DEVELOPMENT OF A TUBULAR FABRIC FILTER
-PHASE II-

by

Michael K. Stenstrom
Associate Professor
and Principal Investigator

Hamid R. Vazirinejad
Post Graduate Research Engineer

and

Seth D. Abramson
Post Graduate Research Engineer

Water Resources Program
School of Engineering and Applied Science
University of California, Los Angeles

A Final Report to The Naval Civil Engineering Laboratories, Port Hueneme, CA., for Contract N62583/81 M R716. UCLA-ENG-83-01.

Table of Contents

page

ACKNOWLEDGEMENTS 2
ABSTRACT 3
LIST OF FIGURES 4
LIST OF TABLES 6
INTRODUCTION 7
EXPERIMENTAL DESIGN 10
  Fabric Types 10
  Apparatus Description 11
  Analytical Methods 19
  Modes of Operation 21
RESULTS AND DISCUSSION 22
  Reverse Flow Results 23
    Type I Fabric 24
    Washed Type I Fabric 28
    Type IV Fabric 29
    Type V Fabric 37
  Cross Flow Results 37
    Type I Fabric 40
    Type IV Fabric 44
  Coagulation/Flocculation Results-Jar Tests 44
  Coagulation/Filtration Results 51
  Fouling Factor Results 60
CONCLUSIONS AND RECOMMENDATIONS 63
REFERENCES 67
APPENDIX 68
  List of Appendix Figures 69
  List of Appendix Tables 72

ACKNOWLEDGEMENTS

This work was supported by the U. S. Naval Civil Engineering Laboratories under Contract N62583/81 M R716. The helpful suggestions and patience of Mr. Ted Kuepper are gratefully acknowledged.

ABSTRACT

This report describes the second phase of the development of a tubular fabric filter device. An earlier report was issued in September, 1981 (UCLA-ENGR-81-41) and describes the first phase of development.

In the second phase evaluation of two of the three original methods of backwashing/filtration continued with increased experimental control over longer periods of operation. A second type of feed water, containing only AC road test dirt was evaluated, and two additional fabrics, a fire hose liner called Type IV, and a new membrane material, called Type V, were introduced.

No improvements in backwashing efficiency were obtained with the cross flow technique during the second phase. Extended runs were performed with the reverse flow technique, resulting in run times of several hundred minutes. Gradually declining fluxes were noted and were not correctable by simple backwashing. To determine if the declining fluxes were reversible, two sections of Type I fabric were removed from the filter and washed in an ordinary washing machine with BIZ enzyme detergent and hot water. The enzyme detergent wash restored most of the original filter flux.

The detergent plus AC road test dirt was the most severe feed water and fouled the filter fabrics many times faster that the dirt-only feed water. The Type I fabric was the most effective fabric for filtration and was more easily backwashed than the Type IV. The Type V fabric did not sufficiently reduce turbidity to be an effective filter. The lack of efficiency was probably due to leakage at the tube seam, which was also problematic with Type II and Type III fabrics in the previous phase.

The last part of the phase investigated pretreatment of feed waters with coagulants to precipitate and destabilize the detergent and road dirt particles. Coagulation with aluminum sulfate with pH control using concentrated sodium hydroxide was very effective, extending filter run time beyond a thousand minutes, but coagulant and sodium hydroxide requirements were high and may be too high for some mobile military applications.

LIST OF FIGURES

Figure 1 Fabric Types.

Figure 2 Detail of Flange Arrangements.

Figure 3 Filter Apparatus.

Figure 4 Filter Schematic Diagram.

Figure 5 Turbidity versus Time for Filter Test 1. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Figure 6 Pressure Drop (PSI) versus Time for Filter Test 1. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Figure 7 Total Filtered Volume (gal/ft^2) versus Time for Test 1. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Figure 8 Pressure Drop (PSI) versus Time for Filter Test 3. (washed Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Figure 9 Turbidity versus Time for Filter Test 9. (Type I Fabric, reverse flow, and AC road dirt wastewater).

Figure 10 Pressure Drop (PSI) versus Time for Filter Test 9. (Type I Fabric, reverse flow, and AC road dirt wastewater).

Figure 11 Total Filtered Volume (gal/ft^2) versus Time for Test 9. (Type I Fabric, reverse flow, and AC road dirt wastewater).

Figure 12 Turbidity versus Time for Filter Test 5. (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Figure 13 Pressure Drop (PSI) versus Time for Filter Test 5. (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Figure 14 Total Filtered Volume (gal/ft^2) versus Time for Test 5. (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Figure 15 Turbidity versus Time for Filter Test 11. (Type IV Fabric, reverse flow, and AC road dirt wastewater).

Figure 16 Pressure Drop (PSI) versus Time for Filter Test 11. (Type IV Fabric, reverse flow, and AC road dirt wastewater).

Figure 17 Turbidity versus Time for Filter Test 4. (Type I Fabric, cross flow, and detergent plus AC road dirt wastewater).

Figure 18 Pressure Drop (PSI) versus Time for Filter Test 4. (Type I Fabric, reverse flow, detergent and AC road dirt wastewater).

Figure 19 Total Filtered Volume (gal/ft^2) versus Time for Test 4. (Type I Fabric, cross flow, and detergent and AC road dirt wastewater).

Figure 20 Turbidity versus Time for Filter Test 7. (Type IV Fabric, cross flow, and detergent plus AC road dirt wastewater).

Figure 21 Pressure Drop (PSI) versus Time for Filter Test 7. (Type IV Fabric, reverse flow, detergent and AC road dirt wastewater).

Figure 22 Turbidity versus Coagulant Dose. (Alum coagulant without pH control).

Figure 23 Turbidity versus Sodium Sulfonate Dose. (Varying sodium sulfonate with 50 mg/l Al^{+3}).

Figure 24 Turbidity versus Coagulant Dose. (Varying Alum dosage with 10 mg/l sodium sulfonate).

Figure 25 Turbidity versus Time for Filter Test 12. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

Figure 26 Pressure Drop (PSI) versus Time for Filter Test 12. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

Figure 27 Filter Cake adhering to Filter Fabric. (Filter Test 12, reverse flow, Type I Fabric, and coagulated detergent plus AC road dirt wastewater).

Figure 28 Air/Water Back Wash. (Filter Test 12, reverse flow, Type I Fabric, and coagulated detergent plus AC road dirt wastewater).

Figure 29 Turbidity versus Time for Filter Test 13. (Type I Fabric, reverse flow, pH control, and coagulated detergent plus AC road dirt wastewater).

Figure 30 Pressure Drop (PSI) versus Time for Filter Test 13. (Type I Fabric, reverse flow, pH control, and coagulated detergent plus AC road dirt wastewater).

LIST OF TABLES

Table 1 Ratios of Areas of Granular Media Filters to Fabric Filters at Various Filtration Rates.

Table 2 AC Road Dirt Size Specifications.

Table 3 Military Detergent Specifications.

Table 4 Filtration Test Summary.

Table 5 Fouling Factor Test Summary.

INTRODUCTION

This report describes the second phase of the development of a tubular fabric filter device. An earlier report was issued in September, 1981 (1) and describes the first phase of development.

The objectives of both investigations were to develop the concept of a light weight filter to be used in removing colloidal and suspended materials from laundry and shower wastewaters as well as natural waters. The filtered water would then be suitable for use as feed water for reverse osmosis or for direct recycle applications. The use of a fabric filter media is critical to the success of this project, since the filter must be sufficiently light and compact to be transported easily by truck or air cargo.

The tubular fabric concept also has significant advantages over granular media filters because of media surface area savings. Since the fabric filter mechanism is predominately a surface phenomena, the fabric filter does not require a deep media, and a sheet of fabric, perhaps 1/32 to 1/4 inch thick, provides excellent filtration efficiency. Particle removal occurs at the fabric surface or within the fabric itself. Conversely, granular filters require deep filter beds since deep floc penetration is required for economical operation.

To obtain economical fabric filter operation, backwashing techniques using a small water volume are required. This need results from the limited volume available to store materials removed from the wastewater, and if the materials are not removed from the filter surface, blinding can occur very rapidly. After effective backwashing techniques are developed, the fabric filter will provide a large area savings over granular filters. To show this difference in superficial area (surface area required for a filter device, not the area available for filtration) Table 1 shows the ratio of area required for a granular filter to the area required for a fabric filter, at various filtration rates (flow rate per unit of filter area) which illustrates the superficial area savings.

TABLE 1 RATIOS OF AREAS OF GRANULAR MEDIA FILTERS TO FABRIC FILTERS AT VARIOUS FILTRATION RATES[+].

GRANULAR FILTRATION RATE (GPM/ft^2)	TUBULAR FABRIC FILTRATION RATE (GPM/ft^2)						
	0.025	0.050	0.10	0.20	0.50	1.0	2.0
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.0	2.25	4.50	9.0	10.	45.	90.	180.
1.5	1.50	3.00	6.0	12.	30.	60.	120.
2.0	1.13	2.26	5.5	11.	28.	55.	110.
2.5	0.90	1.80	3.6	7.2	18.	36.	72.
3.0	0.75	1.50	3.0	6.0	15.	30.	60.
3.5	0.65	1.30	2.6	5.2	13.	26.	52.
4.0	0.56	1.12	2.2	4.5	11.	22.	45.
5.0	0.45	0.90	1.8	3.6	9.	18.	36.
6.0	0.38	0.76	1.5	3.0	8.	15.	30.

[+] Numbers represent ratios of the superficial area of the tubular filter to superficial are of the granular filter. Numbers greater than unity show as area savings for the tubular fabric filter. (For example: assuming a granular filtration rate of 6 GPM/ft^2 (column 1) and a tubular fabric filtration rate of 0.5 GPM/ft^2 (column 6), the fabric filter equipment would require one-eight the area required of the granular media filter.)

In the first phase of the project three types of fabric were evaluated with three types of filtering/contacting methods. The most successful method was reverse filtration (externally pressurized) where the liquid flowed from the outside of the fabric tubes to the inside, where it exited the unit as product water. Operation in this fashion required that the tubes be supported from within and that a reverse pressure gradient be developed. Backwashing was accomplished by pressurizing the inside of the tubes, reversing the flow, which expanded the fabric pores allowing the entrapped solids to be removed. Cross flow and closed-end filtration (internally pressurized) were less effective and it was not possible to effectively remove the trapped solids and restore filter flux.

The second phase of the investigation was initiated with the objective of further evaluating the effectiveness of backwashing techniques, with particular emphasis on the reverse flow method. A second objective was to evaluate fabric life and two additional fabric types.

To further evaluate the reverse flow technique it was necessary to construct a new experimental apparatus, which would apply uniform, constant filtering and backwashing pressures. In the earlier phase it was necessary to use a pulsating suction pump to create negative gage pressures on the inside of the filter tubes during reverse filtration. The pulsating nature of the flow caused the filters to vibrate, which reduced filtration efficiency.

Two new columns were constructed to permit positive gage pressure to be applied to both side of the filter fabric. Additionally, the dead volume of the columns was reduced to allow for more precise measurements of operating conditions.

EXPERIMENTAL DESIGN

The experimental apparatus used in this phase was conceptually very similar to the original apparatus described earlier (1), although a number of mechanical modifications and refinements were made. The major modifications were a reduction in the size of the filter volume and closure of the entire filter vessel to allow pressurization.

Fabric Types

The Type I fabric described in the earlier report was also used in this phase. It is a medium weave polyester which has easily discernible weave but very few observable imperfections. It is woven without a seam in continuous lengths. The second fabric used is a commercial fire hose liner and is called Type IV, and is more coarsely woven and much thicker than Type I fabric. It is a polypropylene material and is woven without a seam in continuous lengths. The third type of fabric is a thin membrane fabric which has a theoretical pore size of 5 microns, and is woven in sheets, which required cutting and sewing to provide a tubular structure. This material is called Type V. Fabric Types II and III were used in the previous phase (1), and were not used in this phase. All fabrics were supplied by the Naval Civil Engineering Laboratories to UCLA.

The Type I material was selected for continued development because of its success in the earlier phase and its low cost. Type IV fabric was evaluated because it had better structural properties allowing it to be used with higher pressures. Type V fabric was evaluated in hope that it would allow easier backwashing due to its thin woven structure. Figure 1 shows the three fabric types.

Apparatus Description

Two new filter columns were constructed from plexiglass tubing, 4 inch i.d. by 1/4 inch wall thickness. The columns were fitted with flanges and 'O" rings on both ends, and sampling taps were made through the column wall near each flange. A special set of flanges was made to fit between the column flange and outermost flange to provide support for the filters and a passage way for filtered water. Several different combinations were used until a satisfactory arrangement was found. Leakage was frequently a problem and was caused by the variations in tube diameter. Figure 2 shows the final flange arrangement used in the phase.

The filter was repiped to allow one pump to provide both feed water and backwash water. The centrifugal circulating pump was retained to allow cross flow operation. Figure 3 shows the apparatus and Figure 4 is a schematic diagram of the filter with its associated pumps and instrumentation. The apparatus is completely contained on a single rolling platform, with the exception of the feed tank.

The fabric tubes were 5.33 ft long and provided a surface area normal to flow of 1.40 ft^2. The tubes were attached to the end flanges with a ribbed hose adapter and secured with worm-gear hose clamps. In the earlier phase it was discovered that leakage occurred when using smooth hose adapters. To assemble the filter without over stretching the fabrics, each tube was cut about 1 inch longer than the space between flanges, to provide sufficient slack.

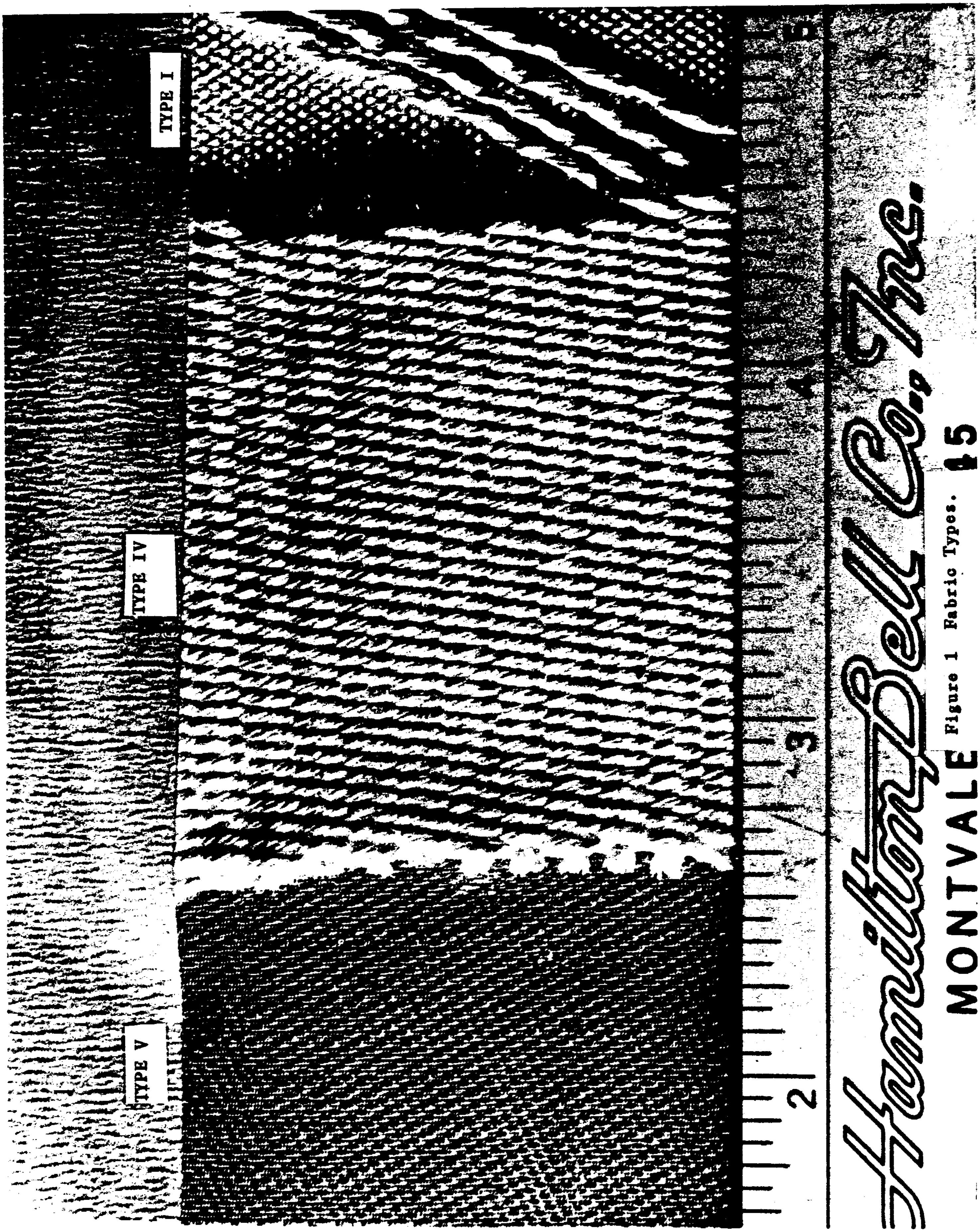
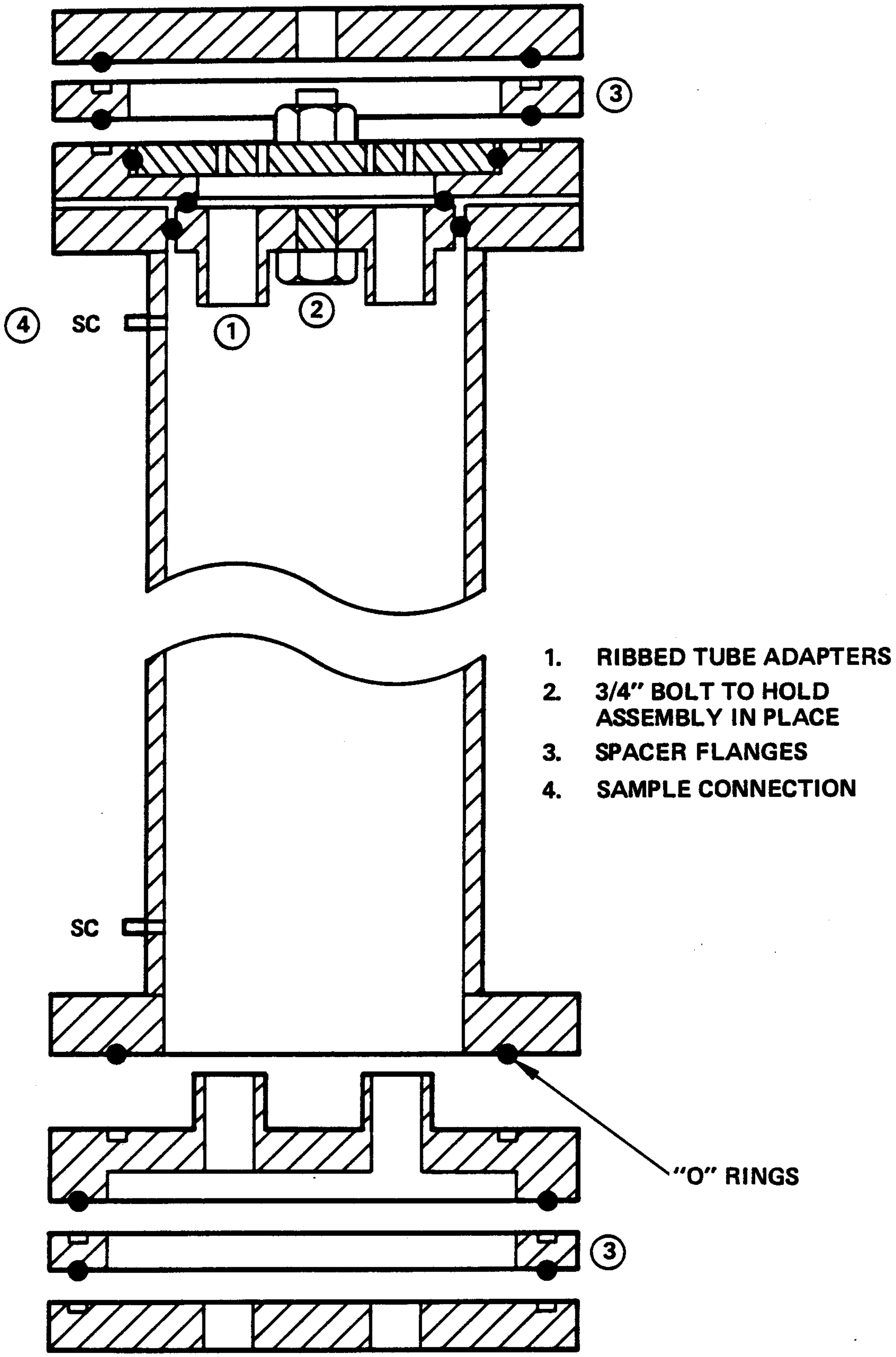


Figure 1 Fabric Types.



1. RIBBED TUBE ADAPTERS
2. 3/4" BOLT TO HOLD ASSEMBLY IN PLACE
3. SPACER FLANGES
4. SAMPLE CONNECTION

Figure 2 Detail of Flange Arrangements.

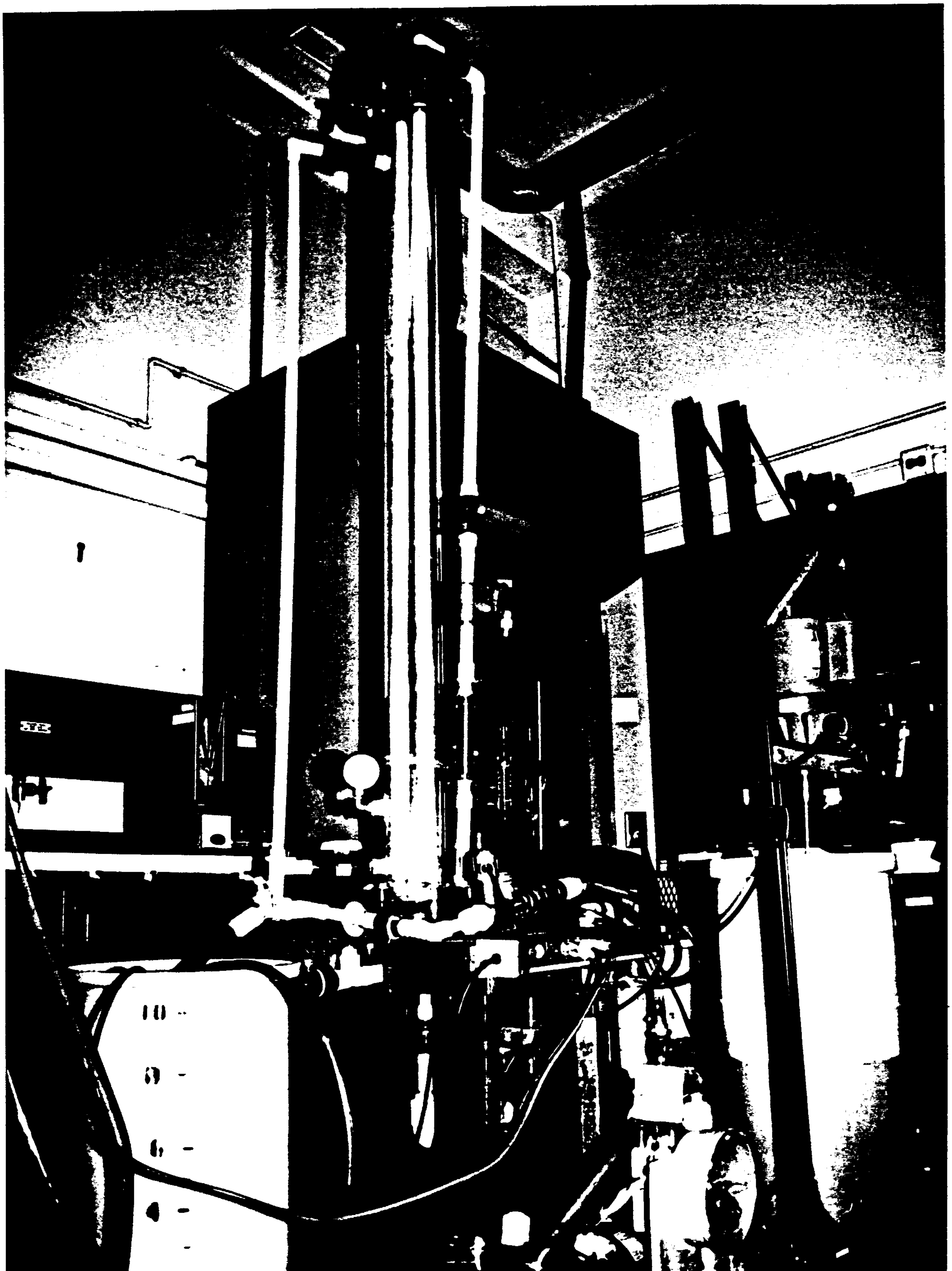


Figure 3 Filter Apparatus.

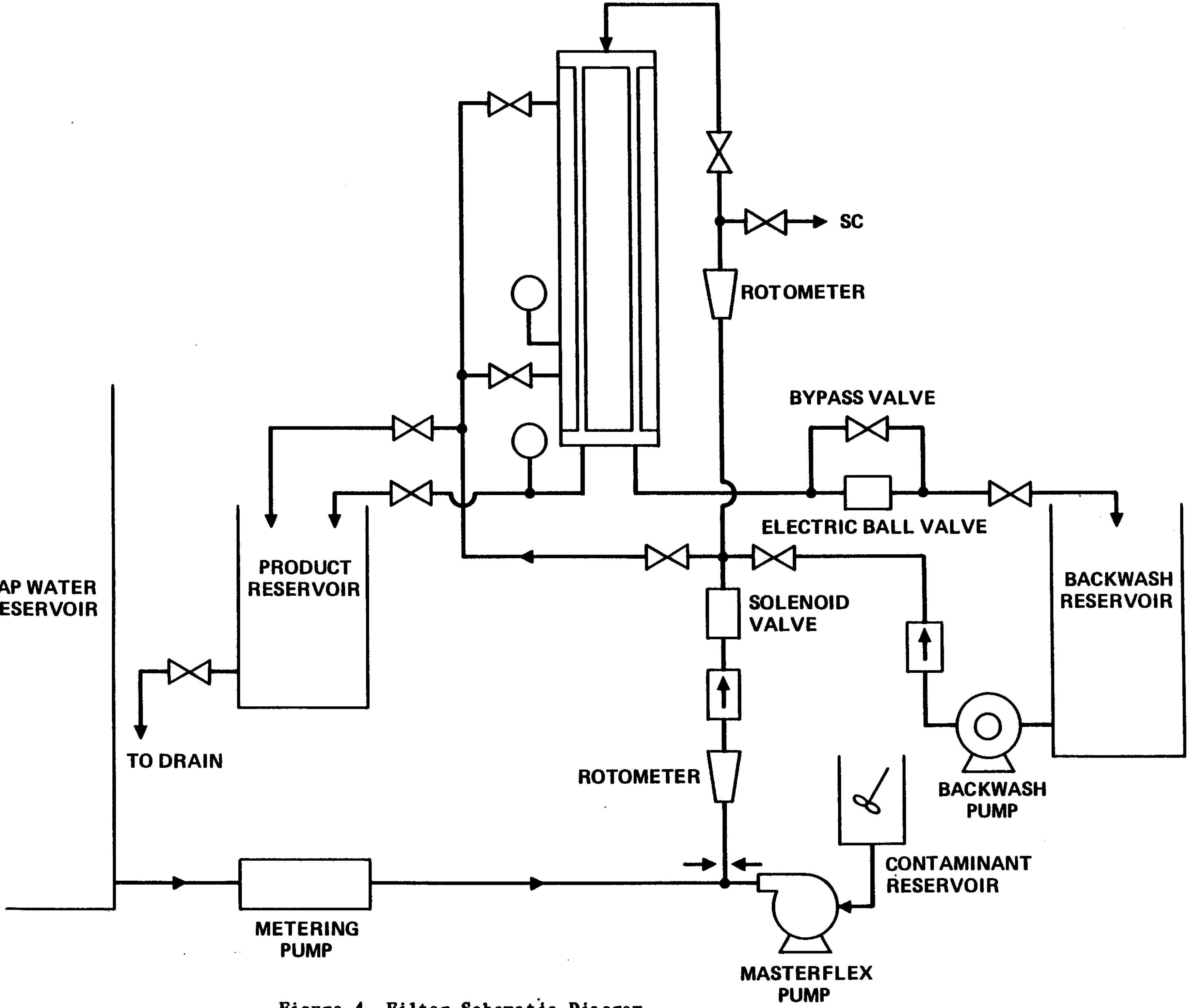


Figure 4 Filter Schematic Diagram.

To operate the filter, the reservoir was first filled with tap water and allowed to stand until it reached room temperature, which was in the range of 65 to 75°C. The main feed pump, a Viking gear pump with variable speed DC motor, was adjusted to provide the desired flow rate. In the earlier phase a range of filtration rates were evaluated. For all tests performed in this phase, filtration rate was held constant at 0.5 GPM/ft^2. This was done in order to minimize experimental variables and concentrate on evaluation of fouling rate and backwash efficiency. For the cross flow mode the initial filtration rate was 0.5 GPM/ft^2, but declined to nearly zero as the test progressed, due to fouling of the fabrics.

The contaminants were introduced on the discharge side of the Viking pump using a variable speed Masterflex peristaltic pump. Concentrated contaminant solution was made by adding 123.0 grams of "AC" road dirt and 532.0 grams of military detergent to 40 liters of tap water. For "dirt-only" wastewater, only the AC road dirt solution was added. Any desired contaminant concentration could be obtained by changing the Masterflex pump flow rate. The normal flow rate to obtain 636 mg/l detergent and 147 mg/l dirt concentration was 0.0682 GPM (252.9 ml/min) of concentrated contaminant solution. For the detergent plus road dirt wastewater, the average turbidity was 24.5 NTU, ranging from 23 to 26, and the pH averaged 8.6. For the road dirt only wastewater the turbidity averaged 15. NTU, ranging from 14 to 16. The pH of the dirt only wastewater was not changed from the pH of the tap water used in making it, and ranged from 6.8 to 7.0.

The road dirt is a product manufactured by the AC spark plug division of General Motors from an Arizona clay source. It is a standard material for use in evaluation of air cleaners in simulated driving conditions. The road dirt is manufactured by sizing clay dust and the particle size distribution is shown in Table 2.

The military detergent is a nonionic detergent used regularly by several branches of the military for laundries. An exact analysis of the detergent was not available, but the specifications are shown in Table 3. The military detergent was selected for evaluation with AC road dirt because it resembles the wastewaters expected in field application.

TABLE 2 AC ROAD DIRT SIZE SPECIFICATIONS

Size Range (microns)	Size Fraction[+] (%)
0-5	12 ± 2
5-10	12 ± 3
10-20	14 ± 3
20-40	23 ± 4
40-80	30 ± 3
80-200	9 ± 9

[+] Size distribution in weight percent from a roller analysis.

AC Spark Plug Division of General Motors, Flint, Mich.,USA

TABLE 3 SPECIFICATIONS FOR TYPE 1 MILITARY DETERGENT+

Requirements	Type I Low sudsing low phosphate Min.	Max
Moisture and matter volatile at 105 °C, %	-	10.0
Nonionic Surfactant, 100% active, %	15.0	-
Chloroform soluble matter, %	22.0	-
Free Alkali, as NaOH, %	-	1.0
Matter Insoluble in hard water, %	-	1.0
Total Phosphate, as P, %	76	8.7
Total Phosphate, asP_2O_5, %	17.4	20.
Polyphosphate, as P_2O_5, %	17.4	20.0
Orthophosphate, as P_2O_5, %	-	2.0
Silicates, as SiO_2, %	4.4	6.6
Sodium Carboxymethylcellulose, 100% active	0.5	-
Borax, as $Na_2B_4O_7 \times 5H_2O$, %	-	-
Optical brightener (fluorescent dye)	present	
pH of 0.1% solution	9.5	11.5
Sudsing, ml of foam at 100 °F	-	30.
Bulk Density, grams/ml	0.6	-
Biodegradability, %	90.	-

Properties of Nonionic surfactants	For detergent Type I Min	Max
Active Ingredient content, %	99.0	-
Alkyl carbon range	C_{10}	C_{12}
Average moles of ethylene oxide	5	8
Molecular weight, avg.	480	550
Cloud Point F	90	140
Flash point, COC, °F	250	-
Biodegradability, %	90	-

+ The specifications further require that the surfactant be a "nonionic, synthetic, organic surfactant, produced by the reaction of linear primary alcohols or linear secondary alcohols with ethylene oxide."

Backwashing was automated through the use of a timer and pressure switch, but automatic operation was seldom possible due to a variety of changing experimental conditions. A differential pressure switch, which was not available in time for the phase, was required to precisely control the filtration and backwashing cycles. Backwashing was normally performed with tap water, since no storage was available for product water. Both the Viking gear pump and the centrifugal pump were used for backwash.

A typical filter test would begin early in the morning after filling the feed reservoir on the previous day. Elapsed time was monitored by stop-watch and manual recordings were made throughout the test. The time for backwashing was not included in elapsed time. Samples for analysis were collected and stored at room temperature for periods of several minutes up to several hours. Many of the tests were continued into subsequent days if the filter clogging rate was low. In these cases the filter was shut down with the column filled with feed solution and operation was resumed the next day.

Analytical Methods

The basic analytical method used in this procedure was turbidity, and was measured on a HF Model DRT 100 Turbidity meter. Standardization was performed at the beginning of each day's analysis. Total Organic Carbon (TOC) and Total Oxygen Demand (TOD) analysis were performed on an Ionics Model 1270 Analyzer. Calibration was performed during each series of analyses. Normal procedure was to remove inorganic carbon (dissolved CO_2 and carbonates) by acidifying the sample to pH 1.0 or less with hydrochloric acid and stripping with high purity nitrogen gas. In early analyses it was noted that stripping removed a significant quantity of detergent; at this point it was decided to change to Total Carbon (TC) analysis, which was performed on the same instrument, but without stripping and acidification.

Surface tension was measured on a Fisher Tensiomat device, Model 21 calibration against deionized tap water. Flow rates and pressure changes were measured with rotometers and process-quality pressure gages. Flow meters were calibrated manually by measuring the time required to fill a container of known volume. The pressure gages were not calibrated, but several gages were selected of the same manufacture and type which gave identical readings for identical pressures. The same gages were used throughout all tests.

Fouling tests were performed with Whatman glass fiber filters, type GF/C. The normal procedure was to collect filtered water during the tests for analysis after test completion. Tests of unfiltered and filtered water were run simultaneously to eliminate the effects of differences in vacuum pressure. The glass fiber filters were placed in Gilman 47 mm filter holders and attached to a standard laboratory vacuum pump. Test solution was poured into the filter flask and allowed to filter until a specific volume was passed. The time required for filtration was recorded, and was indicative of the water's fouling properties which would occur in a reverse osmosis process.

Coagulation tests (jar tests) were performed on a six spindle gang stirrer using one liter beakers. Normal procedure was to add the desired coagulating chemicals to each one-liter beaker containing wastewater, then mix simultaneously at high rate (100 rpm) for 20 seconds, then flocculate for 20 minutes at a very gentle mixing rate (30 rpm), then turn off the stirrer and allow the mixture to settle for 30 minutes. When pH control was used, the coagulants were added and mixed on a magnetic stirrer while adding sodium hydroxide to raise the pH to the desired level. After obtaining the desired pH, the beaker was placed on the gang stirrer.

Modes of Operation

The filter was originally operated in three modes: closed-end, cross flow, and reverse flow. The closed-end and cross flow are internally pressurized while the reverse flow is externally pressurized. The closed-end method was the simplest procedure. Liquid was pumped into the top of the column and all liquid must flow through the filter fabric. Consequently, this method was a constant flow, increasing pressure method. Backwashing was accomplished by reversing flow. This method was the least successful of the three methods in the first phase, and was not selected for further development in the second phase.

The cross flow method extends the closed-end method by allowing the influent flow to return to a collection vessel. Liquid from the collection vessel was pumped back into the column with a high-volume centrifugal pump, which increased the velocity and turbulence inside the filter tubes. It was hoped that the high cross flow velocities would scour the inside of the filters and prevent the build up of solids. The internal area of the fabric tubes available for liquid flow was 0.3479 in^2, after deducting 0.4375 in^2 used for the internal supports. The Reynolds number was 6000. For two of the cross flow tests conducted in this phase, a length of ½ inch PVC pipe (external diameter 7/8 in) was inserted into the fabric tubes, reducing the internal area, and increasing turbulence to a Reynolds number of 11,300. It was hoped that the increased turbulence would maintain fabric permeability. Backwashing was performed in the same manner as in the closed-end method.

In the experimental set-up used for cross flow operation, the total flow to the filter (influent and cross flow) was maintained at a constant value; however, flow through the filter fabric declined with increased clogging. System pressure increased during the test. This resulted in increasing pressure, declining rate operation. An alternate method of cross flow operation, which controls the flow of return liquid, ensuring constant filtration rate was not attempted, since a flow controller was not available.

The reverse-flow method was entirely different than the previous two methods since liquid was introduced on the outside of the fabrics and flowed radially inward through the fabric. The valving of the experimental apparatus was designed to permit flow direction change without disassembling the filter. To backwash, liquid was introduced inside the tubes, and flowed entirely through the fabric. The procedure was termed reverse flow because it was very similar to closed-end operation, with the location of the wastewater and backwash water reversed.

RESULTS AND DISCUSSION

Experiments were performed on the Type I and Type IV fabrics in a systematic way to provide an evaluation of two filter modes (reverse and cross flow) and two wastewaters (detergent plus road dirt and road dirt only). Additionally, coagulated detergent/dirt wastewater was filtered in the reverse flow mode with Type I fabric. Washed Type I fabric was evaluated once in the reverse flow mode with detergent/dirt wastewater, and the new membrane fabric, Type V, was evaluated once in the reverse flow mode with detergent/dirt wastewater. Table 4 summarizes the test modes, fabrics, and wastewater types.

TABLE 4 FILTRATION TEST SUMMARY

WASTEWATER (1)	FABRIC TYPE (2)	FILTRATION MODE (3)	TEST NUMBERS (4)
Detergent and AC Road Dirt	Type I	Reverse	1,2
	Type I (washed)	Reverse	3
	Type I	Cross flow[+]	4
	Type IV	Reverse	5,6
	Type IV	Cross flow[+]	7
	Membrane (Type V)	Reverse	8
AC Road Dirt only	Type I	Reverse	9
	Type I	Cross flow	10
	Type IV	Reverse	11
Coagulated Detergent and AC Road Dirt (no pH control)	Type I	Reverse	12
Coagulated Detergent and AC Road Dirt with pH control	Type I	Reverse	13

[+] Tests 4 and 7 used the PVC pipe insert which increased the Reynolds Number to 11,300.

Reverse Flow Results

The reverse flow results obtained in this part of the fabric filter concept development were the most promising results obtained so far. Filter runs far in excess of anything previously obtained with cross flow or closed-end flow were made.

Type I Fabric Figures 5-7 show the results of Test 1 (reverse flow, Type I, and detergent plus AC road dirt), indicating pressure drop, effluent turbidity, and total volume filtered. Tabular data for this filter test and others not shown in the text are included in Appendix A.

Figure 5 shows the effluent turbidity versus time. The filter reduced the turbidity from the influent value of 24.5 NTU to an minimum of approximately 5 NTU during the first 12 cycles, and declined to less than 4 NTU in the last 6 cycles. Average effluent turbidity was approximately 6 NTU. The separate "peaks and valleys" represent complete filter cycles, including backwashes. The time included for backwashing was not included in elapsed time. The initial decline in turbidity with subsequent increase is characteristic of many filters which have "dynamic" membrane or filter media formation. Granular media (sand, coal, and garnet sand) filters also show this behavior, as well as many other types of filters and reverse osmosis membranes. The filtered material which collects on the surface of the fabric acts as a filter itself, and increases removal efficiency. After a short period the pressure drop increases and forces turbidity causing material through the fabric. This behavior is also typical of other types of filters.

