 11. COD Results During Phase I.

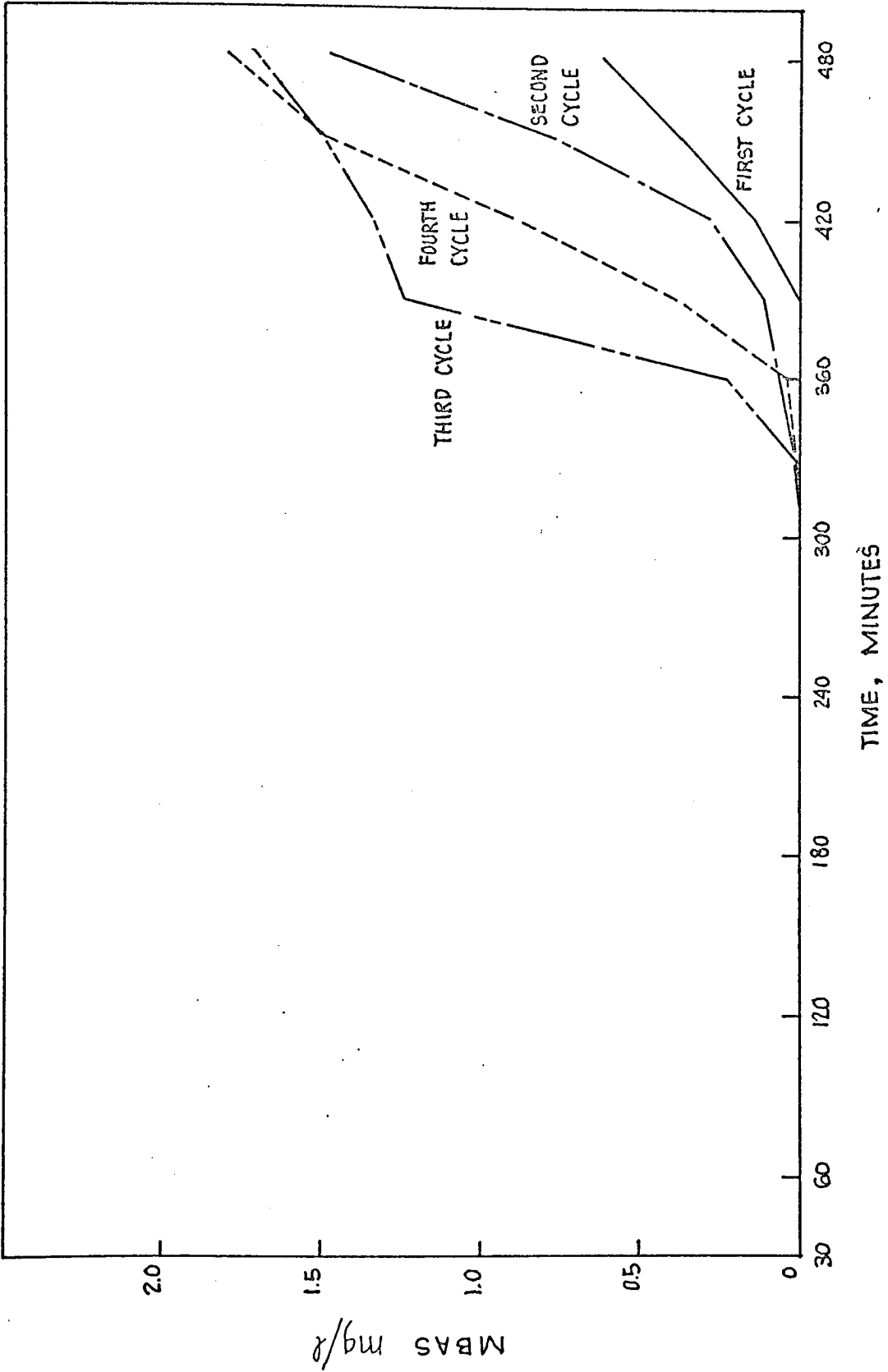


Figure 12. MBAS Results During Phase 1.

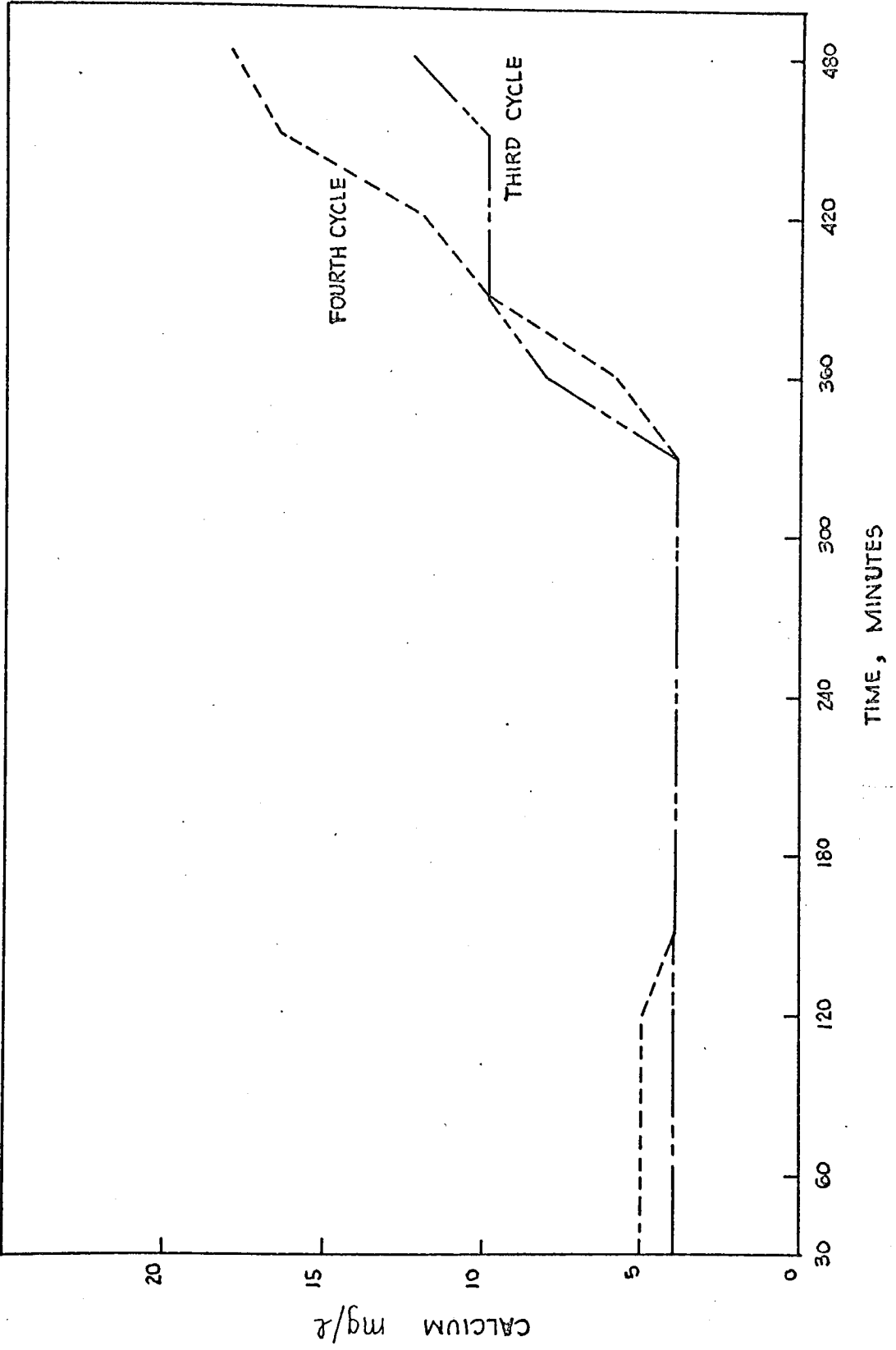


Figure 13. Calcium Results During Phase 1.

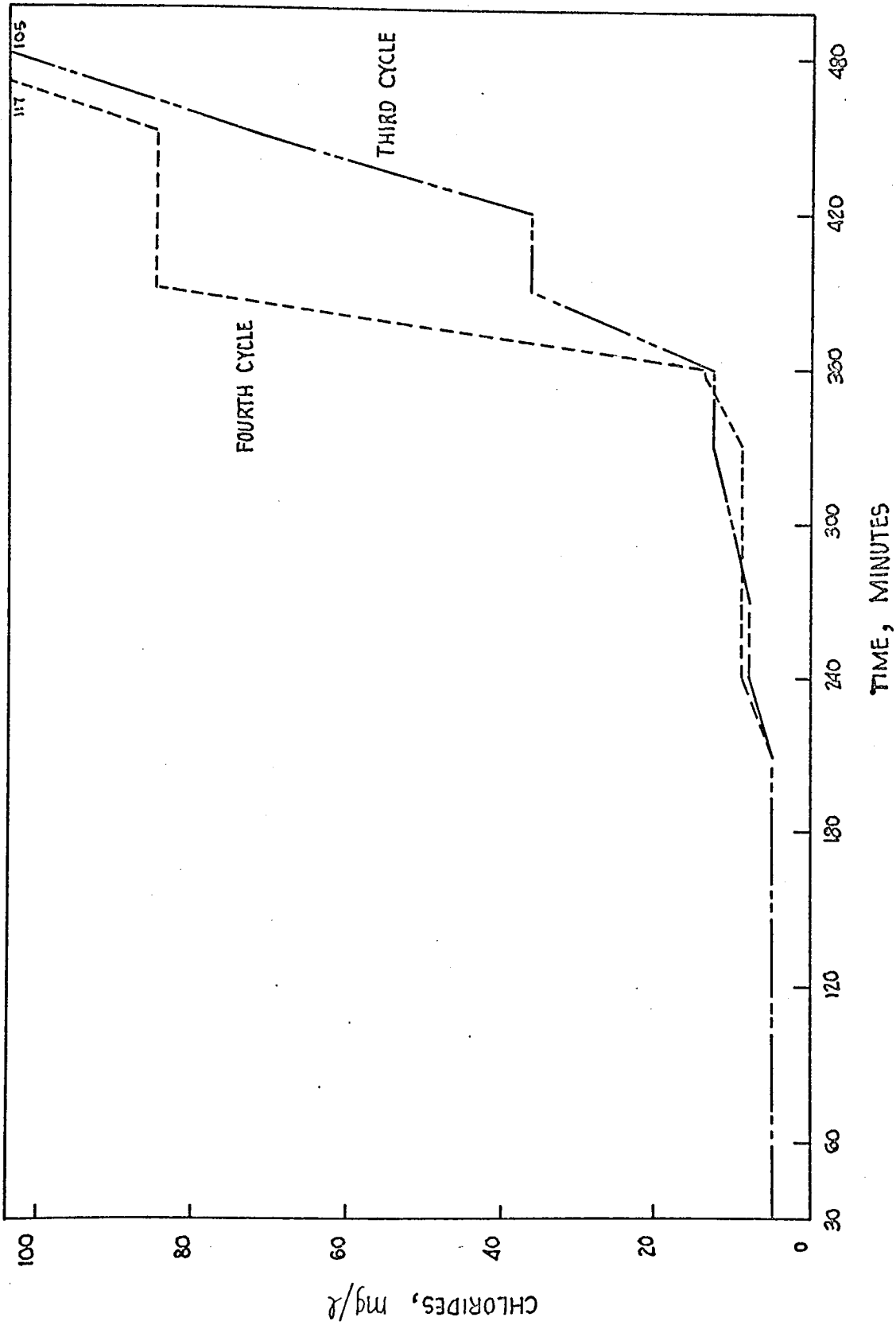


Figure 14. Chloride Results During Phase 1.

## Phase 2. Operation With Organic Screen

The procedure in this phase consisted of the installation of a new anionic resin (Dowex 11) ahead of the system used in Phase 1. As indicated by Horembala and Feldt (11), Dowex 11 has been shown to be effective in removing (scavenging) organic matter and hence prolonging the lifetime of anionic exchange resins.