Figure 6 shows the pressure drop as a function of time. Back washing restores the pressure drop to the static pressure loss, as shown in the figure, and with other types of filters it is normally a sign of excellent backwashing; however, it is not indicative of backwashing performance for this investigation, since the backwashing requires depressurizing the filter. Restarting the filter will always reduce the pressure to the static pressure drop, even if no filter cleaning has occurred. A better indication of

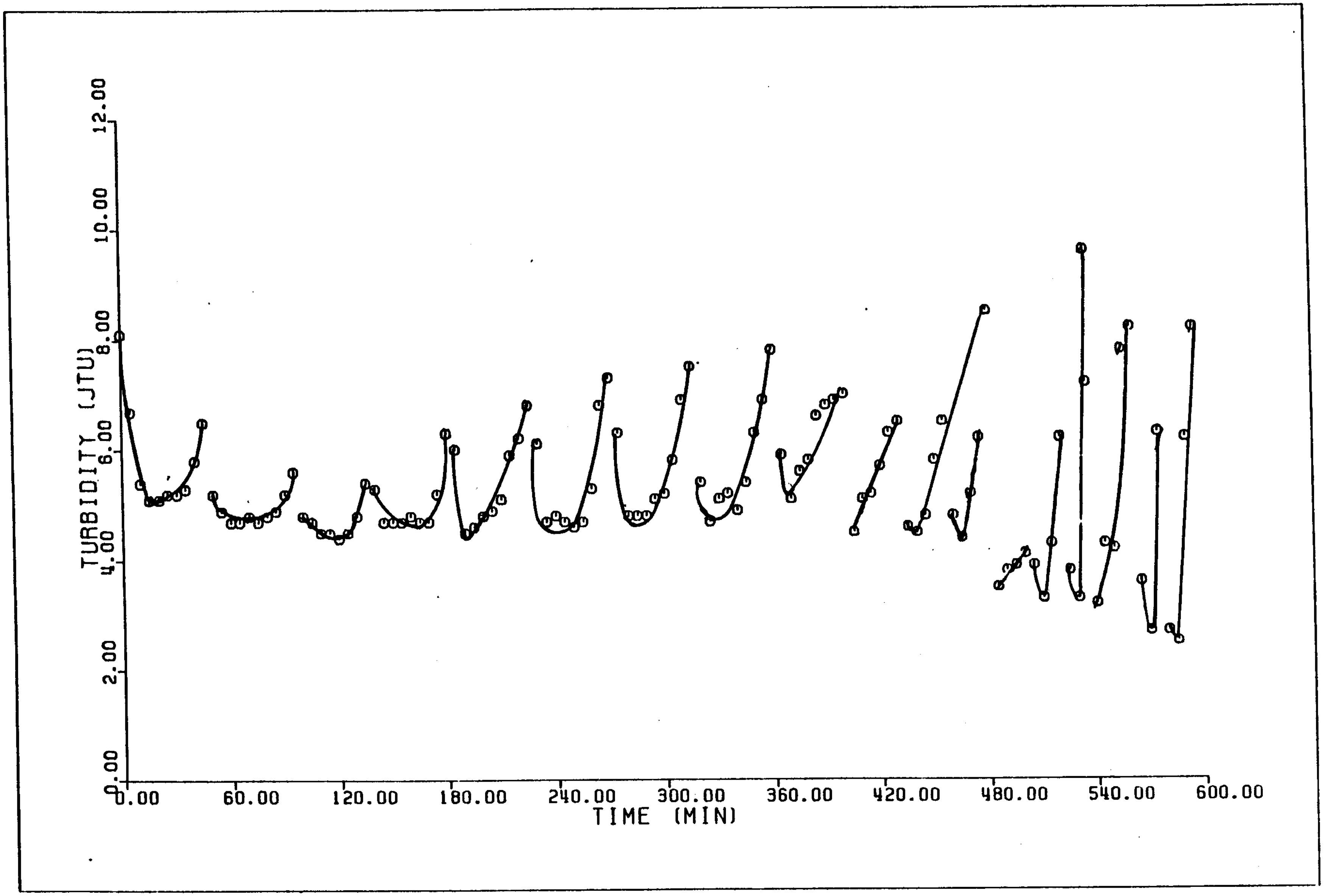


Figure 5 Turbidity versus Time for Filter Test 1. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

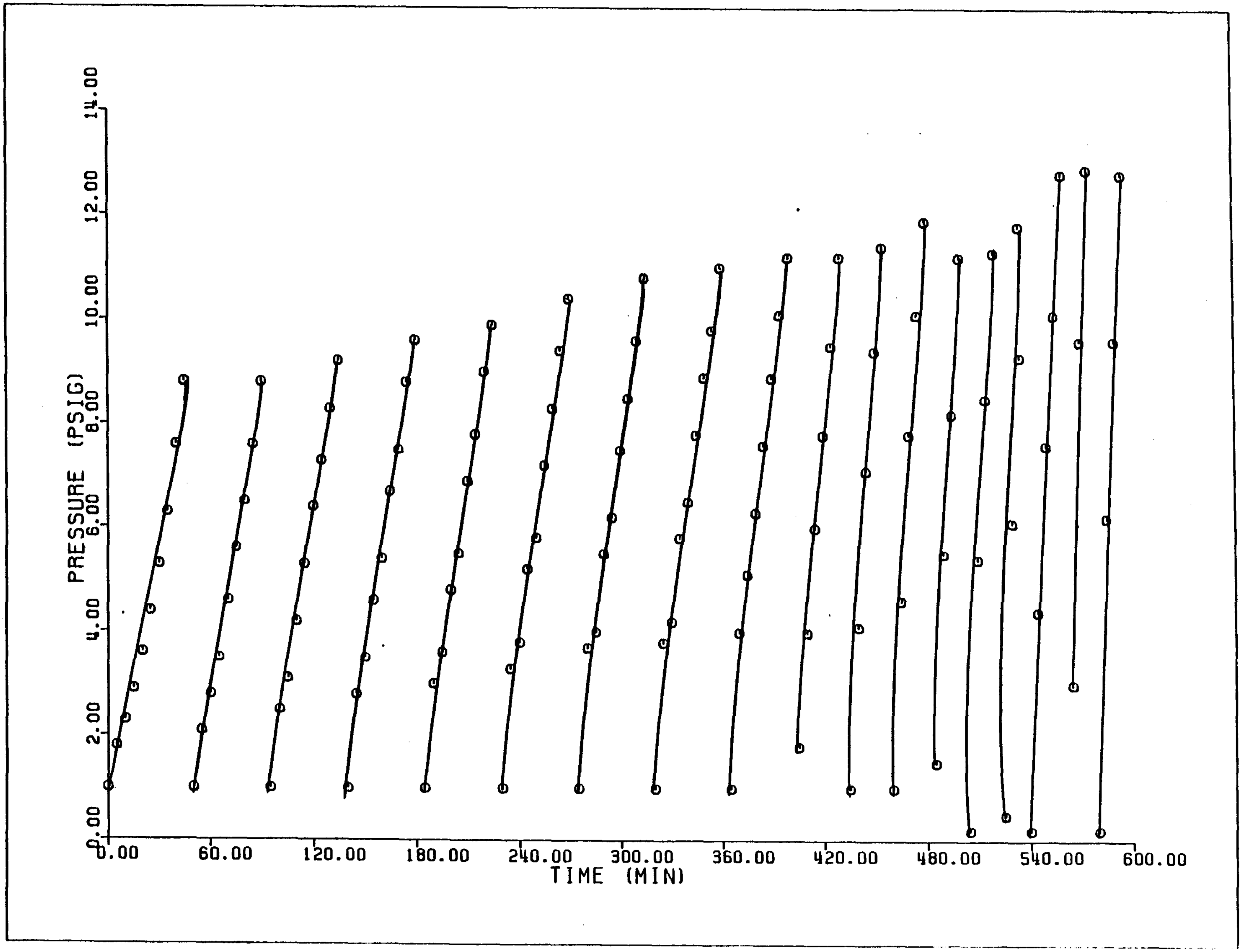


Figure 6 Pressure Drop (PSI) versus Time for Filter Test 1. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

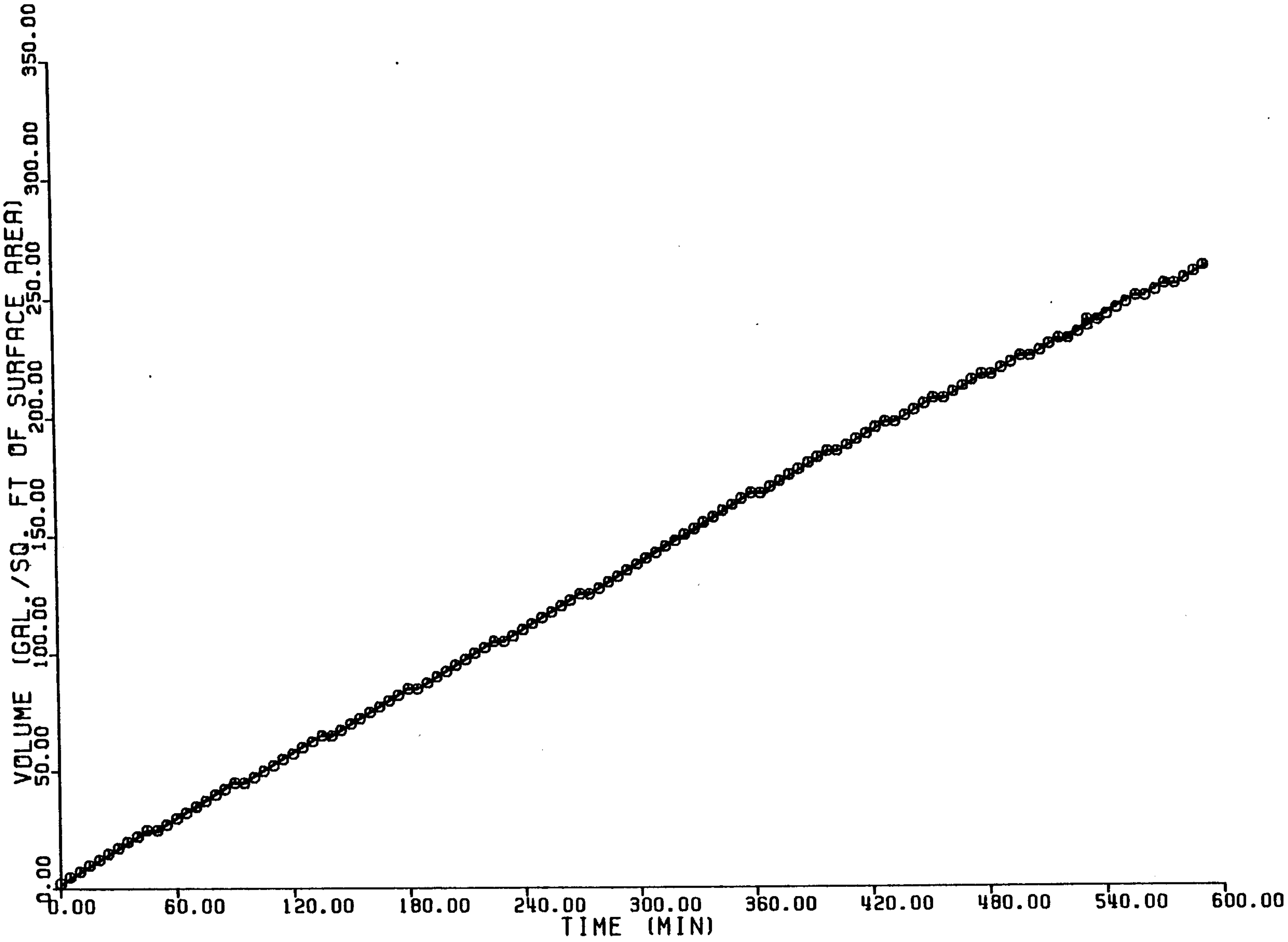


Figure 7 Total Filtered Volume (gal/ft^2) versus Time for Test 1. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

backwash efficiency is the time required to build up pressure from zero to a small positive value. A comparison of the pressure increase per unit time from the start of a test to the end of a test is an indication of back washing efficiency. For tests evaluated hereafter, the rate of pressure change will be calculated as the increase in pressure over the first 10 minutes of operation after backwashing. Initial rate of increase for reverse-flow and cross flow operation are not comparable, since actual filtration rate can be different.

For test 1, the initial rate of pressure change in the first 10 minutes of operation was 0.13 PSI/min. In the middle of the test (275-285 minutes elapsed time), the rate of pressure change increased to 0.30 PSI/min., and at the termination of the test, the rate of change was 0.94 PSI/min. This increasing trend in the rate of pressure change indicates incomplete backwashing, and results in short filter runs and reduced filtered volumes. Test 2 was essentially a duplicate of test 1 and shows a similar increasing trend in rates of pressure change.

<u>Washed Type I Fabric</u> To determine if the increasing trend in rate of pressure increase was reversible, the fabrics used in test 2 were removed, allowed to dry, then washed in an ordinary washing machine with a hot water wash and a warm water rinse, using BIZ enzyme detergent. Figure 8 shows the pressure versus time curve, which is analogous to Figure 4, except that only two filtration cycles were made. The initial rate of pressure change was 0.16 PSI/min and increased to 0.26 PSI/min. for the second cycle, thus indicating an almost complete restoration of permeability. It is not clear that the washing alone restored permeability, because the drying process produced a

backwashing. Pressure drops were not allowed to increase above the 2 to 3 PSI range, as compared to the previous phase were pressure drops as high as 15 PSI were used.

Type I Fabric Figures 17 and 18 show the results of test 4 using detergent plus AC road dirt wastewater. Turbidity was reduced from the influent value of 24.5 NTU to 5 NTU, which was comparable to operation in the reverse flow mode. The initial rate of pressure change was 0.08 PSI/min., and increased to 0.28 for the third filter cycle. Figure 19 shows the total accumulated volume of product water for the three cycles.

In the cross flow mode it is important to note that the accumulated volume relation is not a linear function of time, as it is in reverse flow operation; this results because there was no flow regulator on the exit end of the fabric tubes to maintain a balance between flow through the filter and recirculation flow. Also it was difficult to precisely control the filter with cross flow operation which was also due to this variable flow split. For test 4 the total accumulated product volume was less than the water volume required for backwash. Results for test 10, at the same conditions, except with AC road dirt only wastewater, were similar to results from other tests, in that fouling was less severe, and effluent turbidities were lower. Initial rate of pressure change was 0.02 PSI/min. and increased to 0.09 PSI/min for the second filter cycle.

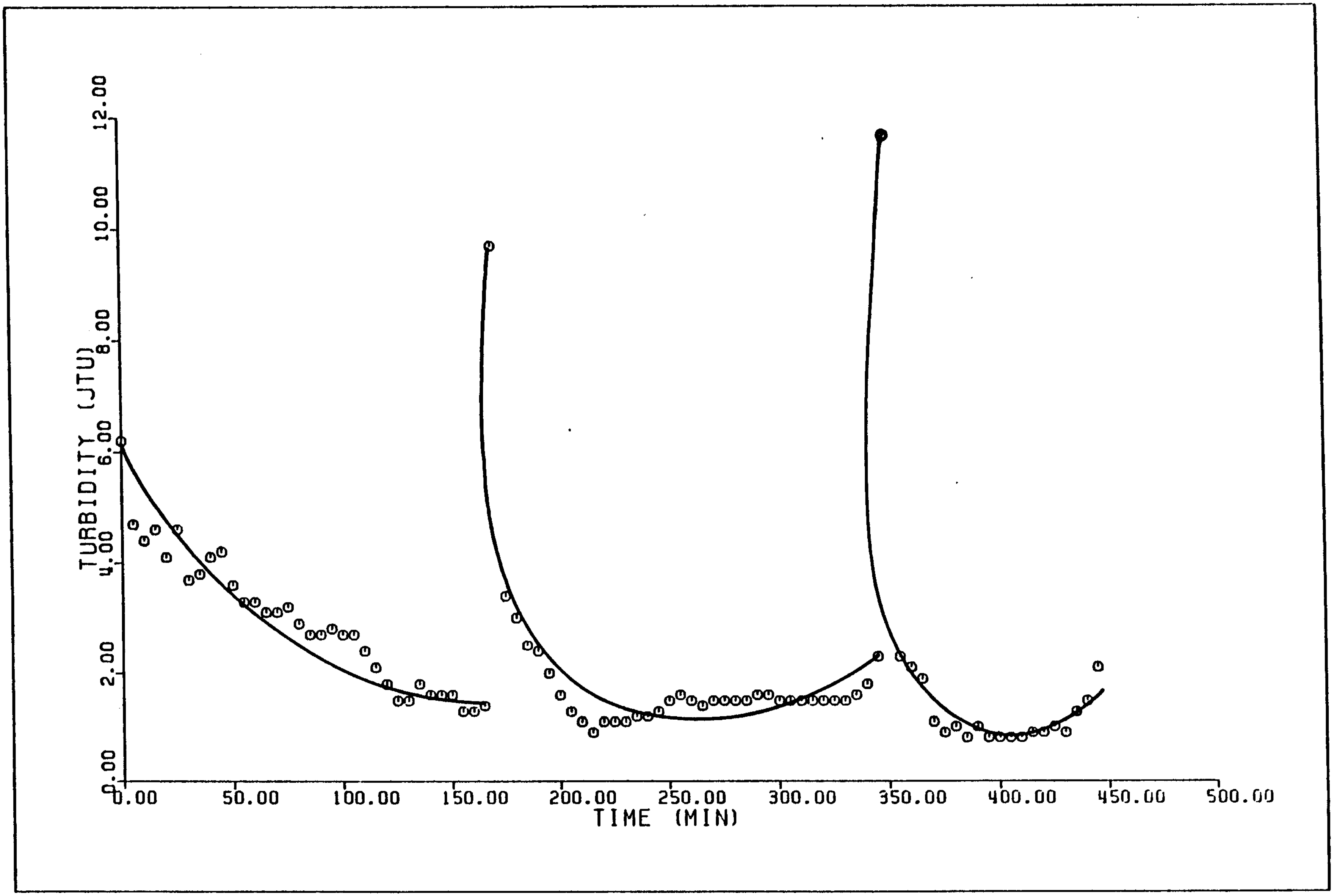


Figure 15 Turbidity versus Time for Filter Test 11. (Type IV Fabric, reverse flow, and AC road dirt wastewater).

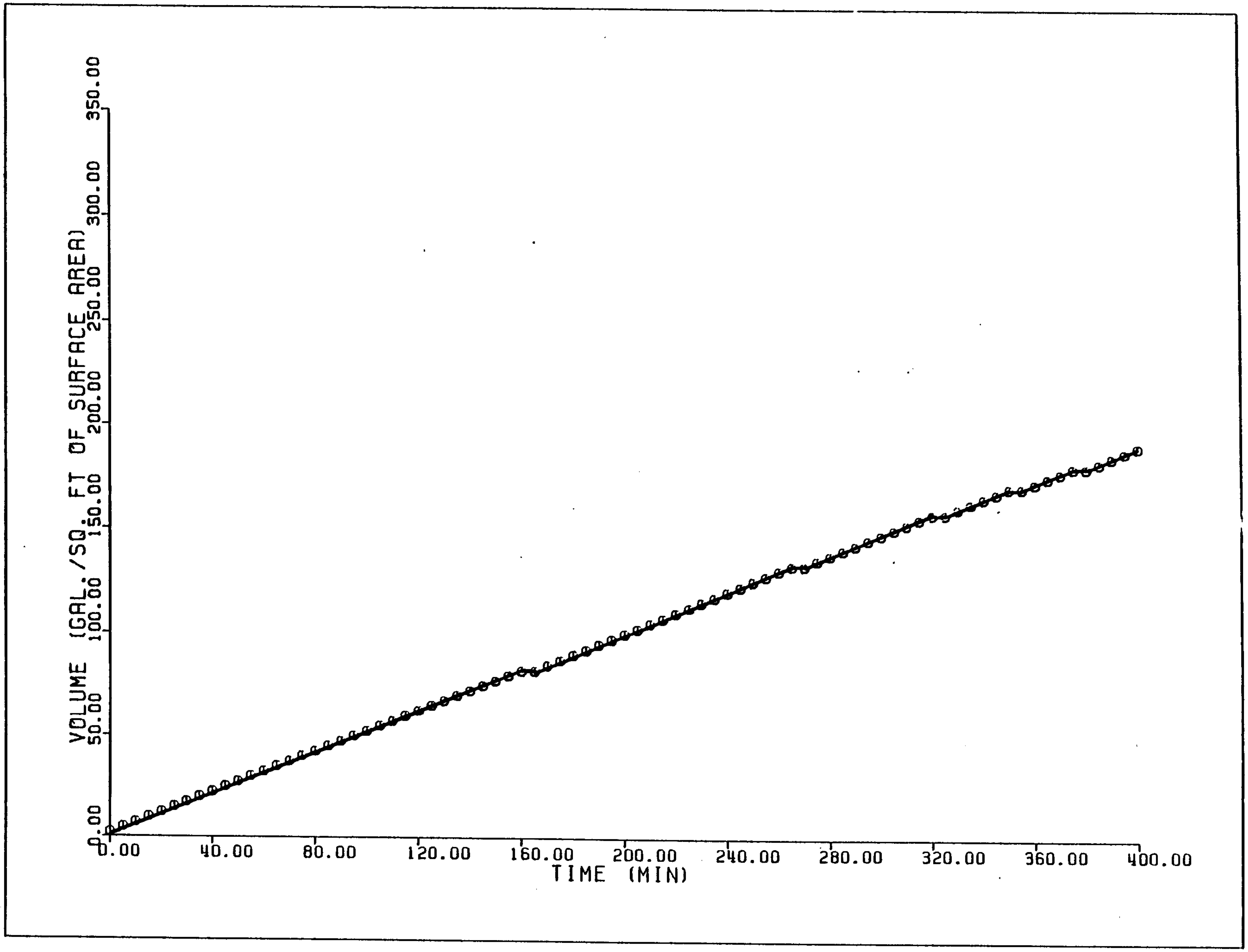


Figure 14 Total Filtered Volume (gal/ft^2) versus Time for Test 5. (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

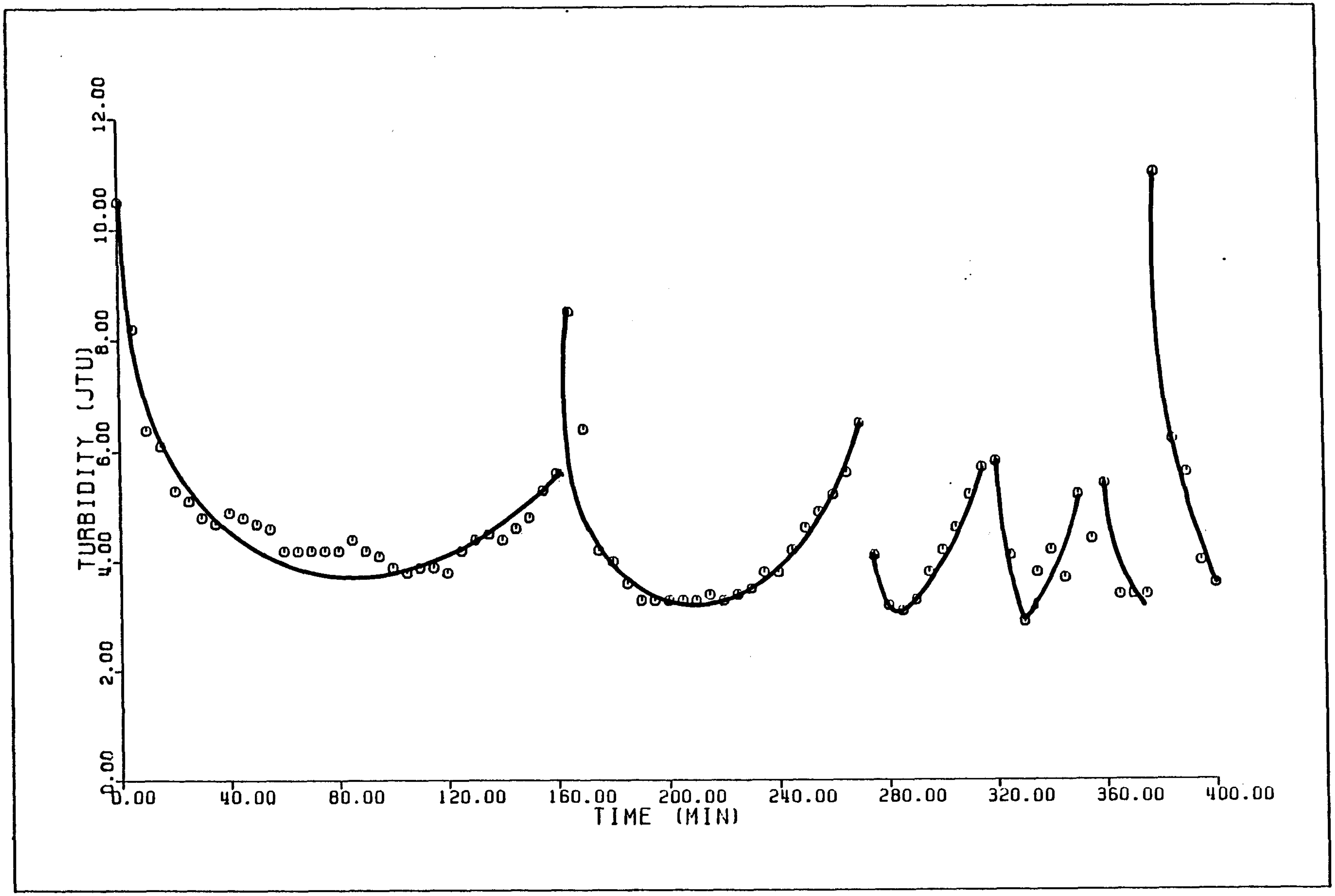


Figure 12 Turbidity versus Time for Filter Test 5. (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

fine layer of white powdery material on the fabric surface, which could be removed by brushing or scraping.

Filtration of the AC road dirt only wastewater produced similar results as the detergent containing wastewater, although clogging was less severe. Figures 9-11 show turbidity, pressure drop and accumulated volume versus time for test 9. The turbidity was reduced from 15 NTU to an average of 2 NTU after dynamic media formation. The initial pressure drop was 0.05 PSI/min. and increased to 0.18 PSI/min. in the second cycle. Dynamic media formation occurred very quickly. Effluent turbidity was lower because of the absence of the detergent.

<u>Type IV Fabric</u> Reverse flow operation with the Type IV fabric was less successful than with the Type I fabric, in that less efficient backwashing was obtained. Figures 12-14 show the results of test 5 using the Type IV fabric, reverse flow, and detergent plus AC road dirt wastewater. The initial rate of pressure increase was only 0.045 PSI/min., but increased to 0.52 PSI/min for the sixth filter cycle. Backwashing only partially restored permeability. Dynamic media formation was a much more important mechanism as shown in Figure 12. Initially effluent turbidity was 12 NTU, which was only a 50% reduction from the influent turbidity of 24.5 NTU. After approximately 40 minutes elapsed, a sufficiently large layer of filtered material was depositied within the fabric to increase filtration efficiency to rates comparable to the results obtained with Type I fabric, producing an effluent turbidity of 4 NTU minimum.

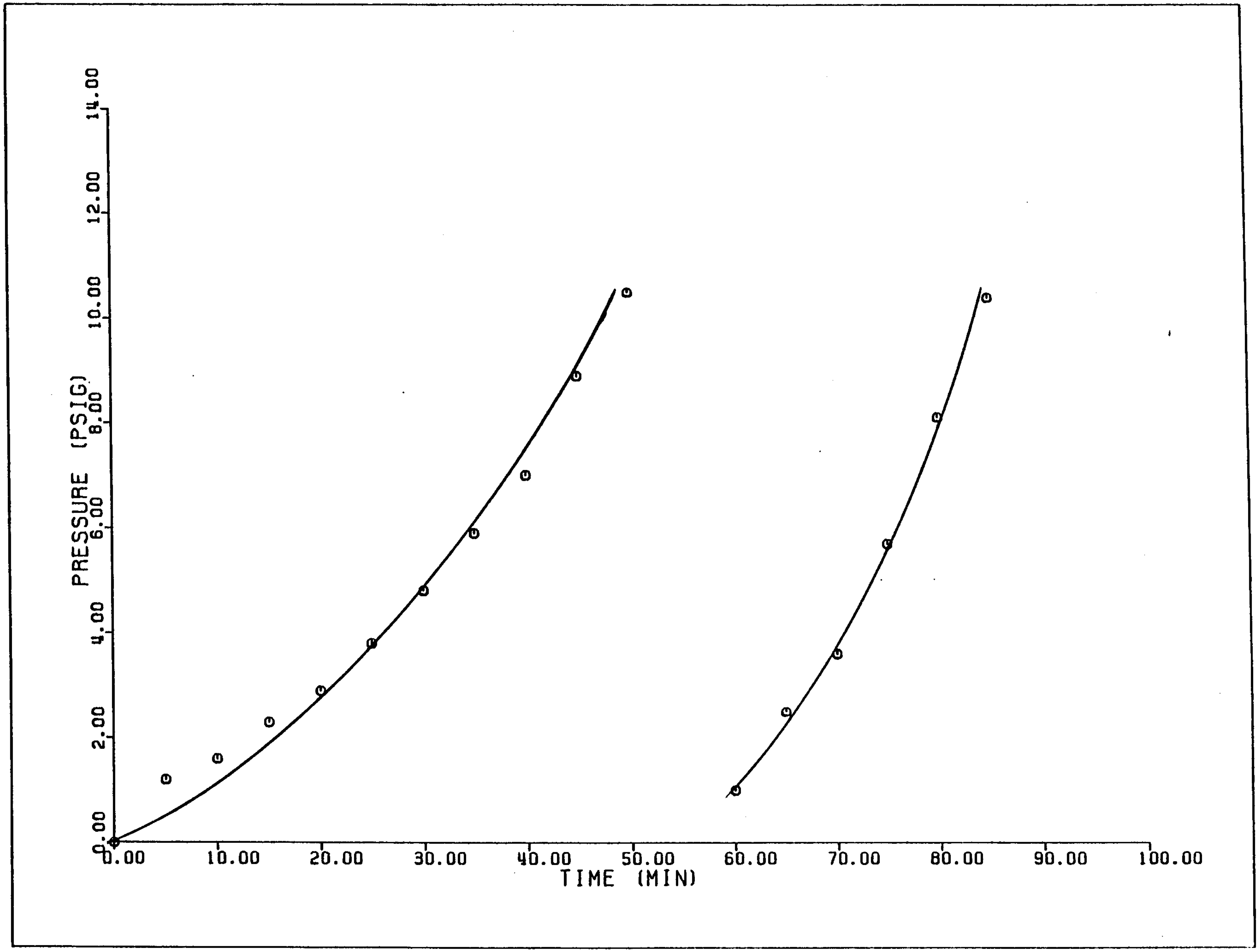


Figure 8 Pressure Drop (PSI) versus Time for Filter Test 3. (washed Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

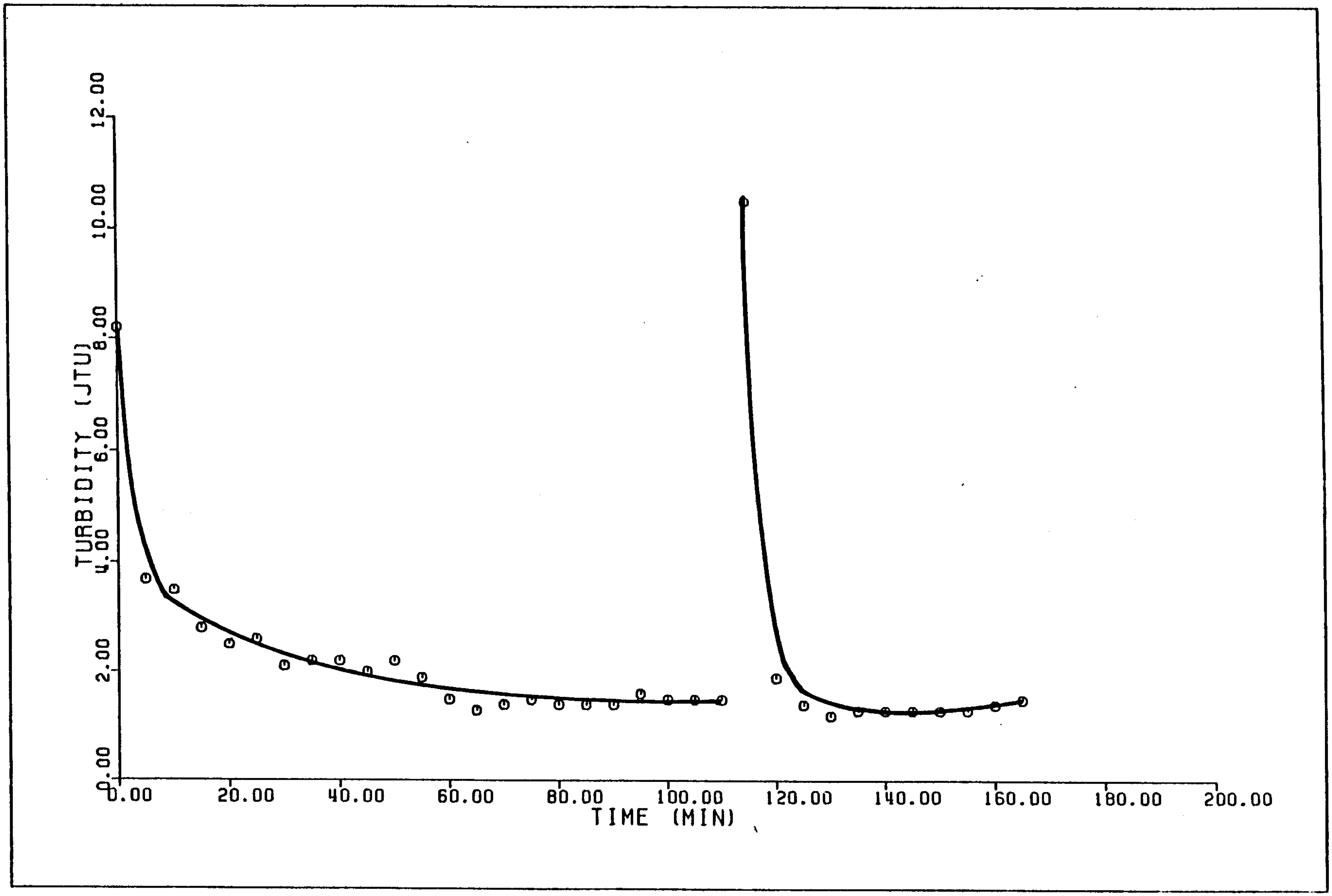


Figure 9 Turbidity versus Time for Filter Test 9. (Type I Fabric, reverse flow, and AC road dirt wastewater).

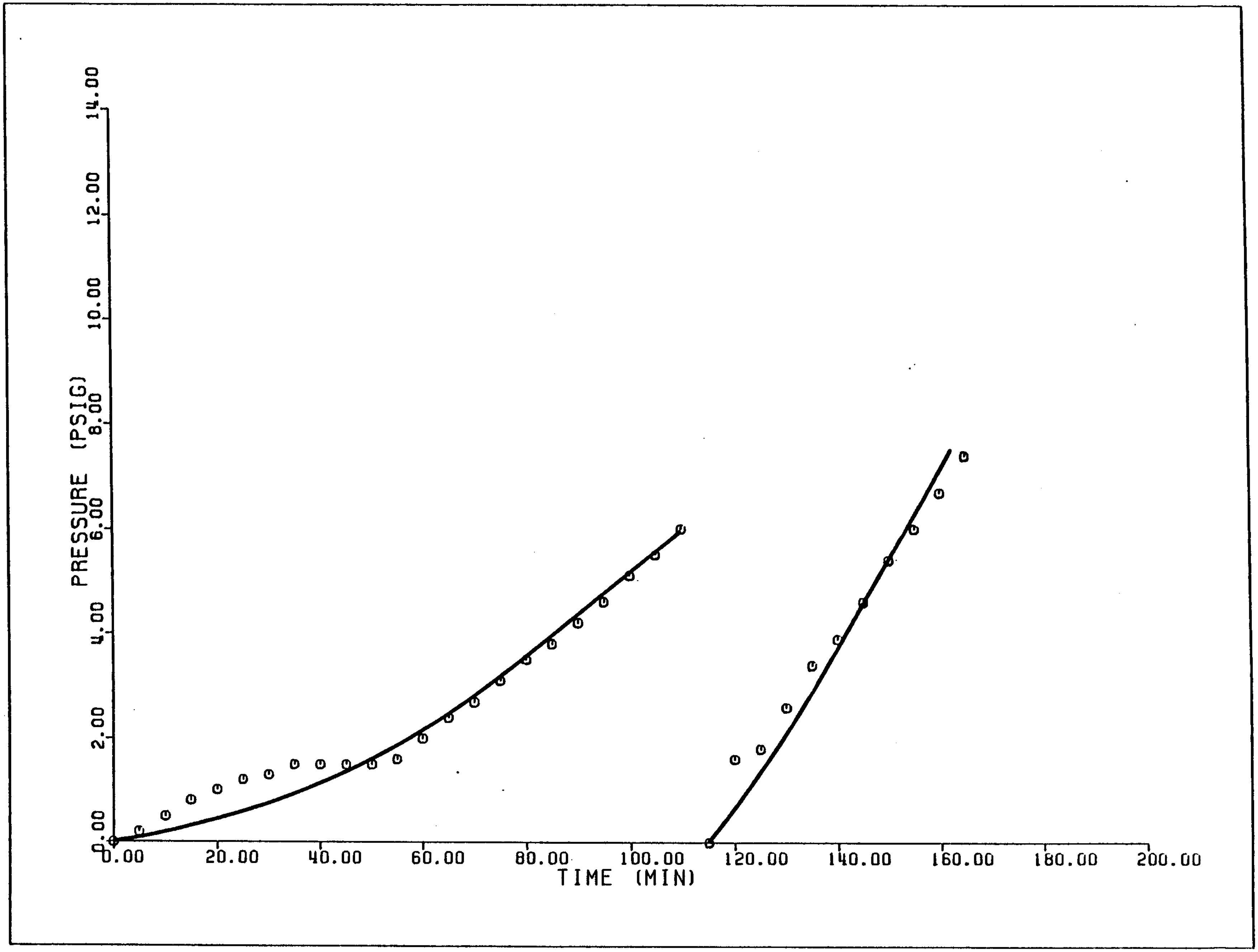


Figure 10 Pressure Drop (PSI) versus Time for Filter Test 9. (Type I Fabric, reverse flow, and AC road dirt wastewater).

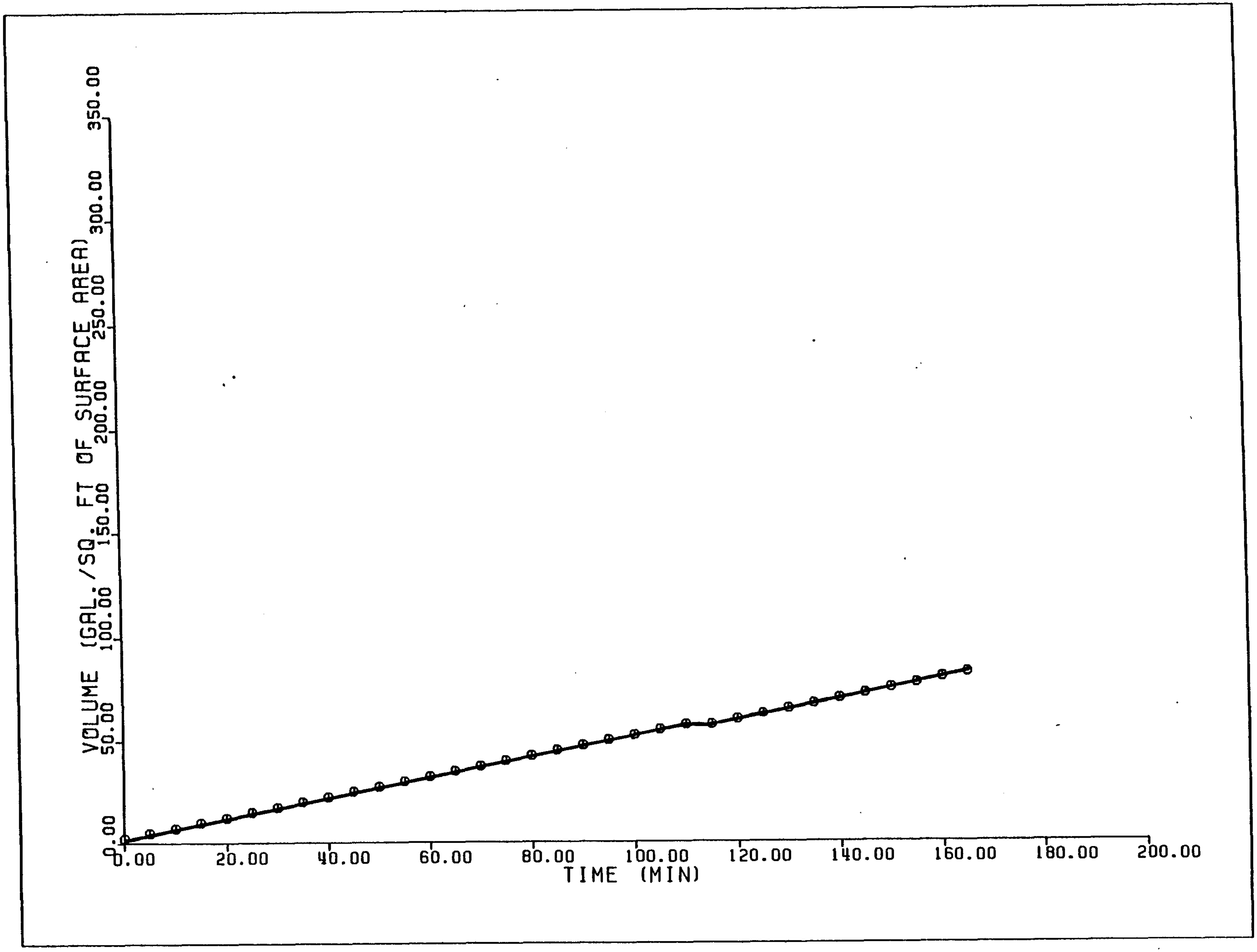


Figure 11 Total Filtered Volume (gal/ft^2) versus Time for Test 9. (Type I Fabric, reverse flow, and AC road dirt wastewater).

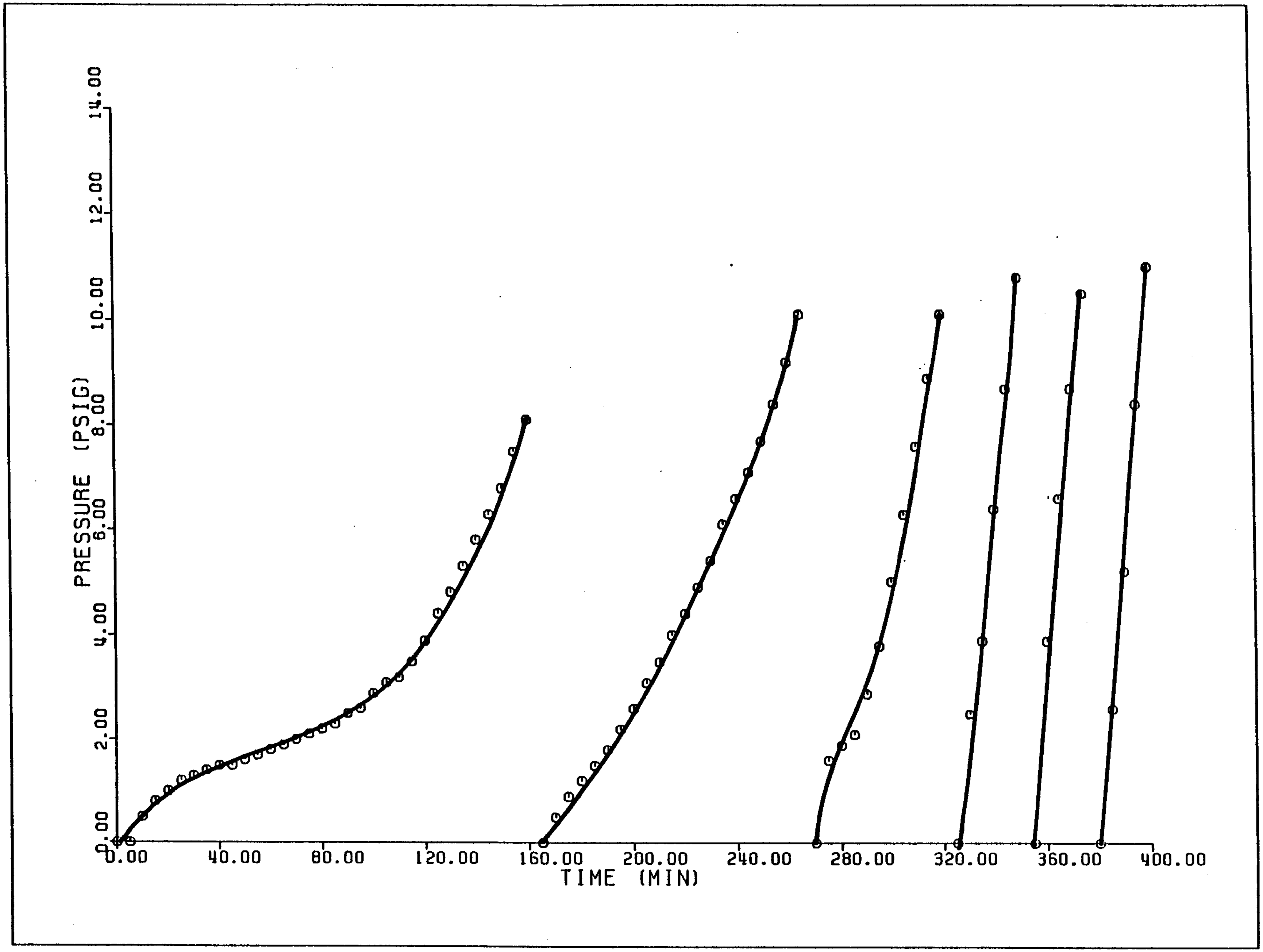


Figure 13 Pressure Drop (PSI) versus Time for Filter Test 5. (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Type IV fabric with AC road dirt only wastewater shows analogous results to the results obtained with Type I fabric. Figures 15 and 16 show turbidity and pressure drop for test 11. Initial rate of pressure increase was only 0.03 PSI/min, but increased to 0.20 for the second filter cycle, indicating incomplete back washing. Effluent turbidities were again low due to the absence of detergent.

Type V Fabric Results with Type V fabric were disappointing in that very little turbidity was removed. Turbidity was reduced from the influent value of 24.5 NTU to 22 NTU, which was only a 5 % reduction. Pressure increased to only 1.7 PSI, which was less than any other test without coagulated feed water. This was a surprising result since 95% of the AC road dirt particles were larger that the 5 micron membrane size. The only explanation for the low turbidity removal and low pressure increase was leakage at the seams, which also occurred with Types II and III fabrics in the previous phase. No visible leakage could be observed at the seams. A color dye test might confirm this hypothesis if future development of this fabric is needed.

Cross Flow Results

Cross flow results showed very little improvement over results obtained in the previous phase. Longer run times were obtained in this phase than in the previous phase, but were largely due to lower filtration rates. In this phase all filtration rates were held as close as possible to 0.5gal/ft^2-min. In the previous phase rates as high as 2.0gal/ft^2-min were evaluated. Also pressures were kept lower in this phase in the hopes that contaminant material would not be forced deeply into the fabrics were it could not be removed by

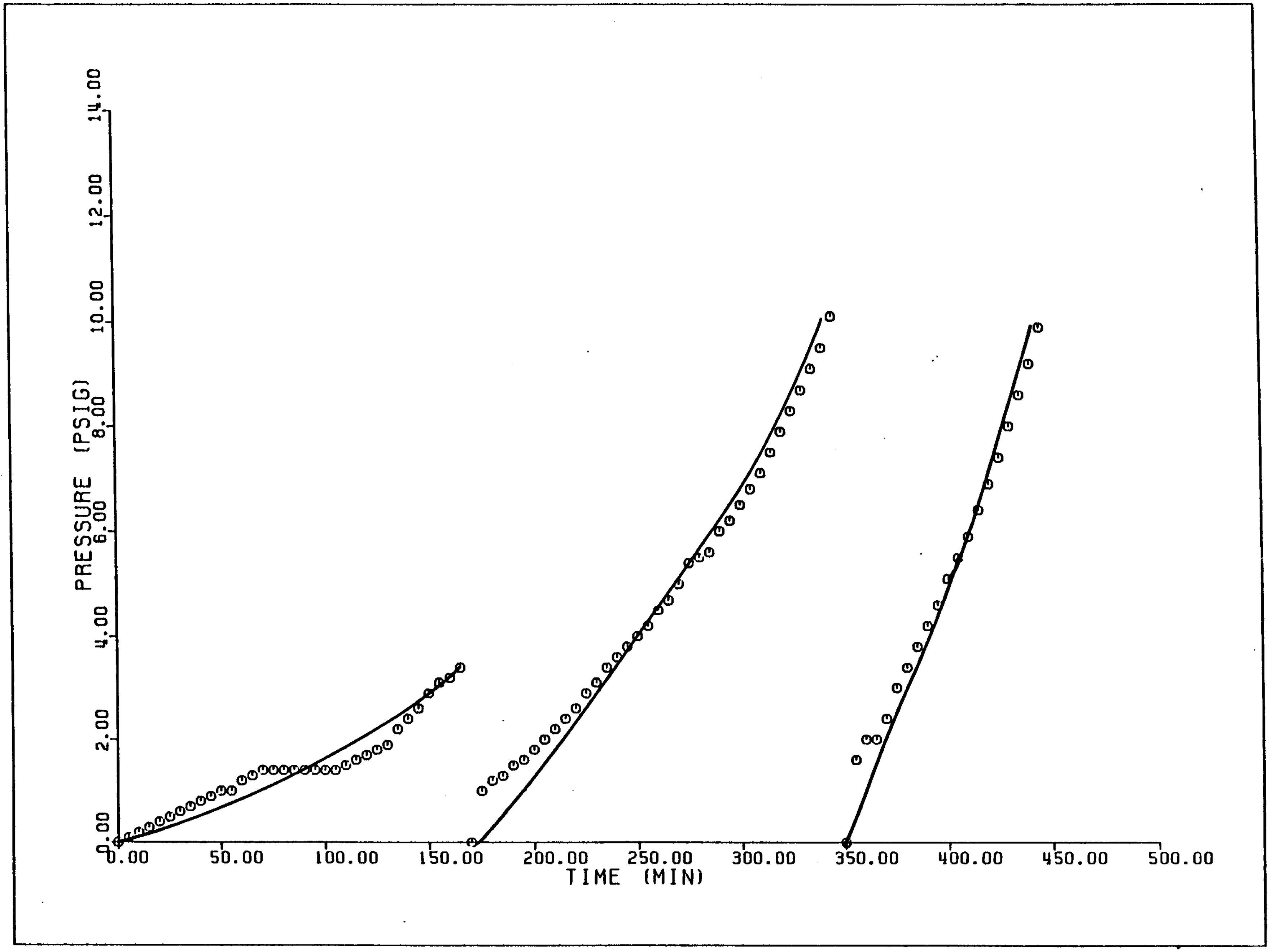


Figure 16 Pressure Drop (PSI) versus Time for Filter Test 11. (Type IV Fabric, reverse flow, and AC road dirt wastewater).