Effluent samples were taken every 30 min (except for total residue and total filterable residue which were taken every 60 min) during the entire cycle. After approximately 600 min, changes indicating that the anion exchangers were becoming exhausted were observed in most tests. The cycle operation was ended after 840 min. The resins were regenerated as previously described, and the process was repeated for a second cycle of 840 min. Figures 15 through 23 show the results of analyses performed during the two operating cycles of Phase 2.

Samples for analyses taken after the alum-clarified effluent passed through the Dowex 11 resin were also conducted for the purpose of evaluating its performance. The results of these analyses can be observed in Tables 10 and 12 of Appendix B and in Figures 24 through 28.

Figures 15, 16, and 17 show the results for pH, specific conductance, and alkalinity during the entire two cycles of Phase 2. In both cycles, for the first 240 min, values of these parameters gave very similar results. At that time the capacity of the cation exchange resin began to diminish and the leakage of cations increased. The increase continued for about 60 min after which the cation exchange resin was completely exhausted.

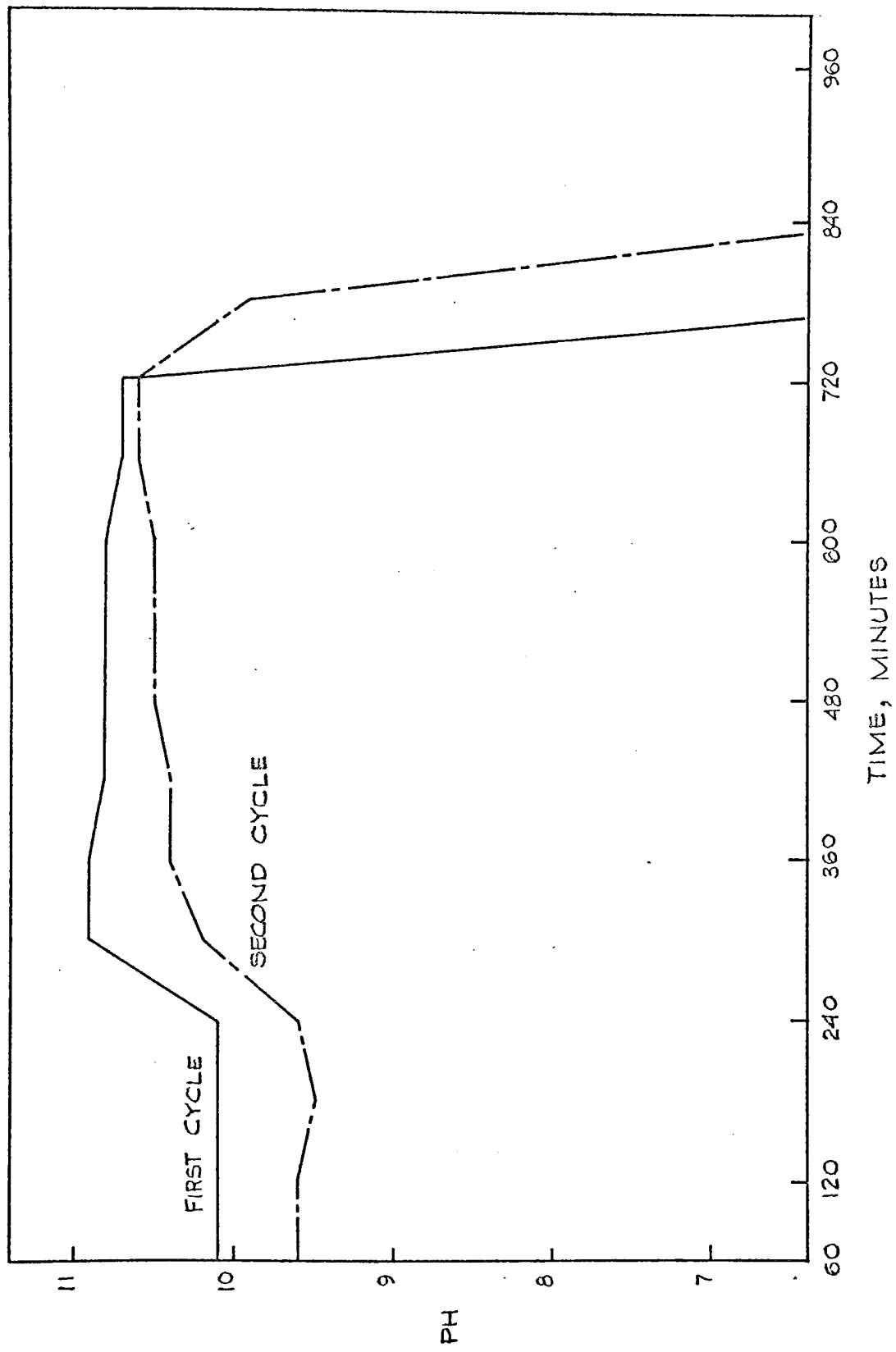


Figure 15. pH Readings During Phase 2.

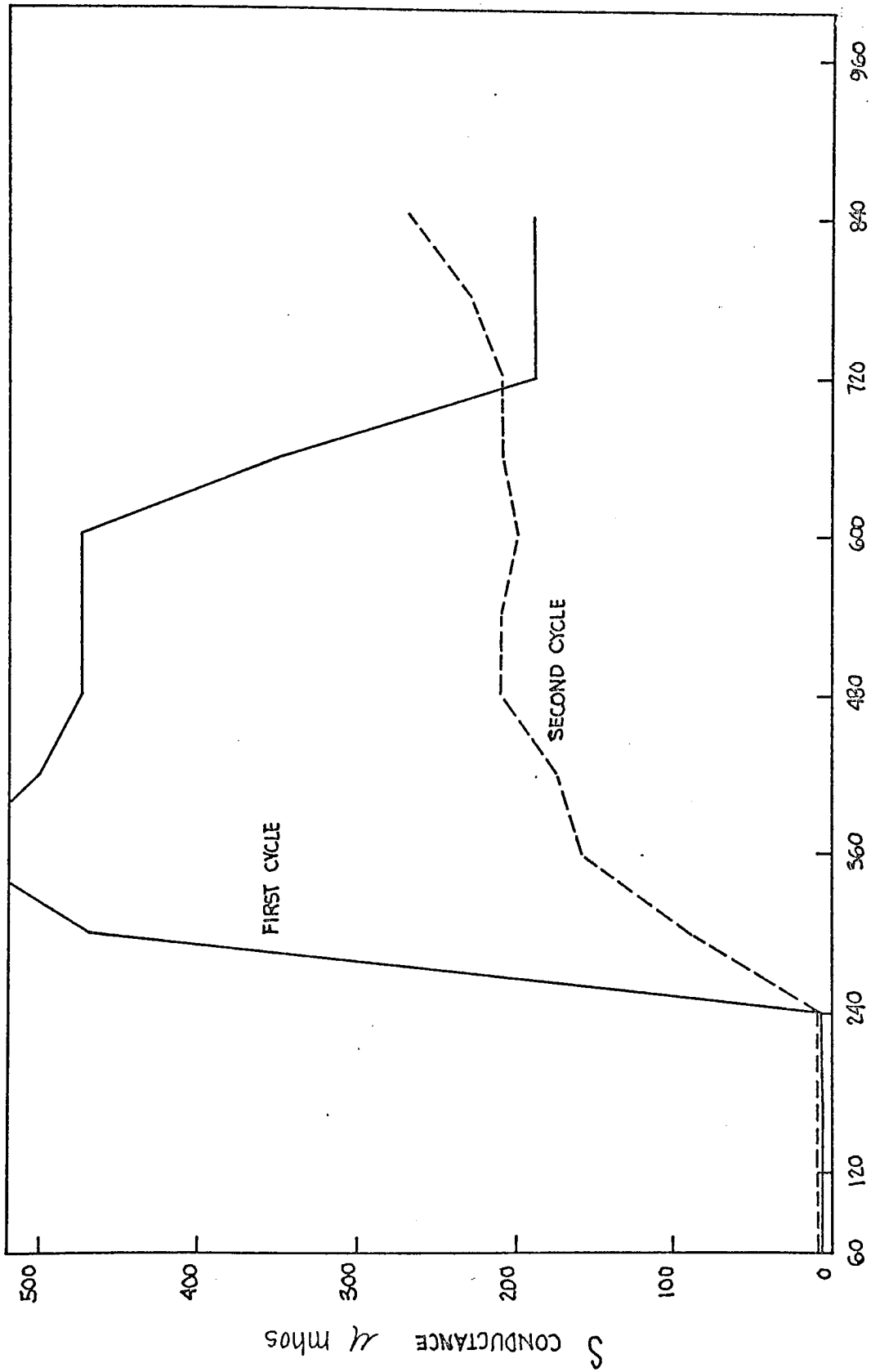


Figure 16. Specific Conductance Readings During Phase 2.

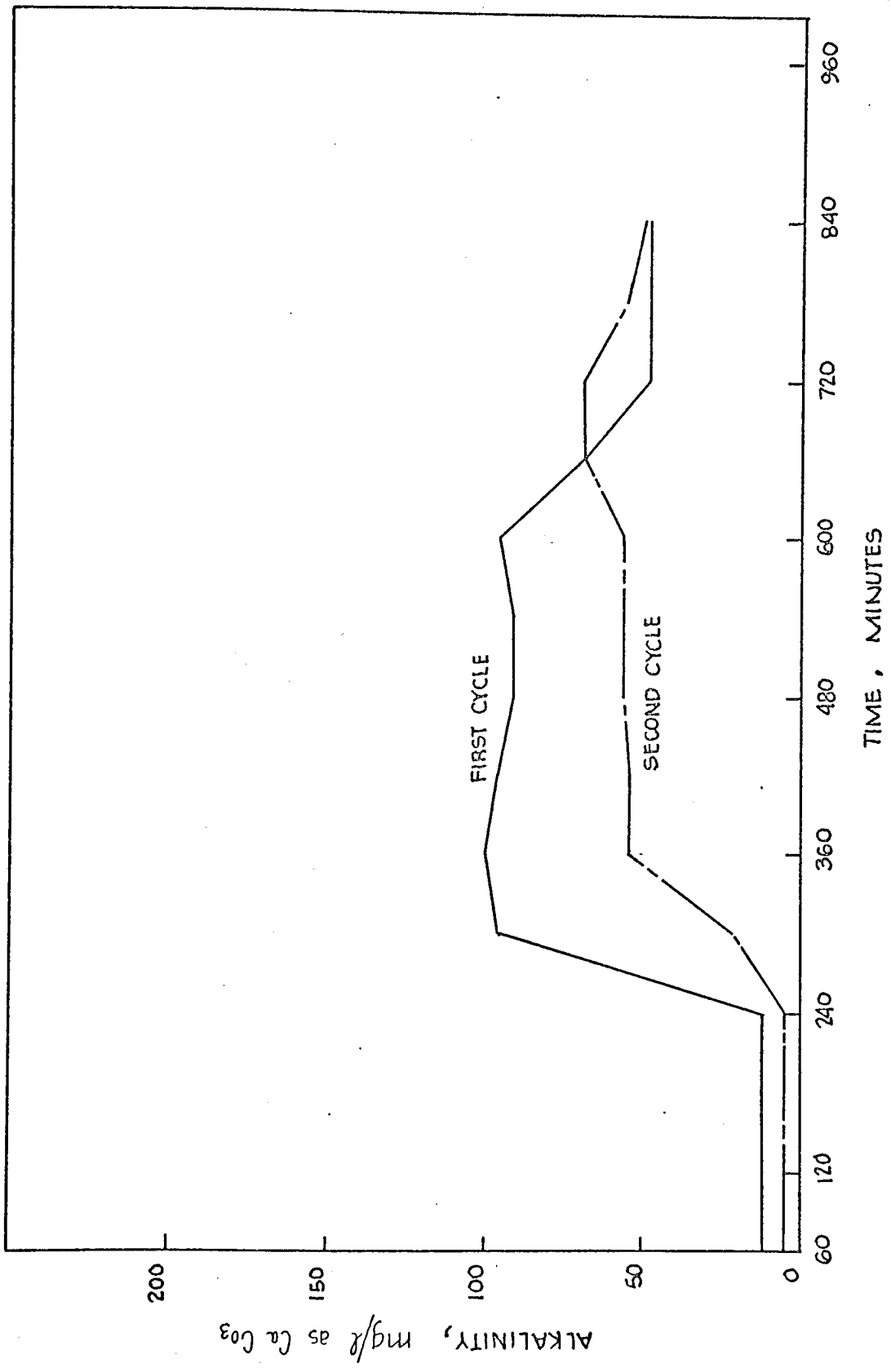


Figure 17. Alkalinity Results During Phase 2.

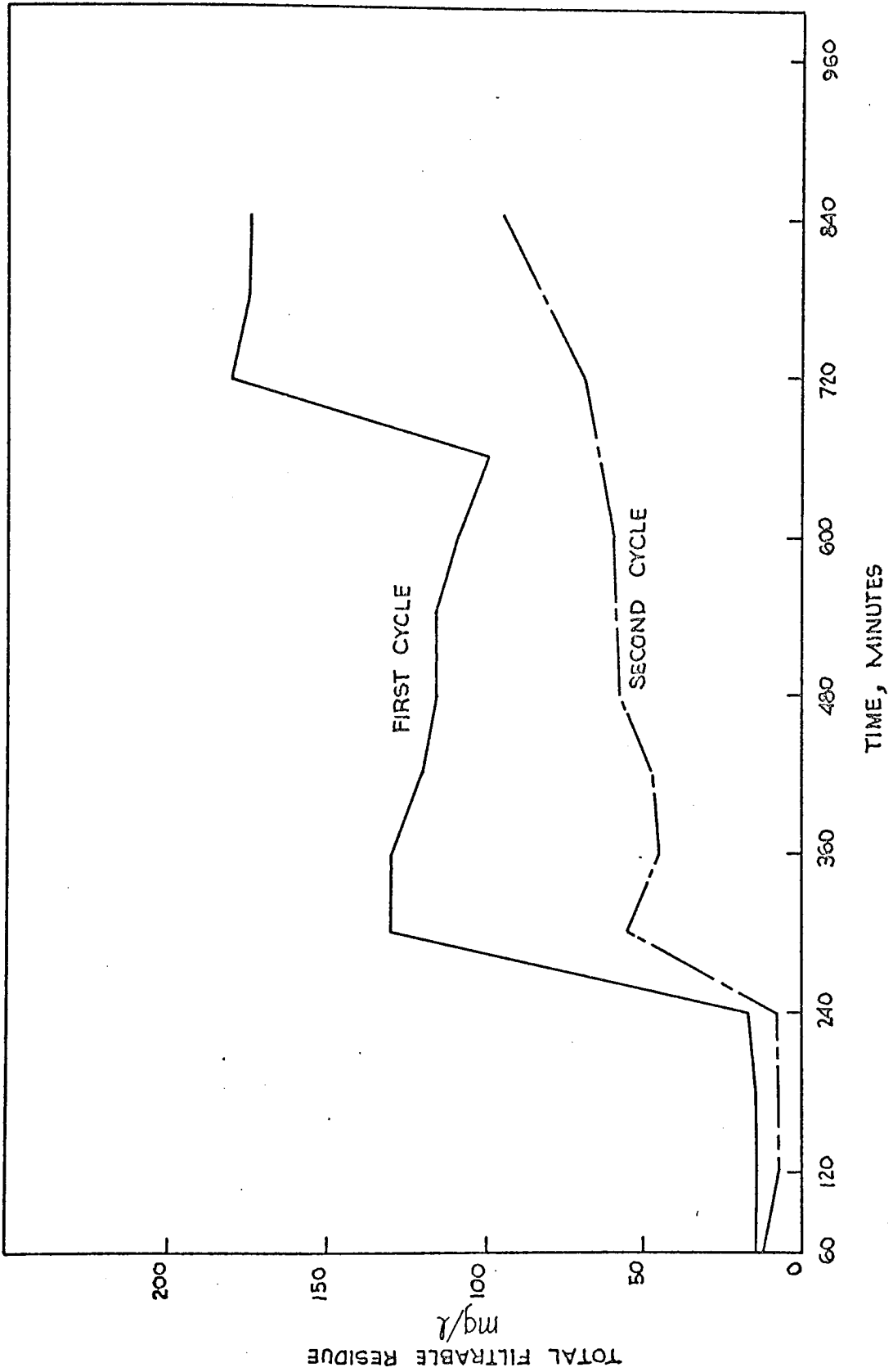


Figure 18. Total Filterable Residue Analyses During Phase 2.

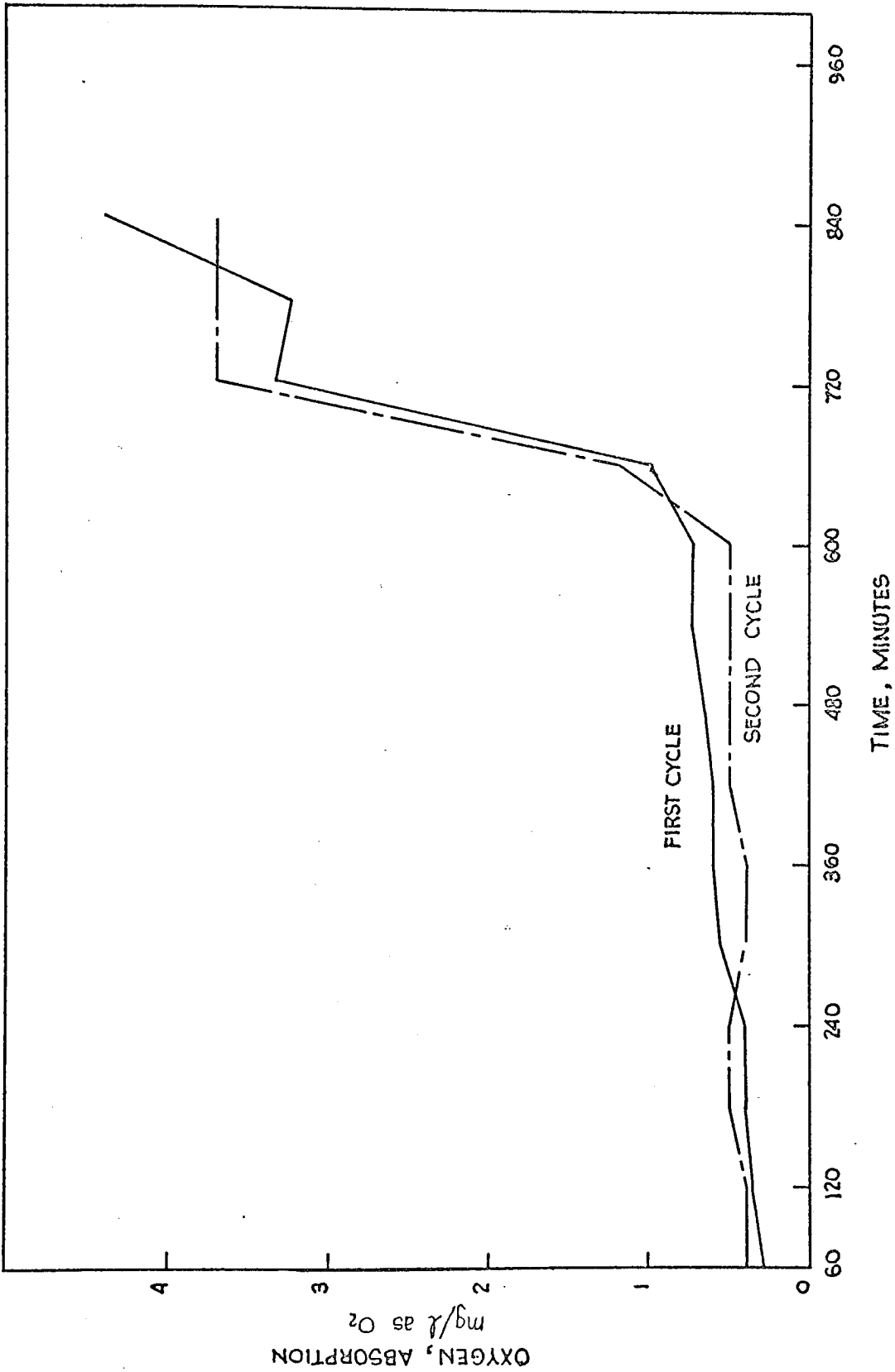


Figure 19. Oxygen Absorption Results During Phase 2.

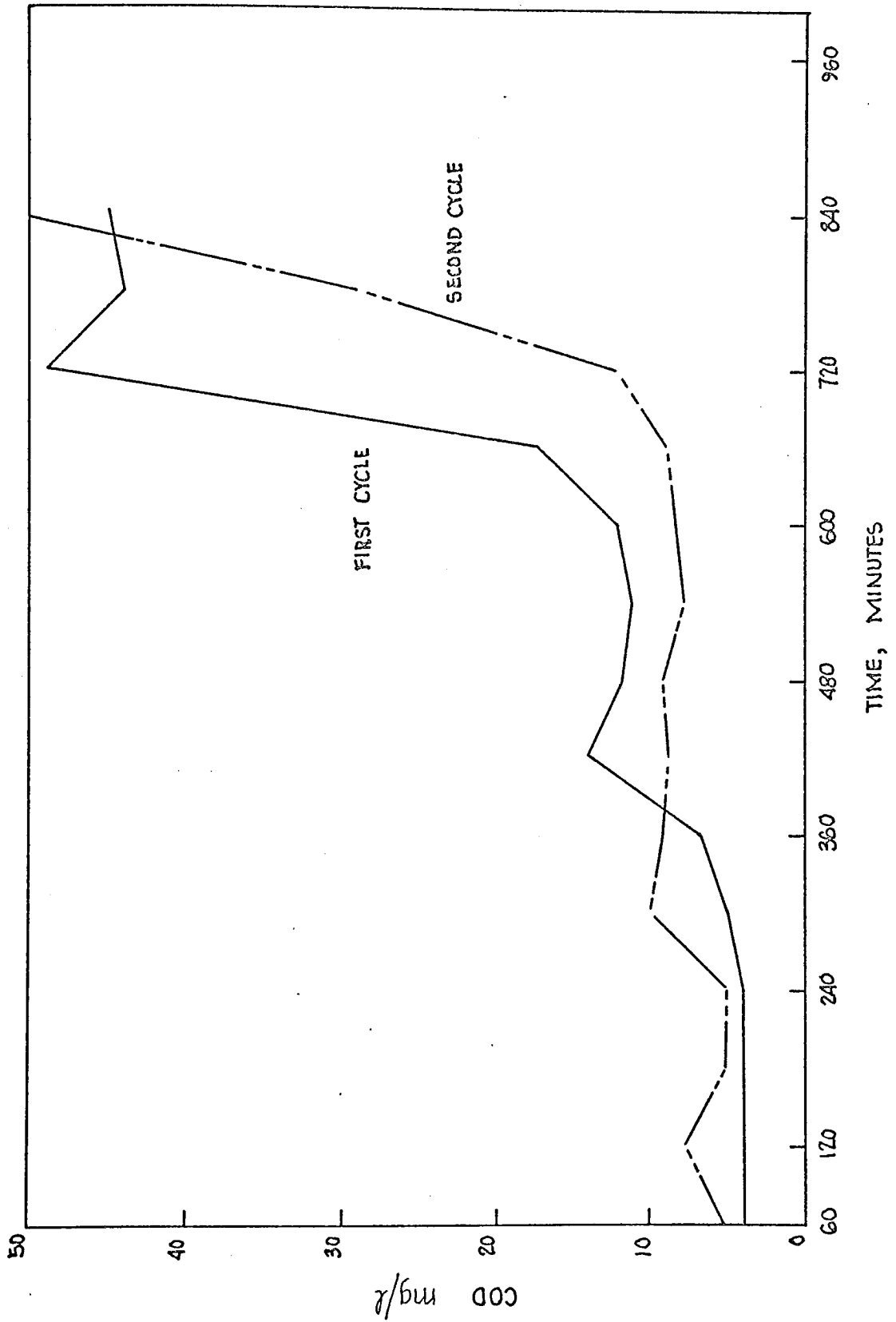


Figure 20. COD Results During Phase 2.