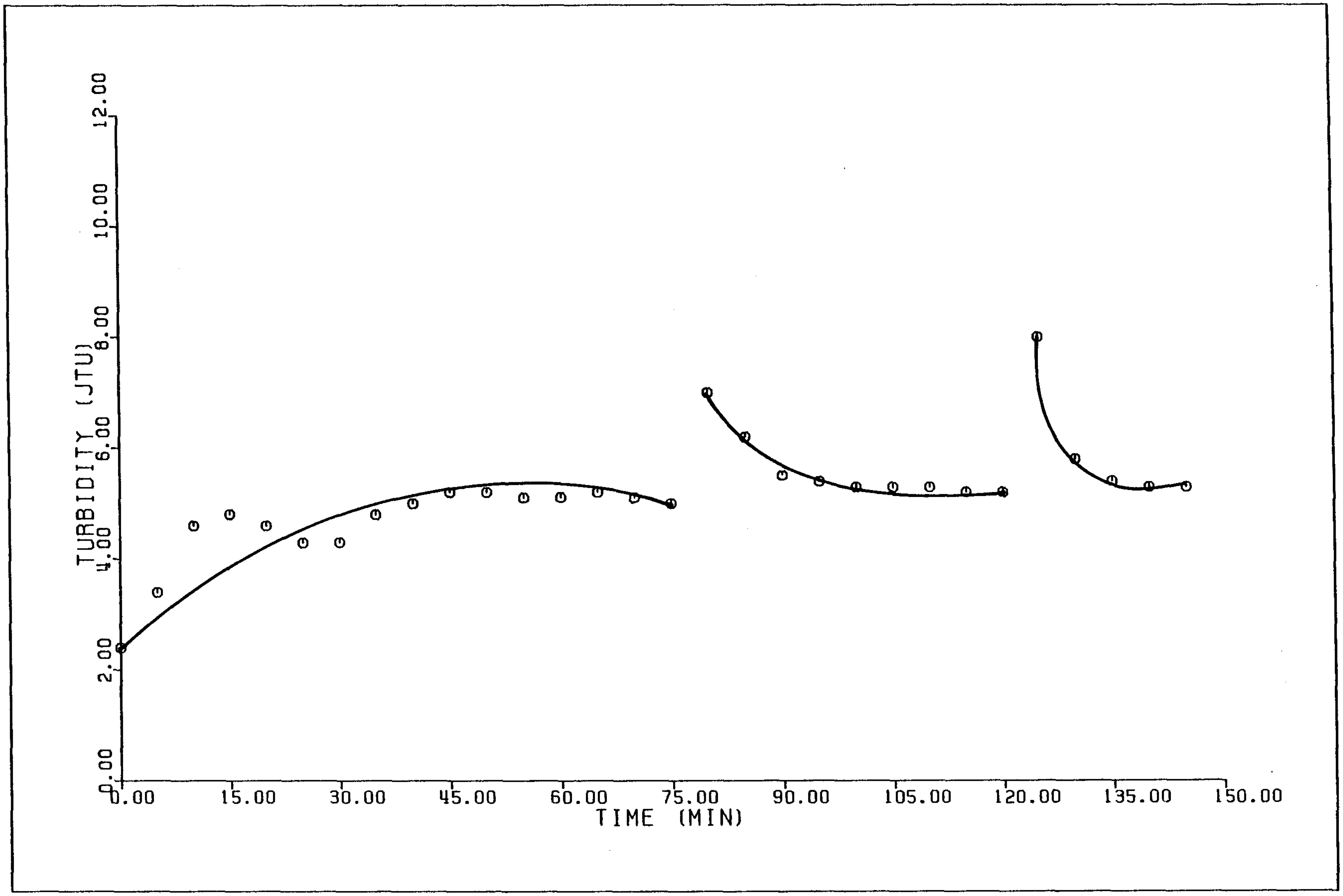


Figure 17 Turbidity versus Time for Filter Test 4. (Type I Fabric, cross flow, and detergent plus AC road dirt wastewater).

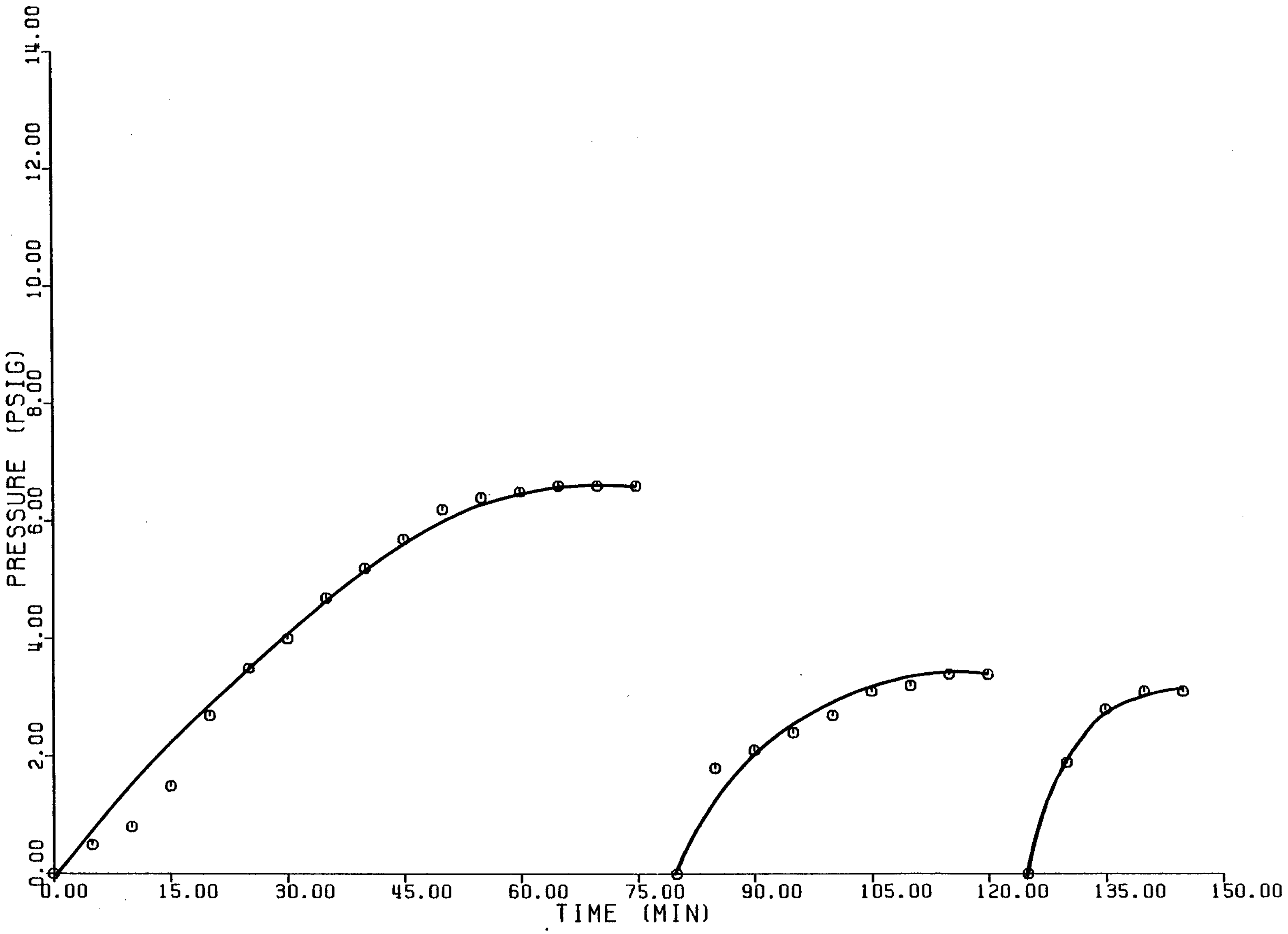


Figure 18 Pressure Drop (PSI) versus Time for Filter Test 4. (Type I Fabric, reverse flow, detergent and AC road dirt wastewater).

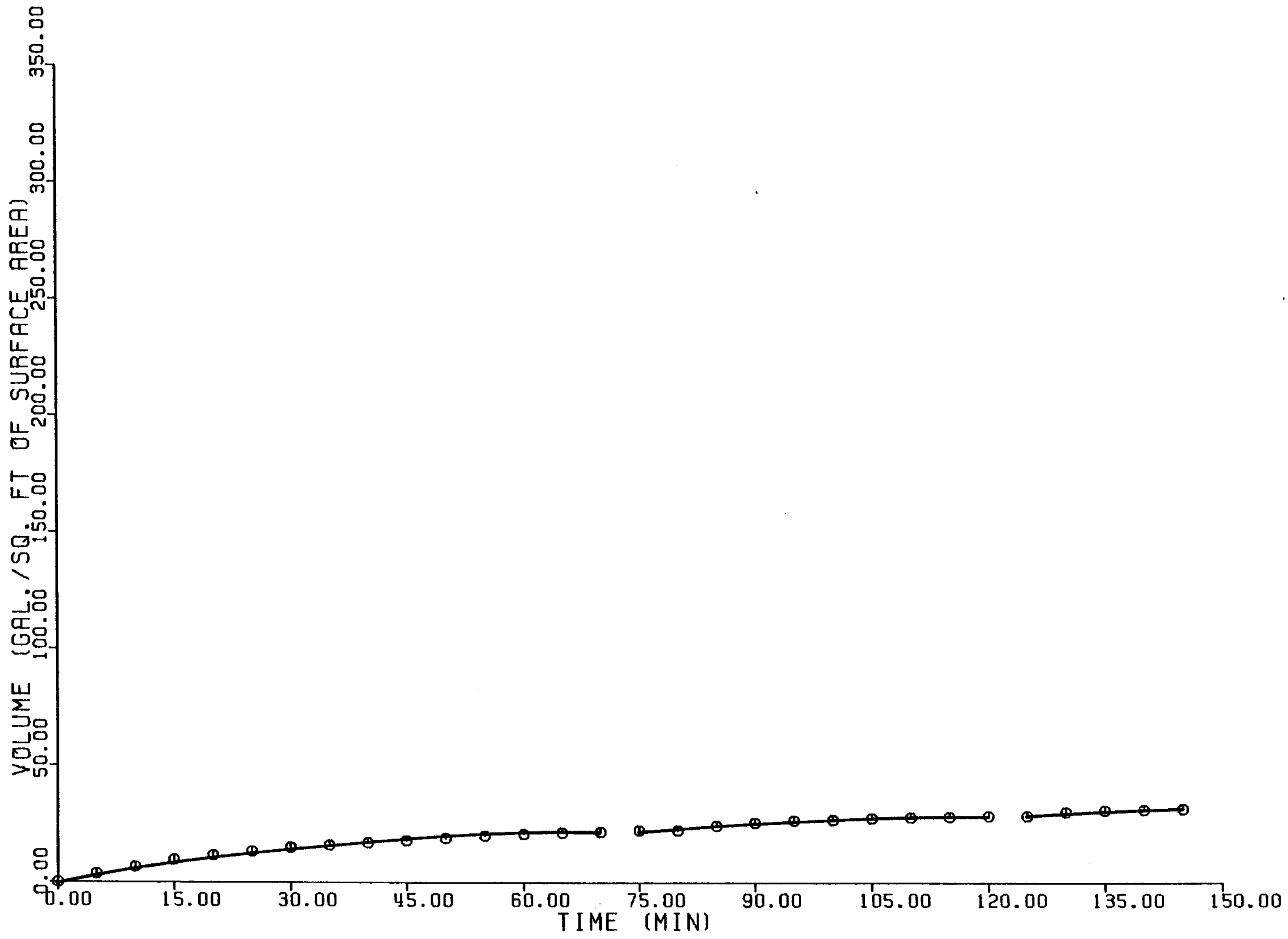


Figure 19 Total Filtered Volume (gal/ft^2) versus Time for Test 4. (Type I Fabric, cross flow, and detergent and AC road dirt wastewater).

Type IV Fabric Figures 20 and 21 show the results of test 7 with Type IV fabric and detergent plus AC road dirt wastewater. Initial rate of pressure increase was 0.02 PSI/min. and increased to 0.27 PSI/min. for the second filter cycle. Total accumulated volume for the two filter cycles was 75 gal/ft^2. Backwashing did not restore fabric permeability.

Coagulation/Flocculation Results-Jar Tests

A large number of coagulation and flocculation tests were performed in order to develop a method of breaking the stability of the detergent. A method was reported previously by Deane (2) to remove synthetic detergents by first reacting the detergent with a water-insoluble, high molecular weight, anionic surface active oil, which produces an emulsion which can be broken by conventional metallic coagulants. Straight forward coagulation with aluminum sulfate (alum) was also attempted.

Figure 22 shows the results of a series of jar tests with varying dosages of alum expressed as Al^{+3}. Expressing alum dosages in aluminum concentration eliminates confusion since no weight of hydration is included. It should be noted that 1.0 mg/l of Al^{+3} is equivalent to 12.7 mg/l of $Al_2(SO_4)_3$, and 22 mg/l of $Al_2(SO_4)_3 \times 14\ H_2O$. (Reagent grad alum is purchased as 16 hydrate, but commercially available alum averages about 10% less than the theoretical value, or about 14 hydrate.)

Several distinct and repeatable trends were noted throughout the jar testing. The turbidity always increased after the initial alum addition, and this was most probably due to the reactions of alum with the phosphates present in the detergent. An exact analysis for the detergent used in the

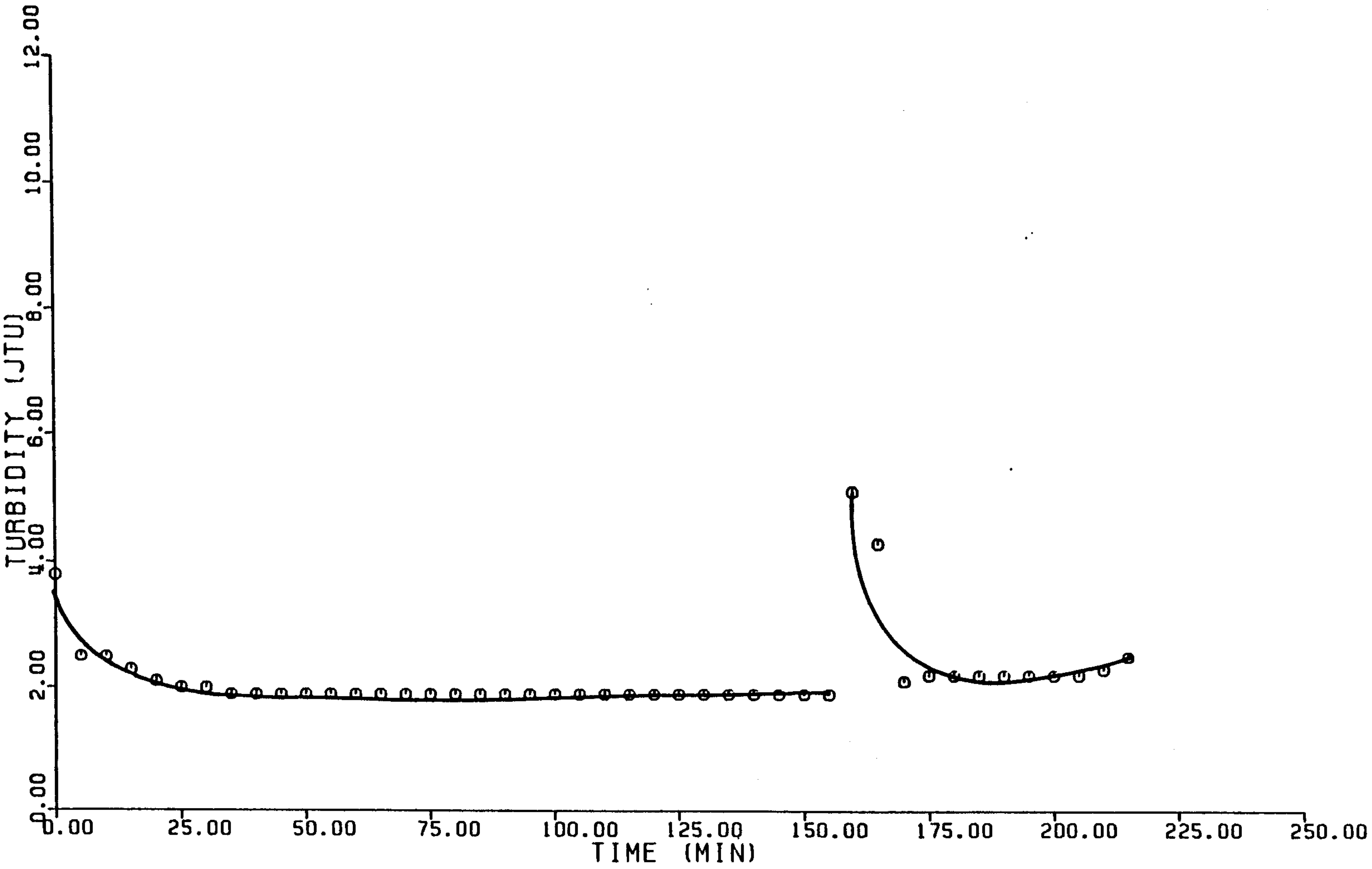


Figure 20 Turbidity versus Time for Filter Test 7. (Type IV Fabric, cross flow, and detergent plus AC road dirt wastewater).

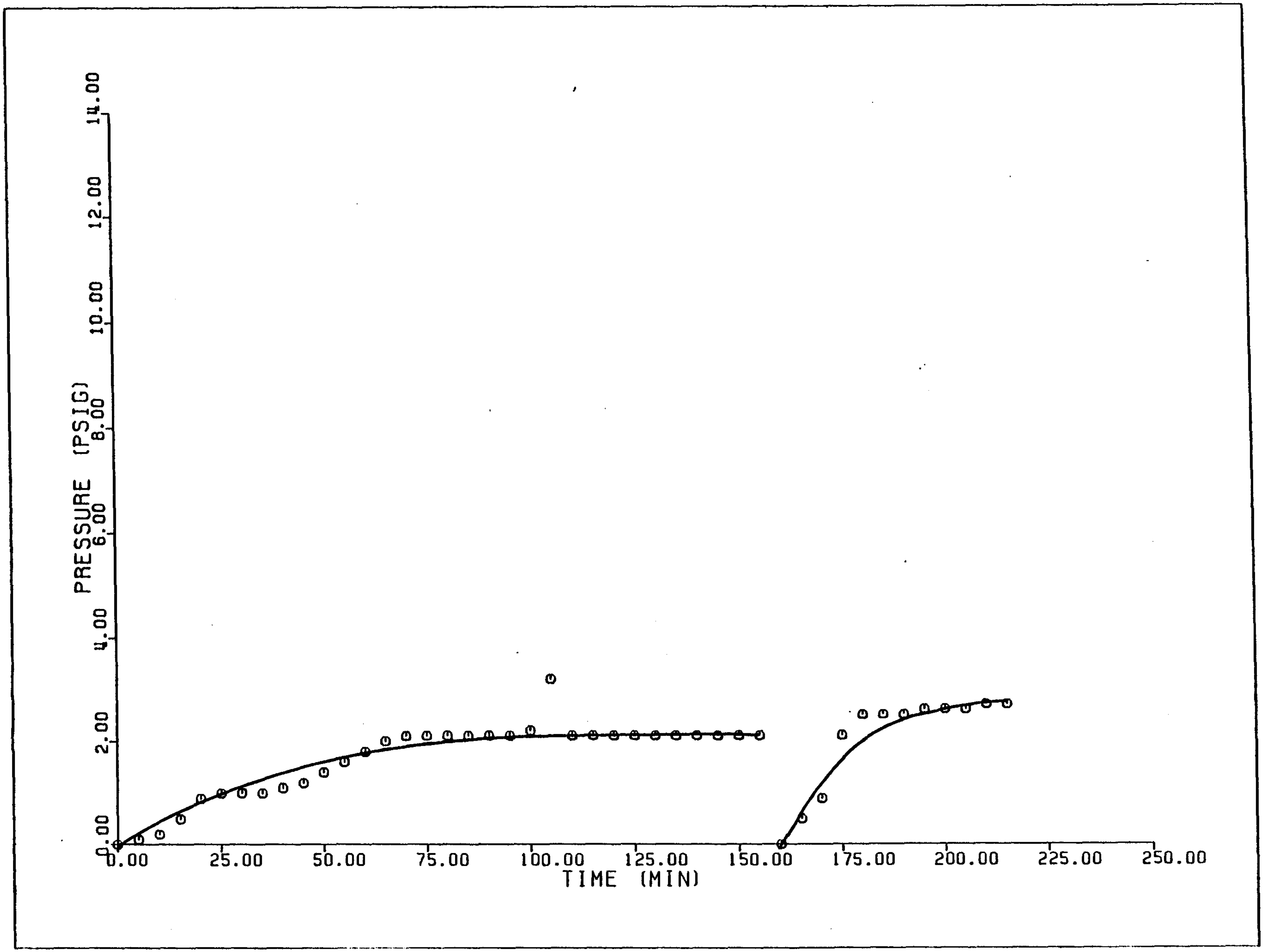


Figure 21 Pressure Drop (PSI) versus Time for Filter Test 7. (Type IV Fabric, reverse flow, detergent and AC road dirt wastewater).

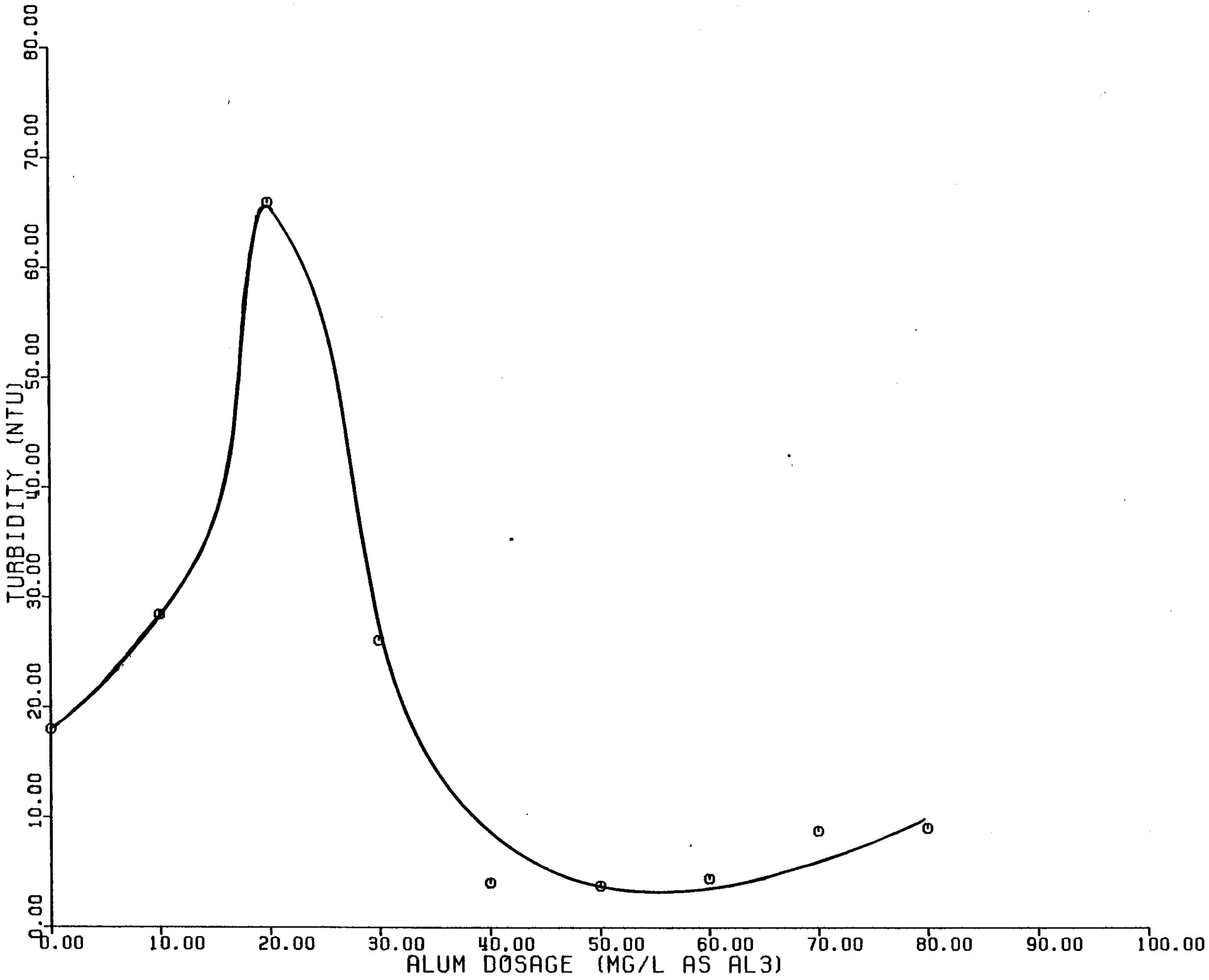


Figure 22 Turbidity versus Coagulant Dose. (Alum coagulant without pH control).

phase was not available, but specifications for Type I military detergent, shown previously in Table 3, require that total phosphate content (as P), be between 7.6 and 8.7% by weight. Orthophosphate content must be less than 2% (as P_2O_5).

After additional alum was added to the detergent containing wastewaters, the aluminum phosphate crystals and AC road dirt particles were effectively coagulated and formed a fine floc which settled within the 30 minute settling period. The resulting decline in turbidity was approximately 50%. Surface tension did not decline, indicating that very little detergent was removed.

Sodium sulfonate was added as a emulsion breaker to aid in coagulation as described in the procedure outlined by Deane (2). The results of a pH controlled jar test using the emulsion breaker and alum are shown in Figure 23. In this test pH was controlled at 6.5 and emulsion breaker dosage was varied from 0.0 to 20.0 mg/1. Alum dosage was held constant at 50 mg/1 (as Al^{3}). Figure 24 shows these results of a third set of jar tests. This set of tests differs from the previous set in that 10 mg/1 of sodium sulfonate was added to each beaker and the alum dosage was varied.

Addition of the emulsion breaker lowered the resulting product turbidity due to increased detergent removal. Turbidity removal was approximately 85% for the optimum dose of alum and sodium sulfonate. It is interesting to note that the range of beneficial coagulant aid dosage was quite narrow, and higher or lower dosages resulted in final turbidity higher than that which would have been obtained without the aid.

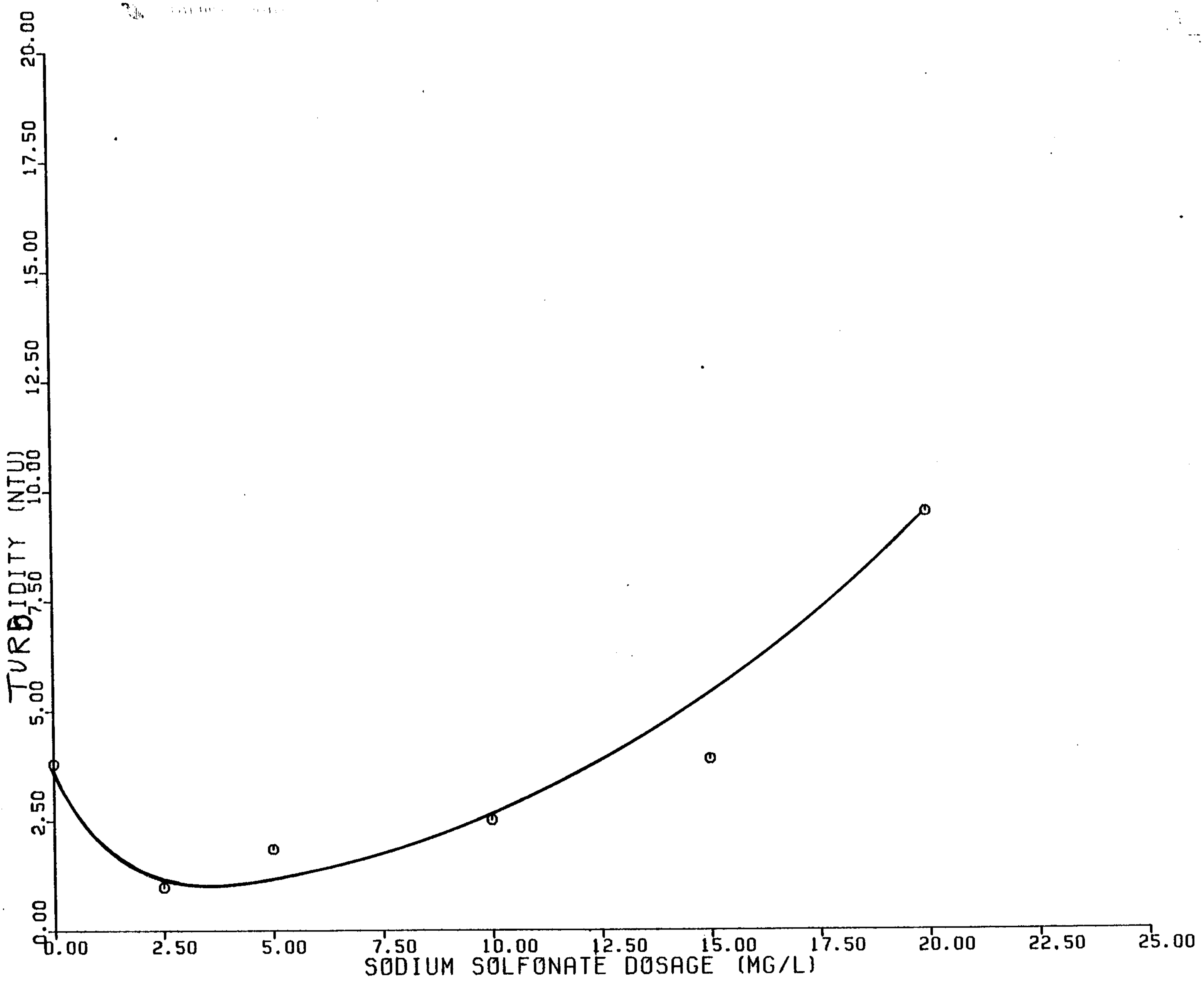


Figure 23 Turbidity versus Sodium Sulfonate Dose. (Varying sodium sulfonate with 50 mg/l Al^{+3}).

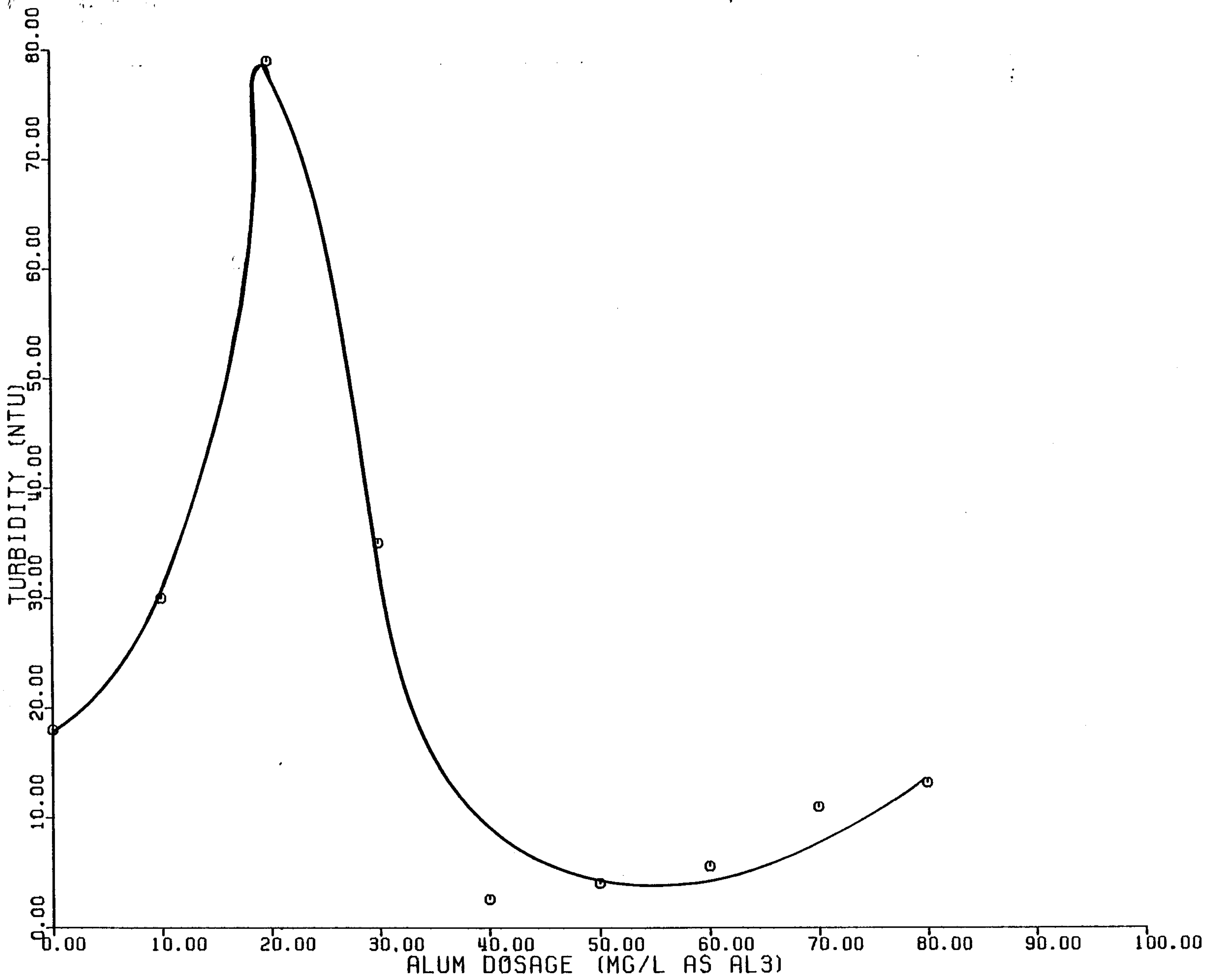


Figure 24 Turbidity versus Coagulant Dose. (Varying Alum dosage with 10 mg/l sodium sulfonate).

Coagulation/Filtration Results

Two filtration tests were performed to determine the effectiveness of fabric filtration after coagulation with alum and sodium sulfonate To obtain sufficient quantities of wastewater, the entire influent tank (375 liters) was filled with tap water. Detergent and AC road dirt were added to the tank and the contents were throughly mixed. After mixing alum and sodium sulfonate were added and the tank was remixed for one minute. Mixing speed was then reduced and the tank was flocculated for the next 20 minutes. A fluffy white floc formed which settled and resulted in the formation of an 8 inch sludge blanket. For test 12 the pH of the mixture was not controlled, and the final pH was 4.0.

In should be noted that the results of the tank coagulation/flocculation procedure was not nearly as good as the results obtained with the jar tests. This resulted primarily because the mixing in the tank could not be maintained as uniform as that obtained in the jar tests. The turbidities obtained in the tank tests were routinely in the 4 to 6 NTU range, which was much higher that the 1 to 1.5 NTU obtained in the best jar tests.

Figure 25 shows turbidity versus time and pressure versus time for reverse flow operation with Type I fabric. Turbidity was reduced from the influent value of 24.5 NTU to 6 NTU after coagulation and sedimentation to less than 2.0 NTU after filtration. As can be seen from the pressure drop data in Figure 26, the first filter cycle lasted over 650 minutes, which was longer than 17 filter cycles without coagulation (as compared to test 1). The initial rate of pressure increase was 0.05 PSI/min., but declined to a stable value of approximately 0.008 PSI/min. after about 40 minutes of filtration.

The reason for the high initial rate is unknown, but may be due to air blinding. The scatter in turbidity values shown in Figure 25 occurred as a result of starting and stopping filtration to prepare and coagulate more feed wastewater.

Effluent turbidities were consistently lower than those obtained in other filtration tests, and occurred as a direct result of coagulation. Influent turbidity for the non-coagulated influent ranged from 23 to 26 NTU for tests 1 through 11, in contrast to 4 to 6 for tests 12 and 13. Other filtration tests produced effluents with turbidities less than 2 NTU and occasionally less that 1.0 NTU, but comparing the average effluent turbidities over all filter cycles for each test, no other test produced an effluent better than test 12. Cross flow tests operated at low system pressure also produced low turbidities, but this was a primarily a manifestation of the lower pressure than the filtration mechanism. If the system pressure for test 12 had been lower, turbidities would have also been lower. This results from the imperfections in the Type I fabric, which expand at higher pressure and allow the influent to leak into the effluent.

An unique phenomena occurred in test 12; alum floc coated the surface of the fabric and formed a cake which was approximately 1/16 inch thick. The filter cake was only partially removed by the normal backwashing procedure. Figure 27 is a photograph of the filter tubes at the end of the first backwash cycle. The filtered material can be seen in broken cakes on the fabric surface. Further back washing was attempted using air with flow rates as high as 4.6 SCFM/ft^2. A combination of pulsing air and backwash water, shown in Figure 28, loosened most of the filter cake, but particles remained loosely

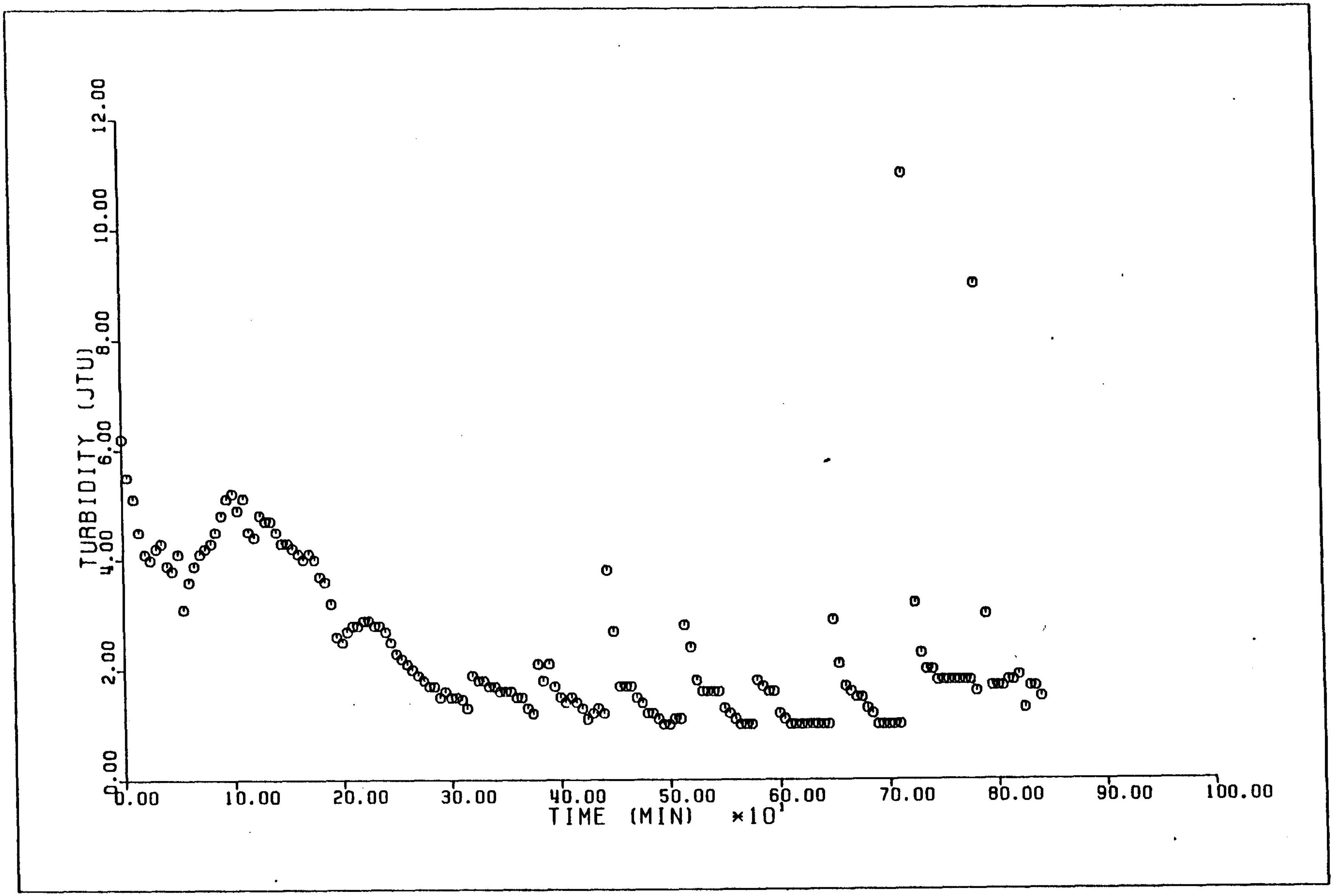


Figure 25 Turbidity versus Time for Filter Test 12. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

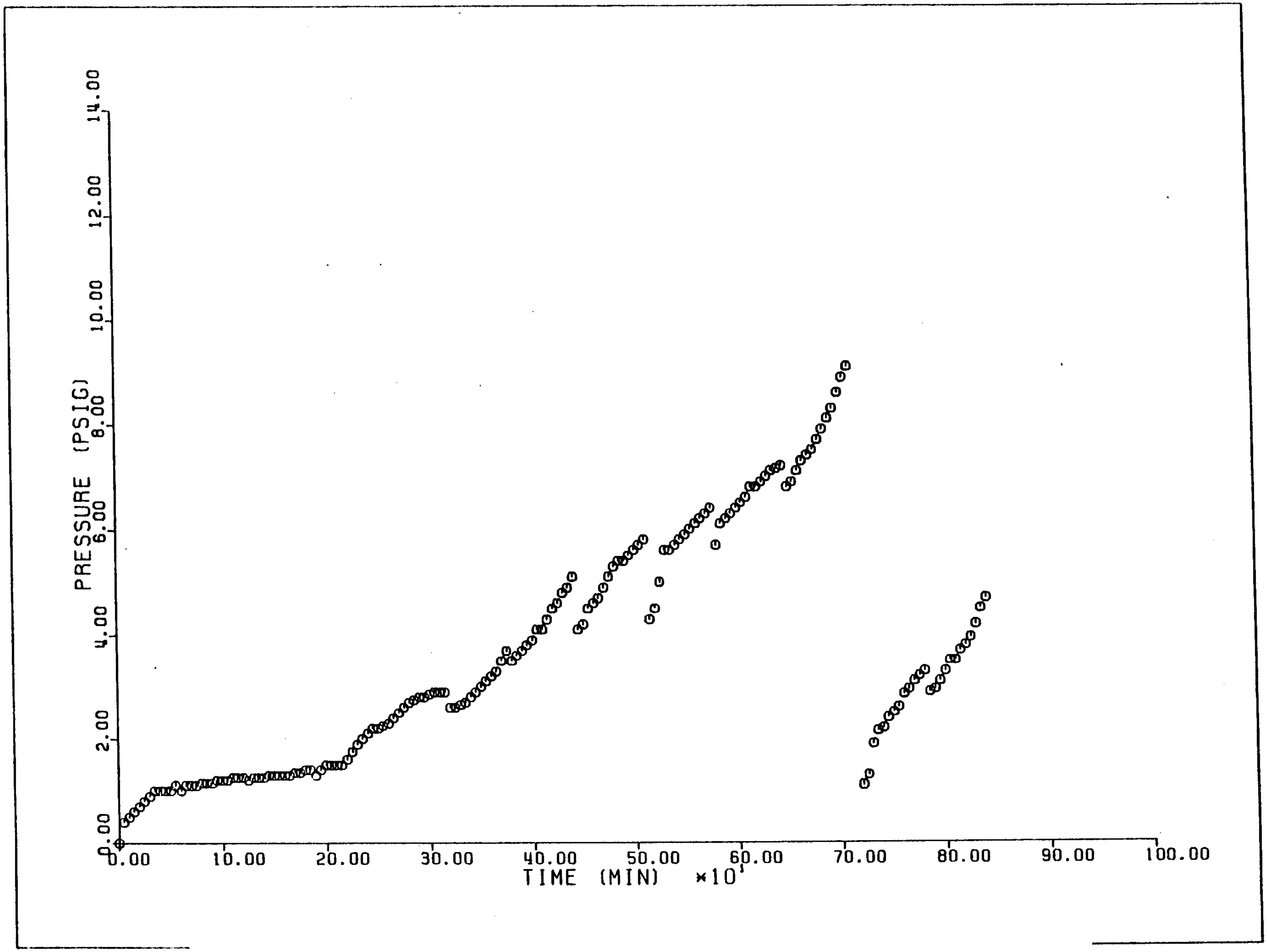


Figure 26 Pressure Drop (PSI) versus Time for Filter Test 12. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

Figure 27 Filter Cake adhering to Filter Fabric. (Filter Test 12, reverse flow, Type I Fabric, and coagulated detergent plus AC road dirt wastewater).

attached to the filter surface, as if they were being held by small fibers. A large number of cake particles could be seen vibrating relative to the fabric surface during the air backwash, but could not be removed.