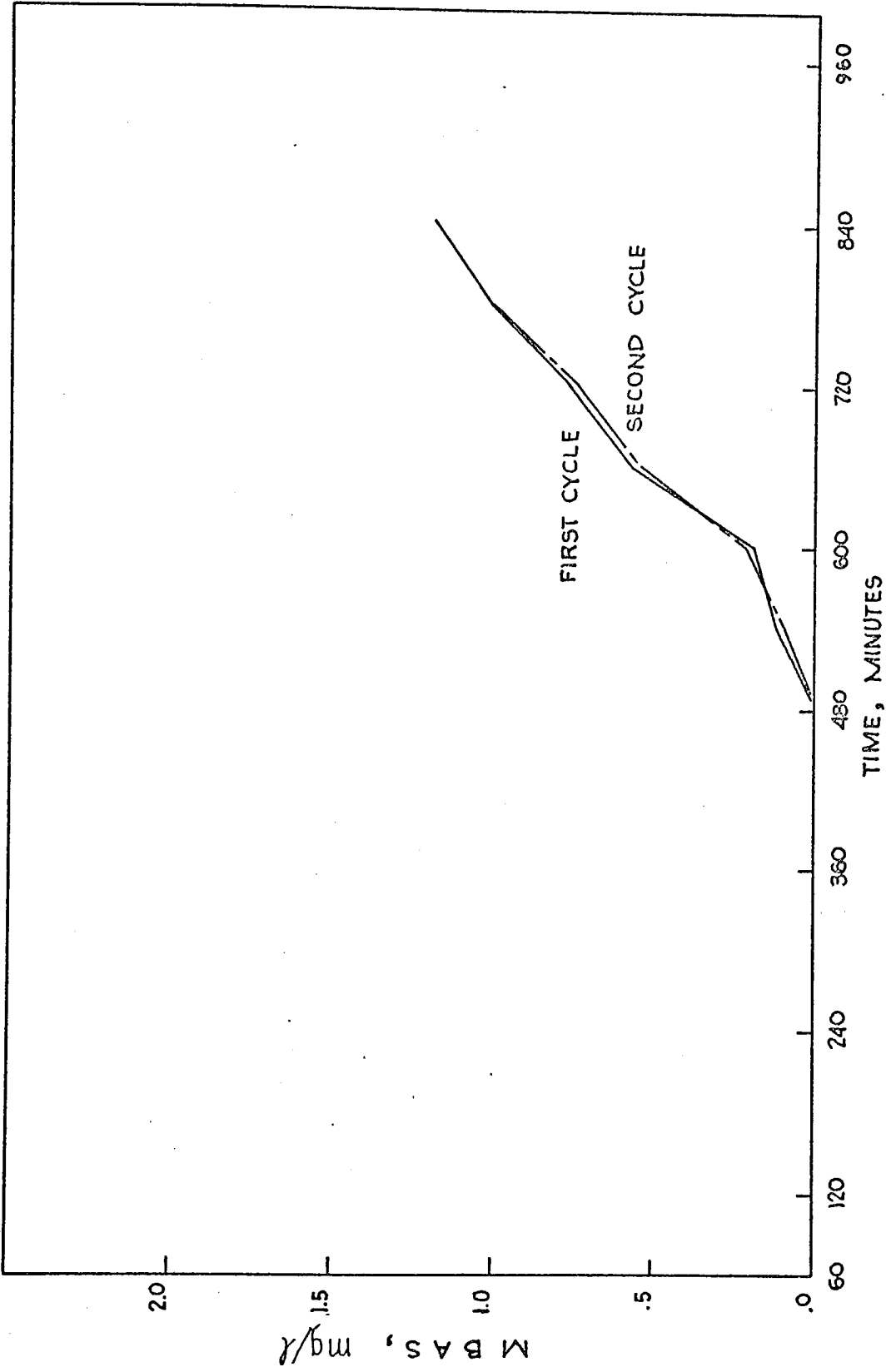


Figure 21. MBAS Results During Phase 2.

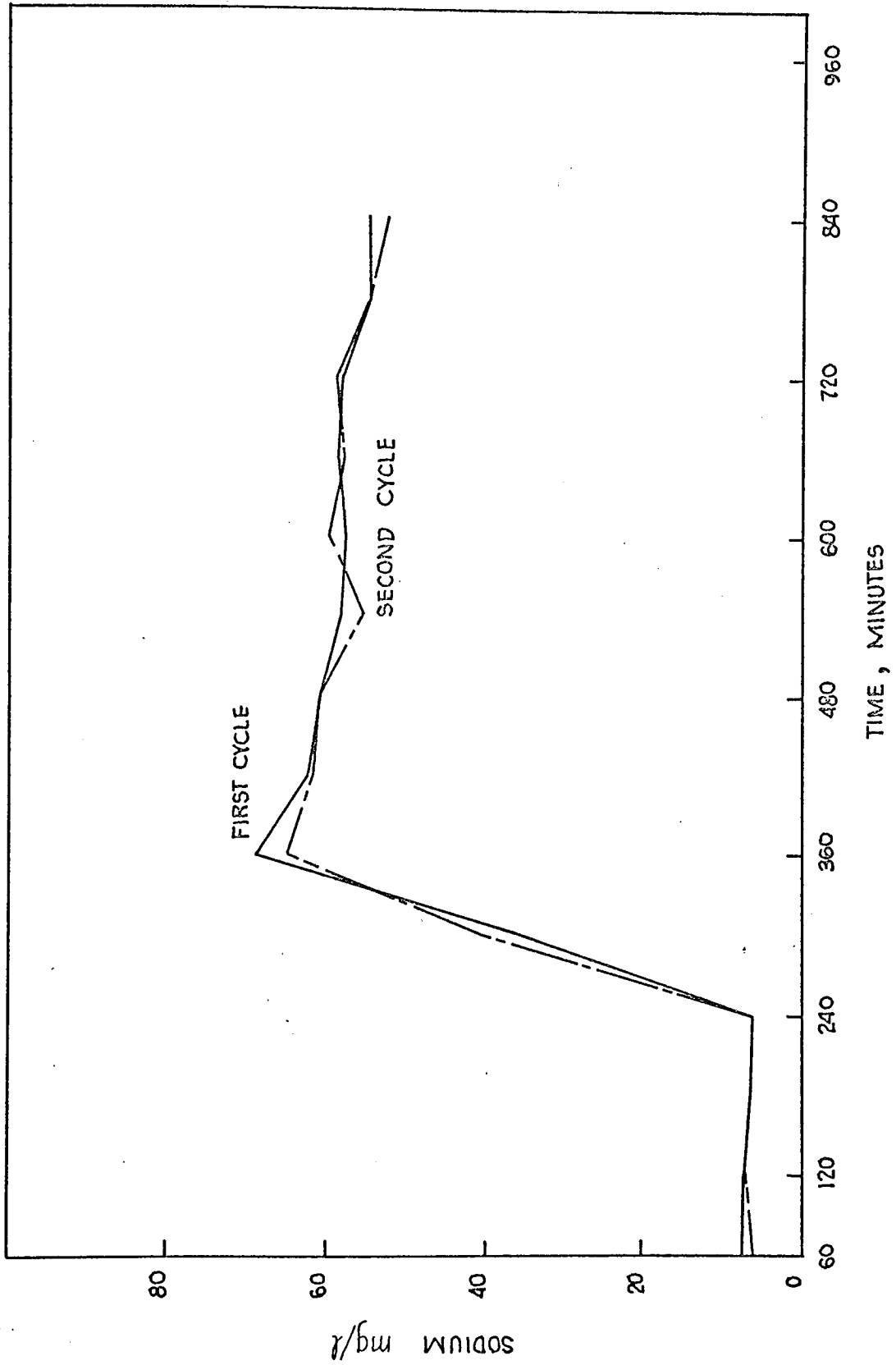


Figure 22. Sodium Results During Phase 2.

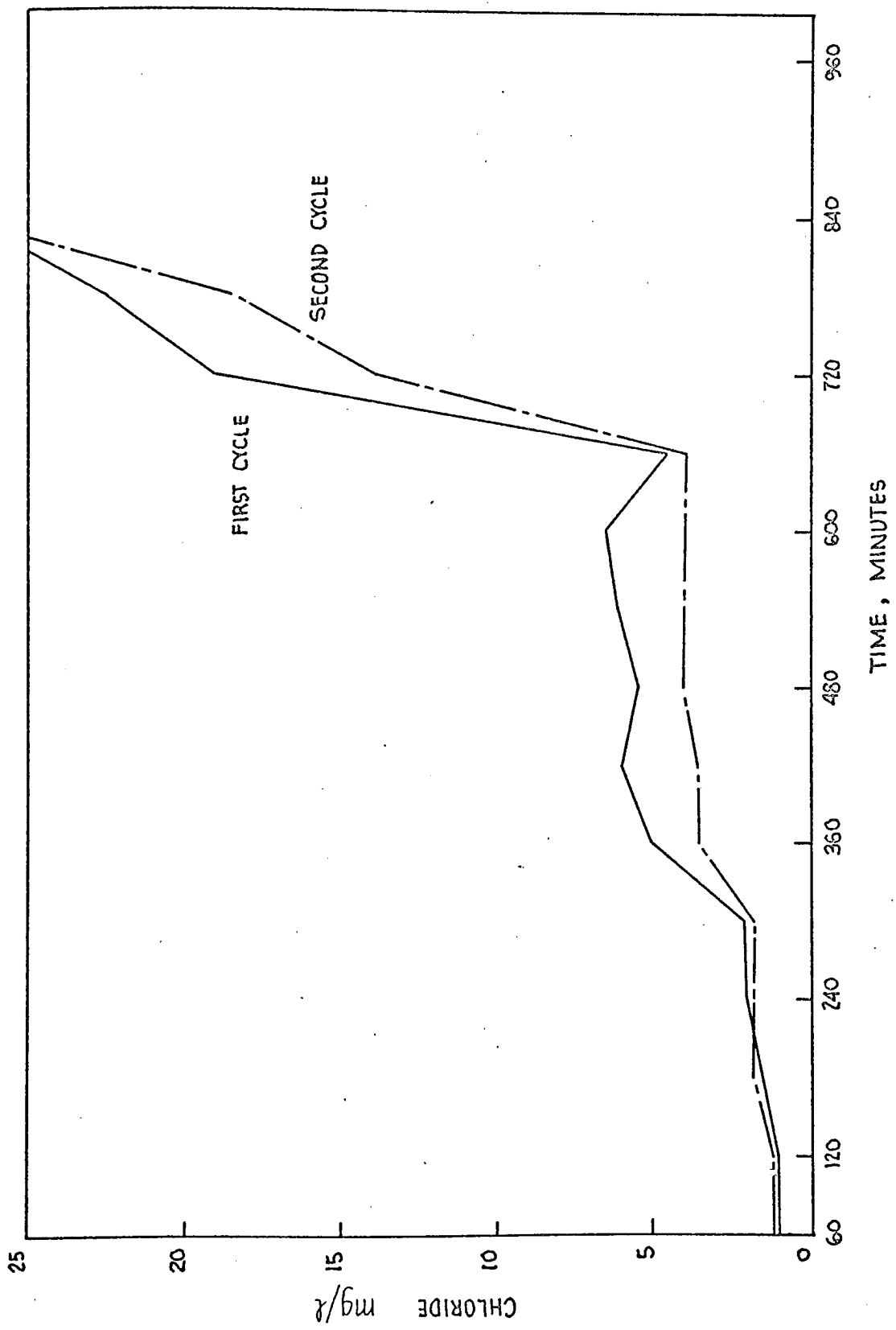


Figure 23. Chloride Results During Phase 2.