After backwashing the rate of pressure change was 0.02 PSI/min., which was slightly higher that the original rate of change. The contribution of the unremoved cake particles to increased pressure build-up was unknown, since they appeared to be loosely attached to the filter surface. It was hypothesized that liquid could flow around the particles, and that the cake particles contribution to pressure build-up was low. Further developments in backwashing would be required to provide more mechanical vibration and shock to the fabric in order to loosen the filter cake.

Figures 29 and 30 show the results of test 13, which was virtually the same as test 12, except that the pH was controlled to 6.5. The turbidity and pressure drop versus time relations were very similar to results obtained in test 12, except that the first cycle was approximately 10% longer. Rates of pressure increase were similar. One important difference not noted on the figures was the difference in filter cake. No filter cake formed in test 13 as in test 12, and no air backwash was required. Apparently the different distribution of aluminum hydroxides formed at the higher pH had different structural properties. This might be explained from a theoretical basis since the distribution of types of aluminum hydroxides at pH 4.0 is different that at pH 6.5.

The implications of this difference have not been explored and may be significant. It may be desirable to provide a thick cake on the external surface of the fabric in order to prevent penetration of the fabric with

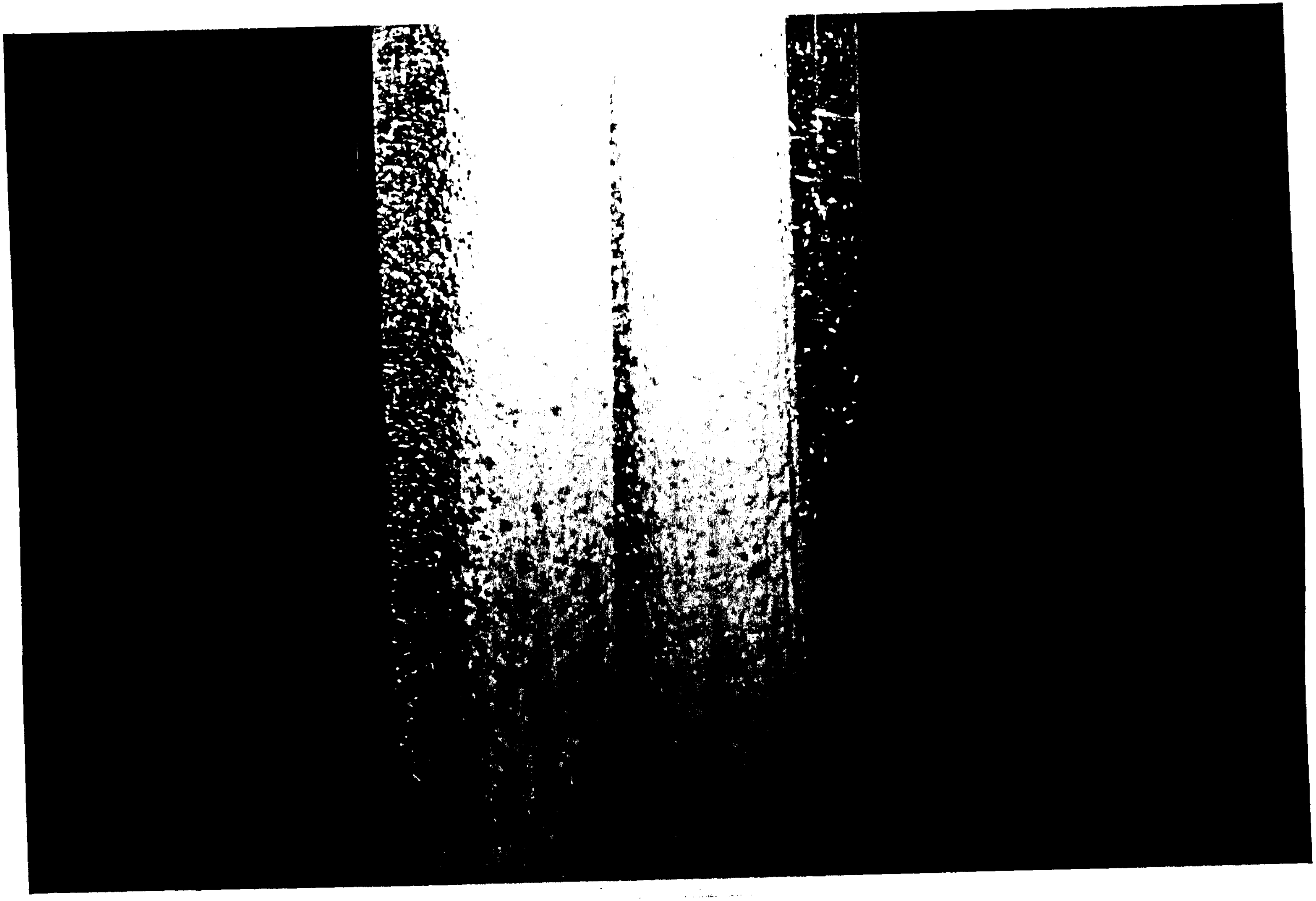


Figure 28 Air/Water Back Wash. (Filter Test 12, reverse flow, Type I Fabric, and coagulated detergent plus AC road dirt wastewater).

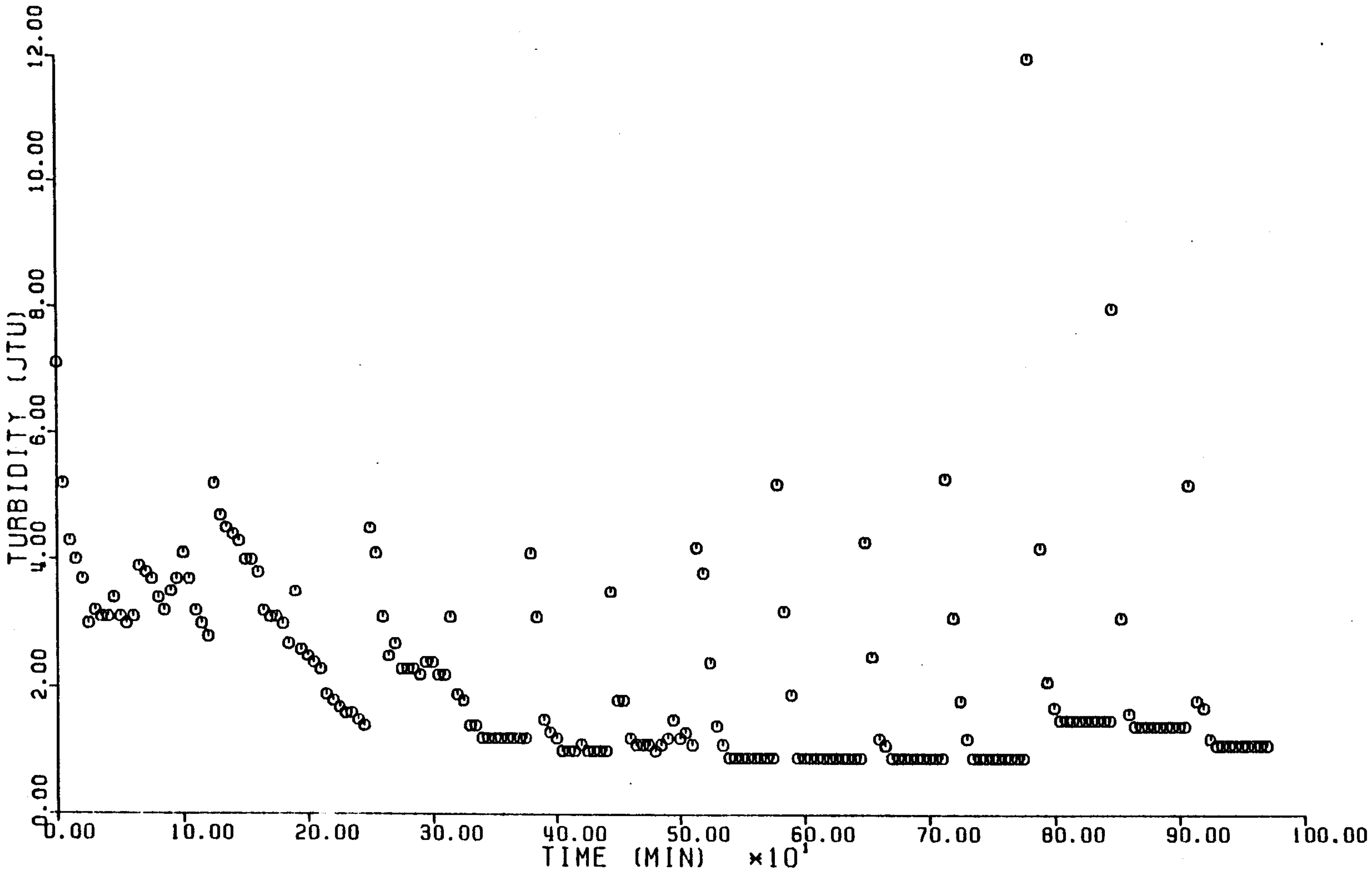


Figure 29 Turbidity versus Time for Filter Test 13. (Type I Fabric, reverse flow, pH control, and coagulated detergent plus AC road dirt wastewater).

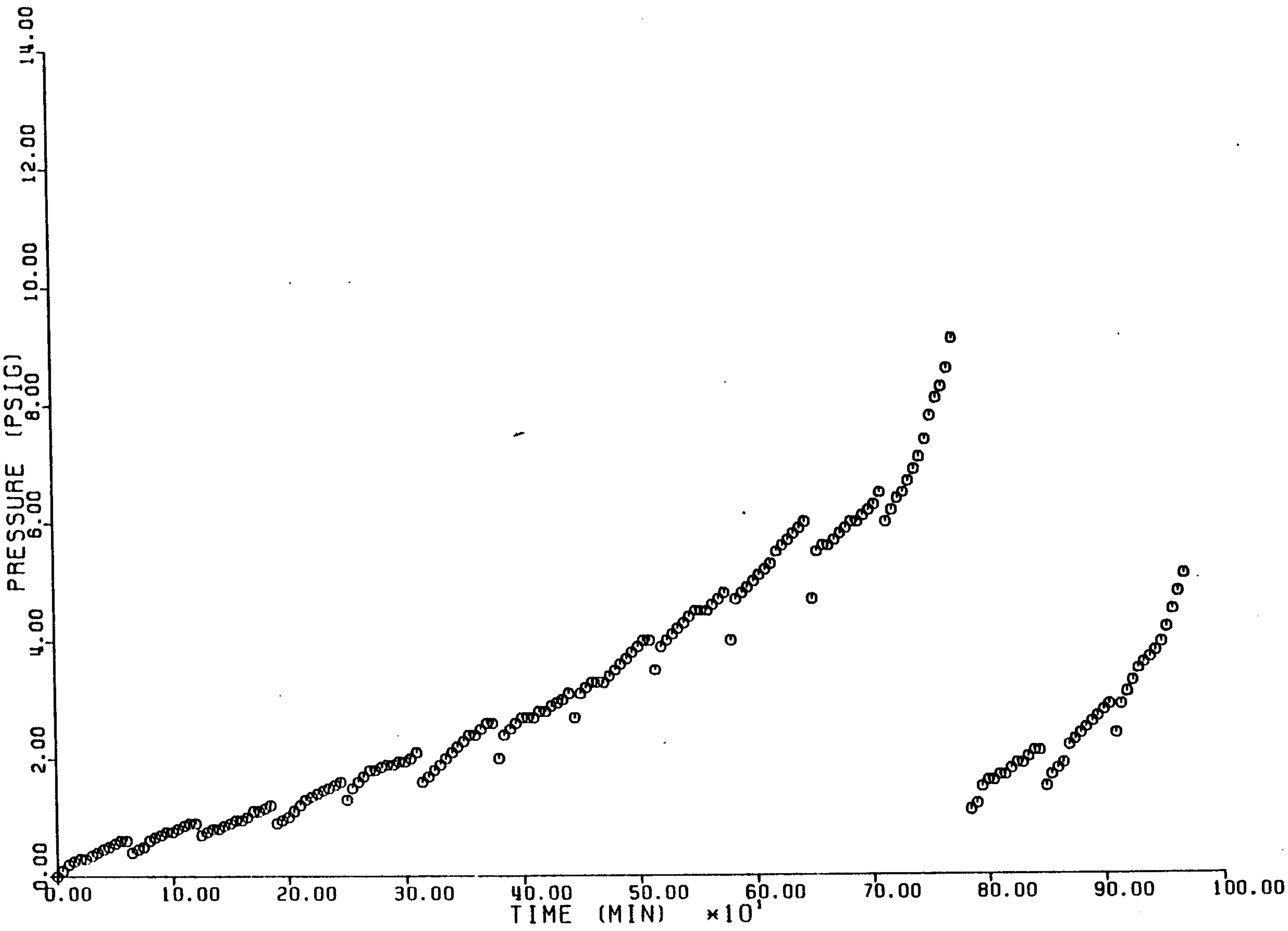


Figure 30 Pressure Drop (PSI) versus Time for Filter Test 13. (Type I Fabric, reverse flow, pH control, and coagulated detergent plus AC road dirt wastewater).

contaminants. Using the cake build up would be very similar to using a precoat for the filter.

Fouling Factor Results

Fouling factor test results are shown in Table 5 for representative filter tests. The results show conclusively that all modes of filtration for both wastewaters significantly decreased the wastewaters' tendency to foul the Whatman GF/C filters. For unfiltered detergent plus AC road dirt wastewater the mean time required to filter 1000 ml was 432 seconds (for all tests shown in Table 5). After filtration the required time declined to 25 seconds. For unfiltered AC road dirt only wastewater it required 23 seconds to filter 1000 ml and only 10 seconds for filtered wastewater. It is clear that fabric filtration significantly reduced the fouling tendency of both wastewaters used in this phase.

Column five in Table 5 shows the final volume of filtered wastewater in the fouling factor tests and the time required to obtain this volume. For the detergent containing wastewater the final values represent near complete blinding of the glass fiber filter, and very little increase in filtered volume could have been obtained by allowing additional filtration time. For the AC road dirt wastewater, especially filtered wastewater, greater volumes of water could have been filtered over longer time. Therefore one should conclude that the fouling tendencies of the two wastewater are quite different, and even more different that Table 5 indicates.

It is difficult to compare the results of the various fouling factor tests. Generally a maximum value of filtered volume is asymptotically approached, if sufficient volume liquid is filtered. For the unfiltered detergent/road dirt wastewater this value was approximately 1200 ml, which was obtained in tests 2, 4, and 5 after an average time of 2,150 seconds, ranging from a low of 1,973 to a high of 2,314. For effluents from tests 2 and 4 the asymptotic values were approximately 5,500 ml, obtained after 2,160 seconds, indicating very little difference in filtration efficiency between cross flow and reverse flow. For test 5 the asymptotic value was approximately 6,300 ml, obtained after 2,210 seconds. The 14 % increase in final volume was tentative evidence for better filtration using the Type IV fabric.

For road dirt only wastewater the asymptotic maximum volume for the influent was approximately 2,250 ml obtained after 550 seconds. Asymptotic final volumes were not obtained for effluent samples, even after filtering as much as 17 liters.

In summarizing Table 5 and other fouling tests, one concludes that very little difference in product water quality exists between filtration modes and fabric types. According to the fouling test results, Type IV fabric filtered as well as or perhaps slightly better than Type I fabric, and the efficiency obtained in the reverse flow method was no different that the cross flow method.

TABLE 5 FOULING FACTOR TESTS RESULTS

	TIME (seconds) REQUIRED TO FILTER SPECIFIED VOLUME(ml)			
Filter Test No.+ (1)	500 ml (2)	1000 ml (3)	2000 ml (4)	Final Volume in ml / Time (5)
2 Influent	18.	451.	-	1200./2289.
2 Influent	17.	423.	-	1200./2015.
2 Effluent	14.	28.	65.	5500./2235.
2 Effluent	12.	25.	60.	5500./2045.
4 Influent	16.	435.	-	1200./2019.
4 Influent	17.	415.	-	1200./1973.
4 Effluent	15.	29.	68.	5480./2384.
4 Effluent	16.	34.	73.	5480./1984.
5 Influent	17.	428.	-	1200./2125.
5 Influent	18.	442.	-	1200./2290.
5 Influent	19.	434.	-	1200./2314.
5 Effluent	14.	28.	62.	6300./2181.
5 Effluent	14.	28.	65.	6300./2350.
5 Effluent	14.	32.	71.	6200./2113.
9 Influent	9.	24.	173.	2250./568.
9 Influent	8.5	21.	160.	2250./540.
9 Influent	8.5	22.	151.	2250./506.
9 Effluent	6.	12.5	25.5	17,000/264.
9 Effluent	5.0	10.	23.0	14,000/199.
9 Effluent	5.0	10.	21.0	15,000/253.
11 Influent	8.5	23.	165.	2250./569.
11 Influent	8.5	23.	168.	2250./593.
11 Effluent	6.0	12.	24.5	15,000/213.
11 Effluent	6.0	12.	25.	16,000/236.

+Results for each fouling factor test tabulated in order performed during the filter test.

CONCLUSIONS AND RECOMMENDATIONS

Three fabric types with two modes of operation were evaluated to determine their potential for development into a light weight portable filter. Tentative evidence from one fouling factor test indicated slightly better filtration by Type IV fabric as compared to Type I fabric. Type V fabric was not effective, which probably resulted from seam leakage rather than poor sieve action by the fabric. Type I fabric backwashed more effectively than Type IV fabric, and did not require contaminant build-up for efficient filtration.

The cross flow technique in the internally pressurized mode of operation did not appear to be a promising technique for this type of wastewater, since no surface filtration layer which can be hydrodynamically controlled occurs. The reverse flow technique, which expands the filter fabric on backwashing, appears to be a much more promising technique. Both filtration methods reduced the laundry shower/road dirt wastewater turbidity from 24-26 NTU to 3 to 5 NTU, and for the road dirt only wastewater, turbidity was reduced from 14-16 NTU to 1 to 3 NTU. For coagulated/settled wastewater effluent, turbidities were reduced from the influent value of 24-26 NTU to 4-6 NTU after sedimentation and to 1-2 NTU after filtration.

Backwashing continued to be a problem. Initial rates of pressure increase for the Type I fabric with detergent/AC road dirt wastewater averaged approximately 0.13 PSI/min for virgin fabric, increased to 0.22 PSI/min for the second filtration cycle, and increased to as high as 0.94 PSI/min after 17 backwashes (test 1). For the AC road dirt only wastewater the initial rate of pressure increase for virgin fabric was 0.05 PSI/min and increased to 0.20 PSI/min on the second cycle. Backwashing was not effective in restoring fabric pressure drop to the original value, and after backwashing pressure drop gradually increased to unacceptably high levels.

Further development is required to determine additional methods to reduce contaminant build-up on the filter fabric during reverse flow operation. Additional methods which may be promising are air/liquid backwashing, backwashing at higher rates, ultrasonics to remove contaminants, and chemical cleaning while backwashing.

Pretreatment of feed wastewater with coagulating chemicals appears promising. This phase showed that pretreatment with high concentrations of alum vastly expanded the filter's usefulness. The optimal alum dose was 50 mg/l as Al^{+3}, which would require 9.4 lb/1000 gal of wastewater treated, or 94 lb/day for a 10,000 gal/day plant. This was calculated assuming commercially available alum would be used, which is 36.4 Baume and contains 4.4 % Al (8.3 % as Al_2O_3). If pH control were required caustic soda requirements would be 3.7 lb/1000gal or 37 lb/day for a 10,000 gal/day plant. Additional work is required with organic coagulants designed to replace primary metallic coagulants. A combination of organic coagulant and emulsion-breaking chemical such as sodium sulfonate could reduce chemical requirements to acceptable levels. The technique described by Deane (2) did function as indicated, and should be further investigated.

The following areas are recommended for future development:

1. A variety of types of emulsion-breaking chemicals should be evaluated in conjunction with conventional organic water treatment polymers. The objective of this work is to find an emulsion breaking/coagulating poly-

mer combination which would provide the same degree of treatment as the alum/sodium sulfonate combination provided in tests 12 and 13, but at much lower dosage. A goal of this work would be to reduce total chemical requirements to 0.47 lb/1000 gal or 20 lb/day for a 30 GPM treatment plant.

2. Extended tests should be performed with Type I fabric in order to evaluate its ability to withstand repeated washing and backwashing. An automated filter apparatus would be required which would allow continuous operation without direct operator interaction. Filter fabrics with several hundred hours operation should be evaluated microscopically to determine wear and ultimate fabric life.

3. Continued development with the reverse flow method is necessary to eliminate the contaminants which gradually build up on the fabric surface and increase pressure drop. Possible mechanisms to improve backwashing efficiency are:

   a. Intermittent backwashing with caustic or other chemical which could dissolve the contaminants on the fabric surface.

   b. Intermittent "super" backwashing at backwash rates perhaps five times greater than normal backwashing.

   c. Air insertion in conjunction with standard backwashing.

4. All testing performed to date has been with the AC road dirt. No testing has been performed with other types of particulate contaminants, such as bentonite, which have a different size distribution. The very

fine size distribution of the road dirt (5 % less than 5 microns) may be causing a portion of the backwashing problems.

5. If no acceptable chemical pretreatment can be developed, alternate detergents should be evaluated which are amenable to chemical pretreatment.

REFERENCES

1. Stenstrom, M. K., Vazirinejad, H. R., Sadeghipour, J., Development of a Tubular Fabric Filter Concept-Phase I, UCLA Engineering Report No. UCLA-ENG-81-41, December, 1981.

2. Deane, T. N., U.S. Patent No. 4,092,242, May 30, 1978.

APPENDIX

List of Appendix Figures

Figure A1 Turbidity versus Time for Test 1.

Figure A2 Pressure versus Time for Test 1.

Figure A3 Filtered Volume versus Time for Test 1.

Figure A4 Turbidity versus Time for Test 2.

Figure A5 Pressure versus Time for Test 2.

Figure A6 Filtered Volume versus Time for Test 2.

Figure A7 Turbidity versus Time for Test 3.

Figure A8 Pressure versus Time for Test 3.

Figure A9 Filtered Volume versus Time for Test 3.

Figure A10 Turbidity versus Time for Test 4.

Figure A11 Pressure versus Time for Test 4.

Figure A12 Filtered Volume versus Time for Test 4.

Figure A13 Turbidity versus Time for Test 5.

Figure A14 Pressure versus Time for Test 5.

Figure A15 Filtered Volume versus Time for Test 5.

Figure A16 Turbidity versus Time for Test 6.

Figure A17 Pressure versus Time for Test 6.

Figure A18 Filtered Volume versus Time for Test 6.

Figure A19 Turbidity versus Time for Test 7.

Figure A20 Pressure versus Time for Test 7.

Figure A21 Filtered Volume versus Time for Test 7.

Figure A22 Turbidity versus Time for Test 8.

Figure A23 Pressure versus Time for Test 8.

Figure A24 Filtered Volume versus Time for Test 8.

Figure A25 Turbidity versus Time for Test 9.

Figure A26 Pressure versus Time for Test 9.

Figure A27 Filtered Volume versus Time for Test 9.

Figure A28 Turbidity versus Time for Test 10.

Figure A29 Pressure versus Time for Test 10.

Figure A30 Filtered Volume versus Time for Test 10.

Figure A31 Turbidity versus Time for Test 11.

Figure A32 Pressure versus Time for Test 11.

Figure A33 Filtered Volume versus Time for Test 11.

Figure A34 Turbidity versus Time for Test 12.

Figure A35 Pressure versus Time for Test 12.

Figure A36 Filtered Volume versus Time for Test 12.

Figure A37 Turbidity versus Time for Test 13.

Figure A38 Pressure versus Time for Test 13.

Figure A39 Filtered Volume versus Time for Test 13.

Figure A40 Flux Decline for Test 2 (first fouling test)

Figure A41 Flux Decline for Test 2 (second fouling test)

Figure A42 Flux Decline for Test 4 (first fouling test)

Figure A43 Flux Decline for Test 4 (second fouling test)

Figure A44 Flux Decline for Test 5 (first fouling test)

Figure A45 Flux Decline for Test 5 (second fouling test)

Figure A46 Flux Decline for Test 5 (third fouling test)

Figure A47 Flux Decline for Test 9 (first fouling test)

Figure A48 Flux Decline for Test 9 (second fouling test)

Figure A49 Flux Decline for Test 9 (third fouling test)

Figure A50 Flux Decline for Test 11 (first fouling test)

Figure A51 Flux Decline for Test 11 (second fouling test)

List of Appendix Tables

Table A1 Summary of Results for Test 1 (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Table A2 Summary of Results for Test 2 (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Table A3 Summary of Results for Test 3 (washed Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Table A4 Summary of Results for Test 4 (Type I Fabric, cross flow, and detergent plus AC road dirt wastewater).

Table A5 Summary of Results for Test 5 (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Table A6 Summary of Results for Test 6 (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

Table A7 Summary of Results for Test 7 (Type IV Fabric, cross flow, and detergent plus AC road dirt wastewater).

Table A8 Summary of Results for Test 8 (membrane fabric, reverse flow, and detergent plus AC road dirt wastewater).

Table A9 Summary of Results for Test 9 (Type I Fabric, reverse flow, and AC road dirt only wastewater).

Table A10 Summary of Results for Test 10 (Type I Fabric, cross flow, and AC road dirt only wastewater).

Table A11 Summary of Results for Test 11 (Type IV Fabric, reverse flow, and AC road dirt only wastewater).

Table A12 Summary of Results for Test 12 (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

Table A13 Summary of Results for Test 13 (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater with pH control).

Table A14 Volume versus Time for Influent in Test 2 (first fouling factor test).

Table A15 Volume versus Time for Effluent in Test 2 (first fouling factor test).

Table A16 Volume versus Time for Influent in Test 2 (second fouling factor test).

Table A17 Volume versus Time for Effluent in Test 2 (second fouling factor test).

Table A18 Volume versus Time for Influent in Test 4 (first fouling factor test).

Table A19 Volume versus Time for Effluent in Test 4 (first fouling factor test).

Table A20 Volume versus Time for Influent in Test 4 (second fouling factor test).

Table A21 Volume versus Time for Effluent in Test 4 (second fouling factor test).

Table A22 Volume versus Time for Influent in Test 5 (first fouling factor test).

Table A23 Volume versus Time for Effluent in Test 5 (first fouling factor test).

Table A24 Volume versus Time for Influent in Test 5 (second fouling factor test).

Table A25 Volume versus Time for Effluent in Test 5 (second fouling factor test).

Table A26 Volume versus Time for Influent in Test 5 (third fouling factor test).

Table A27 Volume versus Time for Effluent in Test 5 (third fouling factor test).

Table A28 Volume versus Time for Influent in Test 9 (first fouling factor test).

Table A29 Volume versus Time for Effluent in Test 9 (first fouling factor test).

Table A30 Volume versus Time for Influent in Test 9 (second fouling factor test).

Table A31 Volume versus Time for Effluent in Test 9 (second fouling factor test).

Table A32 Volume versus Time for Influent in Test 9 (third fouling factor test).

Table A33 Volume versus Time for Effluent in Test 9 (third fouling factor test).

Table A34 Volume versus Time for Influent in Test 11 (first fouling

factor test).

Table A35 Volume versus Time for Effluent in Test 11 (first fouling factor test).

Table A36 Volume versus Time for Influent in Test 11 (second fouling factor test).

Table A37 Volume versus Time for Effluent in Test 11 (second fouling factor test).

Table A1 Summary of Results for Test 1 Cont. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	1.0	8.1	2.5
2	5	1.8	6.7	5.0
3	10	2.3	5.4	7.5
4	15	2.9	5.1	10.0
5	20	3.6	5.1	12.5
6	25	4.4	5.2	15.0
7	30	5.3	5.2	17.5
8	35	6.3	5.3	20.0
9	40	7.6	5.8	22.5
10	45	8.8	6.5	25.0
11	50	1.0	5.2	25.0
12	55	2.1	4.9	27.5
13	60	2.8	4.7	30.0
14	65	3.5	4.7	32.5
15	70	4.6	4.8	35.0
16	75	5.6	4.7	37.5
17	80	6.5	4.8	40.0
18	85	7.6	4.9	42.5
19	90	8.8	5.2	45.0
20	95	1.0	5.6	45.0
21	100	2.5	4.8	47.5
22	105	3.1	4.7	50.0
23	110	4.2	4.5	52.5
24	115	5.3	4.5	55.0
25	120	6.4	4.4	57.5
26	125	7.3	4.5	60.0
27	130	8.3	4.8	62.5
28	135	9.2	5.4	65.0
29	140	1.0	5.3	65.0
30	145	2.8	4.7	67.5
31	150	3.5	4.7	70.0
32	155	4.6	4.7	72.5
33	160	5.4	4.8	75.0
34	165	6.7	4.7	77.5
35	170	7.5	4.7	80.0
36	175	8.8	5.2	82.5
37	180	9.6	6.3	85.0
38	185	1.0	6.0	85.0
39	190	3.0	4.5	87.5
40	195	3.6	4.6	90.0
41	200	4.8	4.8	92.5
42	205	5.5	4.9	95.0
43	210	6.9	5.1	97.5
44	215	7.8	5.9	100.0
45	220	9.0	6.2	102.5
46	225	9.9	6.8	105.0
47	230	1.0	6.1	105.0
48	235	3.3	4.7	107.5
49	240	3.8	4.8	110.0
50	245	5.2	4.7	112.5
51	250	5.8	4.6	115.0
52	255	7.2	4.7	117.5
53	260	8.3	5.3	120.0
54	265	9.4	6.8	122.5
55	270	10.4	7.3	125.0

SOKI

Table A1 Summary of Results for Test 1 Cont. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
56	275	1.0	6.3	125.0
57	280	3.7	4.8	127.5
58	285	4.0	4.8	130.0
59	290	5.5	4.8	132.5
60	295	6.2	5.1	135.0
61	300	7.5	5.2	137.5
62	305	8.5	5.8	140.0
63	310	9.6	6.9	142.5
64	315	10.8	7.5	145.0
65	320	1.0	5.4	147.5
66	325	3.8	4.7	150.0
67	330	4.2	5.1	152.5
68	335	5.8	5.2	155.0
69	340	6.5	4.9	157.5
70	345	7.8	5.4	160.0
71	350	8.9	6.3	162.5
72	355	9.8	6.9	165.0
73	360	11.0	7.8	167.5
74	365	1.0	5.9	167.5
75	370	4.0	5.1	170.0
76	375	5.1	5.6	172.5
77	380	6.3	5.8	175.0
78	385	7.6	6.6	177.5
79	390	8.9	6.8	180.0
80	395	10.1	6.9	182.5
81	400	11.2	7.0	185.0
82	405	1.8	4.5	185.0
83	410	4.0	5.1	187.5
84	415	6.0	5.2	190.0
85	420	7.8	5.7	192.5
86	425	9.5	6.3	195.0
87	430	11.2	6.5	197.5
88	435	1.0	4.6	197.5
89	440	4.1	4.5	200.0
90	445	7.1	4.8	202.5
91	450	9.4	5.8	205.0
92	455	11.4	6.5	207.5
93	460	1.0	4.8	207.5
94	465	4.6	4.4	210.0
95	470	7.8	5.2	212.5
96	475	10.1	6.2	215.0
97	480	11.9	8.5	217.5
98	485	1.5	3.5	217.5
99	490	5.5	3.8	220.0
100	495	8.2	3.9	222.5
101	500	11.2	4.1	225.0
102	505	0.2	3.9	225.0
103	510	5.4	3.3	227.5
104	515	8.5	4.3	230.0
105	520	11.3	6.2	232.5
106	525	0.5	3.8	232.5
107	530	6.1	3.3	235.0
108	535	9.3	7.2	237.5
109	535	11.8	9.6	240.0
110	540	0.2	3.2	240.0

Table A1 Summary of Results for Test 1 (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
111	545	4.4	4.3	242.5
112	550	7.6	4.2	245.0
113	555	10.1	7.8	247.5
114	560	12.8	8.2	250.0
115	565	3.0	3.6	250.0
116	570	9.6	2.7	252.5
117	575	12.9	6.3	255.0
118	580	0.2	2.7	255.0
119	585	6.2	2.5	257.5
120	590	9.6	6.2	260.0
121	595	12.8	8.2	262.5

Table A2 Summary of Results for Test 2 Cont. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	9.2	0.0
2	5	1.1	7.2	2.5
3	10	2.0	5.7	5.0
4	15	2.5	5.3	7.5
5	20	3.1	5.3	10.0
6	25	3.8	5.3	12.5
7	30	4.7	5.5	15.0
8	35	5.8	5.7	17.5
9	40	0.0	6.3	17.5
10	45	1.5	5.2	20.0
11	50	2.4	4.3	22.5
12	55	2.9	4.3	25.0
13	60	3.6	4.2	27.5
14	65	4.3	4.6	30.0
15	70	5.9	4.9	32.5
16	75	0.0	6.5	32.5
17	80	1.9	5.1	35.0
18	85	2.9	4.1	37.5
19	90	3.5	4.0	40.0
20	95	4.2	4.1	42.5
21	100	5.8	4.3	45.0
22	105	7.5	4.7	47.5
23	110	0.0	6.3	47.5
24	115	2.5	4.9	50.0
25	120	3.1	4.0	52.5
26	125	4.2	4.1	55.0
27	130	5.3	4.1	57.5
28	135	6.5	4.5	60.0
29	140	7.8	5.2	62.5
30	145	0.0	6.8	62.5
31	150	2.8	4.7	65.0
32	155	3.5	4.2	67.5
33	160	4.7	4.3	70.0
34	165	5.8	4.3	72.5
35	170	7.1	4.6	75.0
36	175	8.5	6.0	77.5
37	180	0.0	6.5	77.5
38	185	3.1	4.5	80.0
39	190	4.2	4.1	82.5
40	195	5.3	4.1	85.0
41	200	6.5	4.2	87.5
42	205	7.6	4.5	90.0
43	210	8.9	7.0	92.5
44	215	0.0	7.1	92.5
45	220	3.5	4.6	95.0
46	225	4.3	4.2	97.5
47	230	5.5	4.2	100.0
48	235	6.8	4.0	102.5
49	240	7.9	4.9	105.0
50	245	9.2	6.3	107.5
51	250	0.0	6.1	107.5
52	255	3.7	4.2	110.0
53	260	4.5	4.0	112.5
54	265	5.7	4.0	115.0
55	270	7.2	4.1	117.5

Table A2 Summary of Results for Test 2 Cont. (Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
56	275	8.3	4.3	120.0
57	280	9.9	5.2	122.5
58	285	0.0	6.3	122.5
59	290	4.0	4.3	125.0
60	295	5.1	4.4	127.5
61	300	6.2	4.4	130.0
62	305	7.8	4.5	132.5
63	310	8.9	4.7	135.0
64	315	10.7	5.3	137.5
65	320	0.0	5.2	137.5
66	325	4.0	4.3	140.0
67	330	5.8	4.1	142.5
68	335	6.4	4.1	145.0
69	340	7.9	4.7	147.5
70	345	9.5	6.1	150.0
71	350	0.0	5.9	150.0
72	355	4.1	5.2	152.5
73	360	6.2	4.1	155.0
74	365	6.9	4.2	157.5
75	370	8.2	4.1	160.0
76	375	10.4	5.4	162.5
77	380	0.0	6.5	162.5
78	385	4.1	5.1	165.0
79	390	6.4	4.8	167.5
80	395	7.3	4.8	170.0
81	400	9.4	5.3	172.5
82	405	0.0	5.1	172.5
83	410	4.2	4.2	175.0
84	415	6.9	4.2	177.5
85	420	7.9	4.5	180.0
86	425	10.1	5.0	182.5
87	430	0.0	5.0	182.5
88	435	4.3	4.8	185.0
89	440	7.1	4.3	187.5
90	445	8.5	4.3	190.0
91	450	11.2	5.9	192.5
92	455	0.0	5.8	192.5
93	460	4.4	4.2	195.0
94	465	7.5	4.3	197.5
95	470	9.5	5.5	200.0
96	475	0.0	6.9	200.0
97	480	4.4	3.9	202.5
98	485	8.1	4.1	205.0
99	490	10.1	5.2	207.5

Table A3 Summary of Results for Test 3 (washed Type I Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	8.4	0.0
2	5	1.2	6.9	2.5
3	10	1.6	5.8	5.0
4	15	2.3	5.5	7.5
5	20	2.9	5.5	10.0
6	25	3.8	5.4	12.5
7	30	4.8	5.3	15.0
8	35	5.9	5.3	17.5
9	40	7.0	5.3	20.0
10	45	8.9	6.8	22.5
11	50	10.5	9.7	25.0
12	60	1.0	9.5	25.0
13	65	2.5	4.3	27.5
14	70	3.6	4.5	30.0
15	75	5.7	4.6	32.5
16	80	8.1	9.2	35.0
17	85	10.4	11.5	37.5

Table A4 Summary of Results for Test 4 (Type I Fabric, cross flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	2.4	0.0000
2	5	0.5	3.4	3.5393
3	10	0.8	4.6	6.6821
4	15	1.5	4.8	9.5143
5	20	2.7	4.6	11.6107
6	25	3.5	4.3	13.4357
7	30	4.0	4.3	14.8893
8	35	4.7	4.8	16.0214
9	40	5.2	5.0	17.0893
10	45	5.7	5.2	18.1000
11	50	6.2	5.2	19.0143
12	55	6.4	5.1	19.8857
13	60	6.5	5.1	20.6286
14	65	6.6	5.2	21.2500
15	70	6.6	5.1	21.7679
16	75	6.6	5.0	22.2464
17	80	0.0	7.0	22.2464
18	85	1.8	6.2	24.2679
19	90	2.1	5.5	25.6821
20	95	2.4	5.4	26.5179
21	100	2.7	5.3	27.1071
22	105	3.1	5.3	27.5786
23	110	3.2	5.3	28.0071
24	115	3.4	5.2	28.4036
25	120	3.4	5.2	28.8036
26	125	0.0	8.0	28.8036
27	130	1.9	5.8	30.1857
28	135	2.8	5.4	30.9821
29	140	3.1	5.3	31.4179
30	145	3.1	5.3	31.7500

Table A5 Summary of Results for Test 5 (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	10.5	2.5
2	5	0.0	8.2	5.0
3	10	0.5	6.4	7.5
4	15	0.8	6.1	10.0
5	20	1.0	5.3	12.5
6	25	1.2	5.1	15.0
7	30	1.3	4.8	17.5
8	35	1.4	4.7	20.0
9	40	1.5	4.9	22.5
10	45	1.5	4.8	25.0
11	50	1.6	4.7	27.5
12	55	1.7	4.6	30.0
13	60	1.8	4.2	32.5
14	65	1.9	4.2	35.0
15	70	2.0	4.2	37.5
16	75	2.1	4.2	40.0
17	80	2.2	4.2	42.5
18	85	2.3	4.4	45.0
19	90	2.5	4.2	47.5
20	95	2.6	4.1	50.0
21	100	2.9	3.9	52.5
22	105	3.1	3.8	55.0
23	110	3.2	3.9	57.5
24	115	3.5	3.9	60.0
25	120	3.9	3.8	62.5
26	125	4.4	4.2	65.0
27	130	4.8	4.4	67.5
28	135	5.3	4.5	70.0
29	140	5.8	4.4	72.5
30	145	6.3	4.6	75.0
31	150	6.8	4.8	77.5
32	155	7.5	5.3	80.0
33	160	8.1	5.6	82.5
34	165	0.0	8.5	82.5
35	170	0.5	6.4	85.0
36	175	0.9	4.2	87.5
37	180	1.2	4.0	90.0
38	185	1.5	3.6	92.5
39	190	1.8	3.3	95.0
40	195	2.2	3.3	97.5
41	200	2.6	3.3	100.0
42	205	3.1	3.3	102.5
43	210	3.5	3.3	105.0
44	215	4.0	3.4	107.5
45	220	4.4	3.3	110.0
46	225	4.9	3.4	112.5
47	230	5.4	3.5	115.0
48	235	6.1	3.8	117.5
49	240	6.6	3.8	120.0
50	245	7.1	4.2	122.5
51	250	7.7	4.6	125.0
52	255	8.4	4.9	127.5
53	260	9.2	5.2	130.0
54	265	10.1	5.6	132.5
55	270	0.0	6.5	132.5

Table A5 Summary of Results for Test 5 Cont.(Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
56	275	1.6	4.1	135.0
57	280	1.9	3.2	137.5
58	285	2.1	3.1	140.0
59	290	2.9	3.3	142.5
60	295	3.8	3.8	145.0
61	300	5.0	4.2	147.5
62	305	6.3	4.6	150.0
63	310	7.6	5.2	152.5
64	315	8.9	5.7	155.0
65	320	10.1	5.8	157.5
66	325	0.0	4.1	157.5
67	330	2.5	2.9	160.0
68	335	3.9	3.8	162.5
69	340	6.4	4.2	165.0
70	345	8.7	3.7	167.5
71	350	10.8	5.2	170.0
72	355	0.0	4.4	170.0
73	360	3.9	5.4	172.5
74	365	6.6	3.4	175.0
75	370	8.7	3.4	177.5
76	375	10.5	3.4	180.0
77	380	0.0	11.0	180.0
78	385	2.6	6.2	182.5
79	390	5.2	5.6	185.0
80	395	8.4	4.0	187.5
81	400	11.0	3.6	190.0

Table A6 Summary of Results for Test 6 (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	10.5	2.5
2	5	0.0	6.6	5.0
3	10	0.0	6.7	7.5
4	15	0.1	5.5	10.0
5	20	0.4	5.6	12.5
6	25	0.8	5.1	15.0
7	30	0.9	4.9	17.5
8	35	0.9	4.7	20.0
9	40	1.0	4.8	22.5
10	45	1.1	4.5	25.0
11	50	1.2	4.6	27.5
12	55	1.2	4.6	30.0
13	60	1.3	4.3	32.5
14	65	1.3	4.4	35.0
15	70	1.4	4.3	37.5
16	75	1.4	4.5	40.0
17	80	1.4	4.3	42.5
18	85	1.3	4.5	45.0
19	90	1.3	4.1	47.5
20	95	1.4	4.1	50.0
21	100	1.5	4.2	52.5
22	105	1.6	4.4	55.0
23	110	2.0	4.5	57.5
24	115	2.2	5.4	60.0
25	120	2.6	5.5	62.5
26	125	3.1	5.8	65.0
27	130	3.5	7.8	67.5
28	135	4.1	7.9	70.0
29	140	4.7	8.4	72.5
30	145	5.3	8.5	75.0
31	150	5.9	8.6	77.5
32	155	6.2	8.5	80.0
33	160	0.0	9.0	80.0
34	165	0.4	7.1	82.5
35	170	0.9	4.3	85.0
36	175	1.3	3.8	87.5
37	180	1.7	3.5	90.0
38	185	2.1	3.5	92.5
39	190	2.6	3.5	95.0
40	195	3.2	3.4	97.5
41	200	3.6	3.5	100.0
42	205	4.1	3.5	102.5
43	210	4.6	3.4	105.0
44	215	5.1	3.6	107.5
45	220	5.7	3.7	110.0
46	225	6.3	3.7	112.5
47	230	6.9	3.9	115.0
48	235	7.5	4.1	117.5
49	240	8.1	5.2	120.0
50	245	9.3	5.5	122.5
51	250	0.0	12.0	122.5
52	255	1.2	8.4	125.0
53	260	1.5	6.4	127.5
54	265	1.6	7.1	130.0
55	270	1.7	5.9	132.5

Table A6 Summary of Results for Test 6 Cont. (Type IV Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
56	275	2.4	5.3	135.0
57	280	3.1	5.1	137.5
58	285	3.9	5.2	140.0
59	290	4.9	5.2	142.5
60	295	6.0	5.5	145.0
61	300	7.1	5.8	147.5