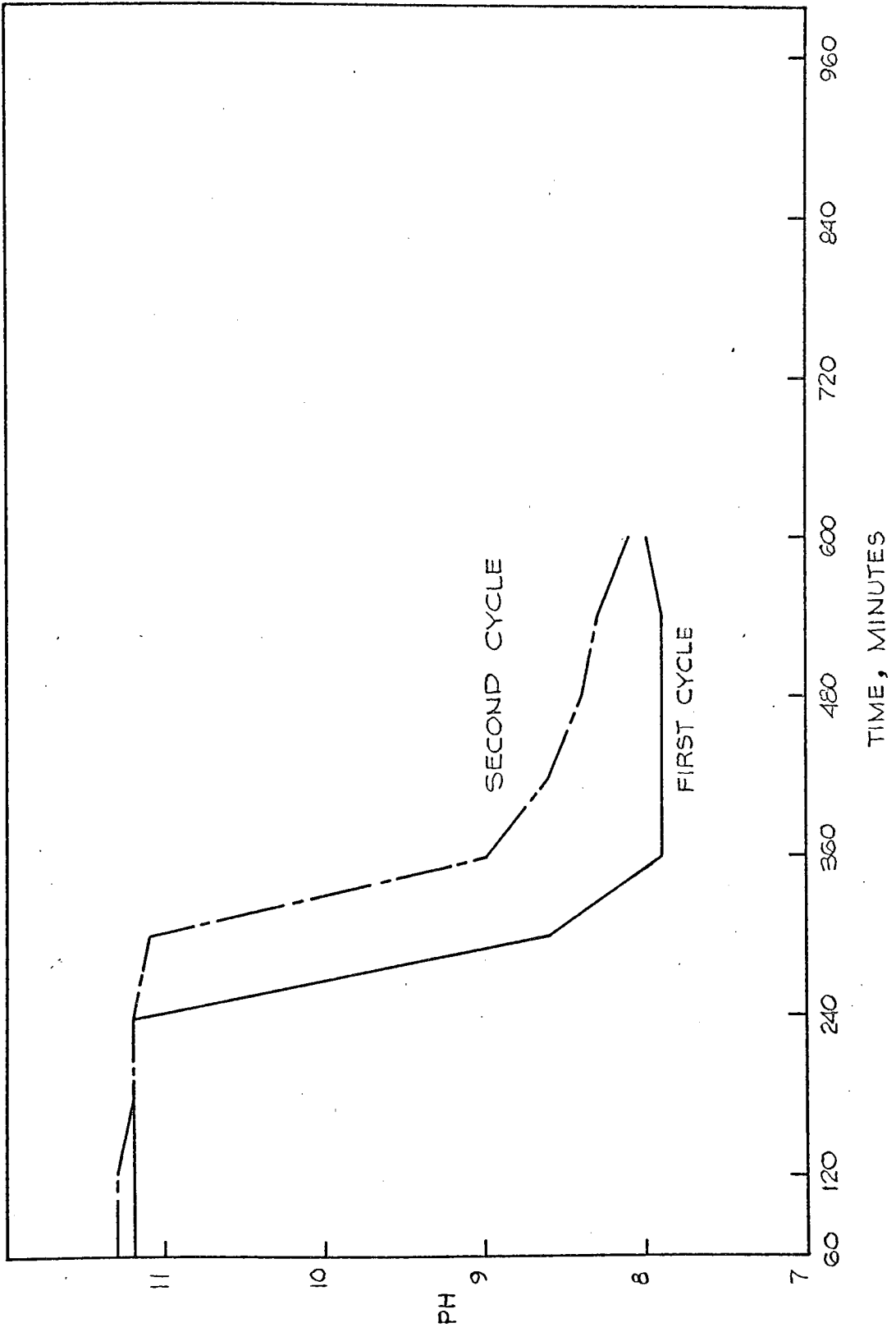


Figure 24. pH Readings After Dowex 11 Resin.

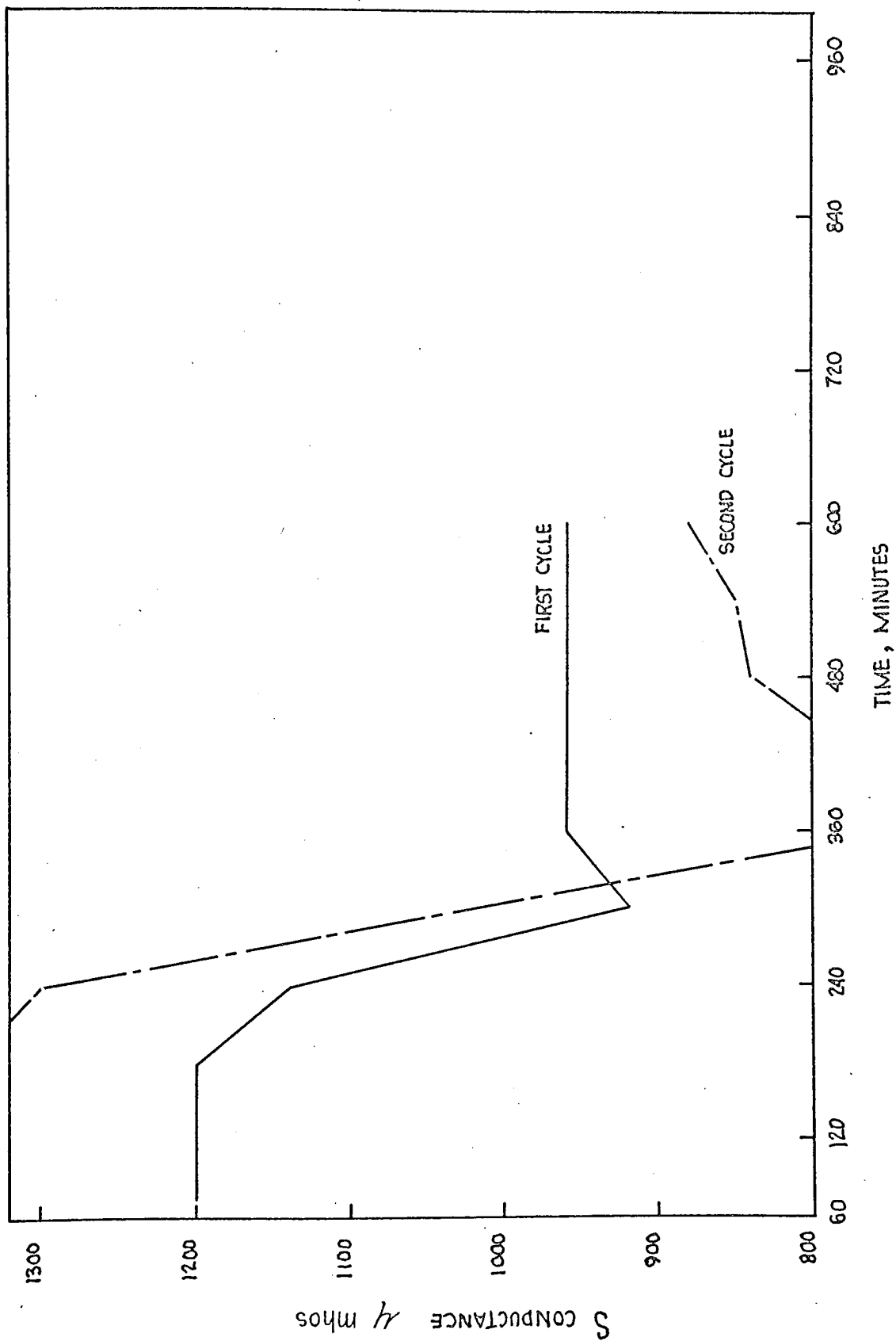


Figure 25. Specific Conductance Readings After Dowex 11 Resin.

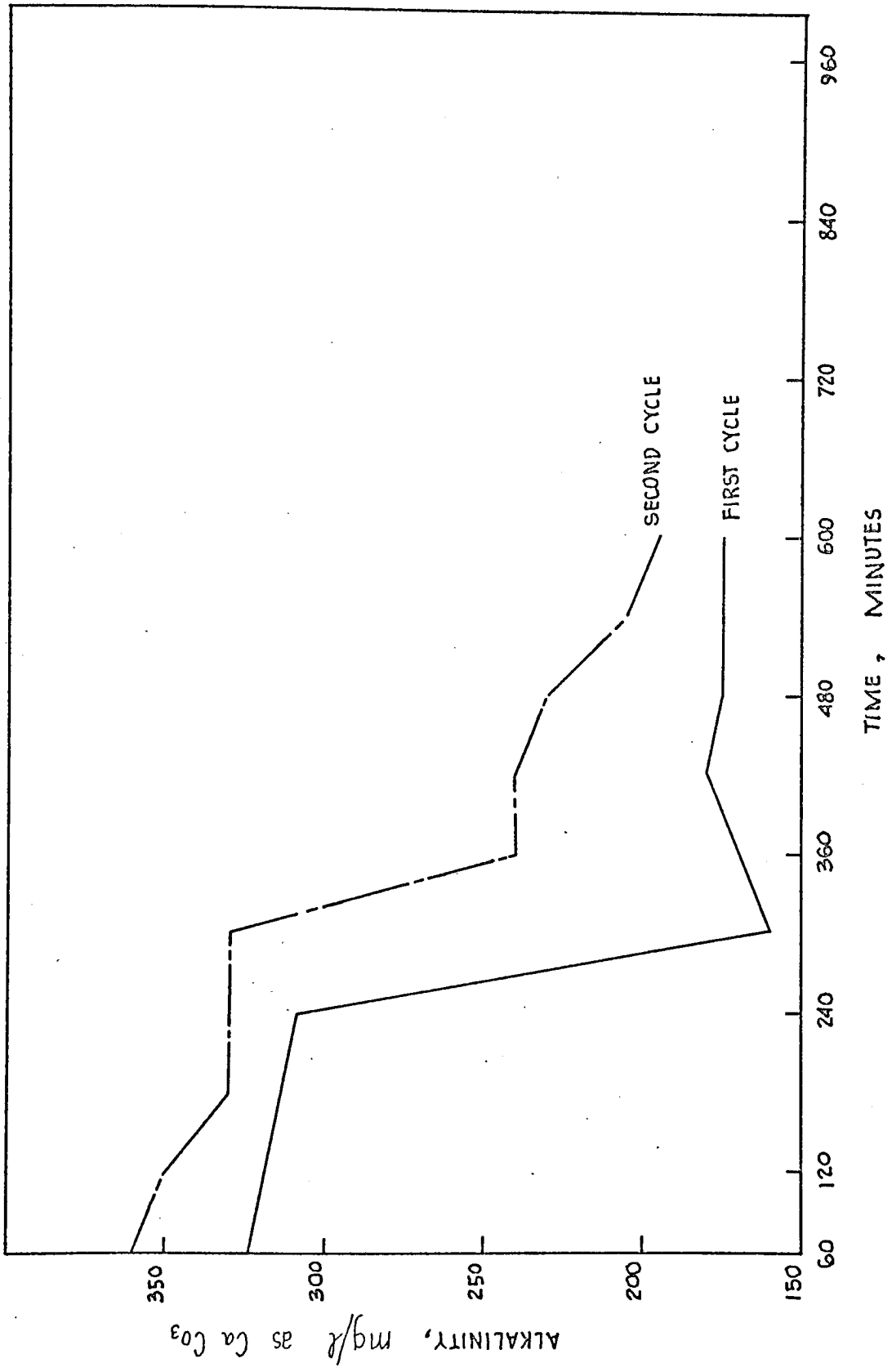


Figure 26. Alkalinity Results After Dowex 11 Resin.