Table A7 Summary of Results for Test 7 (Type IV Fabric, cross flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	5.1	0.0000
2	5	0.2	5.0	3.7679
3	10	0.2	4.7	6.9107
4	15	0.4	4.4	9.7500
5	20	0.5	4.3	12.4464
6	25	0.5	4.4	14.9107
7	30	0.5	4.4	17.3750
8	35	0.6	4.5	19.6250
9	40	0.6	4.5	21.8036
10	45	0.6	4.6	23.9107
11	50	0.6	4.7	26.0000
12	55	0.6	4.9	28.1071
13	60	0.6	5.4	30.1250
14	65	0.6	5.7	32.1429
15	70	0.6	6.1	34.1607
16	75	0.7	6.5	36.2143
17	80	0.7	6.8	38.1429
18	85	1.2	6.6	40.1071
19	90	1.7	6.8	42.0714
20	95	2.1	6.1	43.8214
21	100	2.7	6.6	45.6429
22	105	3.4	6.1	47.3929
23	110	4.0	6.1	49.1786
24	115	4.9	6.3	50.9286
25	120	5.7	5.9	52.6071
26	125	6.5	5.9	54.0357
27	130	7.0	6.1	55.5000
28	135	7.6	6.2	56.7500
29	140	8.3	5.8	57.8571
30	145	8.8	6.0	58.7857
31	150	9.2	6.0	59.5714
32	160	0.7	11.0	59.5714
33	165	2.7	7.2	63.9286
34	170	4.1	6.4	66.6429
35	175	4.8	6.5	68.6429
36	180	5.4	5.4	70.2500
37	185	5.8	5.1	71.6429
38	190	6.4	5.1	72.8929
39	195	6.8	5.4	74.0000
40	200	7.4	5.4	74.8929
41	205	8.1	5.7	75.6071

Table A8 Summary of Results for Test 8 (Type V Fabric, reverse flow, and detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	22	0.0
2	5	0.0	20	2.5
3	10	0.0	20	5.0
4	15	0.2	21	7.5
5	20	0.6	22	10.0
6	25	0.7	22	12.5
7	30	0.8	20	15.0
8	35	0.9	20	17.5
9	40	1.0	21	20.0
10	45	1.0	21	22.5
11	50	1.0	22	25.0
12	55	1.0	22	27.5
13	60	1.1	22	30.0
14	65	1.1	22	32.5
15	70	1.1	20	35.0
16	75	1.1	21	37.5
17	80	1.2	21	40.0
18	85	1.2	22	42.5
19	90	1.2	20	45.0
20	95	1.4	21	47.5
21	100	1.5	21	50.0
22	105	1.6	20	52.5
23	110	1.6	20	55.0
24	115	1.7	21	57.5
25	120	1.7	22	60.0

Table A9 Summary of Results for Test 9 (Type I Fabric, reverse flow, and AC road dirt only wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	8.2	2.5
2	5	0.2	3.7	5.0
3	10	0.5	3.5	7.5
4	15	0.8	2.8	10.0
5	20	1.0	2.5	12.5
6	25	1.2	2.6	15.0
7	30	1.3	2.1	17.5
8	35	1.5	2.2	20.0
9	40	1.5	2.2	22.5
10	45	1.5	2.0	25.0
11	50	1.5	2.2	27.5
12	55	1.6	1.9	30.0
13	60	2.0	1.5	32.5
14	65	2.4	1.3	35.0
15	70	2.7	1.4	37.5
16	75	3.1	1.5	40.0
17	80	3.5	1.4	42.5
18	85	3.8	1.4	45.0
19	90	4.2	1.4	47.5
20	95	4.6	1.6	50.0
21	100	5.1	1.5	52.5
22	105	5.5	1.5	55.0
23	110	6.0	1.5	57.5
24	115	0.0	10.5	57.5
25	120	1.6	1.9	60.0
26	125	1.8	1.4	62.5
27	130	2.6	1.2	65.0
28	135	3.4	1.3	67.5
29	140	3.9	1.3	70.0
30	145	4.6	1.3	72.5
31	150	5.4	1.3	75.0
32	155	6.0	1.3	77.5
33	160	6.7	1.4	80.0
34	165	7.4	1.5	82.5

Table A10 Summary of Results for Test 10 (Type I Fabric, cross flow, and AC road dirt only wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	3.8	0.0000
2	5	0.1	2.5	5.6607
3	10	0.2	2.5	11.0536
4	15	0.5	2.3	15.9750
5	20	0.9	2.1	20.6179
6	25	1.0	2.0	24.5179
7	30	1.0	2.0	27.6679
8	35	1.0	1.9	30.4964
9	40	1.1	1.9	33.1929
10	45	1.2	1.9	35.6036
11	50	1.4	1.9	37.8571
12	55	1.6	1.9	39.8571
13	60	1.8	1.9	41.6071
14	65	2.0	1.9	43.1786
15	70	2.1	1.9	44.6786
16	75	2.1	1.9	46.0714
17	80	2.1	1.9	47.3214
18	85	2.1	1.9	48.5000
19	90	2.1	1.9	49.5714
20	95	2.1	1.9	50.6071
21	100	2.2	1.9	51.5714
22	105	3.2	1.9	52.4643
23	110	2.1	1.9	53.3214
24	115	2.1	1.9	54.0000
25	120	2.1	1.9	54.6786
26	125	2.1	1.9	55.3214
27	130	2.1	1.9	55.8929
28	135	2.1	1.9	56.4643
29	140	2.1	1.9	56.9643
30	145	2.1	1.9	57.4643
31	150	2.1	1.9	57.8929
32	155	2.1	1.9	58.2500
33	160	0.0	5.1	58.2500
34	165	0.5	4.3	60.9643
35	170	0.9	2.1	62.8214
36	175	2.1	2.2	63.8929
37	180	2.5	2.2	64.6786
38	185	2.5	2.2	65.3214
39	190	2.5	2.2	65.8929
40	195	2.6	2.2	66.4643
41	200	2.6	2.2	66.9286
42	205	2.6	2.2	67.3571
43	210	2.7	2.3	67.7500
44	215	2.7	2.5	68.1071

Table A11 Summary of Results for Test 11 (Type IV Fabric, reverse flow, and AC road dirt only wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	6.2	2.5
2	5	0.1	4.7	5.0
3	10	0.2	4.4	7.5
4	15	0.3	4.6	10.0
5	20	0.4	4.1	12.5
6	25	0.5	4.6	15.0
7	30	0.6	3.7	17.5
8	35	0.7	3.8	20.0
9	40	0.8	4.1	22.5
10	45	0.9	4.2	25.0
11	50	1.0	3.6	27.5
12	55	1.0	3.3	30.0
13	60	1.2	3.3	32.5
14	65	1.3	3.1	35.0
15	70	1.4	3.1	37.5
16	75	1.4	3.2	40.0
17	80	1.4	2.9	42.5
18	85	1.4	2.7	45.0
19	90	1.4	2.7	47.5
20	95	1.4	2.8	50.0
21	100	1.4	2.7	52.5
22	105	1.4	2.7	55.0
23	110	1.5	2.4	57.5
24	115	1.6	2.1	60.0
25	120	1.7	1.8	62.5
26	125	1.8	1.5	65.0
27	130	1.9	1.5	67.5
28	135	2.2	1.8	70.0
29	140	2.4	1.6	72.5
30	145	2.6	1.6	75.0
31	150	2.9	1.6	77.5
32	155	3.1	1.3	80.0
33	160	3.2	1.3	82.5
34	165	3.4	1.4	85.0
35	170	0.0	9.7	85.0
36	175	1.0	3.4	87.5
37	180	1.2	3.0	90.0
38	185	1.3	2.5	92.5
39	190	1.5	2.4	95.0
40	195	1.6	2.0	97.5
41	200	1.8	1.6	100.0
42	205	2.0	1.3	102.5
43	210	2.2	1.1	105.0
44	215	2.4	0.9	107.5
45	220	2.6	1.1	110.0
46	225	2.9	1.1	112.5
47	230	3.1	1.1	115.0
48	235	3.4	1.2	117.5
49	240	3.6	1.2	120.0
50	245	3.8	1.3	122.5
51	250	4.0	1.5	125.0
52	255	4.2	1.6	127.5
53	260	4.5	1.5	130.0
54	265	4.7	1.4	132.5
55	270	5.0	1.5	135.0

Table A11 Summary of Results for Test 11 Cont. (Type IV Fabric, reverse flow, and AC road dirt only wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
56	275	5.4	1.5	137.5
57	280	5.5	1.5	140.0
58	285	5.6	1.5	142.5
59	290	6.0	1.6	145.0
60	295	6.2	1.6	147.5
61	300	6.5	1.5	150.0
62	305	6.8	1.5	152.5
63	310	7.1	1.5	155.0
64	315	7.5	1.5	157.5
65	320	7.9	1.5	160.0
66	325	8.3	1.5	162.5
67	330	8.7	1.5	165.0
68	335	9.1	1.6	167.5
69	340	9.5	1.8	170.0
70	345	10.1	2.3	172.5
71	350	0.0	15.0	172.5
72	355	1.6	2.3	175.0
73	360	2.0	2.1	177.5
74	365	2.0	1.9	180.0
75	370	2.4	1.1	182.5
76	375	3.0	0.9	185.0
77	380	3.4	1.0	187.5
78	385	3.8	0.8	190.0
79	390	4.2	1.0	192.5
80	395	4.6	0.8	195.0
81	400	5.1	0.8	197.5
82	405	5.5	0.8	200.0
83	410	5.9	0.8	202.5
84	415	6.4	0.9	205.0
85	420	6.9	0.9	207.5
86	425	7.4	1.0	210.0
87	430	8.0	0.9	212.5
88	435	8.6	1.3	215.0
89	440	9.2	1.5	217.5
90	445	9.9	2.1	220.0

Table A12 Summary of Results for Test 12 (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.00	6.2	0.0
2	5	0.40	5.5	2.5
3	10	0.50	5.1	5.0
4	15	0.60	4.5	7.5
5	20	0.70	4.1	10.0
6	25	0.80	4.0	12.5
7	30	0.90	4.2	15.0
8	35	1.00	4.3	17.5
9	40	1.00	3.9	20.0
10	45	1.00	3.8	22.5
11	50	1.00	4.1	25.0
12	55	1.10	3.1	27.5
13	60	1.00	3.6	30.0
14	65	1.10	3.9	32.5
15	70	1.10	4.1	35.0
16	75	1.10	4.2	37.5
17	80	1.15	4.3	40.0
18	85	1.15	4.5	42.5
19	90	1.15	4.8	45.0
20	95	1.20	5.1	47.5
21	100	1.20	5.2	50.0
22	105	1.20	4.9	52.5
23	110	1.25	5.1	55.0
24	115	1.25	4.5	57.5
25	120	1.25	4.4	60.0
26	125	1.20	4.8	62.5
27	130	1.25	4.7	65.0
28	135	1.25	4.7	67.5
29	140	1.25	4.5	70.0
30	145	1.30	4.3	72.5
31	150	1.30	4.3	75.0
32	155	1.30	4.2	77.5
33	160	1.30	4.1	80.0
34	165	1.30	4.0	82.5
35	170	1.35	4.1	85.0
36	175	1.35	4.0	87.5
37	180	1.40	3.7	90.0
38	185	1.40	3.6	92.5
39	190	1.30	3.2	95.0
40	195	1.40	2.6	97.5
41	200	1.50	2.5	100.0
42	205	1.50	2.7	102.5
43	210	1.50	2.8	105.0
44	215	1.50	2.8	107.5
45	220	1.60	2.9	110.0
46	225	1.75	2.9	112.5
47	230	1.90	2.8	115.0
48	235	2.00	2.8	117.5
49	240	2.10	2.7	120.0
50	245	2.20	2.5	122.5
51	250	2.20	2.3	125.0
52	255	2.25	2.2	127.5
53	260	2.30	2.1	130.0
54	265	2.40	2.0	132.5
55	270	2.50	1.9	135.0

Table A12 Summary of Results for Test 12 Cont. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
56	275	2.60	1.80	137.5
57	280	2.70	1.70	140.0
58	285	2.75	1.70	142.5
59	290	2.80	1.50	145.0
60	295	2.80	1.60	147.5
61	300	2.85	1.50	150.0
62	305	2.90	1.50	152.5
63	310	2.90	1.45	155.0
64	315	2.90	1.30	157.5
65	320	2.60	1.90	160.0
66	325	2.60	1.80	162.5
67	330	2.65	1.80	165.0
68	335	2.70	1.70	167.5
69	340	2.80	1.70	170.0
70	345	2.90	1.60	172.5
71	350	3.00	1.60	175.0
72	355	3.10	1.60	177.5
73	360	3.20	1.50	180.0
74	365	3.30	1.50	182.5
75	370	3.50	1.30	185.0
76	375	3.70	1.20	187.5
77	380	3.50	2.10	190.0
78	385	3.60	1.80	192.5
79	390	3.70	2.10	195.0
80	395	3.80	1.70	197.5
81	400	3.90	1.50	200.0
82	405	4.10	1.40	202.5
83	410	4.10	1.50	205.0
84	415	4.30	1.40	207.5
85	420	4.50	1.30	210.0
86	425	4.60	1.10	212.5
87	430	4.80	1.20	215.0
88	435	4.90	1.30	217.5
89	440	5.10	1.20	220.0
90	445	4.10	3.80	222.5
91	450	4.20	2.70	225.0
92	455	4.50	1.70	227.5
93	460	4.60	1.70	230.0
94	465	4.70	1.70	232.5
95	470	4.90	1.50	235.0
96	475	5.10	1.40	237.5
97	480	5.30	1.20	240.0
98	485	5.40	1.20	242.5
99	490	5.40	1.10	245.0
100	495	5.50	1.00	247.5
101	500	5.60	1.00	250.0
102	505	5.70	1.10	252.5
103	510	5.80	1.10	255.0
104	515	4.30	2.80	257.5
105	520	4.50	2.40	260.0
106	525	5.00	1.80	262.5
107	530	5.60	1.60	265.0
108	535	5.60	1.60	267.5
109	540	5.70	1.60	270.0
110	545	5.80	1.60	272.5

Table A12 Summary of Results for Test 12 Cont. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
111	550	5.90	1.3	275.0
112	555	6.00	1.2	277.5
113	560	6.10	1.1	280.0
114	565	6.20	1.0	282.5
115	570	6.30	1.0	285.0
116	575	6.40	1.0	287.5
117	580	5.70	1.8	290.0
118	585	6.10	1.7	292.5
119	590	6.20	1.6	295.0
120	595	6.30	1.6	297.5
121	600	6.40	1.2	300.0
122	605	6.50	1.1	302.5
123	610	6.60	1.0	305.0
124	615	6.80	1.0	307.5
125	620	6.80	1.0	310.0
126	625	6.90	1.0	312.5
127	630	7.00	1.0	315.0
128	635	7.10	1.0	317.5
129	640	7.15	1.0	320.0
130	645	7.20	1.0	322.5
131	650	6.80	2.9	325.0
132	655	6.90	2.1	327.5
133	660	7.10	1.7	330.0
134	665	7.30	1.6	332.5
135	670	7.40	1.5	335.0
136	675	7.50	1.5	337.5
137	680	7.70	1.3	340.0
138	685	7.90	1.2	342.5
139	690	8.10	1.0	345.0
140	695	8.30	1.0	347.5
141	700	8.60	1.0	350.0
142	705	8.90	1.0	352.5
143	710	9.10	1.0	355.0
144	720	1.10	11.0	355.0
145	725	1.30	3.2	357.5
146	730	1.90	2.3	360.0
147	735	2.15	2.0	362.5
148	740	2.20	2.0	365.0
149	745	2.40	1.8	367.5
150	750	2.50	1.8	370.0
151	755	2.60	1.8	372.5
152	760	2.85	1.8	375.0
153	765	2.95	1.8	377.5
154	770	3.10	1.8	380.0
155	775	3.20	1.8	382.5
156	780	3.30	1.6	385.0
157	785	2.90	9.0	387.5
158	790	2.95	3.0	390.0
159	795	3.10	1.7	392.5
160	800	3.30	1.7	395.0
161	805	3.50	1.7	397.5
162	810	3.50	1.8	400.0
163	815	3.70	1.8	402.5
164	820	3.80	1.9	405.0
165	825	3.95	1.3	407.5

Table A12 Summary of Results for Test 12 Cont. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater).

OBS	TIME	PRESSURE	TURB	VOLUME
166	830	4.2	1.7	410.0
167	835	4.5	1.7	412.5
168	840	4.7	1.5	415.0

Table A13 Summary of Results for Test 13 (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater with pH control).

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.00	7.1	0.0
2	5	0.10	5.2	2.5
3	10	0.20	4.3	5.0
4	15	0.25	4.0	7.5
5	20	0.30	3.7	10.0
6	25	0.30	3.0	12.5
7	30	0.35	3.2	15.0
8	35	0.40	3.1	17.5
9	40	0.45	3.1	20.0
10	45	0.50	3.4	22.5
11	50	0.55	3.1	25.0
12	55	0.60	3.0	27.5
13	60	0.60	3.1	30.0
14	65	0.40	3.9	32.5
15	70	0.45	3.8	35.0
16	75	0.50	3.7	37.5
17	80	0.60	3.4	40.0
18	85	0.65	3.2	42.5
19	90	0.70	3.5	45.0
20	95	0.75	3.7	47.5
21	100	0.75	4.1	50.0
22	105	0.80	3.7	52.5
23	110	0.85	3.2	55.0
24	115	0.90	3.0	57.5
25	120	0.90	2.8	60.0
26	125	0.70	5.2	62.5
27	130	0.75	4.7	65.0
28	135	0.80	4.5	67.5
29	140	0.80	4.4	70.0
30	145	0.85	4.3	72.5
31	150	0.90	4.0	75.0
32	155	0.95	4.0	77.5
33	160	0.95	3.8	80.0
34	165	1.00	3.2	82.5
35	170	1.10	3.1	85.0
36	175	1.10	3.1	87.5
37	180	1.15	3.0	90.0
38	185	1.20	2.7	92.5
39	190	0.90	3.5	95.0
40	195	0.95	2.6	97.5
41	200	1.00	2.5	100.0
42	205	1.10	2.4	102.5
43	210	1.20	2.3	105.0
44	215	1.30	1.9	107.5
45	220	1.35	1.8	110.0
46	225	1.40	1.7	112.5
47	230	1.45	1.6	115.0
48	235	1.50	1.6	117.5
49	240	1.55	1.5	120.0
50	245	1.60	1.4	122.5
51	250	1.30	4.5	125.0
52	255	1.50	4.1	127.5
53	260	1.60	3.1	130.0
54	265	1.70	2.5	132.5
55	270	1.80	2.7	135.0

Table A13 Summary of Results for Test 13 Cont. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater with pH control).

OBS	TIME	PRESSURE	TURB	VOLUME
56	275	1.80	2.3	137.5
57	280	1.85	2.3	140.0
58	285	1.90	2.3	142.5
59	290	1.90	2.2	145.0
60	295	1.95	2.4	147.5
61	300	1.95	2.4	150.0
62	305	2.00	2.2	152.5
63	310	2.10	2.2	155.0
64	315	1.60	3.1	157.5
65	320	1.70	1.9	160.0
66	325	1.80	1.8	162.5
67	330	1.90	1.4	165.0
68	335	2.00	1.4	167.5
69	340	2.10	1.2	170.0
70	345	2.20	1.2	172.5
71	350	2.30	1.2	175.0
72	355	2.40	1.2	177.5
73	360	2.40	1.2	180.0
74	365	2.50	1.2	182.5
75	370	2.60	1.2	185.0
76	375	2.60	1.2	187.5
77	380	2.00	4.1	190.0
78	385	2.40	3.1	192.5
79	390	2.50	1.5	195.0
80	395	2.60	1.3	197.5
81	400	2.70	1.2	200.0
82	405	2.70	1.0	202.5
83	410	2.70	1.0	205.0
84	415	2.80	1.0	207.5
85	420	2.80	1.1	210.0
86	425	2.90	1.0	212.5
87	430	2.95	1.0	215.0
88	435	3.00	1.0	217.5
89	440	3.10	1.0	220.0
90	445	2.70	3.5	222.5
91	450	3.10	1.8	225.0
92	455	3.20	1.8	227.5
93	460	3.30	1.2	230.0
94	465	3.30	1.1	232.5
95	470	3.30	1.1	235.0
96	475	3.40	1.1	237.5
97	480	3.50	1.0	240.0
98	485	3.60	1.1	242.5
99	490	3.70	1.2	245.0
100	495	3.80	1.5	247.5
101	500	3.90	1.2	250.0
102	505	4.00	1.3	252.5
103	510	4.00	1.1	255.0
104	515	3.50	4.2	257.5
105	520	3.90	3.8	260.0
106	525	4.00	2.4	262.5
107	530	4.10	1.4	265.0
108	535	4.20	1.1	267.5
109	540	4.30	0.9	270.0
110	545	4.40	0.9	272.5

Table A13 Summary of Results for Test 13 Cont. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater with pH control).

OBS	TIME	PRESSURE	TURB	VOLUME
111	550	4.5	0.9	275.0
112	555	4.5	0.9	277.5
113	560	4.5	0.9	280.0
114	565	4.6	0.9	282.5
115	570	4.7	0.9	285.0
116	575	4.8	0.9	287.5
117	580	4.0	5.2	290.0
118	585	4.7	3.2	292.5
119	590	4.8	1.9	295.0
120	595	4.9	0.9	297.5
121	600	5.0	0.9	300.0
122	605	5.1	0.9	302.5
123	610	5.2	0.9	305.0
124	615	5.3	0.9	307.5
125	620	5.5	0.9	310.0
126	625	5.6	0.9	312.5
127	630	5.7	0.9	315.0
128	635	5.8	0.9	317.5
129	640	5.9	0.9	320.0
130	645	6.0	0.9	322.5
131	650	4.7	4.3	325.0
132	655	5.5	2.5	327.5
133	660	5.6	1.2	330.0
134	665	5.6	1.1	332.5
135	670	5.7	0.9	335.0
136	675	5.8	0.9	337.5
137	680	5.9	0.9	340.0
138	685	6.0	0.9	342.5
139	690	6.0	0.9	345.0
140	695	6.1	0.9	347.5
141	700	6.2	0.9	350.0
142	705	6.3	0.9	352.5
143	710	6.5	0.9	355.0
144	715	6.0	5.3	357.5
145	720	6.2	3.1	360.0
146	725	6.4	1.8	362.5
147	730	6.5	1.2	365.0
148	735	6.7	0.9	367.5
149	740	6.9	0.9	370.0
150	745	7.1	0.9	372.5
151	750	7.4	0.9	375.0
152	755	7.8	0.9	377.5
153	760	8.1	0.9	380.0
154	765	8.3	0.9	382.5
155	770	8.6	0.9	385.0
156	775	9.1	0.9	387.5
157	785	1.1	12.0	387.5
158	790	1.2	4.2	390.0
159	795	1.5	2.1	392.5
160	800	1.6	1.7	395.0
161	805	1.6	1.5	397.5
162	810	1.7	1.5	400.0
163	815	1.7	1.5	402.5
164	820	1.8	1.5	405.0
165	825	1.9	1.5	407.5

Table A13 Summary of Results for Test 13 Cont. (Type I Fabric, reverse flow, and coagulated detergent plus AC road dirt wastewater with pH control).

OBS	TIME	PRESSURE	TURB	VOLUME
166	830	1.90	1.5	410.0
167	835	2.00	1.5	412.5
168	840	2.10	1.5	415.0
169	845	2.10	1.5	417.5
170	850	1.50	8.0	420.0
171	855	1.70	3.1	422.5
172	860	1.80	1.6	425.0
173	865	1.90	1.4	427.5
174	870	2.20	1.4	430.0
175	875	2.30	1.4	432.5
176	880	2.40	1.4	435.0
177	885	2.50	1.4	437.5
178	890	2.60	1.4	440.0
179	895	2.70	1.4	442.5
180	900	2.80	1.4	445.0
181	905	2.90	1.4	447.5
182	910	2.40	5.2	450.0
183	915	2.90	1.8	452.5
184	920	3.10	1.7	455.0
185	925	3.30	1.2	457.5
186	930	3.50	1.1	460.0
187	935	3.60	1.1	462.5
188	940	3.70	1.1	465.0
189	945	3.80	1.1	467.5
190	950	3.95	1.1	470.0
191	955	4.20	1.1	472.5
192	960	4.50	1.1	475.0
193	965	4.80	1.1	477.5
194	970	5.10	1.1	480.0

```
OBS     TIME     VOLUME

  1        7       250
  2       18       500
  3       49       750
  4      111       850
  5      295       950
  6      451      1000
  7      767      1050
  8     1150      1100
  9     1632      1150
 10     2289      1200
```

Table A14 Volume versus Time for Influent in Test 2 (first fouling factor test).

OBS	TIME	VOLUME
1	14	500
2	28	1000
3	46	1500
4	65	2000
5	75	2500
6	97	3000
7	140	3500
8	172	4000
9	196	4250
10	228	4500
11	258	4750
12	307	5000
13	348	5100
14	423	5200
15	561	5300
16	683	5350
17	912	5400
18	1342	5450
19	2235	5500

Table A15 Volume versus Time for Effluent in Test 2 (first fouling factor test).

OBS	TIME	VOLUME
1	7	250
2	17	500
3	46	750
4	105	850
5	281	950
6	423	1000
7	757	1050
8	1091	1100
9	1423	1150
10	2015	1200

Table A16 Volume versus Time for Influent in Test 2 (second fouling factor test).

OBS	TIME	VOLUME
1	12	500
2	25	1000
3	42	1500
4	60	2000
5	73	2500
6	91	3000
7	132	3500
8	165	4000
9	187	4250
10	201	4500
11	234	4750
12	283	5000
13	312	5100
14	401	5200
15	533	5300
16	651	5350
17	876	5400
18	1225	5450
19	2045	5500

Table A17 Volume versus Time for Effluent in Test 2 (second fouling factor test).

```
OBS     TIME     VOLUME

  1        7        250
  2       16        500
  3       43        750
  4      105        850
  5      282        950
  6      435       1000
  7      725       1050
  8     1032       1100
  9     1545       1150
 10     2019       1200
```

Table A18 Volume versus Time for Influent in Test 4 (first fouling factor test).

OBS	TIME	VOLUME
1	15	500
2	29	1000
3	48	1500
4	68	2000
5	82	2500
6	101	3000
7	152	3500
8	183	4000
9	252	4500
10	297	4750
11	343	5000
12	523	5250
13	713	5350
14	1523	5450
15	2384	5480

Table A19 Volume versus Time for Effluent in Test 4 (first fouling factor test).

```
OBS    TIME    VOLUME

  1       7      250
  2      17      500
  3      45      750
  4     109      850
  5     285      950
  6     415     1000
  7     712     1050
  8     985     1100
  9    1493     1150
 10    1973     1200
```

Table A20 Volume versus Time for Influent in Test 4 (second fouling factor test).

OBS	TIME	VOLUME
1	16	500
2	34	1000
3	52	1500
4	73	2000
5	95	2500
6	134	3000
7	175	3500
8	191	4000
9	283	4500
10	314	4750
11	363	5000
12	578	5250
13	734	5350
14	1050	5450
15	1984	5480

Table A21 Volume versus Time for Effluent in Test 4 (second fouling factor test).

OBS	TIME	VOLUME
1	7	250
2	17	500
3	48	750
4	106	850
5	218	900
6	286	950
7	428	1000
8	740	1050
9	1068	1100
10	1502	1150
11	2125	1200

Table A22 Volume versus Time for Influent in Test 5 (first fouling factor test).

OBS	TIME	VOLUME
1	14	500
2	28	1000
3	44	1500
4	62	2000
5	82	2500
6	100	3000
7	122	3500
8	146	4000
9	175	4500
10	196	4750
11	223	5000
12	254	5250
13	304	5500
14	370	5750
15	408	5850
16	574	5950
17	682	6050
18	898	6150
19	1059	6200
20	1318	6250
21	2181	6300

Table A23 Volume versus Time for Effluent in Test 5 (first fouling factor test).

```
OBS    TIME    VOLUME

  1       7      250
  2      18      500
  3      51      750
  4     111      850
  5     227      900
  6     298      950
  7     442     1000
  8     768     1050
  9    1110     1100
 10    1650     1150
 11    2290     1200
```

Table A24 Volume versus Time for Influent in Test 5 (second fouling factor test).

```
OBS    TIME    VOLUME

  1      14       500
  2      28      1000
  3      45      1500
  4      65      2000
  5      88      2500
  6     108      3000
  7     131      3500
  8     156      4000
  9     183      4500
 10     235      5000
 11     282      5250
 12     329      5500
 13     393      5750
 14     675      6000
 15     842      6100
 16    1125      6200
 17    2350      6300
```

Table A25 Volume versus Time for Effluent in Test 5 (second fouling factor test).

```
OBS    TIME    VOLUME

  1       7       250
  2      19       500
  3      52       750
  4     113       850
  5     225       900
  6     299       950
  7     434      1000
  8     752      1050
  9    1125      1100
 10    1612      1150
 11    2314      1200
```

Table A26 Volume versus Time for Influent in Test 5 (third fouling factor test).

OBS	TIME	VOLUME
1	14	500
2	32	1000
3	48	1500
4	71	2000
5	92	2500
6	115	3000
7	136	3500
8	158	4000
9	171	4250
10	193	4500
11	213	4750
12	245	5000
13	298	5250
14	320	5500
15	350	5600
16	370	5700
17	409	5800
18	575	5900
19	675	6000
20	795	6050
21	986	6100
22	1220	6150
23	2113	6200

Table A27 Volume versus Time for Effluent in Test 5 (third fouling factor test).

OBS	TIME	VOLUME
1	9	500
2	24	1000
3	41	1500
4	83	1750
5	173	2000
6	223	2050
7	275	2100
8	363	2150
9	465	2200
10	568	2250

Table A28 Volume versus Time for Influent in Test 9 (first fouling factor test).

OBS	TIME	VOLUME
1	6.0	500
2	12.5	1000
3	19.0	1500
4	25.5	2000
5	32.0	2500
6	39.0	3000
7	46.0	3500
8	53.0	4000
9	60.0	4500
10	67.0	5000
11	74.0	5500
12	81.0	6000
13	88.0	6500
14	96.0	7000
15	104.0	7500
16	112.5	8000
17	120.0	8500
18	128.0	9000
19	136.0	9500
20	144.0	10000
21	152.0	10500
22	160.0	11000
23	168.0	11500
24	176.0	12000
25	184.0	12500
26	192.0	13000
27	201.0	13500
28	210.0	14000
29	219.0	14500
30	228.0	15000
31	237.0	15500
32	246.0	16000
33	255.0	16500
34	264.0	17000

Table A29 Volume versus Time for Effluent in Test 9 (first fouling factor test).

OBS	TIME	VOLUME
1	4.0	250
2	8.5	500
3	14.5	750
4	21.0	1000
5	28.0	1250
6	38.0	1500
7	76.0	1750
8	86.0	1800
9	97.0	1850
10	111.0	1900
11	132.0	1950
12	160.0	2000
13	209.0	2050
14	266.0	2100
15	341.0	2150
16	436.0	2200
17	540.0	2250

Table A30 Volume versus Time for Influent in Test 9 (second fouling factor test).

```
OBS     TIME    VOLUME

  1       5.0      500
  2      10.0     1000
  3      16.0     1500
  4      23.0     2000
  5      30.0     2500
  6      37.0     3000
  7      44.0     3500
  8      51.0     4000
  9      58.0     4500
 10      65.0     5000
 11      72.0     5500
 12      79.0     6000
 13      86.0     6500
 14      93.0     7000
 15     100.5     7500
 16     108.0     8000
 17     115.5     8500
 18     123.0     9000
 19     130.5     9500
 20     138.0    10000
 21     145.5    10500
 22     153.0    11000
 23     160.5    11500
 24     168.0    12000
 25     175.5    12500
 26     183.0    13000
 27     191.0    13500
 28     199.0    14000
```

Table A31 Volume versus Time for Effluent in Test 9 (second fouling factor test).

```
OBS      TIME     VOLUME

  1       8.5       500
  2      15.0       750
  3      22.0      1000
  4      29.0      1250
  5      37.0      1500
  6      72.0      1750
  7     151.0      2000
  8     198.0      2050
  9     254.0      2100
 10     321.0      2150
 11     426.0      2200
 12     506.0      2250
```

Table A32 Volume versus Time for Influent in Test 9 (third fouling factor test).

```
OBS      TIME      VOLUME

  1       5.0         500
  2      10.0        1000
  3      15.0        1500
  4      21.0        2000
  5      27.0        2500
  6      33.0        3000
  7      39.0        3500
  8      46.0        4000
  9      53.0        4500
 10      60.0        5000
 11      67.0        5500
 12      74.0        6000
 13      81.0        6500
 14      89.0        7000
 15      97.0        7500
 16     105.0        8000
 17     113.0        8500
 18     122.0        9000
 19     131.0        9500
 20     141.0       10000
 21     151.0       10500
 22     161.0       11000
 23     171.5       11500
 24     182.0       12000
 25     192.5       12500
 26     203.0       13000
 27     215.0       13500
 28     227.0       14000
 29     239.0       14500
 30     253.0       15000
```

Table A33 Volume versus Time for Effluent in Test 9 (third fouling factor test).

OBS	TIME	VOLUME
1	8.5	500
2	23.0	1000
3	39.0	1500
4	81.0	1750
5	165.0	2000
6	203.0	2050
7	261.0	2100
8	352.0	2150
9	434.0	2200
10	569.0	2250

Table A34 Volume versus Time for Influent in Test 11 (first fouling factor test).

```
OBS      TIME     VOLUME

  1       6.0        500
  2      12.0       1000
  3      18.0       1500
  4      24.5       2000
  5      31.0       2500
  6      37.5       3000
  7      43.5       3500
  8      50.0       4000
  9      57.0       4500
 10      64.0       5000
 11      71.0       5500
 12      78.0       6000
 13      85.0       6500
 14      92.0       7000
 15      99.0       7500
 16     106.0       8000
 17     113.0       8500
 18     120.0       9000
 19     127.0       9500
 20     133.0      10000
 21     140.5      10500
 22     148.0      11000
 23     155.5      11500
 24     162.0      12000
 25     170.0      12500
 26     178.0      13000
 27     186.0      13500
 28     195.0      14000
 29     204.0      14500
 30     213.0      15000
```

Table A35 Volume versus Time for Effluent in Test 11 (first fouling factor test).

OBS	TIME	VOLUME
1	8.5	500
2	23.0	1000
3	39.0	1500
4	83.0	1750
5	168.0	2000
6	212.0	2050
7	272.0	2100
8	375.0	2150
9	462.0	2200
10	593.0	2250

Table A36 Volume versus Time for Influent in Test 11 (second fouling factor test).

```
OBS      TIME     VOLUME

  1       6.0        500
  2      12.0       1000
  3      18.5       1500
  4      25.0       2000
  5      31.5       2500
  6      38.0       3000
  7      44.5       3500
  8      51.0       4000
  9      57.5       4500
 10      64.0       5000
 11      71.0       5500
 12      78.0       6000
 13      85.0       6500
 14      92.0       7000
 15      99.0       7500
 16     106.5       8000
 17     114.0       8500
 18     121.5       9000
 19     128.0       9500
 20     135.5      10000
 21     143.0      10500
 22     151.0      11000
 23     159.0      11500
 24     167.0      12000
 25     175.0      12500
 26     183.5      13000
 27     192.0      13500
 28     200.5      14000
 29     209.0      14500
 30     218.0      15000
 31     227.0      15500
 32     236.0      16000
```

Table A37 Volume versus Time for Effluent in Test 11 (second fouling factor test).

Figure A1 Turbidity versus Time for Test 1.

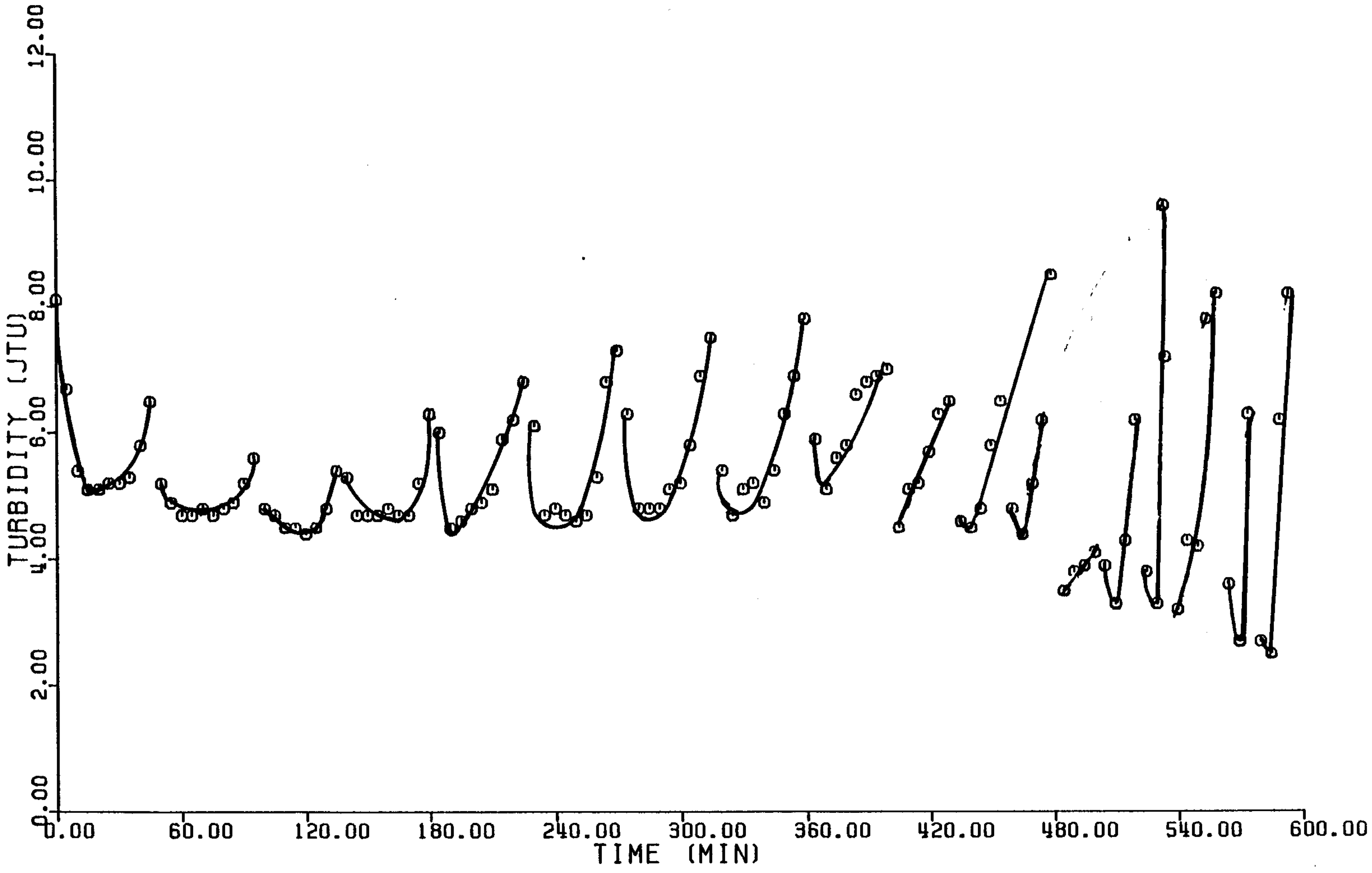


Figure A2 Pressure versus Time for Test 1.

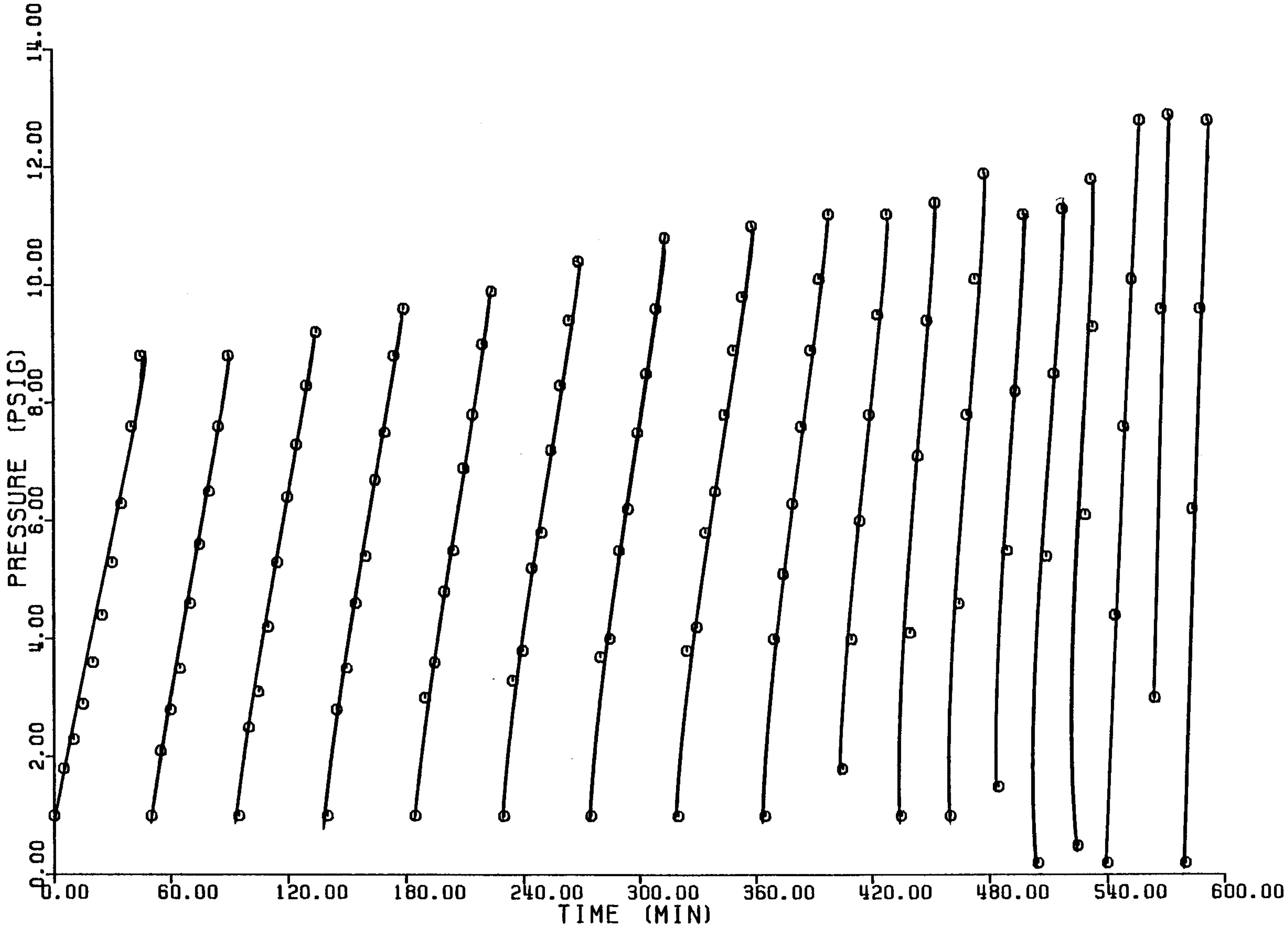


Figure A3 Filtered Volume versus Time for Test 1.

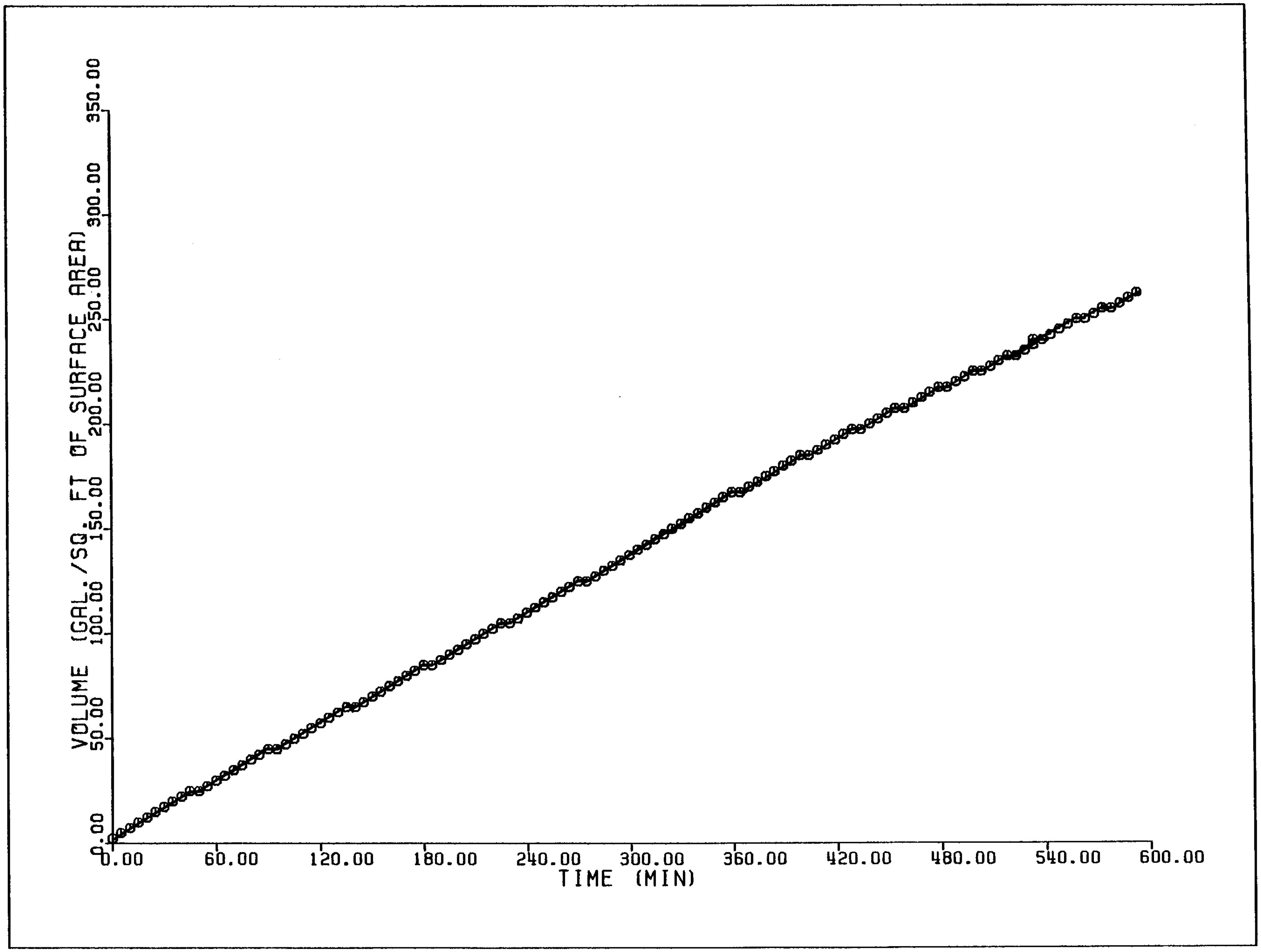


Figure A4 Turbidity versus Time for Test 2.