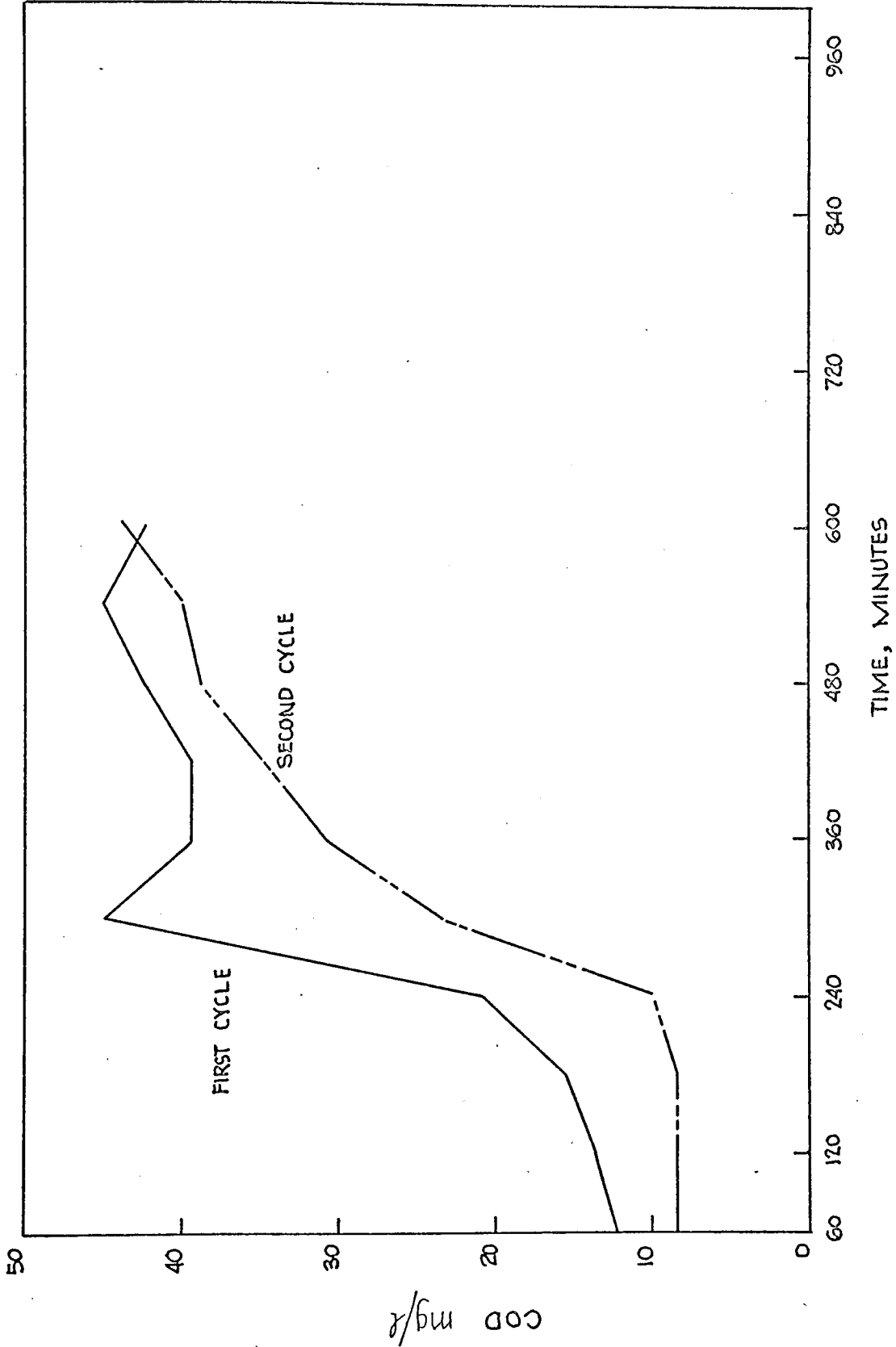


Figure 27. COD Results After Dowex 11 Resin.

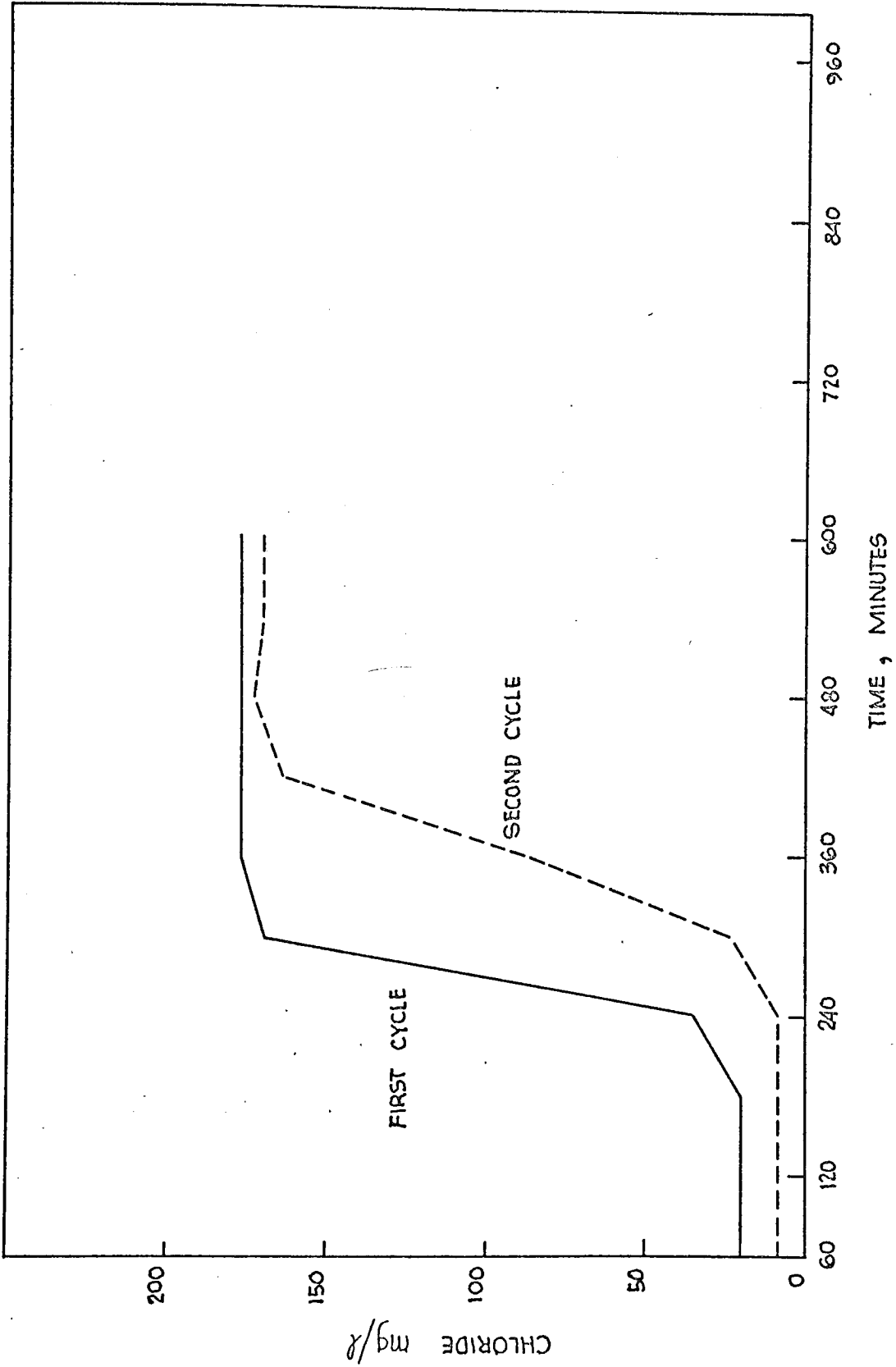


Figure 28. Chloride Results After Dowex 11 Resin.

After 240 min, the concentration of hydroxide ions in the effluent rose, causing the pH, specific conductance, and alkalinity to increase. After 300 min, when the cation exchange resin was considered to be exhausted, the values became more stable until a greater amount of leakage started to be detected in the anionic exchangers. This greater amount of leakage occurred at approximately 600 min and was the beginning of exhaustion for the anion exchange resins.

The results for the second phase showed a greater removal of ions than during the first cycle. If organic poisoning of the resins were occurring, one would expect that the reverse would be true--that capacity would be reduced. Since this did not occur it appears that the addition of the Dowex 11 ahead of the other two resins was effective in preventing fouling. In this case, however, there should have been no change rather than the improved capacity found. This inconsistency is perhaps due to side wall effect in the columns, uneven distribution of the flow through the columns, or the original conversion of the resin to the proper ionic form.

Total filterable residue analyses remained very low for the first 240 min of both cycles (Figure 18). An increase in total filterable residue occurred when cation exchange resin was beginning to exhaust. Afterwards, these results became more stable for as long as the anion exchange resins show no exhausting symptoms.

Organic matter analyses determined by the OA and COD tests (Figures 19 and 20) showed very low residuals for the first 600 min,

indicating that anion exchange resins were mainly responsible for this removal.

Concentrations of MBAS were almost identical during the two operating cycles (Figure 21) and did not appear before 480 min in either cycle. Residuals of these substances started to appear when the anion exchange resin was decreasing in capacity and increasing in leakage.

Sodium and chloride analyses (Figures 22 and 23), which were indicators of the performance of the system throughout the entire operation, gave almost identical results during both cycles. This was an indication that the column operation was retaining the original capacity.

Dowex 11 installed ahead of the other two resins proved to maintain its original capacity and properties since no indication of fouling was observed (Figures 24 through 28). There is no doubt that during the two cycles of this phase much lower concentrations were obtained among the different components analyzed, showing that the performance of a demineralizing system can be improved with longer column paths and proper protection for fouling agents. Concentrations of these components analyzed did not have a tendency to increase during the second cycle as happened with successive cycles of Phase 1.

#### Application for Industrial Needs

The ideal quality of water required for industrial use varies widely for the many purposes to which water is put. Needless to say, it is impossible to organize the quality requirements of the water used for each of the many different industrial processes into a single set of standards. Such quality requirements differ

far too much to allow any broad generalization or simplification. Within any industrial plant, water may have several functions, the quality requirements for which vary markedly (5, p. 250).

In general, industries are willing to accept for most processes water that meets drinking water standards. Where water of higher quality is required, industries must rely upon appropriate in-plant treatment.

The quality of the water obtained in this study meets most of the suggested limits of tolerance for waters intended for general industrial uses. Among the different industrial uses where the water obtained might be used, only two applications will be mentioned in this thesis. Tables 3 and 4 show the comparison between the suggested limits for boiler feed waters and textile manufacture water with water obtained during this experiment.

#### Operating Cost

With the installation of the Dowex 11 resin ahead of the demineralizer, it was possible to increase the operating cycle from 300 min to 660 min. At this time, exhaustion started in the anion exchange resins, causing the concentration of anionic ions to increase and reach values similar to those of the influent water.

An operating cycle was assumed to be that period of time before a sharp reduction in the quality of the effluent was observed. For the purpose of this study, 660 min was considered the service time for the operating cycles of Phase 2.

Table 3. Comparison between the suggested limits of tolerance for boiler feed waters and the water obtained during this study.\*

	Boiler Feed Water (15)			A
	0-150	150-250	250-400	
Pressure, psi	0-150	150-250	250-400	-
Turbidity, JTU	20	10	5	1
Hardness as CaCO <sub>3</sub>	80	40	10	0
Bicarbonate as CaCO <sub>3</sub>	41	24.5	4.1	5
Carbonate as CaCO <sub>3</sub>	333	166	66	52
Hydroxyl as CaCO <sub>3</sub>	147	117	88	29
Total solids	3000-500	2500-500	1500-100	135
pH value (minimum)	8.0	8.4	9.0	9.9

\*Units are in mg/l except for those specified.

A - Water obtained during this study.