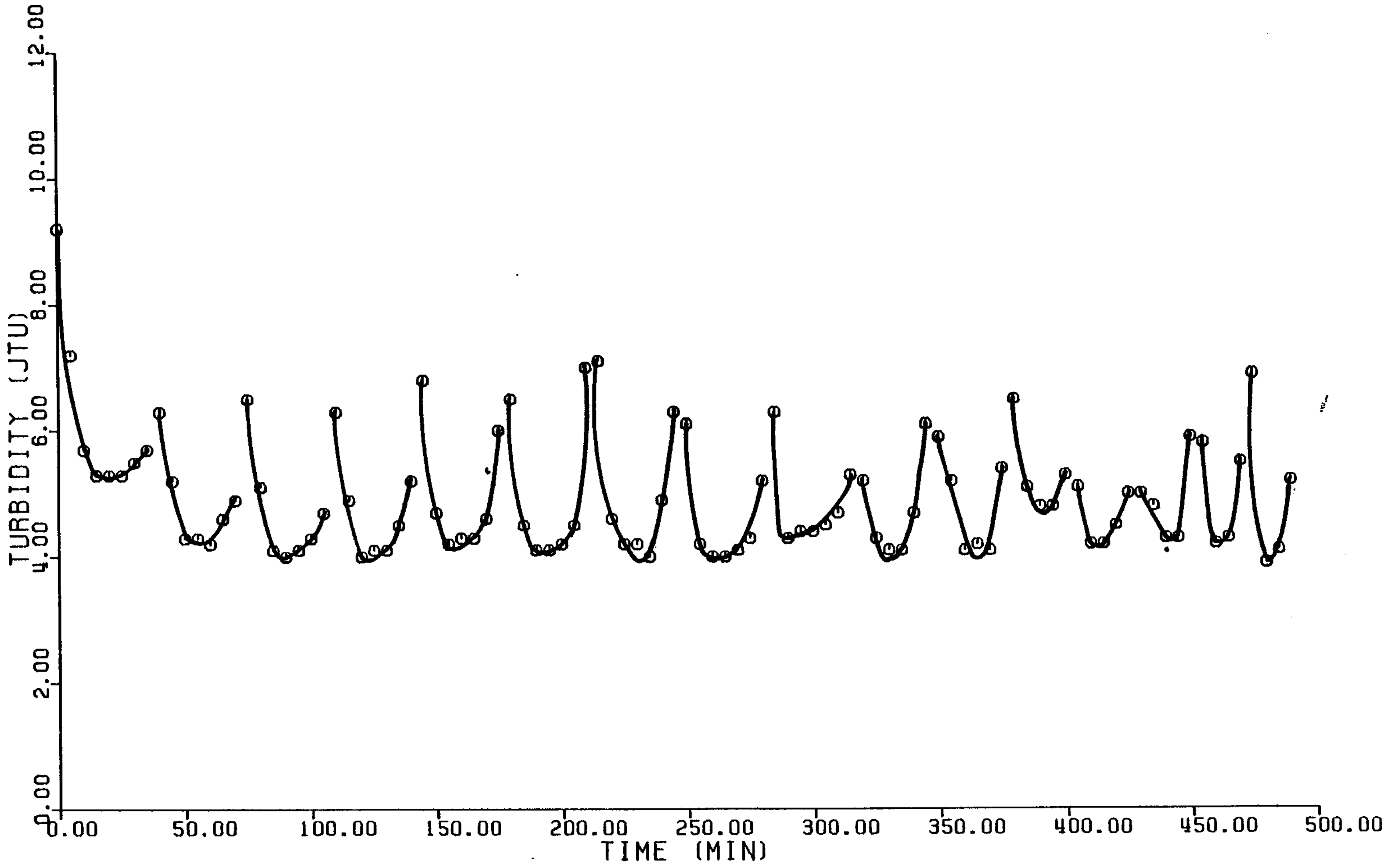


Figure A5 Pressure versus Time for Test 2.

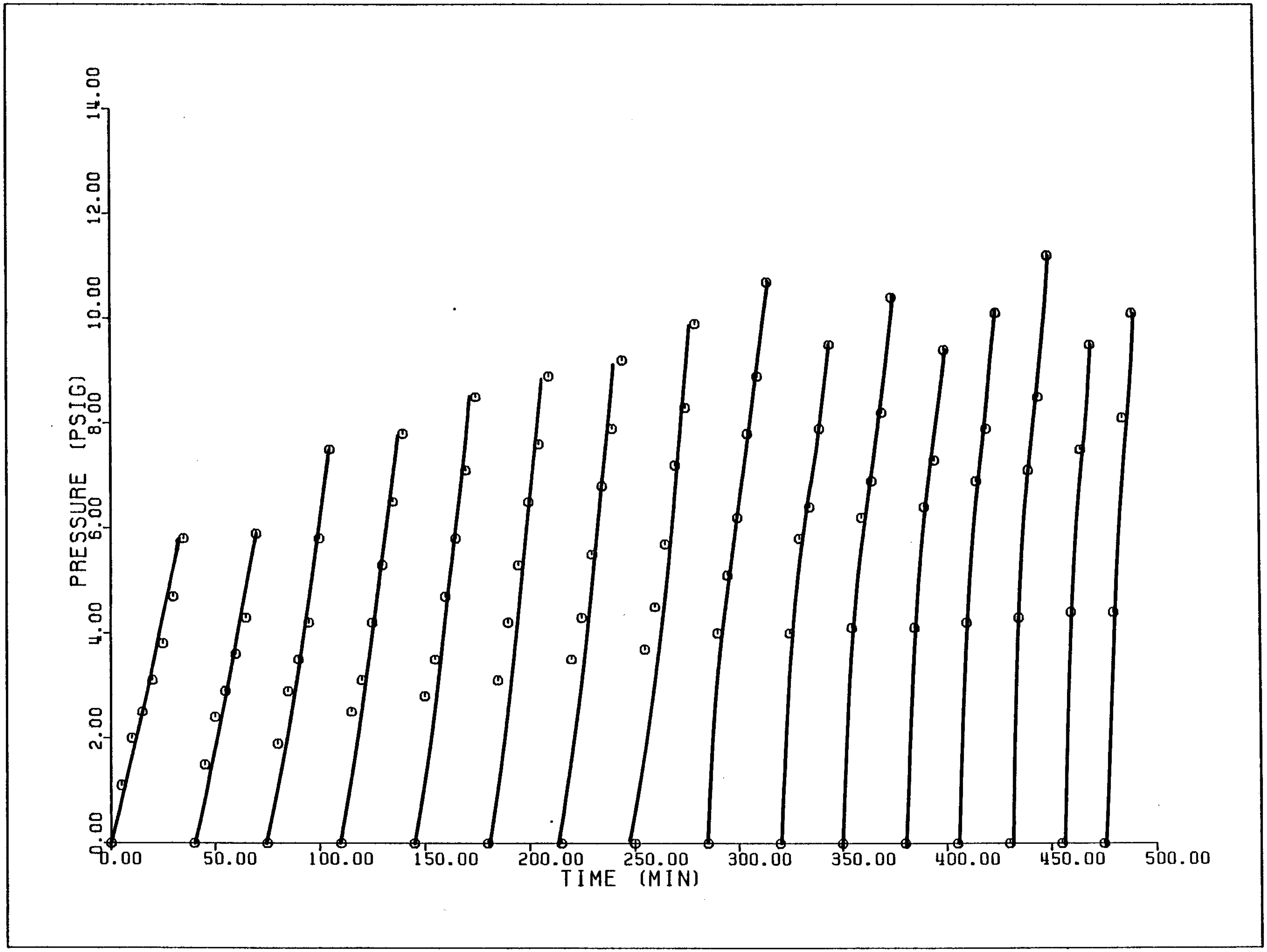


Figure A6 Filtered Volume versus Time for Test 2.

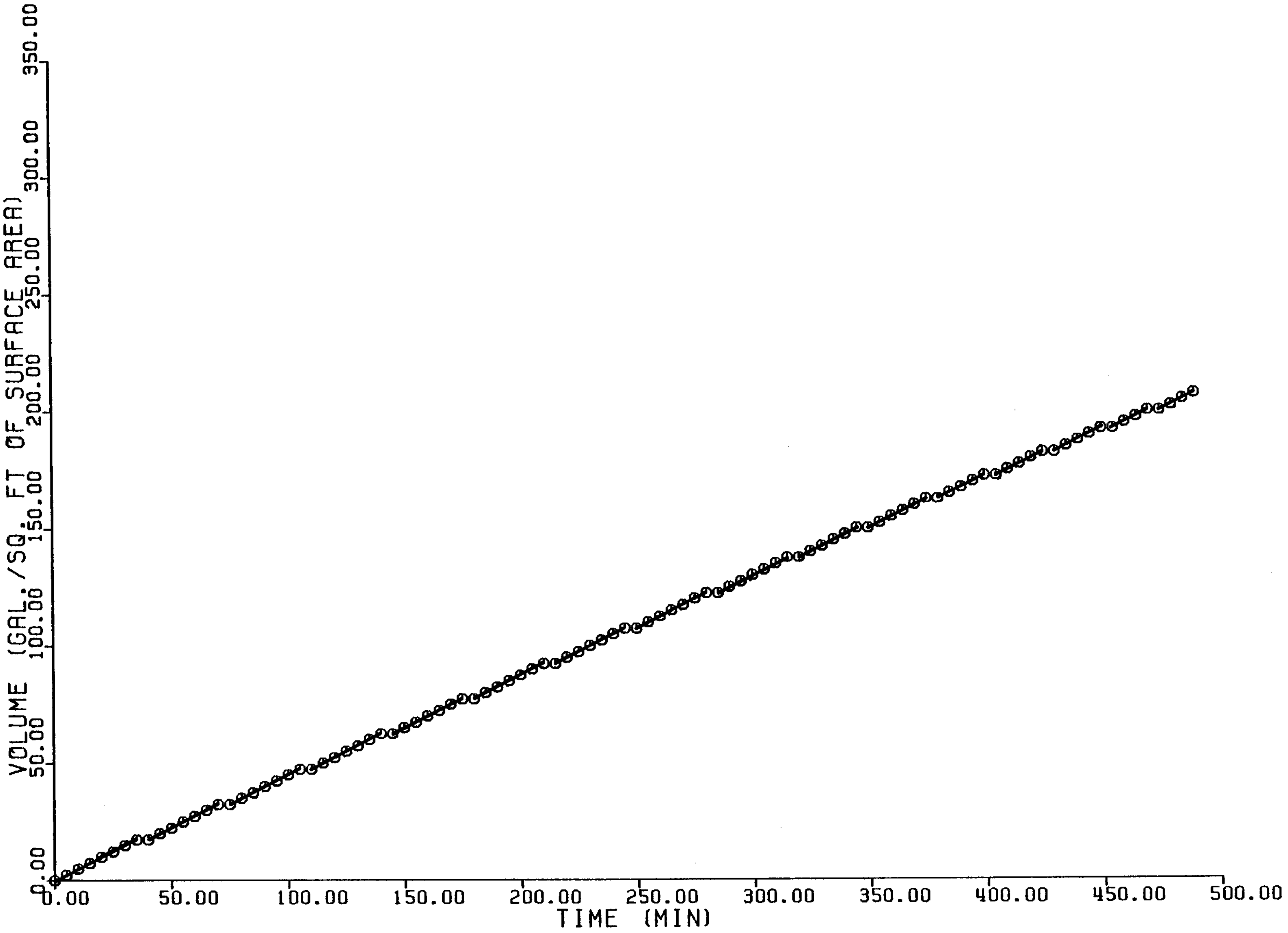


Figure A7 Turbidity versus Time for Test 3.

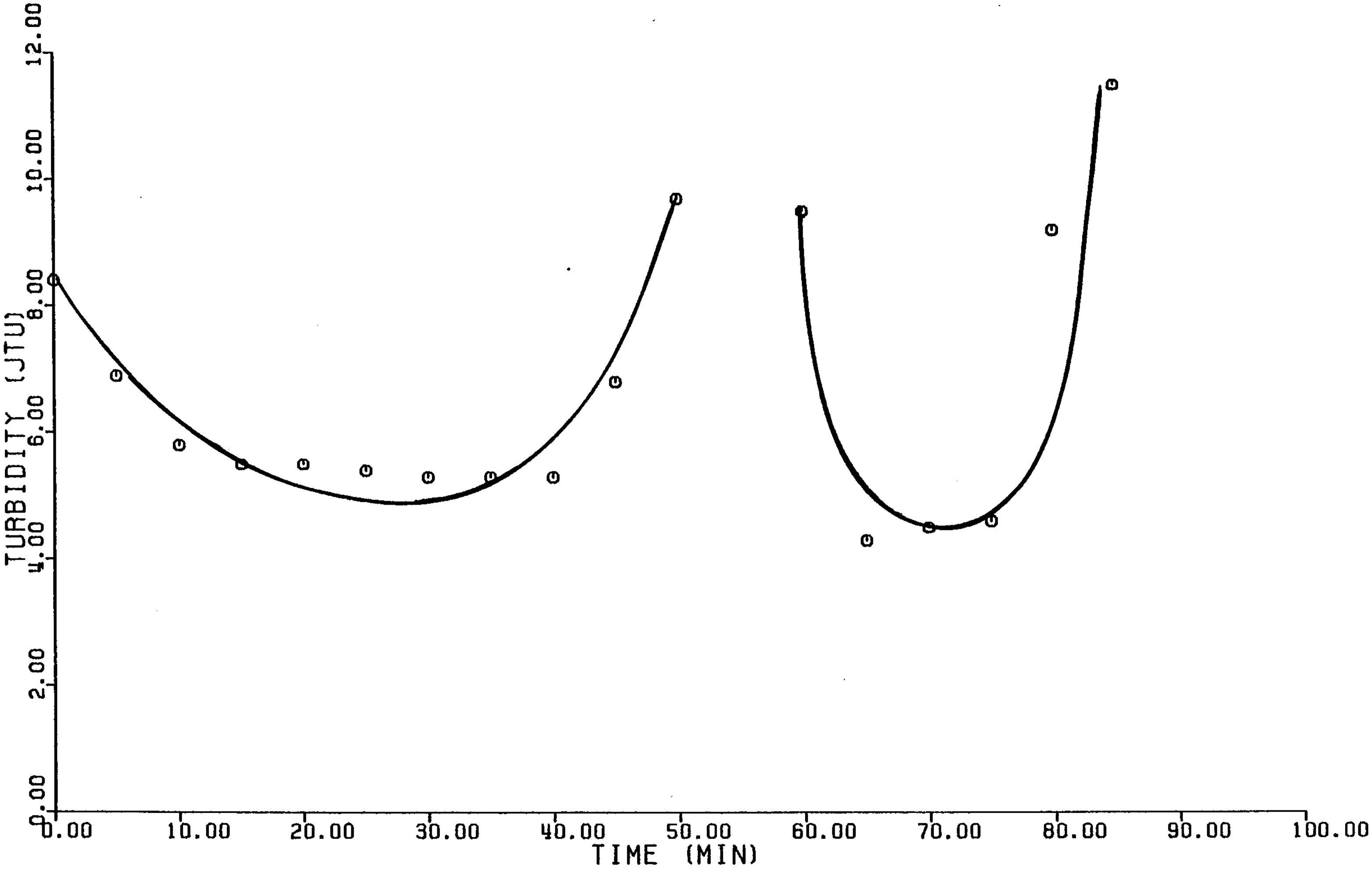


Figure A8 Pressure versus Time for Test 3.

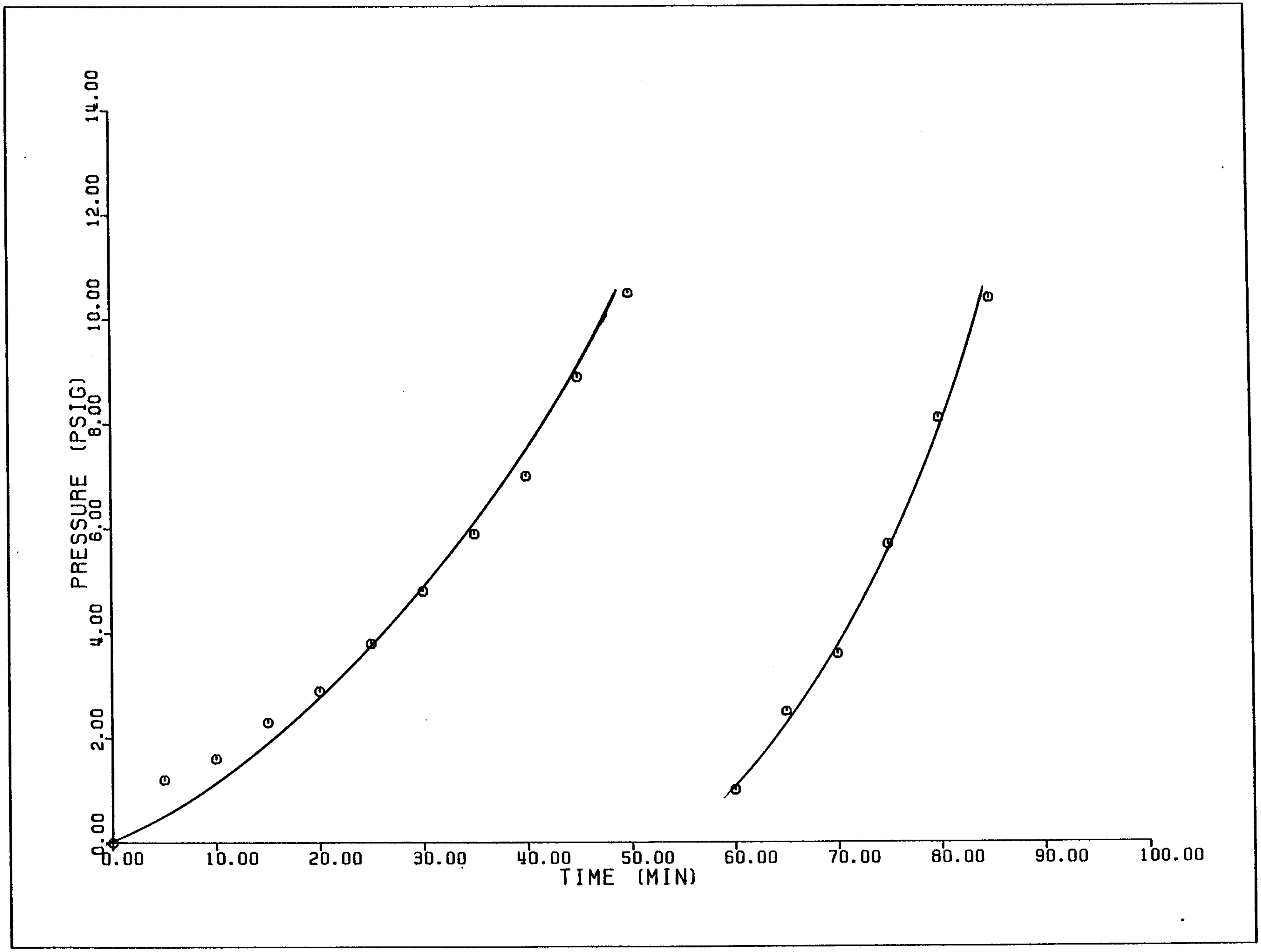


Figure A9 Filtered Volume versus Time for Test 3.

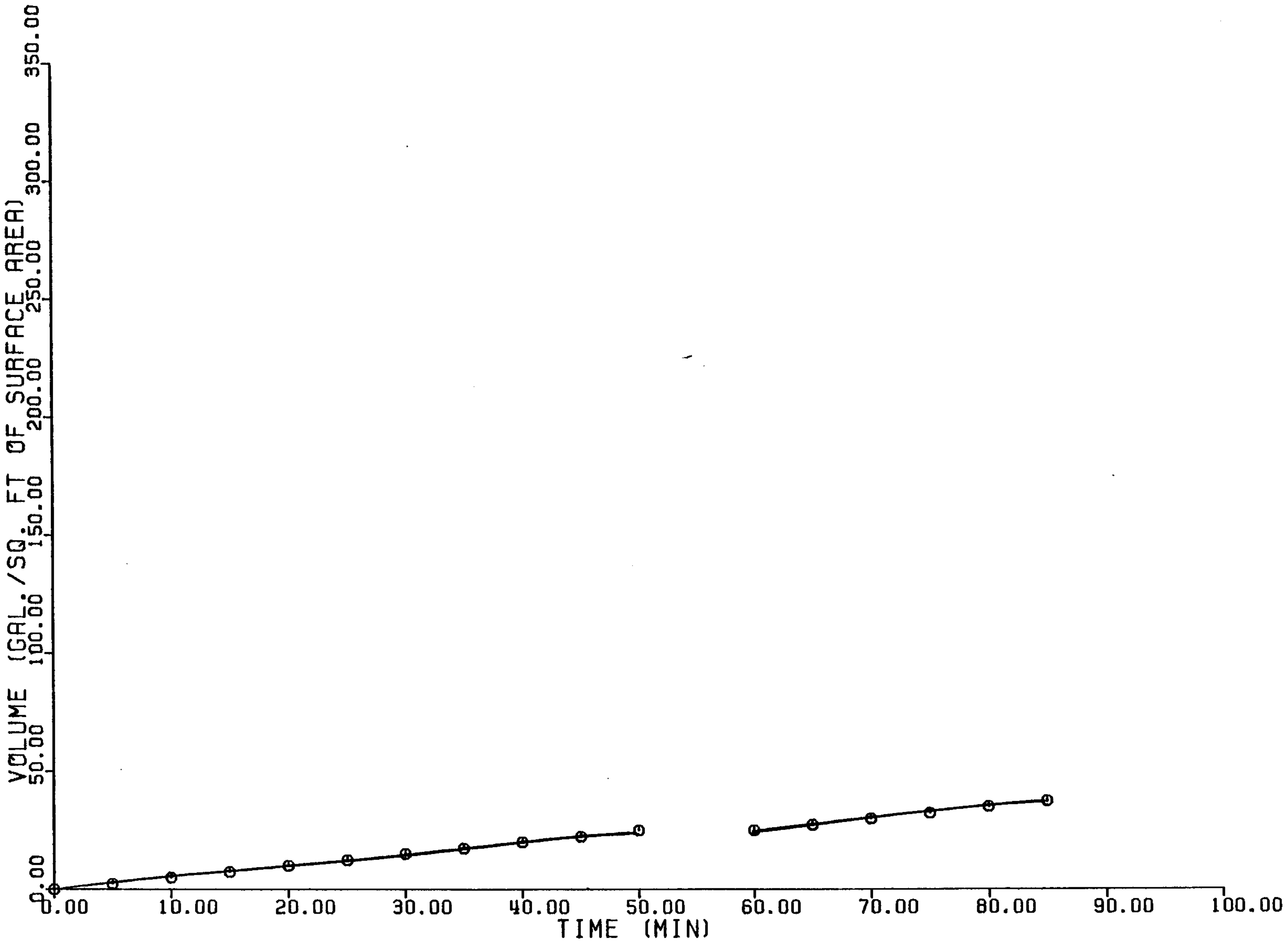


Figure A10 Turbidity versus Time for Test 4.

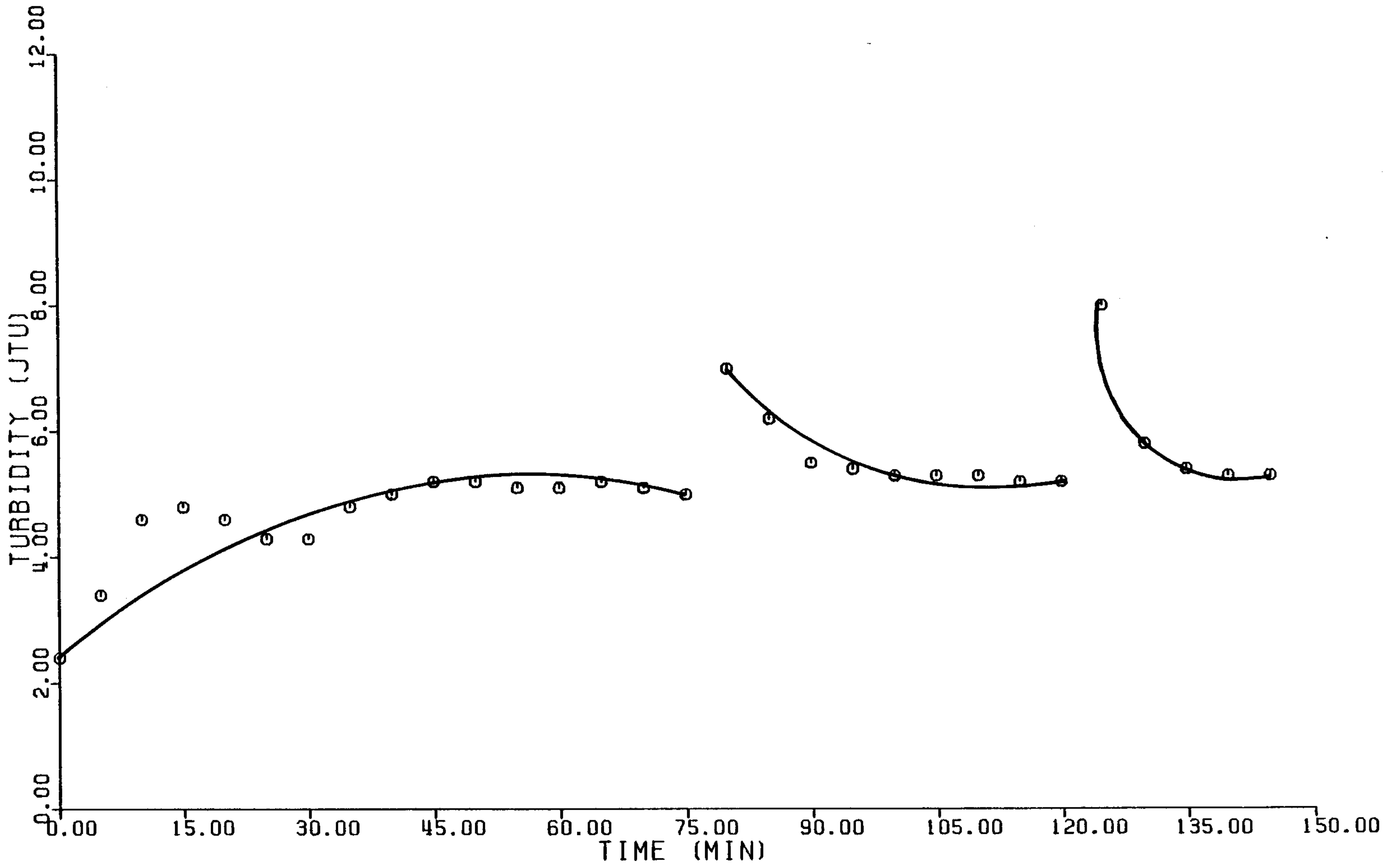


Figure A11 Pressure versus Time for Test 4.

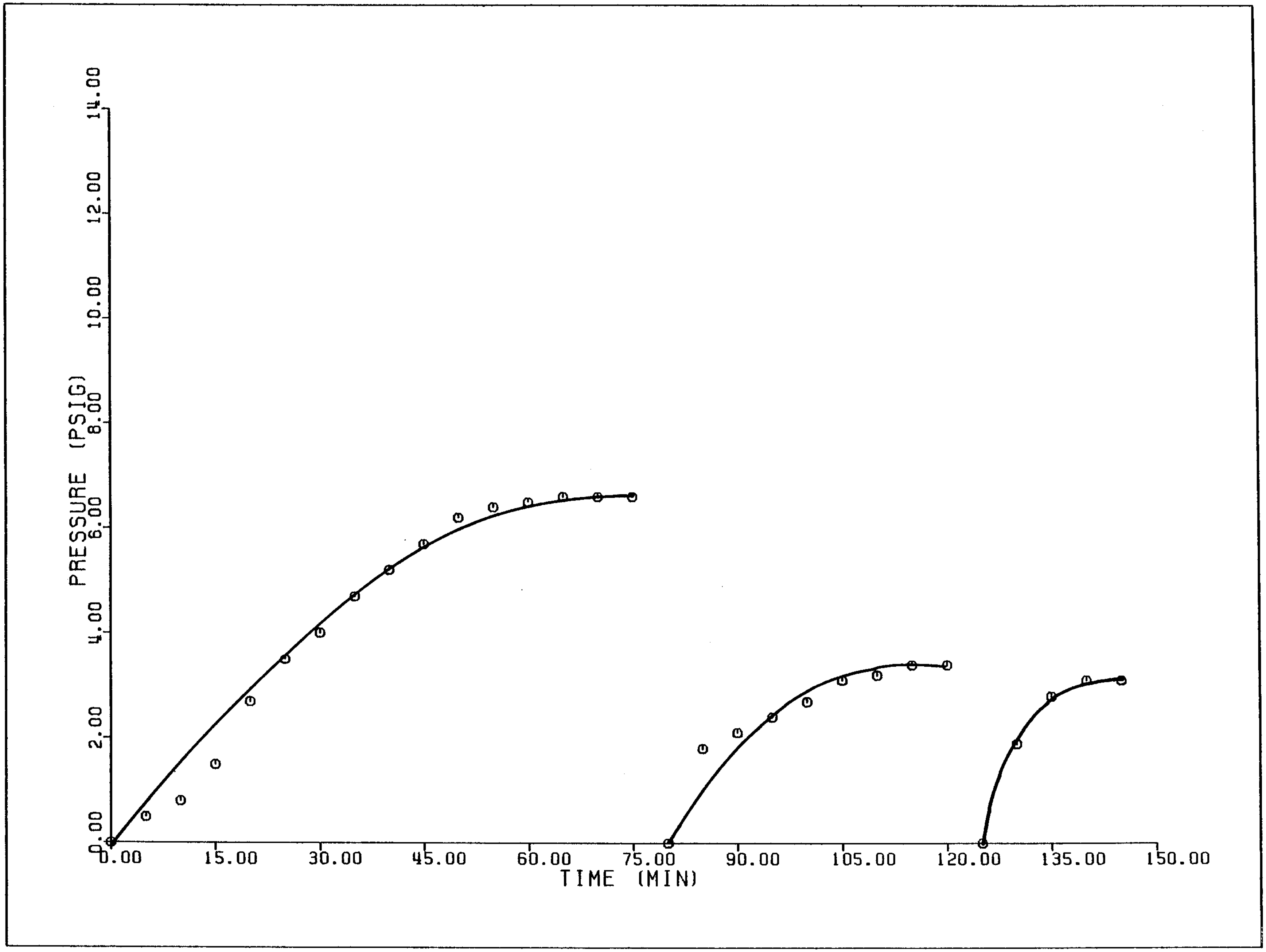


Figure A12 Filtered Volume versus Time for Test 4.

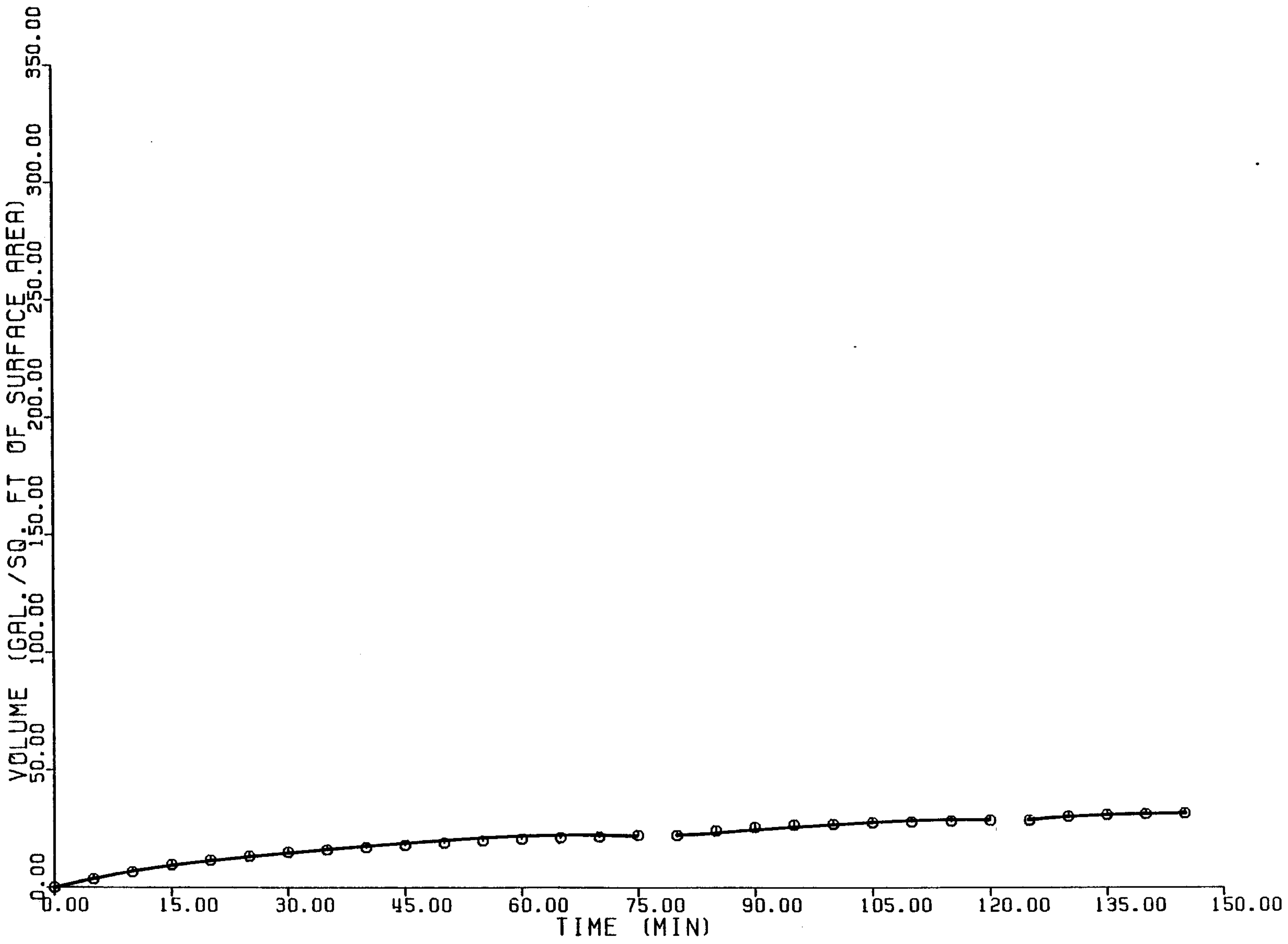


Figure A13 Turbidity versus Time for Test 5.

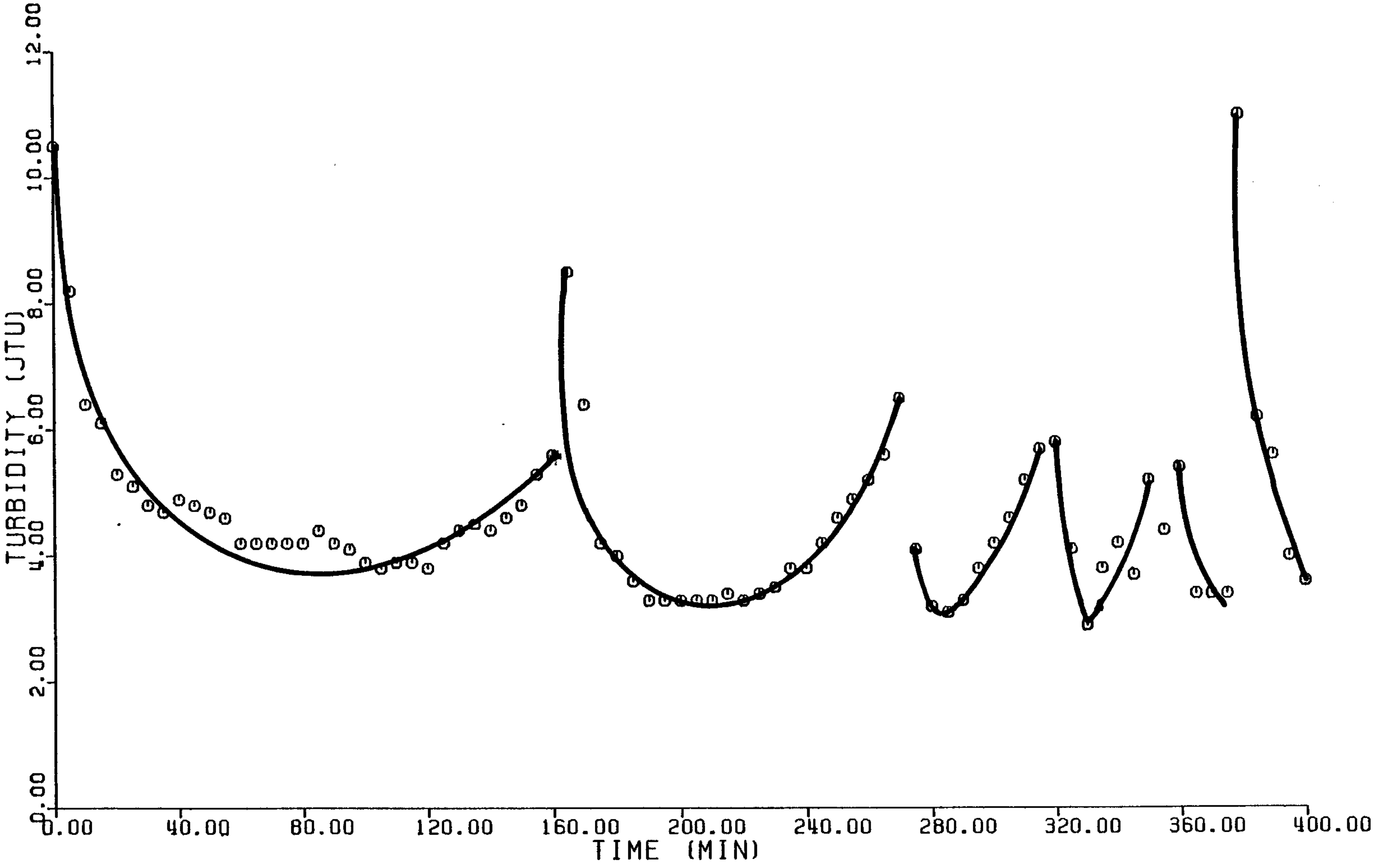


Figure A14 Pressure versus Time for Test 5.

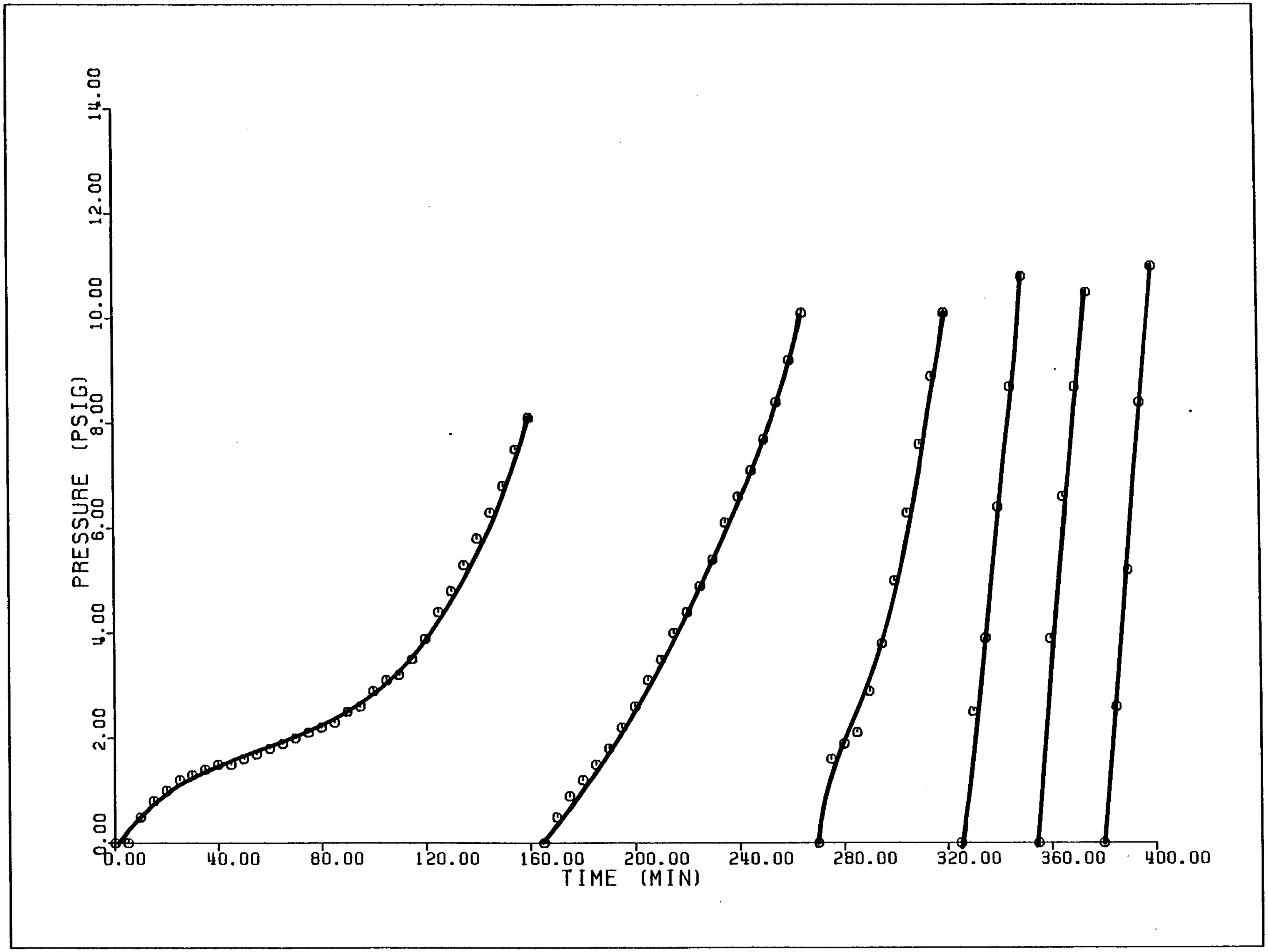


Figure A15 Filtered Volume versus Time for Test 5.