Table 4. Comparison between the requirements for textile manufacture waters and the water obtained during this study.\*

Analyses	Requirements for Textile Manufacture Water (15)	Water Obtained During This Study
Turbidity, JTU	0.3-25	1
Color	0-70	-
Hardness	0-50	0
COD	15	14.2
Calcium	10	0
Magnesium	5	0
Sulfate	100	-
Chloride	100	6.5
Bicarbonate	200	9

\*Units are in mg/l except for those specified.

Operating costs for ion exchange processes are limited principally to the quantity of chemicals used in the process. The cost of chemicals per unit volume of water treated is almost directly proportional to the amount of mineral removed. In demineralization by ion exchange resins, the amount of solids present in the feed water is a dominant factor since the cost of chemicals could reach prohibitive figures.

Ahlgren (16) has estimated that total costs per ion exchange treatment of water with a total filterable residue level similar to those in this study are approximately \$1.10/1000 gal. He has also shown that the chemical cost for waters with total filterable residue (mg/l as  $\text{CaCO}_3$ ) of 100, 250, and 500 can be treated for \$0.13, \$0.35, and \$0.70 per 1000 gal, respectively. The calculated chemical treatment cost for water used in this study was \$0.36/1000 gal at total filterable residue values of about 600 mg/l. This assumes a cost for sulfuric acid of 1.7¢/lb and caustic soda of 3.3¢/lb (17). The calculation for chemical treatment was done as follows:

$$\text{Volume of resin: } 8.36 \times 10^{-3} \text{ cu ft}$$

$$\text{Time: } 660 \text{ min}$$

$$\text{Flow rate: } 2 \text{ gpm/cu ft}$$

$$\text{Chemical cost: } 2(8.36 \times 10^{-3}) \times 660 \text{ min} \times 2 = 22.07 \text{ gal}$$

$$\frac{16.72 \times 10^{-3} \text{ cu ft} \times 1000 \text{ gal}}{22.07 \text{ gal}} = 0.757 \text{ cu ft}$$

$$9 \text{ lb/cu ft} \times 1.7\text{¢/lb} \times 0.757 \text{ cu ft} = 11.68\text{¢/} \\ 1000 \text{ gal}$$

$$9.5 \text{ lb/cu ft} \times 3.3\text{¢/lb} \times 0.757 \text{ cu ft} = 23.92$$

$$11.68\text{¢/}1000 \text{ gal} + 23.92\text{¢/}1000 \text{ gal} = 35.60\text{¢/} \\ 1000 \text{ gal}$$

It should be noted that neither overhead and maintenance nor capital recovery are included in the computations. Cost for the disposal of liquid wastes generated by backwashing, regeneration, and rinse steps should be also considered according to the feasibility of disposal.

## CHAPTER V

### SUMMARY AND CONCLUSIONS

Ion exchange treatment of coagulated and filtered sewage oxidation pond effluent produced a water of high quality provided that steps are taken to prevent damage to the resins because of fouling by organic matter.

The utilization of the ion exchange demineralizing process for upgrading and reuse of waste waters has been seriously hampered because of the relatively high organic content of the water. Recently developed anion exchange resins such as Dowex 11 have been demonstrated to be effective as organic scavengers, preventing deterioration in the capacity of the normal resins used.

A combination of two resins, Dowex HGR-W and Amberlite XE-258, such as might be used in a demineralizing process, have shown to have their initial capacity reduced during subsequent operating cycles. This reduction in capacity has been attributed to the deterioration of the cation resin and to the fouling of the anion resin.

Deterioration of the cation exchange resin was due to the wide variety of suspended matter present in the influent water and to the filtering action that this resin was performing. The anion exchange resin which was operated in the hydroxyl cycle also showed a decrease in its original capacity after the first operating cycle. This loss in capacity was shown by the greater concentration of detergents and

organic matter found in each successive operating cycle. The decrease in capacity was attributed to organic molecules in water which enter the pores of the anion resin and are retained because of the affinity they have with the ion exchange sites. Normal regeneration techniques and rinse requirements do not allow sufficient time for removal of the organic substances because of unfavorable conditions within the resin.

With the installation of the Dowex 11 anion exchange resin ahead of the previous resin combination, the performance and water quality of the system was greatly improved. The use of longer column paths and special "screen" resins are recommended in the application of ion exchange for oxidation pond effluents.

APPENDIX A

SUGGESTED OPERATING CONDITIONS FOR RESINS USED

## DOWEX HGR-W

pH range	0 - 14
Max temperature	300 °F
Min bed depth	30 in.
Service flow rate	2-4 gpm/cu ft (2)
Backwash flow rate	8 gpm/sq ft
Regenerant level	Dependent on capacity desired
Regenerant concentration	2-8% H <sub>2</sub> SO <sub>4</sub> (6%)
Regenerant flow rate	0.5-2.0 gpm/cu ft (0.5)
Displacement rinse rate	Equal to regeneration rate
Final rinse rate	Equal to service rate
Rinse requirement	40-100 gal/cu ft (100)

( ) Indicates actual rates used during this study

## AMBERLITE XE-258

pH range	0 - 14
Max temperature	100 °F
Minimum bed depth	24 in.
Service flow rate	1-3 gpm/cu ft (2)
Backwash flow rate	50% expansion
Regenerant level	Dependent on capacity desired
Regenerant concentration	4% NaOH
Regenerant flow rate	0.5 gpm/cu ft (0.5)
Displacement rinse rate	0.5 gpm/cu ft
Final rinse rate	1.5 gpm/cu ft
Rinse requirement	About 25 gal/cu ft (25)

( ) Indicates actual rates used during this study

## DOWEX 11

pH range	0 - 14
Max temperature	140°F
Minimum bed depth	30 in.
Service flow rate	2.0 gpm/cu ft (2)
Backwash flow rate	Sufficient to produce at least 50% expansion in bed volume
Regenerant level	Dependent on capacity desired
Regenerant concentration	4% NaOH
Regenerant flow rate	0.25-1.0 gpm/cu ft (0.5)
Displacement rinse rate	Same as regenerant rate
Final rinse rate	Approx. 1 gpm/cu ft
Rinse requirement	Approx. 50 gal/cu ft (50)

( ) Indicates actual rates used during this study

APPENDIX B

RESULTS OF ANALYSES PERFORMED DURING PHASE 1 AND PHASE 2

Table 5. Results of analyses during the first cycle (Phase I).

Time (minutes)	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480
pH	9.2	9.5	9.4	9.4	9.3	9.3	9.3	9.4	9.6	10.0	10.5	10.9	11.1	11.3	9.5	8.9
Temp., °C	21	20	21	22	22	22	22	22.3	22.5	23	21.5	21.5	21.5	21.5	21.5	21.5
Spec. cond., umhos	36	16.5	15	15	14	13	13	13.5	18	38	90	230	400	860	800	850
Turbidity, JTU	1	1	1	1	1	2	2	2	2	2	4	6	7	7	8	12
Alkalinity, mg/l as CaCO <sub>3</sub>	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	5.65	12.3	26.0	61.0	131.0	180.0	215.5	195.0
Total residue, mg/l	-	20	-	20	-	21	-	20	-	37	-	90	-	429	-	627
Filterable residue, mg/l	-	9	-	18	-	17	-	9	-	17	-	75	-	400	-	595
Total hardness, mg/l as CaCO <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.20	12.20	12.30
Oxygen absorption, mg/l	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.36	0.52	0.80	1.1	4.35	4.35	4.7
COD, mg/l	3.7	3.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0	7.8	9.45	12.35	19.8	45.0	44.5	45.2
MBAS, mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.14	0.357	0.625

Table 6. Results of analyses during the second cycle (Phase 1).

Time (minutes)	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480
pH	9.9	9.9	10.0	9.9	9.9	9.9	9.85	9.8	9.8	9.9	10.2	10.7	11.2	11.5	11.2	8.9
Temp., °C	21	20.0	17	20	20	20	21	21	21	21	22	22	22	22	22	22
Spec. cond., umhos	42	40	38	38	38	36	36	33	33	42	76	265	880	1600	1500	880
Turbidity, JTU	1	2	2	2	3	3	3	3	3	4	6	6	6	7	8	12
Alkalinity, mg/l as CaCO <sub>3</sub>	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	26.0	81.0	297.0	395	380	174
Total residue, mg/l	-	52	-	57	-	62	-	64	-	59	-	139	-	556	-	685
Filterable residue, mg/l	-	14	-	16	-	18	-	20	-	18	-	82	-	516	-	621
Total hardness, mg/l as CaCO <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.08	16.30	20.50
Oxygen absorption, mg/l	0.28	0.28	0.32	0.38	0.38	0.40	0.42	0.42	0.42	0.42	0.50	0.56	1.44	4.2	4.8	4.8
COD, mg/l	3.0	3.0	3.0	3.0	4.6	5.7	5.7	5.8	6.15	6.15	7.85	9.9	19.0	19.0	45.9	46.2
MEAS, mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.012	0.057	0.12	0.29	0.77	1.47

Table 7. Results of analyses during the third cycle (Phase 1).

Time (minutes)	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480
pH	9.8	10.0	9.9	9.85	9.9	9.8	9.7	9.8	9.9	10.2	10.85	11.0	9.9	7.9	7.7	7.4
Temp., °C	21	20	21	21	21	21	21	22	22	22	22	21	21	21	21	22
Spec. cond., umhos	42	45	44	43	40	40	36	37	42	88	370	880	880	870	950	1040
Turbidity, JTU	2	4	4	6	7	7	7	7	8	7	7	7	11	11	11	13
Alkalinity, mg/l as CaCO <sub>3</sub>	16.5	22.4	29.5	17.7	16.5	16.5	14.2	15.4	15.4	28.8	98.0	301.0	560	520	440	360
Total residue, mg/l	-	58	-	55	-	60	-	65	-	73	-	482	-	686	-	692
Filterable residue, mg/l	-	32	-	24	-	21	-	26	-	37	-	399	-	663	-	595
Total hardness, mg/l as CaCO <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.2	16.4	20.4
Oxygen absorption, mg/l	0.36	0.36	0.40	0.56	0.60	0.60	0.60	0.72	0.75	1.04	3.80	5.05	5.05	5.05	4.90	4.90
COD, mg/l	3.26	3.66	3.66	4.90	6.21	5.70	5.60	5.50	5.60	8.95	16.4	39.5	47.0	47.8	45.6	40.8
MBAS, mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.012	0.23	1.25	1.35	1.54	1.71
Calcium, mg/l	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	8.15	10.02	10.02	10.02	12.4
Chloride, mg/l	4.5	4.5	4.5	4.5	4.5	4.5	4.5	8.0	8.0	10.0	12.4	12.4	36.4	36.4	72.0	105.0

Table 8. Results of analyses during the fourth cycle (Phase 1).

Time (minutes)	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480	510
pH	10.8	10.6	10.6	10.6	10.5	10.5	10.45	10.45	10.7	10.90	11.3	11.5	11.6	10.6	8.8	8.1	7.1
Temp., °C	21	21	21	21	21.5	22	22.3	22.5	22.5	23	22.3	21.5	21.5	21.5	22	22	22
Spec. cond., umbhos	75	71	64	60	55	51	50	52	70	190	630	1500	1800	1200	980	980	1050
Turbidity, JTU	1	1	1	1	1	2	2	4	4	6	6	6	8	15	17	21	20
Alkalinity, mg/l as CaCO <sub>3</sub>	41.4	39.2	30.5	28.4	21.8	24.0	26.1	28.4	63.1	181.0	385	490	426.0	418.0	405	405	334
Total residue, mg/l	52	-	-	56	-	62	-	49	-	64	-	450	-	704	-	685	-
Filterable residue, mg/l	-	39	-	35	-	28	-	31	-	50	-	443	-	680	-	570	-
Total hardness, mg/l as CaCO <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.2	12.2	14.3	18.3	26.3
Oxygen absorption, mg/l	0.48	0.60	0.52	0.60	0.60	0.60	0.60	0.60	0.68	0.80	0.84	1.68	3.8	5.03	4.67	4.67	4.56
COD, mg/l	4.49	4.49	7.75	5.7	6.52	6.52	7.33	8.57	9.4	11.0	14.3	24.8	49.0	51.0	49.0	42.3	-
MBAS, mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.012	0.08	0.38	0.90	1.49	1.8	1.85
Calcium, mg/l	5.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	6.01	10.02	12.0	16.5	18.0	18
Chloride, mg/l	4.5	4.5	4.5	4.5	2.3	4.5	4.5	9.0	9.0	9.0	9.0	12.4	85.5	85.5	85.5	117.0	117.0

Table 9. Results of analyses during the first cycle (Phase 2).