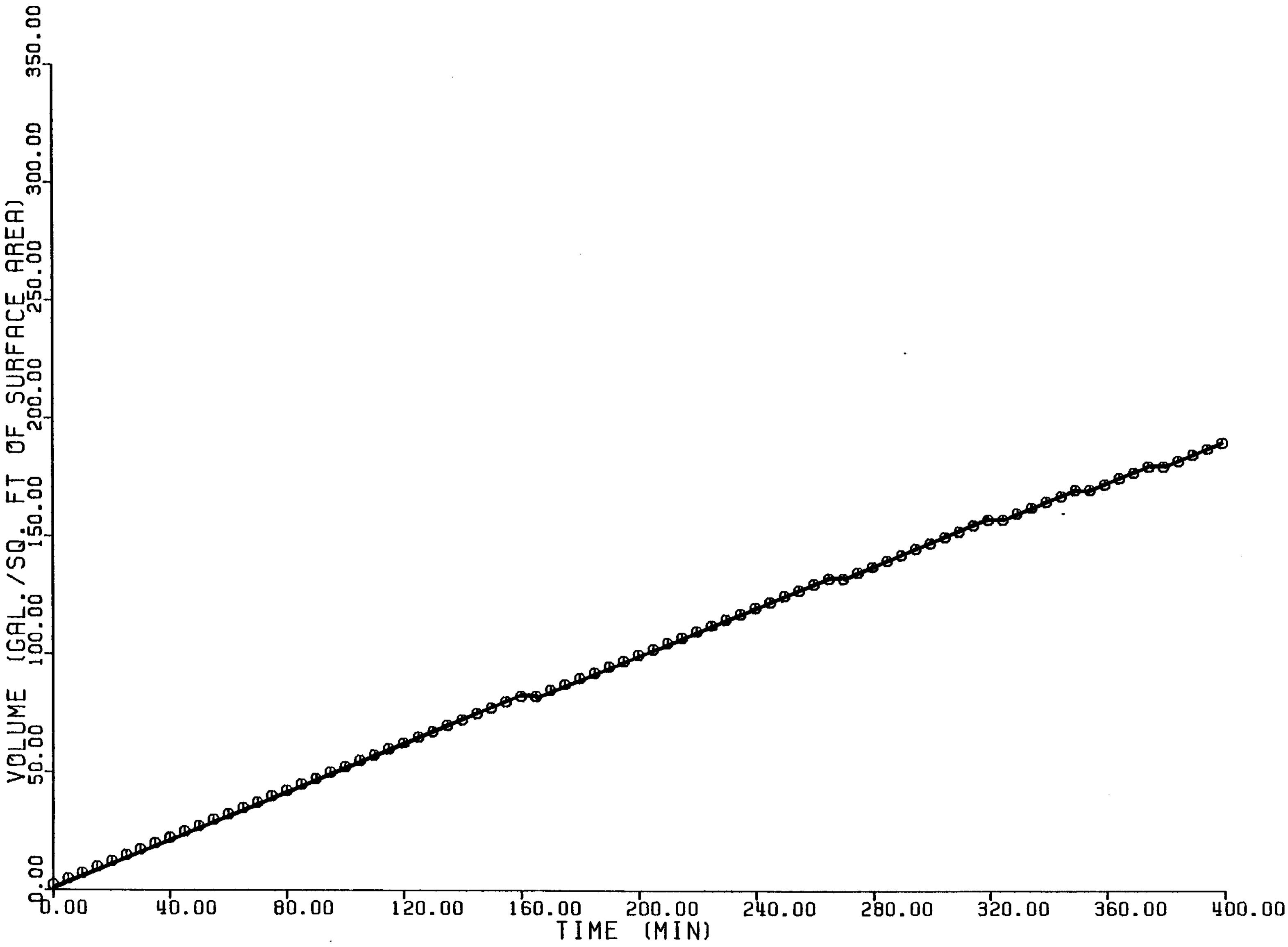


Figure A16 Turbidity versus Time for Test 6.

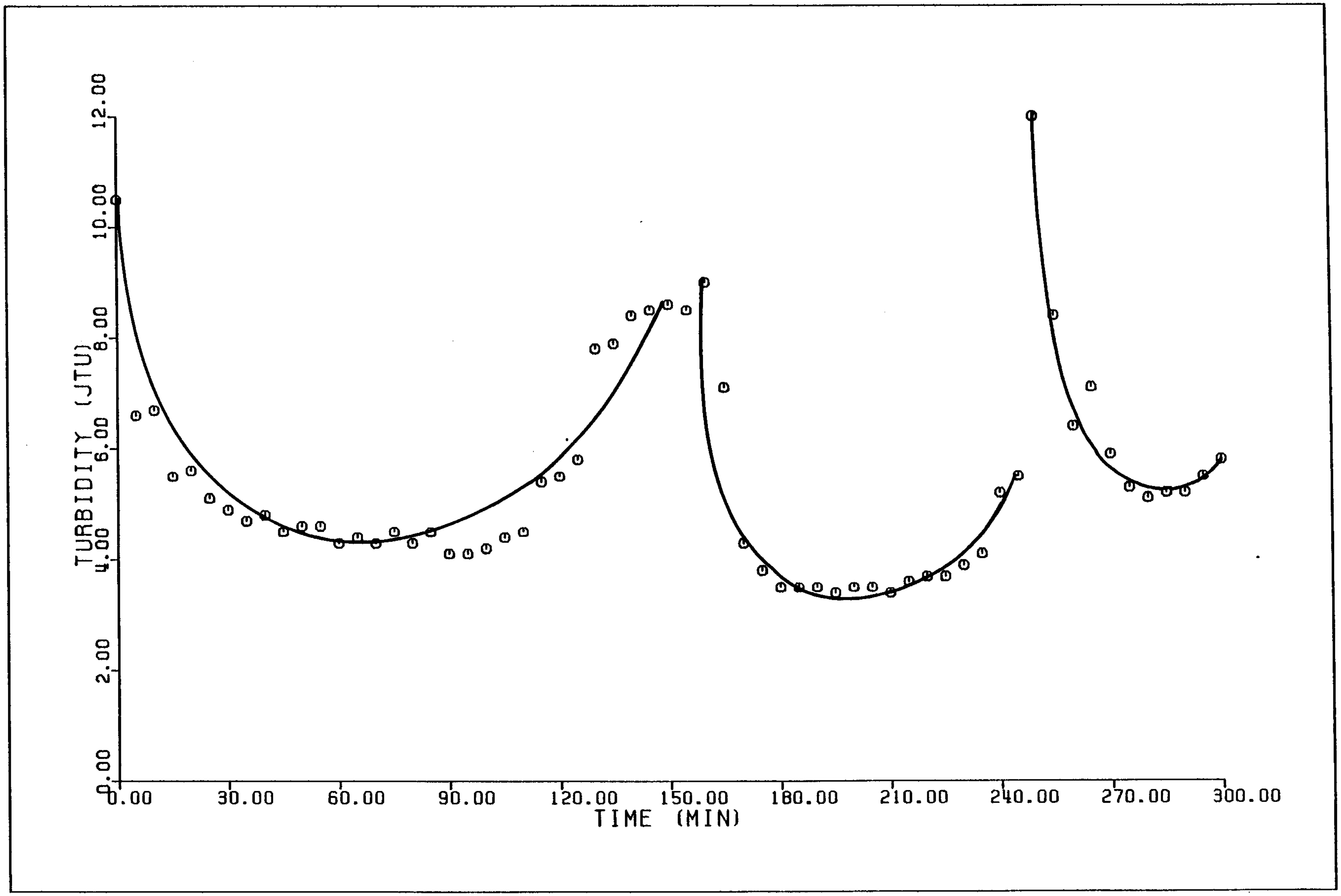


Figure A17 Pressure versus Time for Test 6.

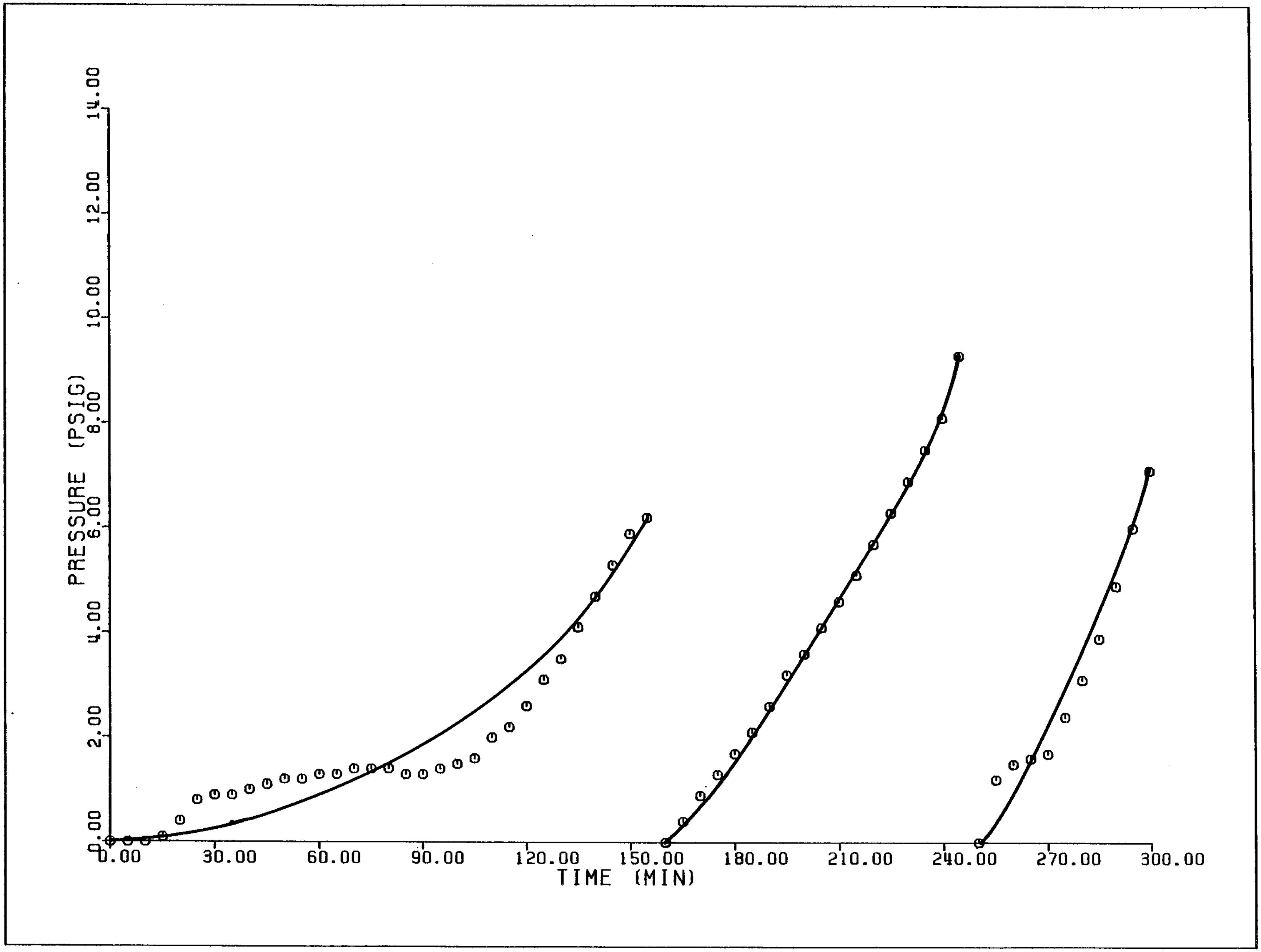


Figure A18 Filtered Volume versus Time for Test 6.

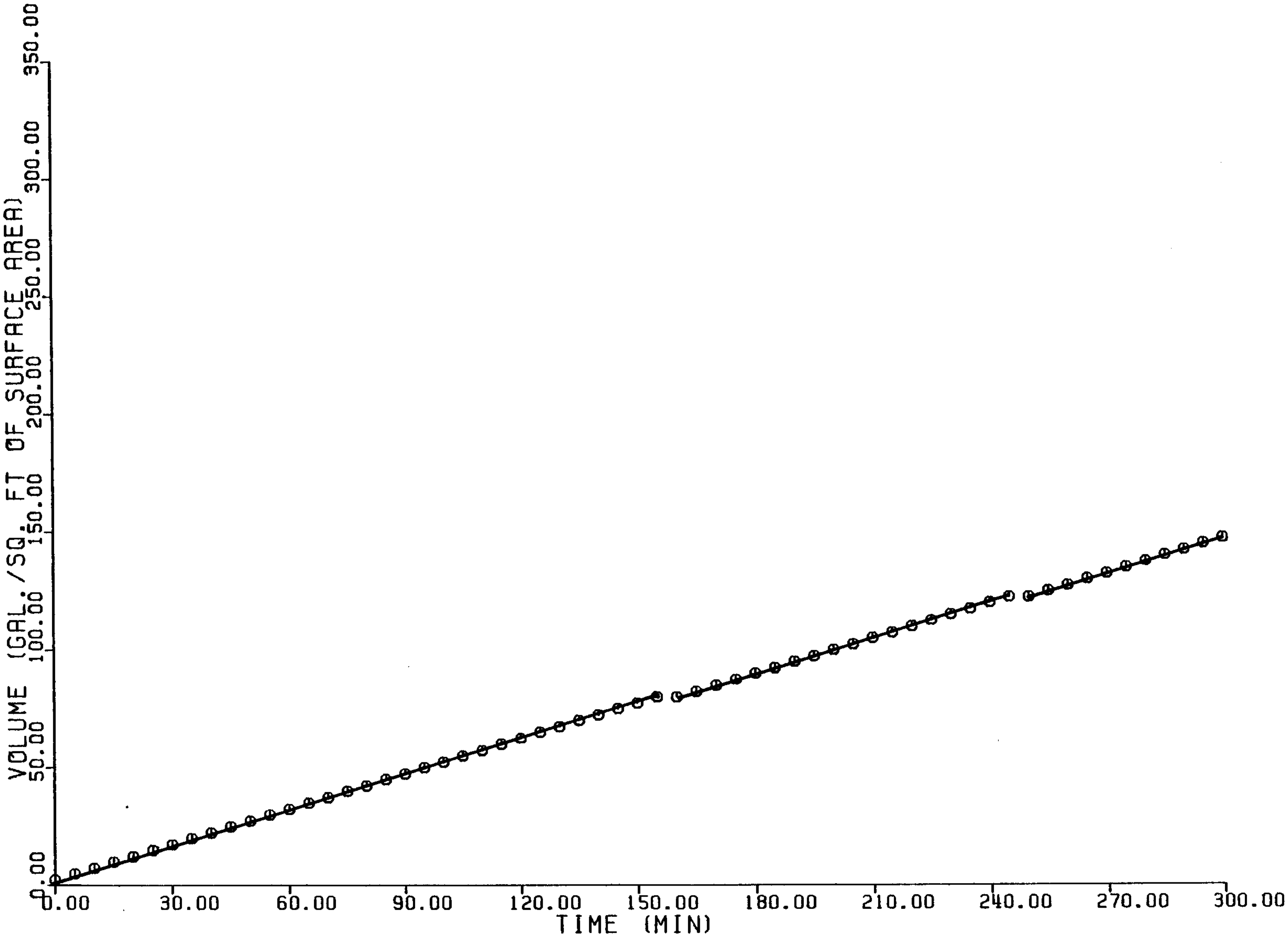


Figure A19 Turbidity versus Time for Test 7.

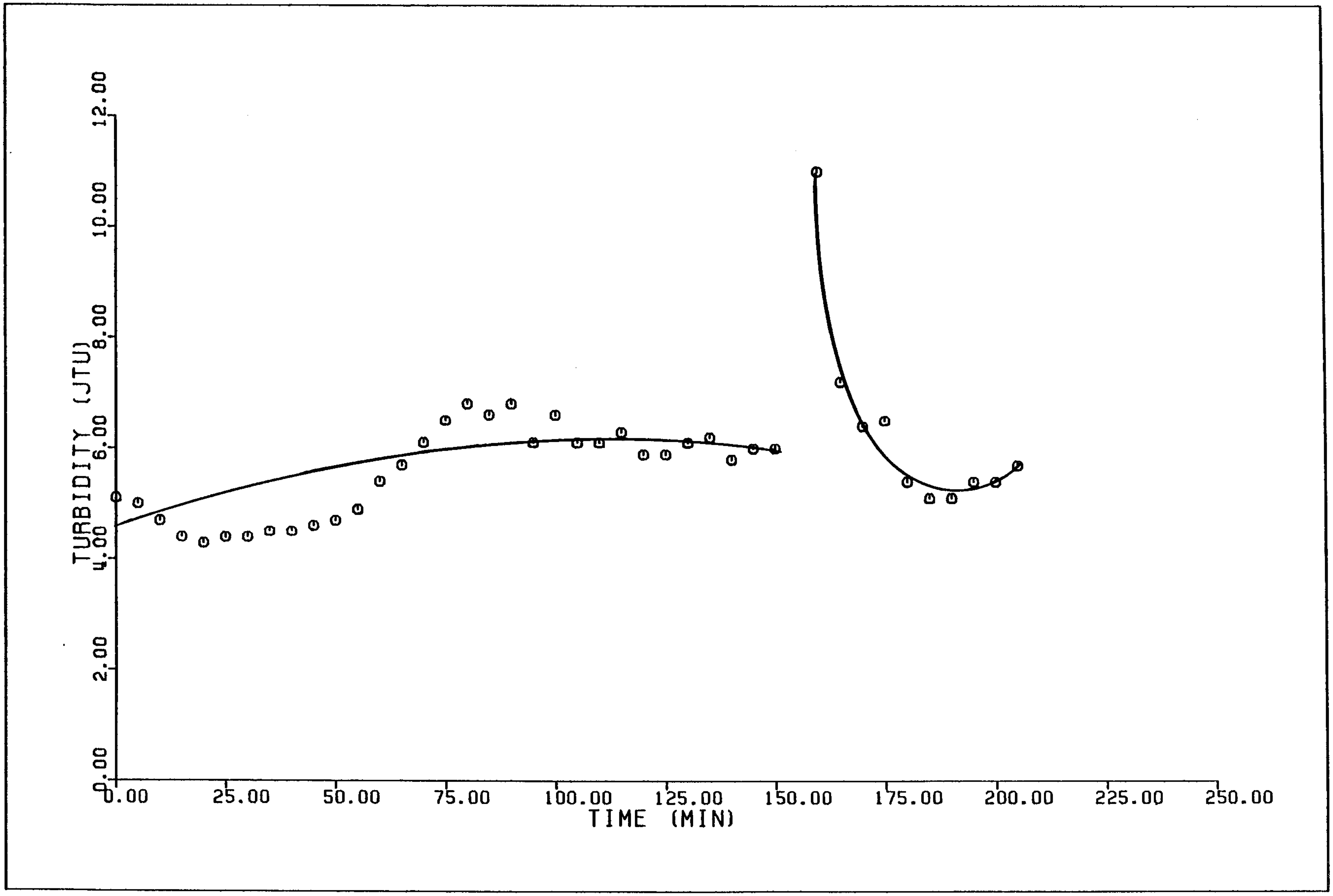


Figure A20 Pressure versus Time for Test 7.

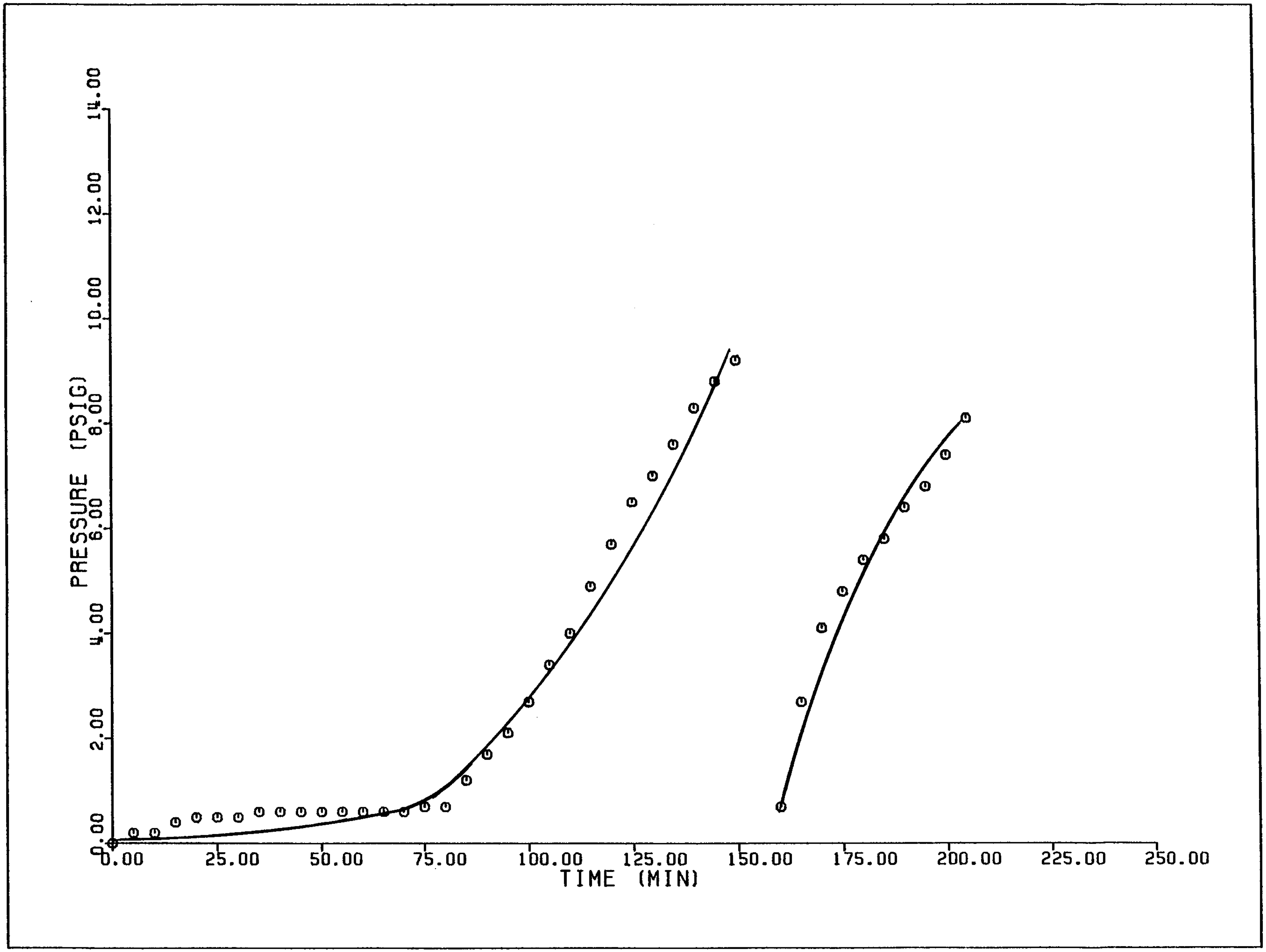


Figure A21 Filtered Volume versus Time for Test 7.

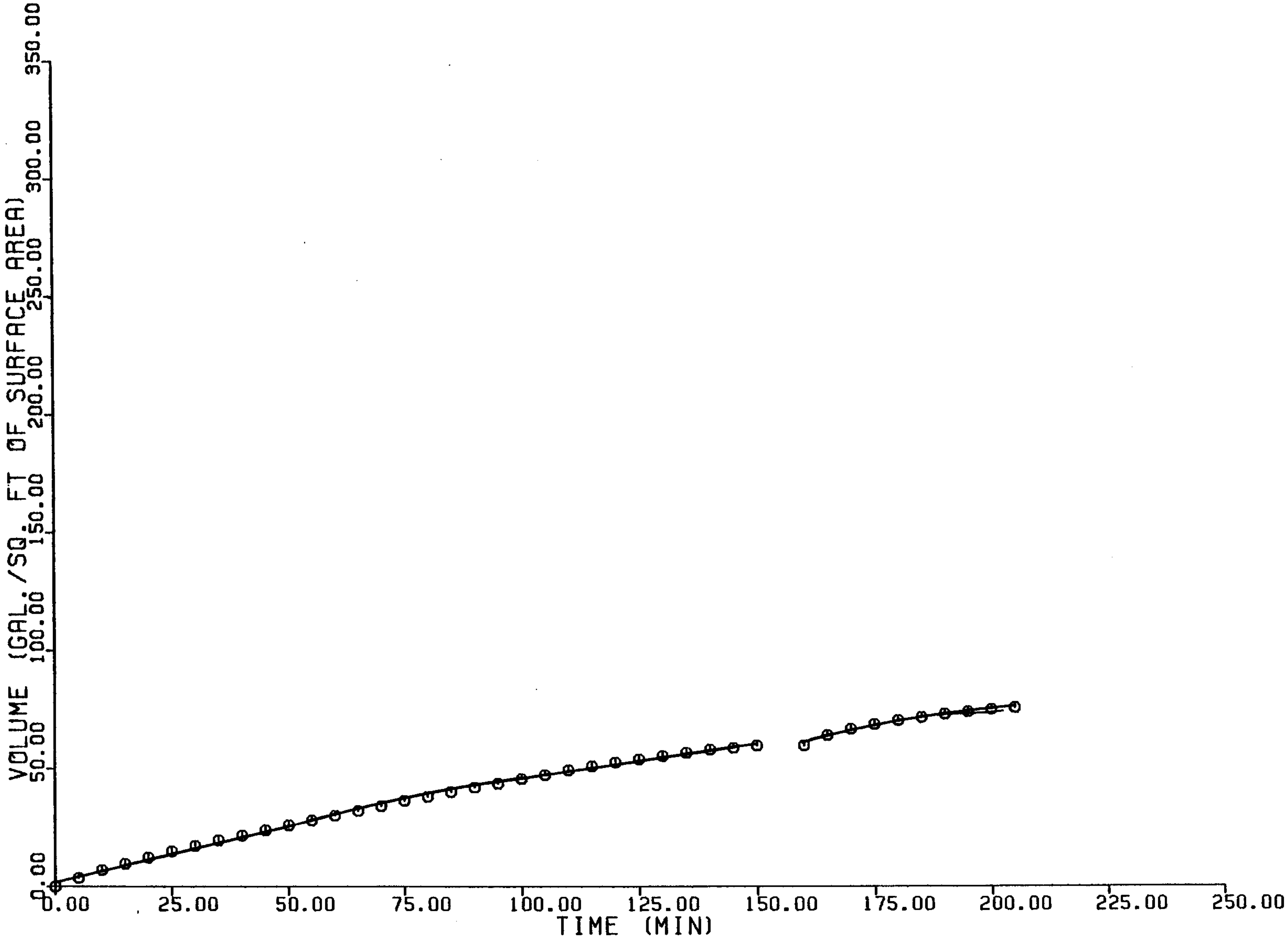


Figure A22 Turbidity versus Time for Test 8.

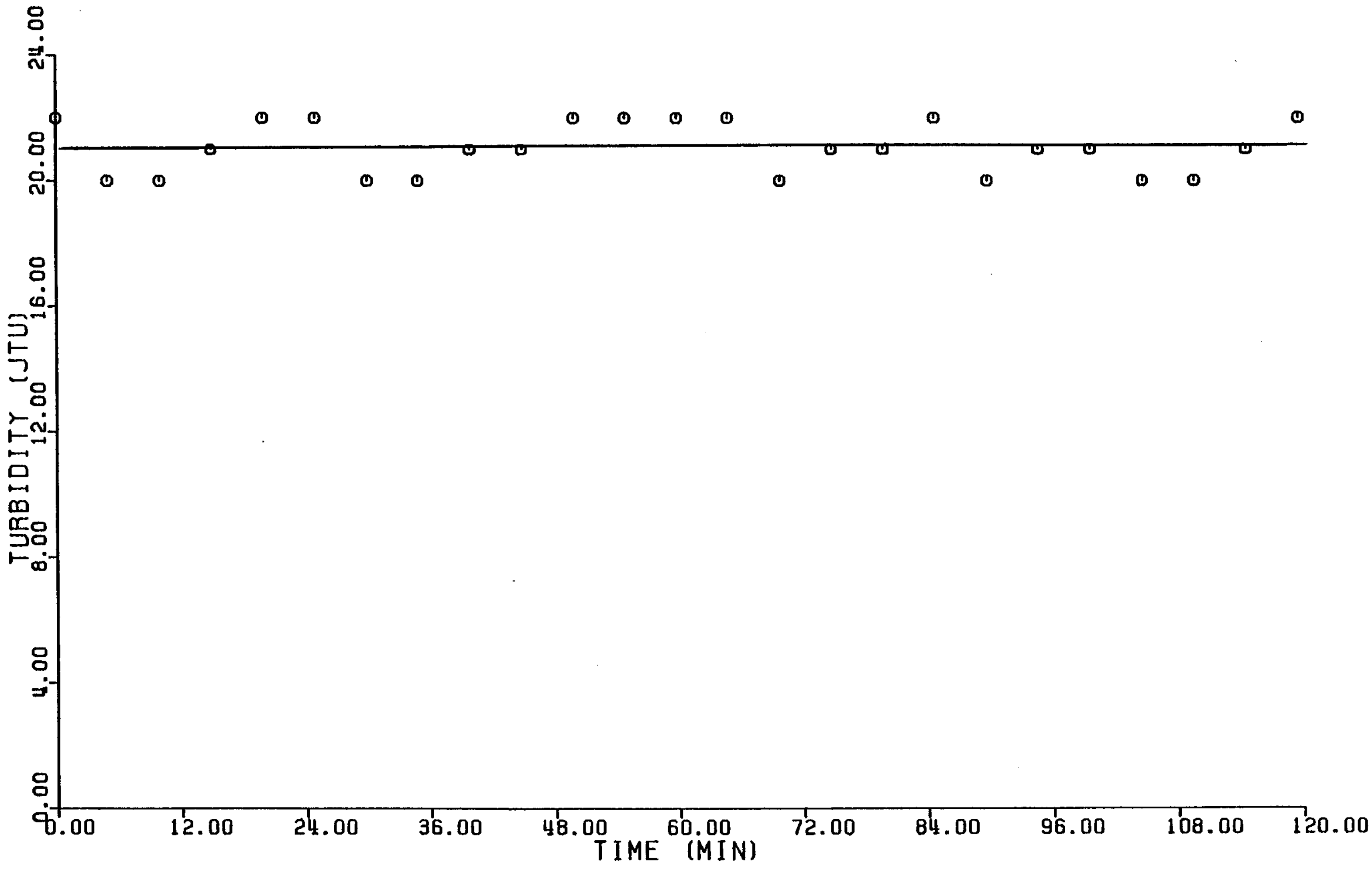


Figure A23 Pressure versus Time for Test 8.

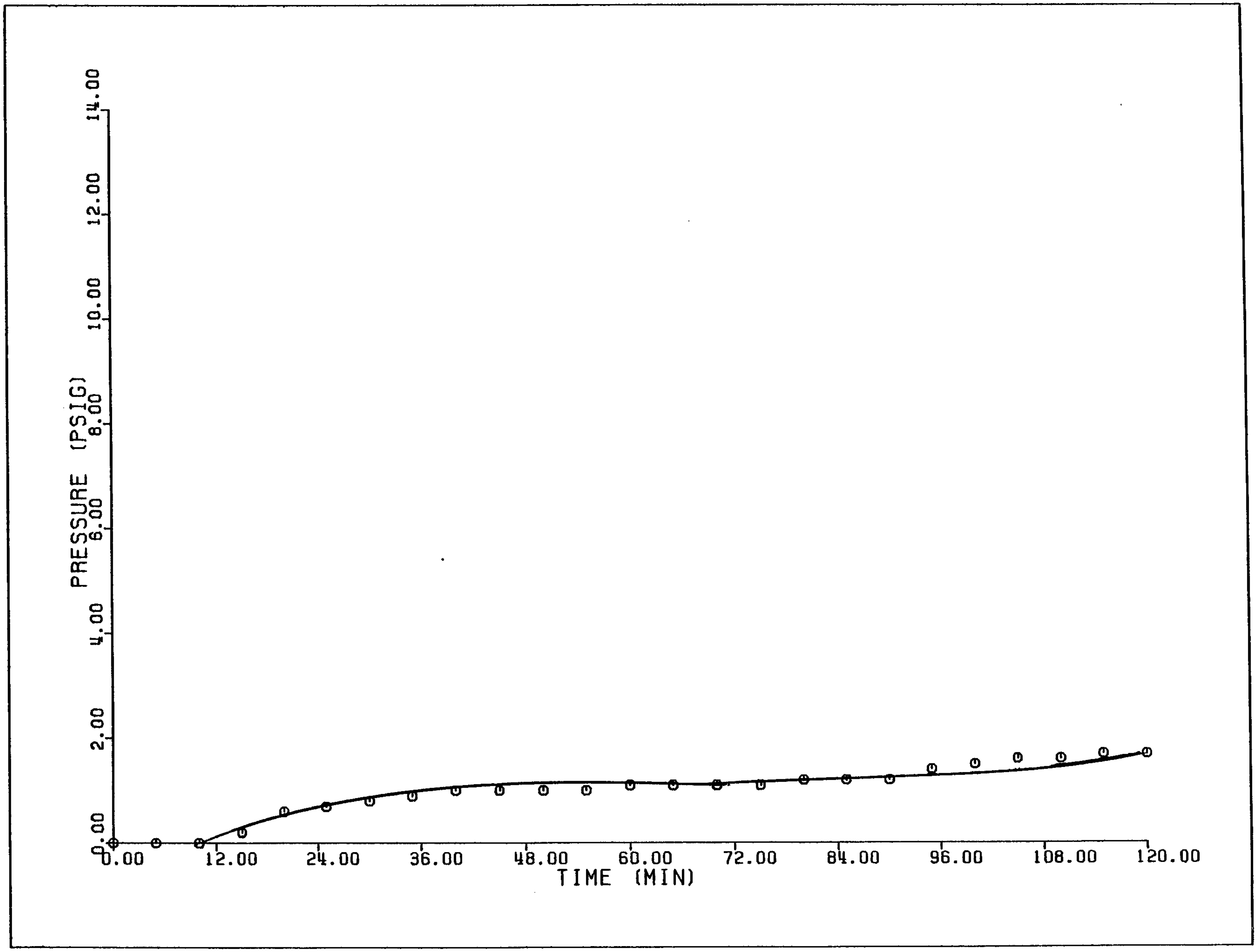


Figure A24 Filtered Volume versus Time for Test 8.

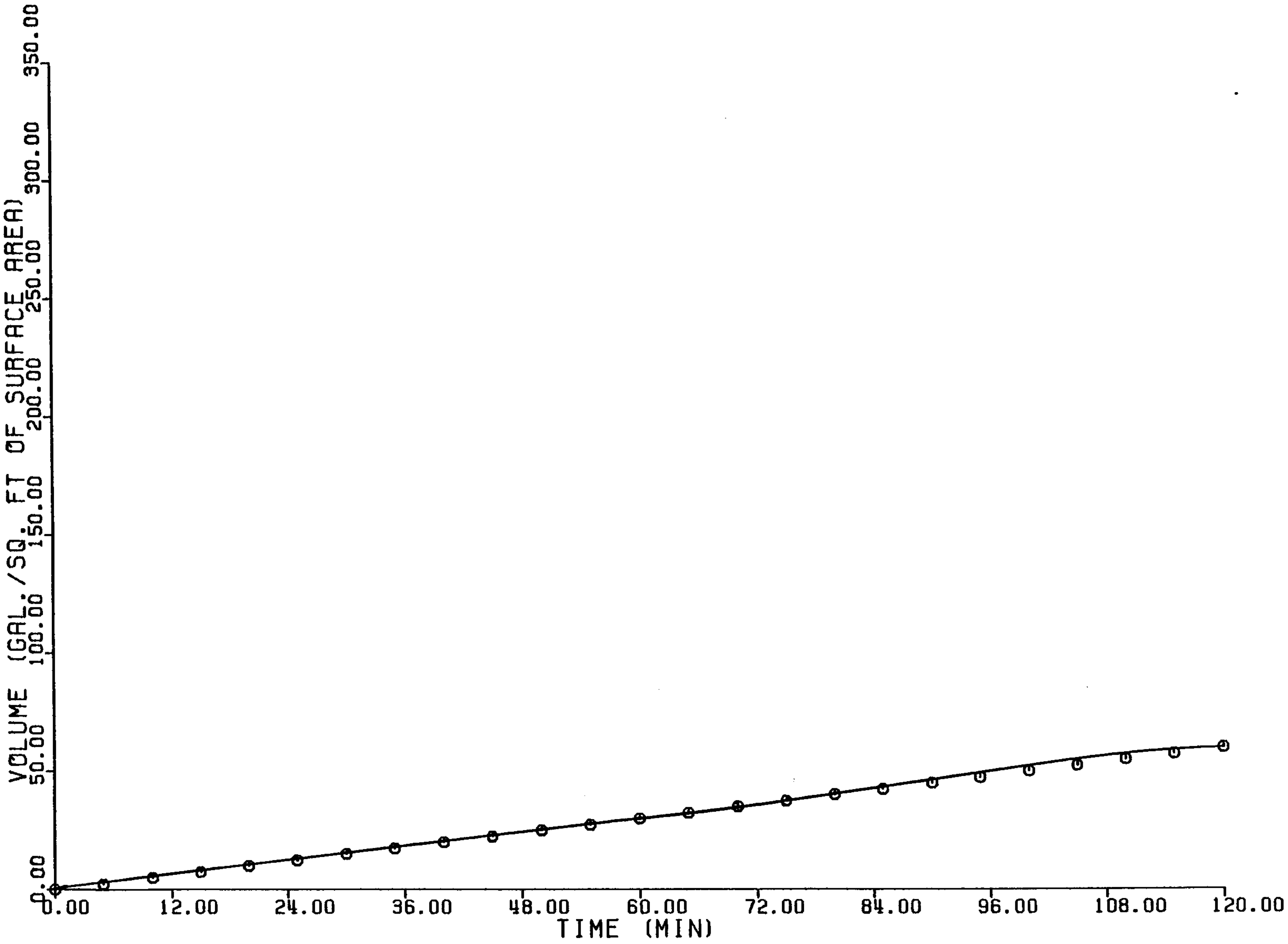


Figure A25 Turbidity versus Time for Test 9.

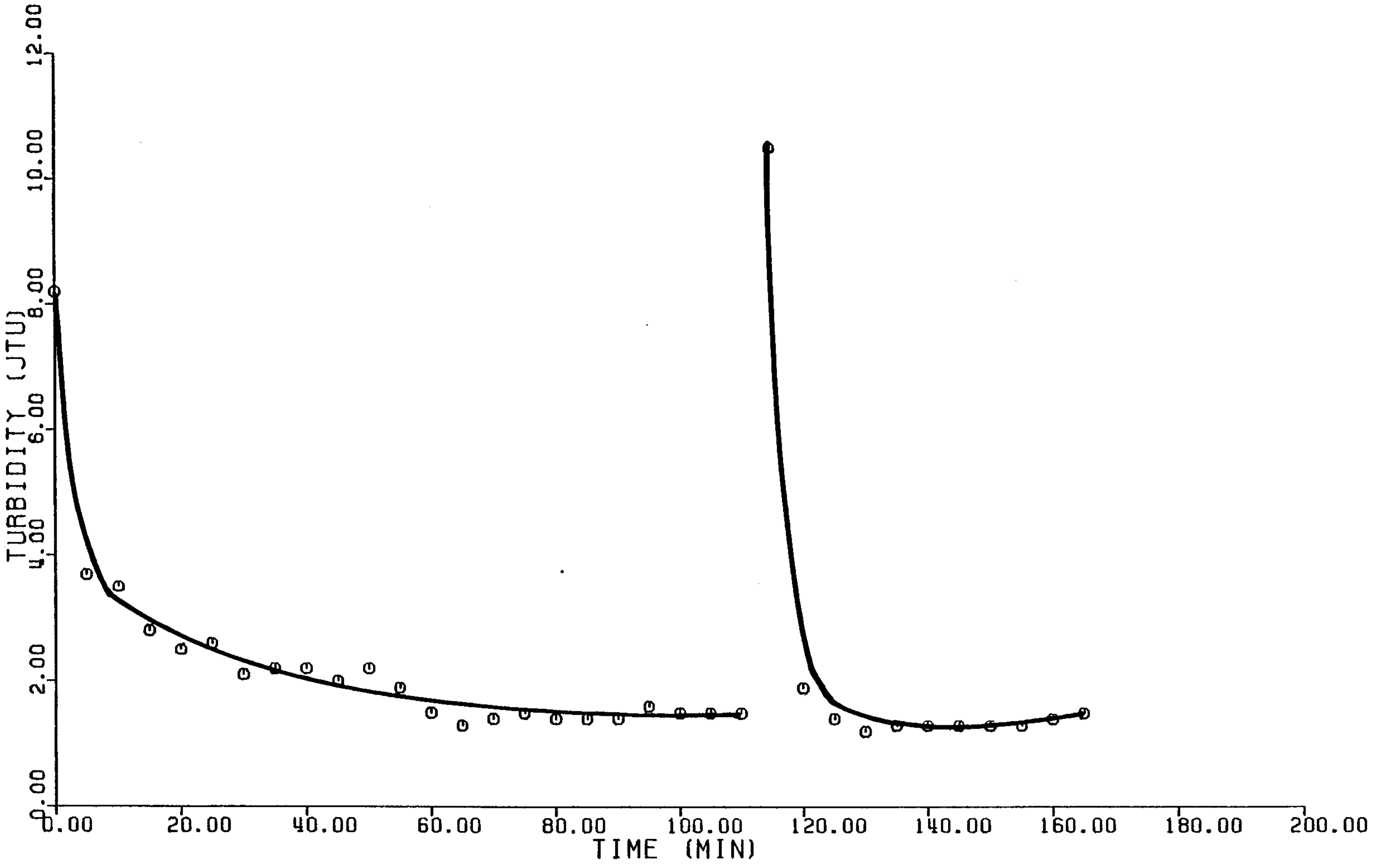


Figure A26 Pressure versus Time for Test 9.

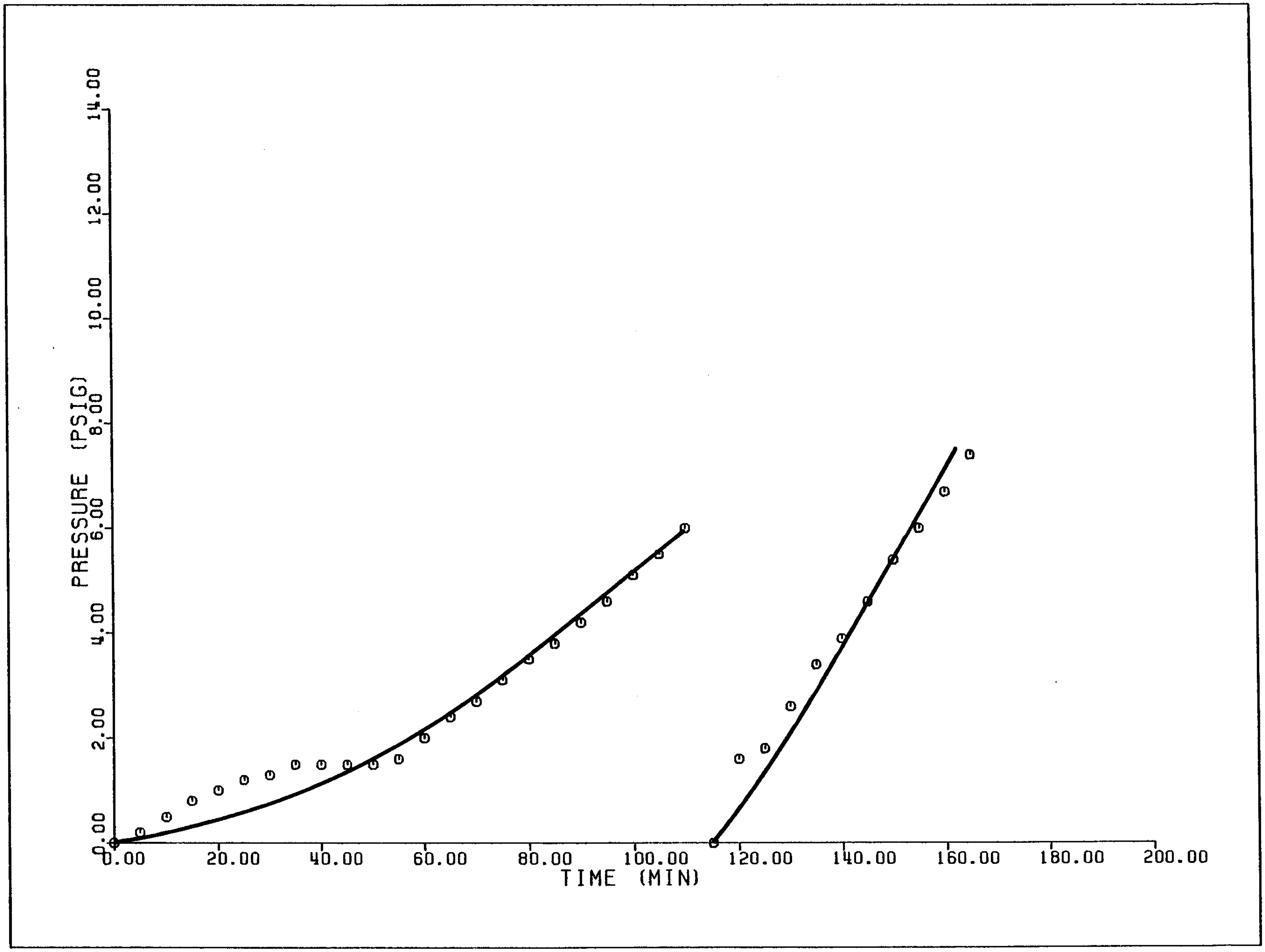


Figure A27 Filtered Volume versus Time for Test 9.