Time (minutes)	450	480	510	540	570	600	630	660	690	720	750	780	810	840
pH	10.8	10.8	10.8	10.8	10.7	10.8	10.7	10.7	9.9	5.6	5.6	5.6	5.6	5.8
Temp., °C	24	24	24	24	24	23	22.5	22	23	24.5	24.5	24.5	24.5	24.5
Spec. cond., umhos	475	475	475	475	450	450	350	350	170	185	185	190	190	190
Turbidity, JTU	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Alkalinity, mg/l as CaCO <sub>3</sub>	92	92	92	92	100	96	80	68	72	48	48	48	50	50
Total residue, mg/l	-	125	-	125	-	117	-	108	-	187	-	185	-	185
Filterable residue, mg/l	-	116	-	117	-	108	-	101	-	180	-	175	-	175
Total hardness, mg/l as CaCO <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen absorption, mg/l	0.60	0.64	0.66	0.72	0.92	0.70	0.74	1.00	4.92	3.34	3.15	3.25	3.50	4.4
COD, mg/l	8.9	11.8	11.8	11.3	12.2	12.2	15.7	17.7	51.9	49.0	44.3	44	44.1	45
MBAS, mg/l	0.01	0.014	0.05	0.12	0.17	0.20	0.29	0.58	0.65	0.77	0.90	1.05	1.11	1.2
Calcium, mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride, mg/l	6.1	5.5	6.5	6.1	6.3	6.5	4.5	4.55	8.5	19.0	19.0	22.5	25.0	27.5
Sodium, mg/l	63.2	60.7	62.5	58.4	58.4	58.0	58.4	59.0	58.4	58.4	55.6	55.0	56.2	55.0

Table 9.--Continued

Time (minutes)	30	60	90	120	150	180	210	240	270	300	330	360	390	420
pH	10.2	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.2	10.9	10.9	10.9	10.9	10.8
Temp., °C	22	22.2	23	23	24	23	24	24	24	24	24	24	24	24
Spec. cond., umhos	5.4	6.2	6.2	6.4	6.2	6.2	6.2	6.2	8.5	460	550	550	550	500
Turbidity, JTU	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Alkalinity, mg/l as CaCO <sub>3</sub>	12	12	12	12	12	12	12	12	20	96	108	100	104	96
Total residue, mg/l	-	15	-	21	-	18	-	23	-	135	-	136	-	123
Filterable residue, mg/l	-	14	-	14	-	15	-	17	-	130	-	130	-	120
Total hardness, mg/l as CaCO <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen absorption, mg/l	0.28	0.28	0.33	0.36	0.36	0.40	0.40	0.40	0.40	0.56	0.48	0.60	0.60	0.60
COD, mg/l	3.92	3.92	6.85	3.92	3.92	3.92	3.92	3.92	3.92	4.9	6.35	6.85	9.30	14.2
MBAS, mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Calcium, mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride, mg/l	1.01	1.01	1.01	1.01	1.01	1.51	1.51	1.51	2.02	2.02	2.02	2.52	5.05	6.1
Sodium, mg/l	6.25	7.64	6.68	7.10	6.25	6.42	6.25	6.42	12.9	36.4	60.5	68.7	68.7	62.6

Table 10. Results of analyses after the Dowex 11 (first cycle - Phase 2).

	60	120	180	240	300	360	420	480	540	600
pH	11.2	11.2	11.2	11.2	8.6	7.9	7.9	7.9	7.9	8
Temp., °C	23.5	24	23	23	23	23	23	23	23	23
Spec. cond., umhos	1200	1200	1200	1140	920	960	960	960	960	960
Turbidity, JTU	2	2	2	2	7	7	7	7	7	8
Alkalinity, mg/l as CaCO <sub>3</sub>	325	320	316	309	160	170	180	174	174	174
Total residue, mg/l	279	269	300	291	508	518	508	509	509	491
Filterable residue, mg/l	258	256	256	260	482	474	480	479	483	472
Oxygen absorption, mg/l	0.48	0.68	0.68	0.76	2.52	2.35	2.8	3.0	3.25	2.47
COD, mg/l	12.2	13.7	15.7	21.0	45.0	39.3	39.3	42.6	45.0	42.6
Chloride, mg/l	20.2	20.2	20.2	35.0	170	177	177	176	176	176

Table 11. Results of analyses during the second cycle (Phase 2).

Time (minutes)	450	480	510	540	570	600	630	660	690	720	750	780	810	840
pH	10.5	10.5	10.5	10.5	10.5	10.5	-	10.6	-	10.6	-	9.9	-	9.8
Temp., °C	24	24	24	24	24	24	-	22	-	24	-	24	-	24
Spec. cond., umhos	200	210	220	220	220	210	-	220	-	220	-	240	-	280
Turbidity, JTU	1	1	1	1	1	1	-	1	-	1	-	1	-	1
Alkalinity, mg/l as CaCO <sub>3</sub>	52	56	56	56	56	56	-	70	-	70	-	56	-	50
Total residue, mg/l	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Filterable residue, mg/l	-	59	-	61	-	61	-	65	-	70	-	82	-	95
Total hardness, mg/l as CaCO <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00
Oxygen absorption, mg/l	0.50	0.50	0.55	0.50	0.60	0.50	0.70	1.2	1.8	3.7	3.9	3.7	3.8	3.7
COD, mg/l	9.0	9.2	7.5	7.8	9.0	7.5	-	9.00	-	12.2	-	29.5	-	52.0
MBAS, mg/l	0.01	0.01	0.06	0.10	0.17	0.22	0.28	0.55	-	0.75	-	1.05	-	1.2
Calcium, mg/l	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	-	0.00	-	0.00	-	0.00
Chloride, mg/l	3.40	3.98	3.98	3.98	3.98	3.98	-	3.98	-	13.8	-	18.5	-	28.5
Sodium, mg/l	65.5	61.7	65.7	55.9	57.1	60.1	56.9	60.5	56.7	61.0	56.8	52.3	-	53.1

Table 11.--Continued

Time (minutes)	30	60	90	120	150	180	210	240	270	300	330	360	390	420
pH	9.6	9.6	9.6	9.6	9.6	9.5	8.9	9	8.9	10.2	10.2	10.4	10.4	10.4
Temp., °C	24	23	23.5	23.5	23	23.5	23.5	24	24	24	24	24	24	24
Spec. cond., umhos	7	6.7	6.7	6.6	6.6	6.5	6.6	6.3	10.2	90	100	160	175	175
Turbidity, JTU	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Alkalinity, mg/l as CaCO <sub>3</sub>	18	4	4	4	4	4	4	4	4	21.6	21.6	54	54	54
Total residue, mg/l	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Filterable residue, mg/l	12	7	7	7	7	8	8	8	55	55	43	43	47	47
Total hardness, mg/l as CaCO <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen absorption, mg/l	0.40	0.40	0.40	0.40	0.45	0.50	0.40	0.50	0.45	0.40	0.50	0.40	0.45	0.50
COD, mg/l	5.2	5.2	6.25	7.70	5.2	5.2	5.2	5.2	5.2	10.3	10.3	9.2	6.5	8.8
MBAS, mg/l	0.01	0.01	-	0.01	-	0.01	-	0.01	0.01	0.01	-	0.01	0.01	0.01
Calcium, mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride, mg/l	1.14	1.14	1.14	1.14	1.70	1.70	1.70	1.70	1.70	1.70	3.40	3.40	3.40	3.40
Sodium, mg/l	6.30	6.75	6.50	7.15	6.80	6.50	6.50	6.20	11.5	40.7	58.7	65.0	65.0	62.0

Table 12. Results of analyses after the Dowex 11 (second cycle - Phase 2).

Time (minutes)	60	120	180	240	300	360	420	480	540	600	660	720
pH	11.3	11.3	11.2	11.2	11.1	9.0	8.6	8.4	8.3	8.2	8.0	7.9
Temp., °C	21	21	23	24	24	24	24	24	24	24	22	23.5
Spec. cond., umhos	1400	1400	1350	1300	1000	740	770	840	850	880	880	900
Turbidity, JTU	2	2	2	2	2	6	6	7	7	7	-	-
Alkalinity, mg/l as CaCO <sub>3</sub>	360	350	330	330	330	240	240	230	210	200	2.5/10	2.0/10
Total residue, mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Filterable residue, mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Total hardness, mg/l as CaCO <sub>3</sub>	-	-	-	-	-	-	-	-	-	-	-	-
Oxygen absorption, mg/l	-	-	-	-	-	-	-	-	-	-	-	-
COD, mg/l	8.5	8.5	8.5	10.0	23.4	31.0	35	38.9	40.85	44.2	-	-
MBAS, mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Chloride, mg/l	8.1	8.1	8.1	8.1	20.4	89.0	165.5	172.9	170	170	-	-

## REFERENCES

1. Fair, G. M., and Geyer, J. C., Water Supply and Waste Water Disposal, John Wiley and Sons, Inc., New York, 1967.
2. Warrington, S. L., "Effects of Using Lagooned Sewage Effluent on Farmland," *Sewage Works Journal*, 24, 1243 (1952).
3. Dow Chemical Company, Dowex Ion Exchange, Dow Chemical Co., Midland, Michigan (1964).
4. Ward, R. F., and Edgerly, E., Jr., "Organic Fouling of Anion Exchange Resins," *Environmental and Sanitary Engineering Laboratories*, Washington University, St. Louis, Missouri (1965).
5. Anonymous, "Ion Exchange Resins Due for Sales Growth," *Chemical and Engineering News*, 40, 34 (1962).
6. Morrison, W. S., and Tompson, J., "Twenty Years' Progress in Ion Exchange," *Water and Sewage Works*, 107, 225 (1960).
7. Klumb, G. H., "Control of Bacterial Reproduction in Cation Exchange Layers," *Jour. Amer. Water Works Assoc.*, 41, 933 (1949).
8. Wirth, L. F., "Effects of Oxidants on Ion Exchange," *Industrial and Engineering Chemistry*, 53, 638 (1961).
9. Bacon, H. E., and Lewis, W. J., "Interference of the Organic Contaminants with the Ion Exchange Process," *Combustion*, 32, 153 (1960).
10. Frish, N. W., and Kunin, R., "Organic Fouling of Anion Exchange Resins," *Jour. Amer. Water Works Assoc.*, 52, 875 (1960).
11. Horembala, L. E., and Feldt, C. A., "Ion Exchange Screens," *Power*, 112, 67 (May, 1968).
12. Sawyer, C. N., and McCarty, P. L., "Chemistry for Sanitary Engineers," 2nd Ed., McGraw-Hill Book Co., New York (1970).
13. Nalco Chemical Co., Dowex Ion Exchange Resins, Chicago, Ill., (1970).
14. Standard Methods for the Examination of Water, Sewage and Industrial Wastes, 12th Ed., Amer. Pub. Health Assoc., New York (1965).

15. McKee, J. E., and Wolf, H. W., Water Quality Criteria, State Water Quality Control Board, Sacramento, Calif. (1969).
16. Ahlgren, R. M., "Membrane vs. Resinous Ion Exchange Demineralization," *Industrial Water Engineering*, 8, 1, 12 (1971).
17. Oil, Paint, and Drug Reporter, "The Chemical Marketing Newspaper," Schnell Publishing Company, Inc. (May, 1971).