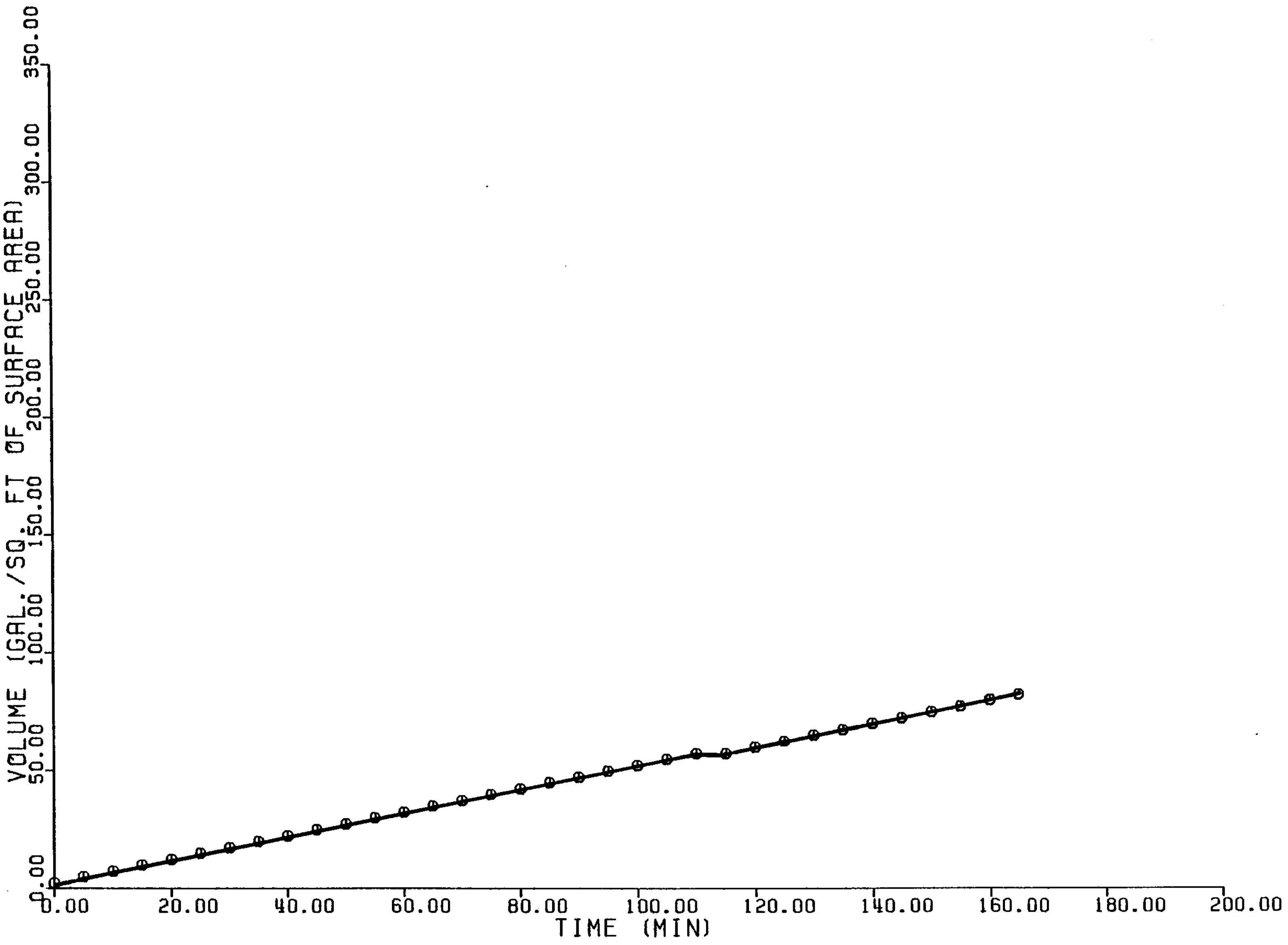


Figure A28 Turbidity versus Time for Test 10.

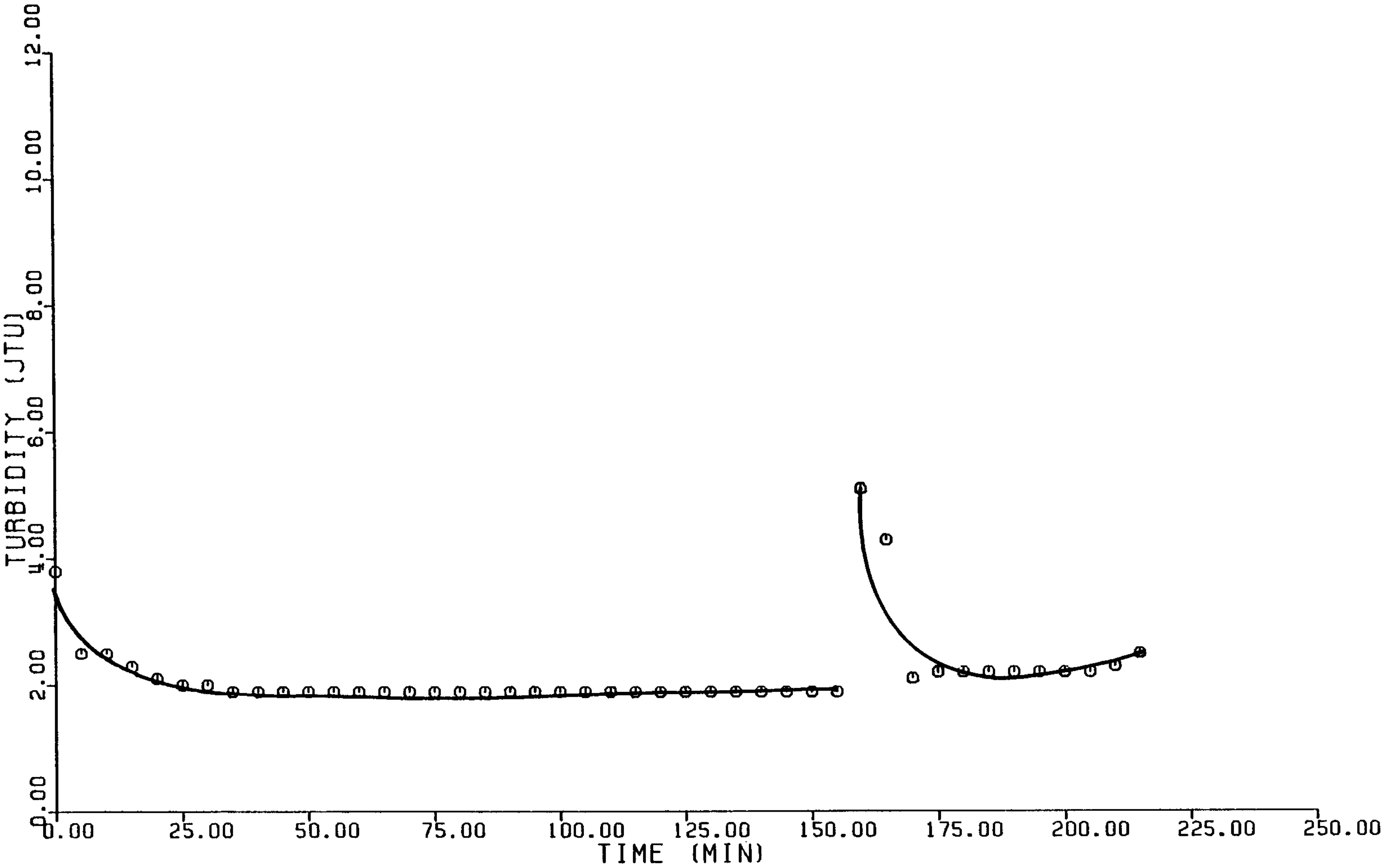


Figure A29 Pressure versus Time for Test 10.

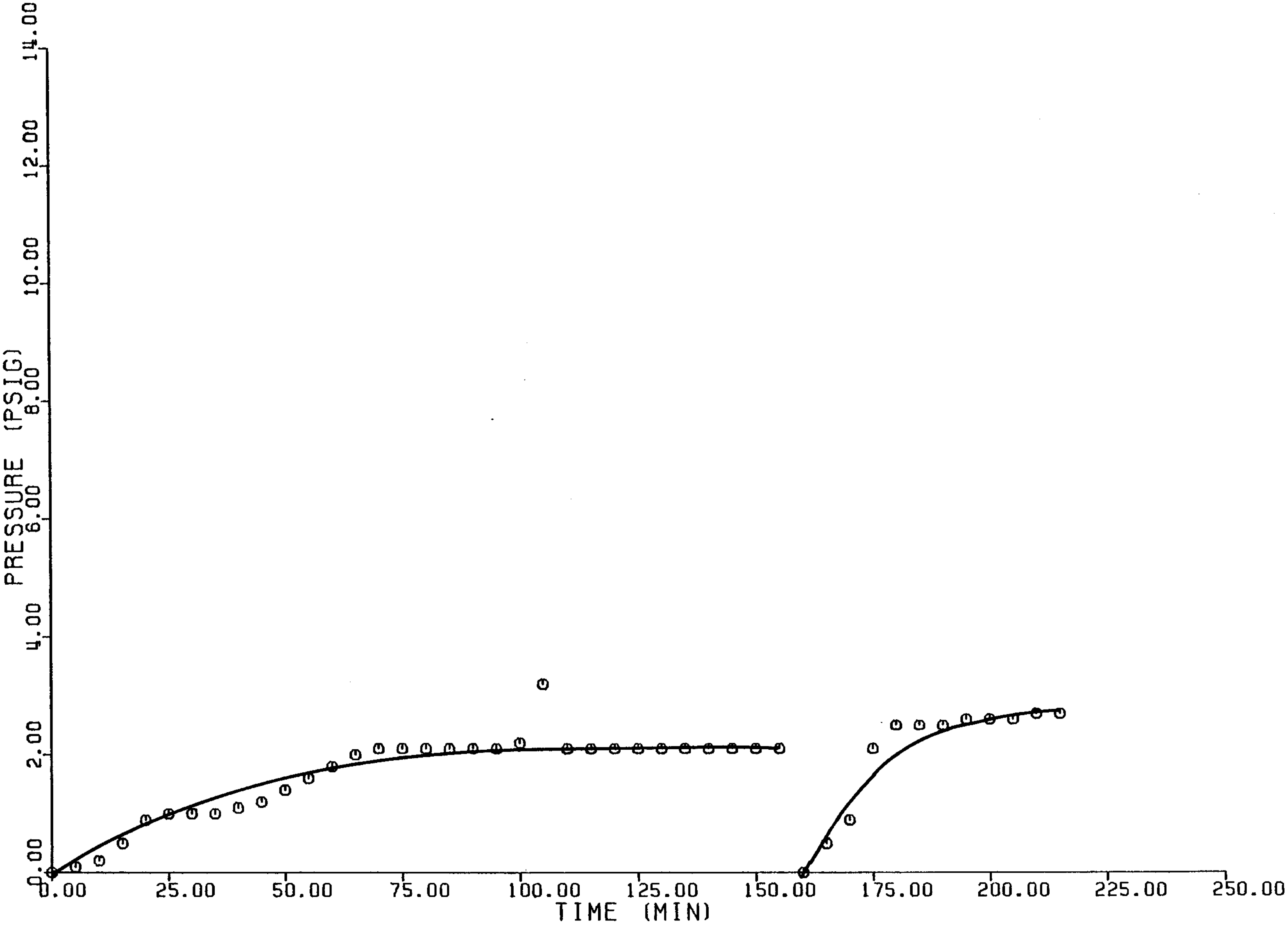


Figure A30 Filtered Volume versus Time for Test 10.

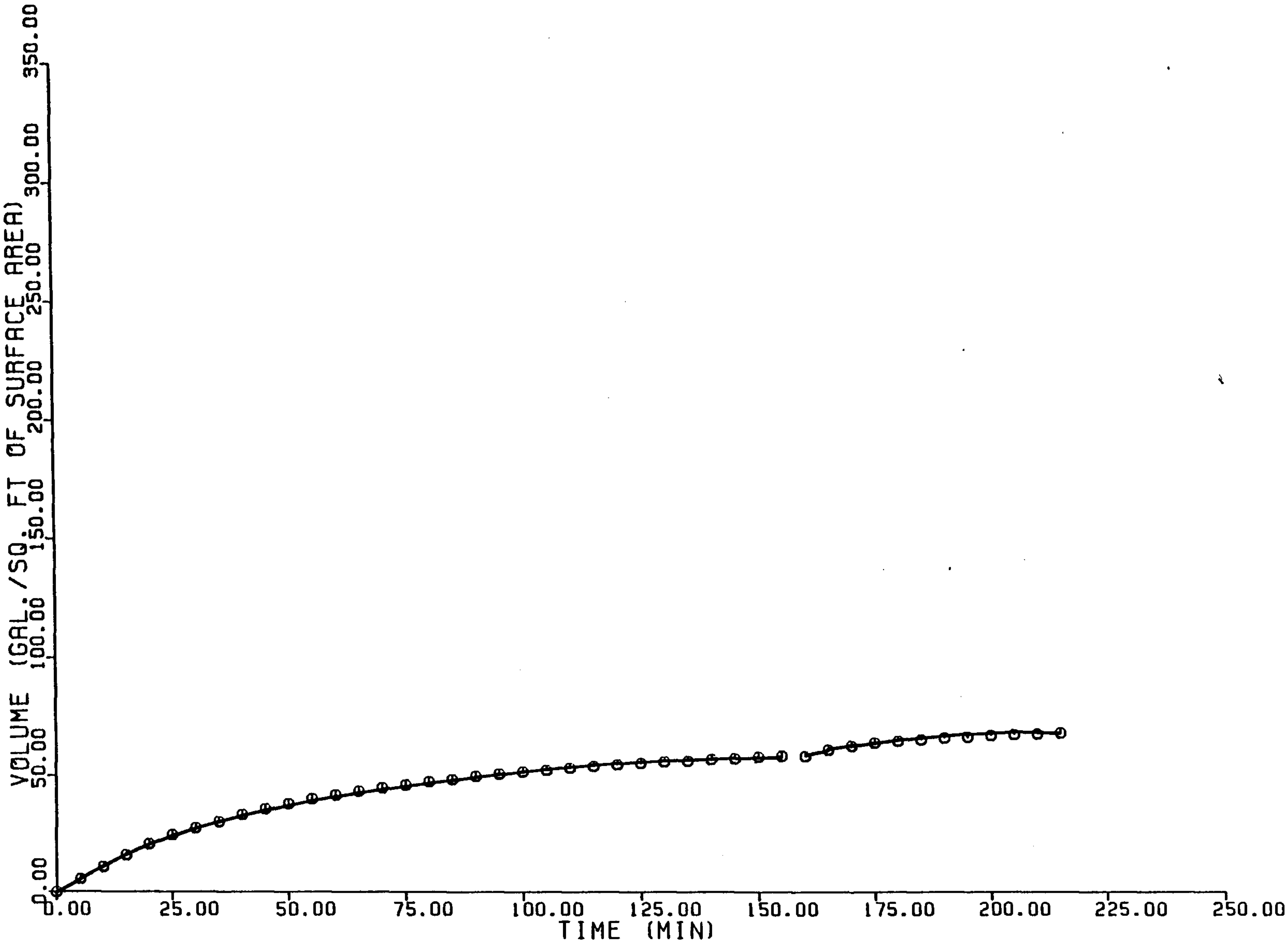


Figure A31 Turbidity versus Time for Test 11.

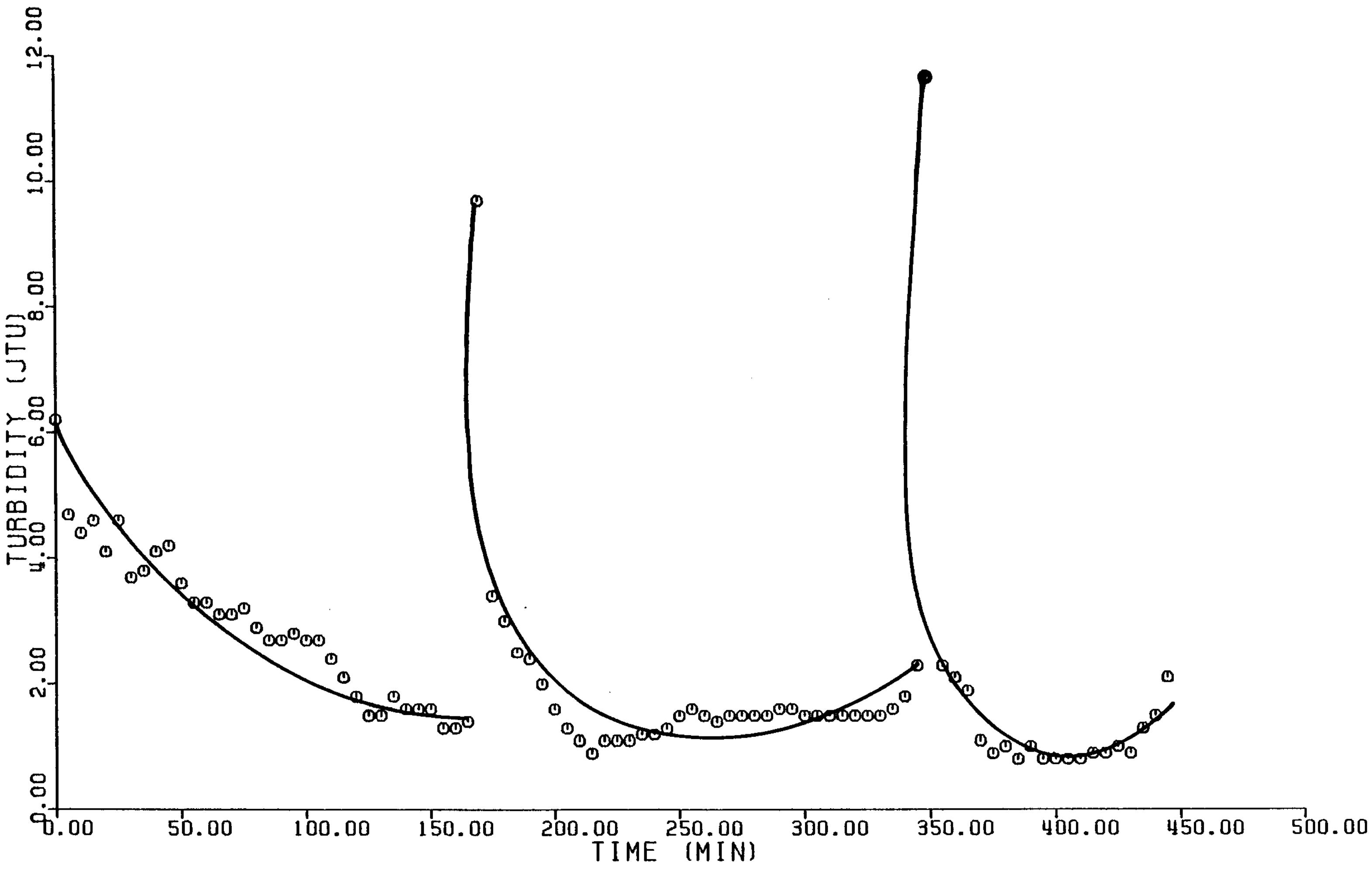


Figure A32 Pressure versus Time for Test 11.

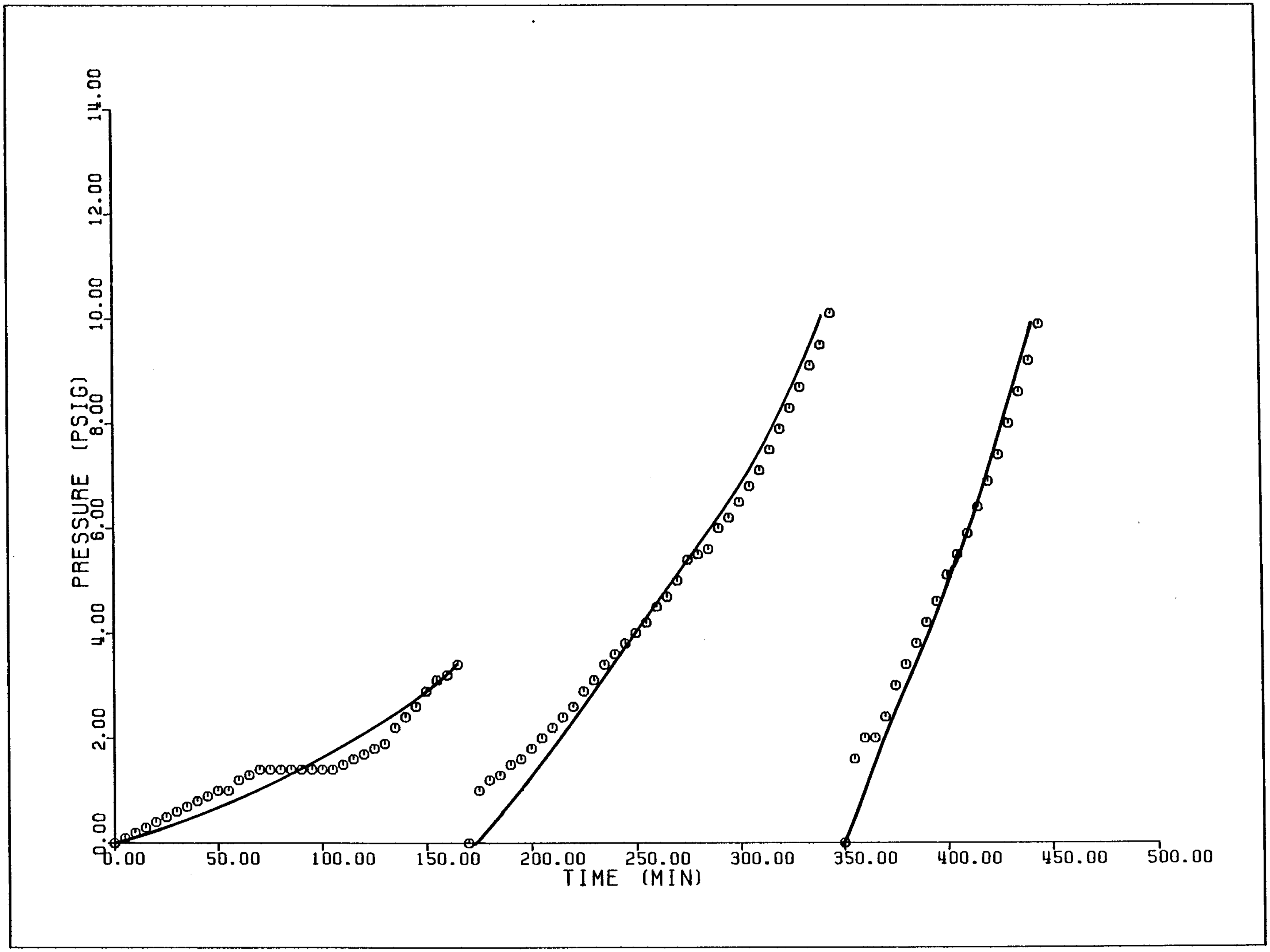


Figure A33 Filtered Volume versus Time for Test 11.

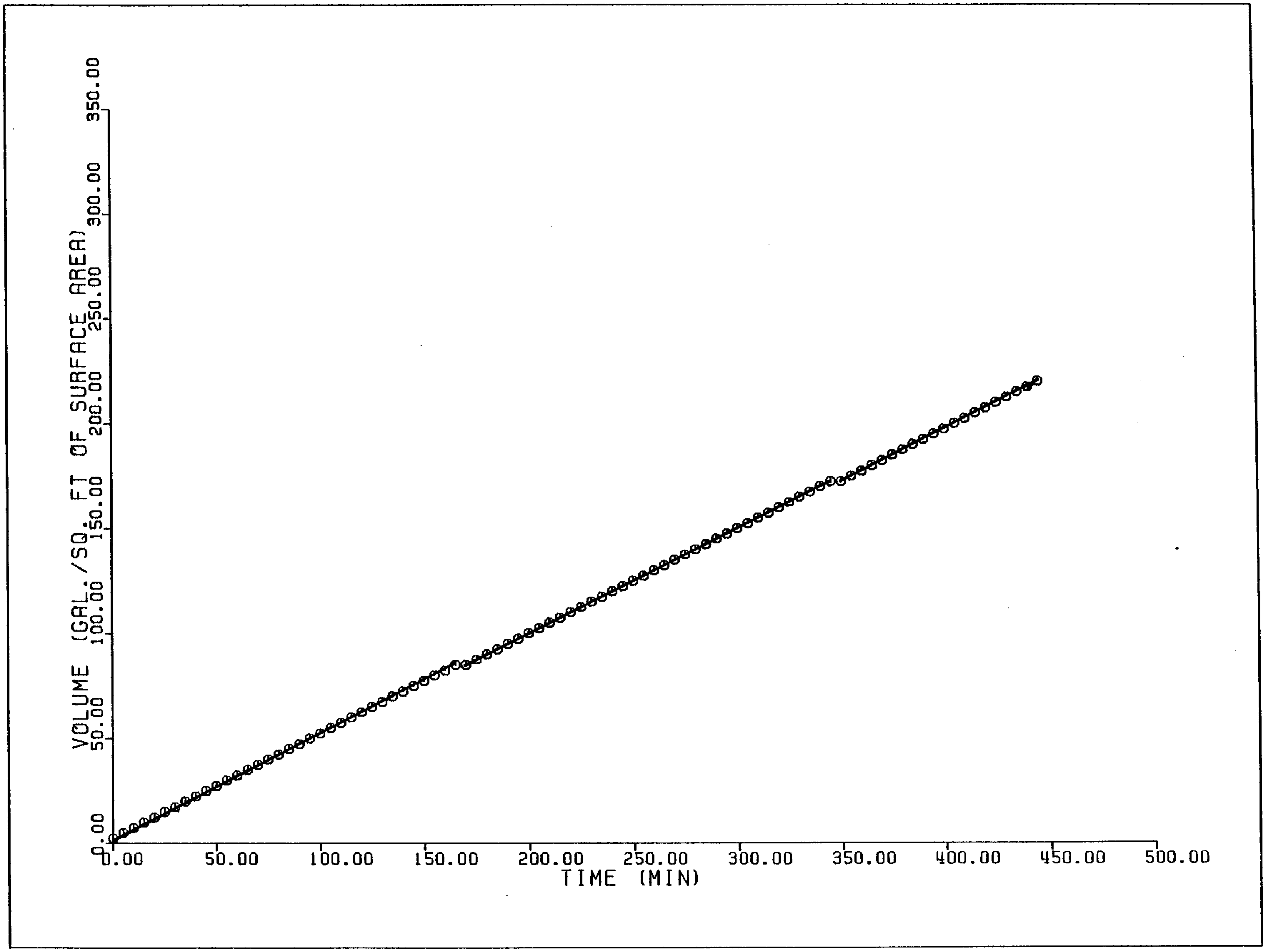


Figure A34 Turbidity versus Time for Test 12.

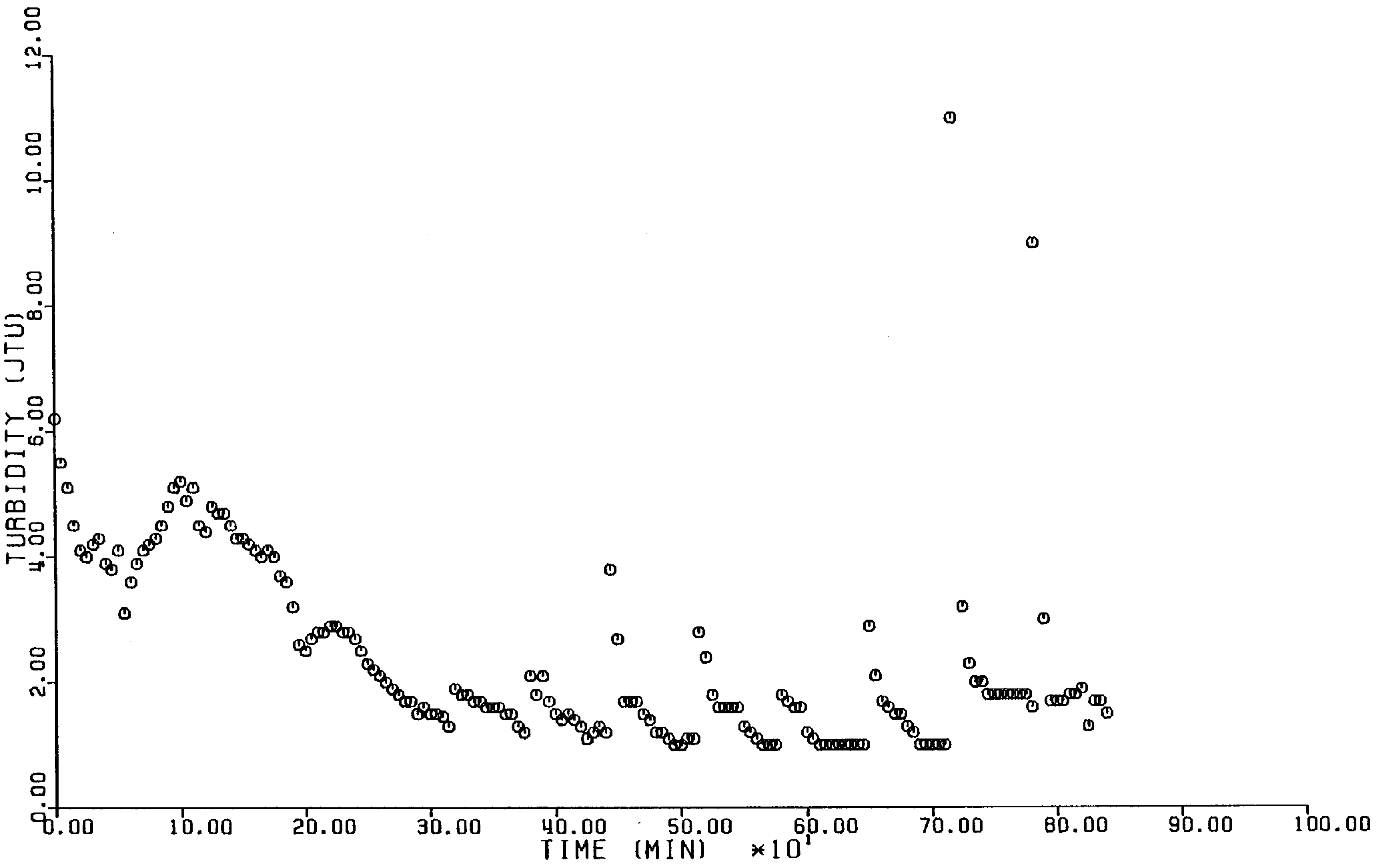


Figure A35 Pressure versus Time for Test 12.

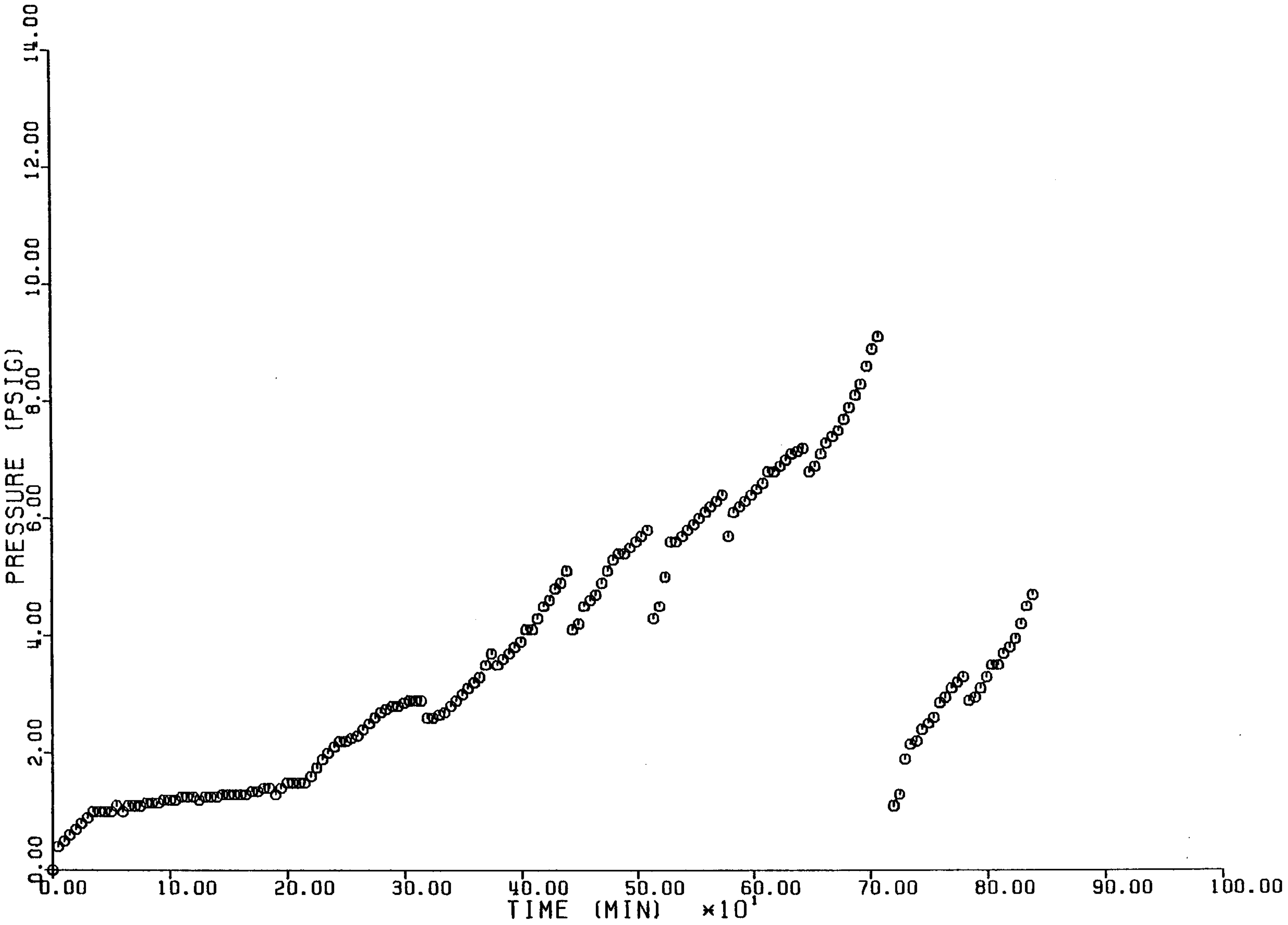


Figure A36 Filtered Volume versus Time for Test 12.

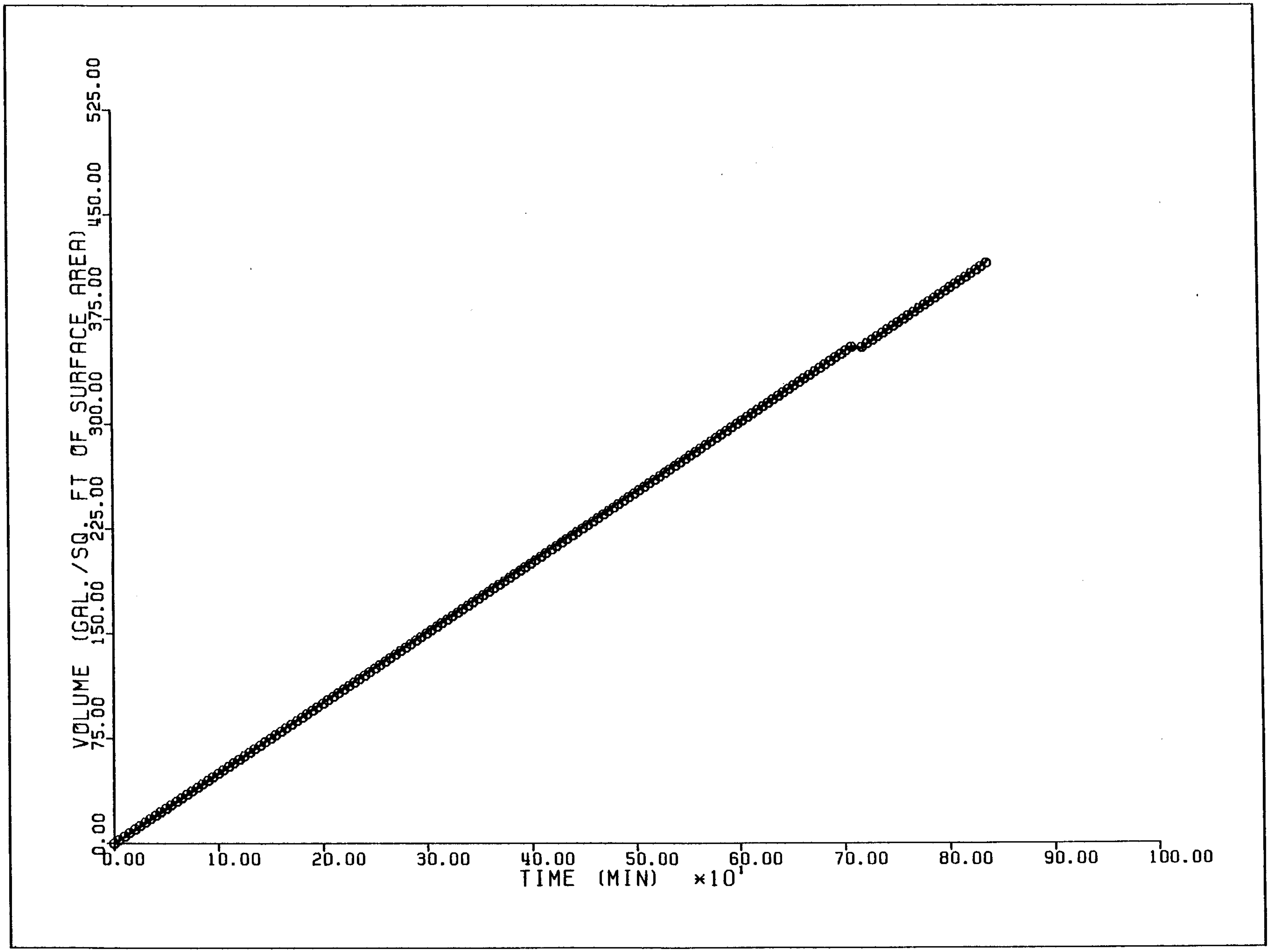


Figure A37 Turbidity versus Time for Test 13.

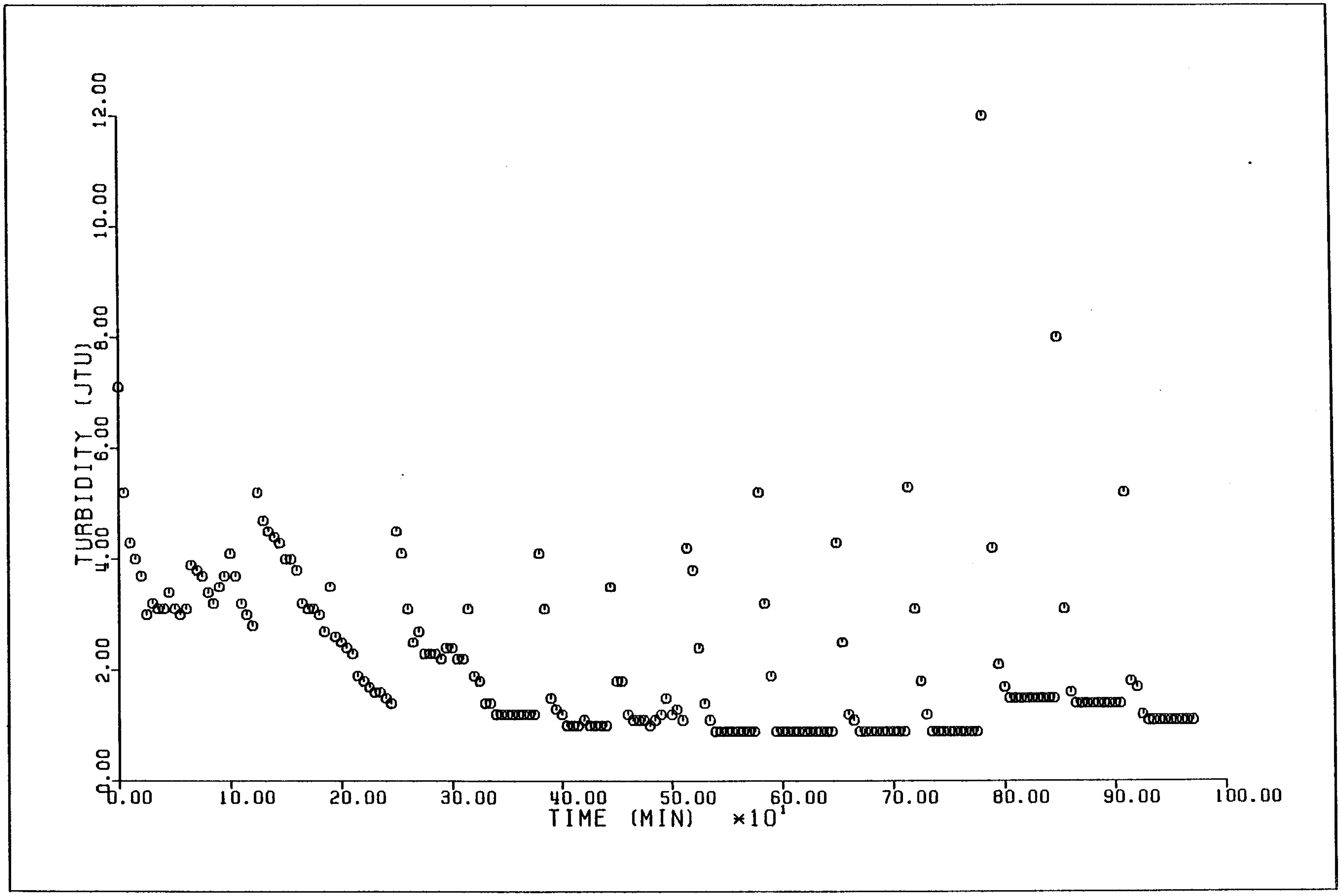


Figure A38 Pressure versus Time for Test 13.

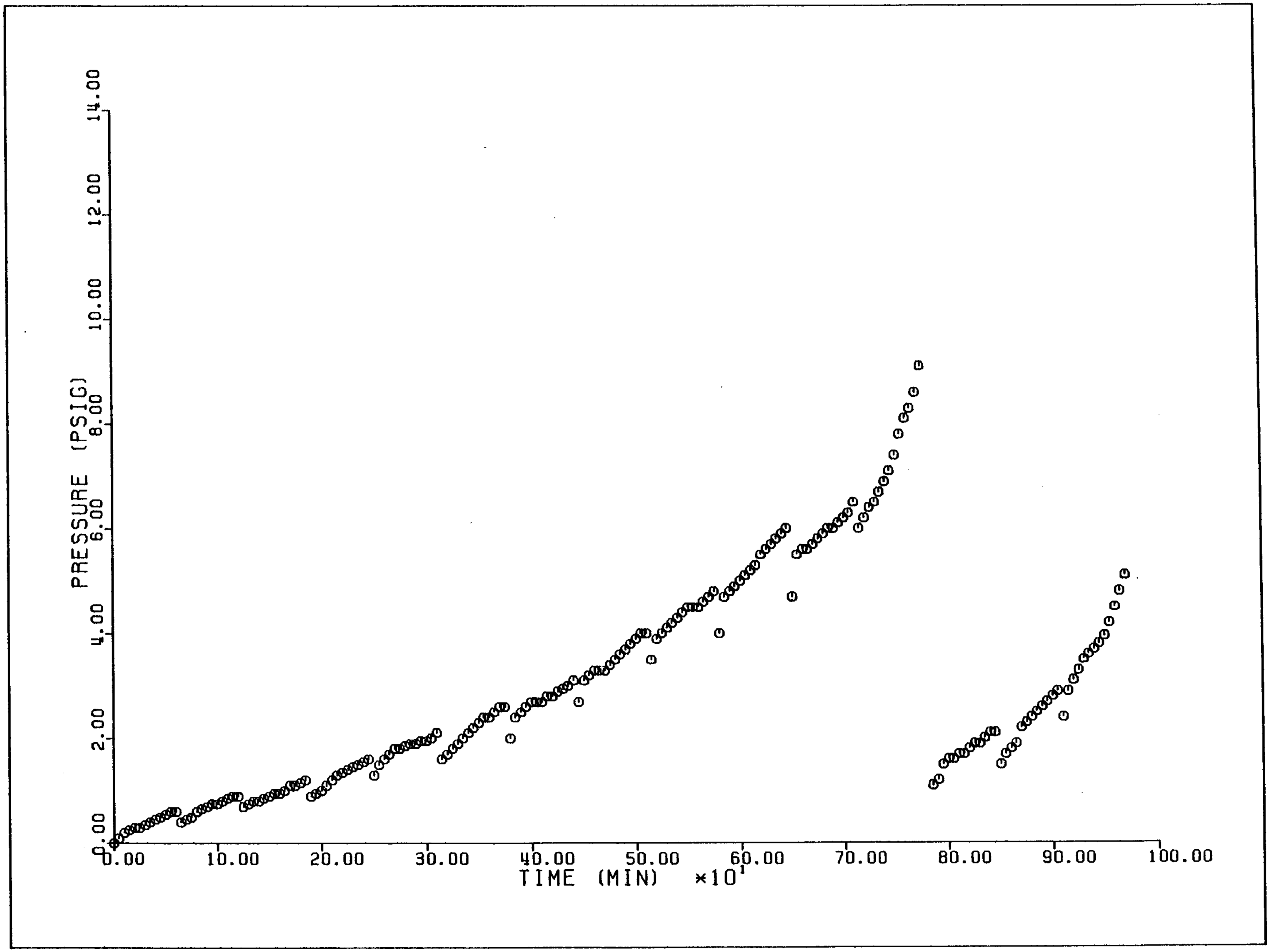


Figure A39 Filtered Volume versus Time for Test 13.

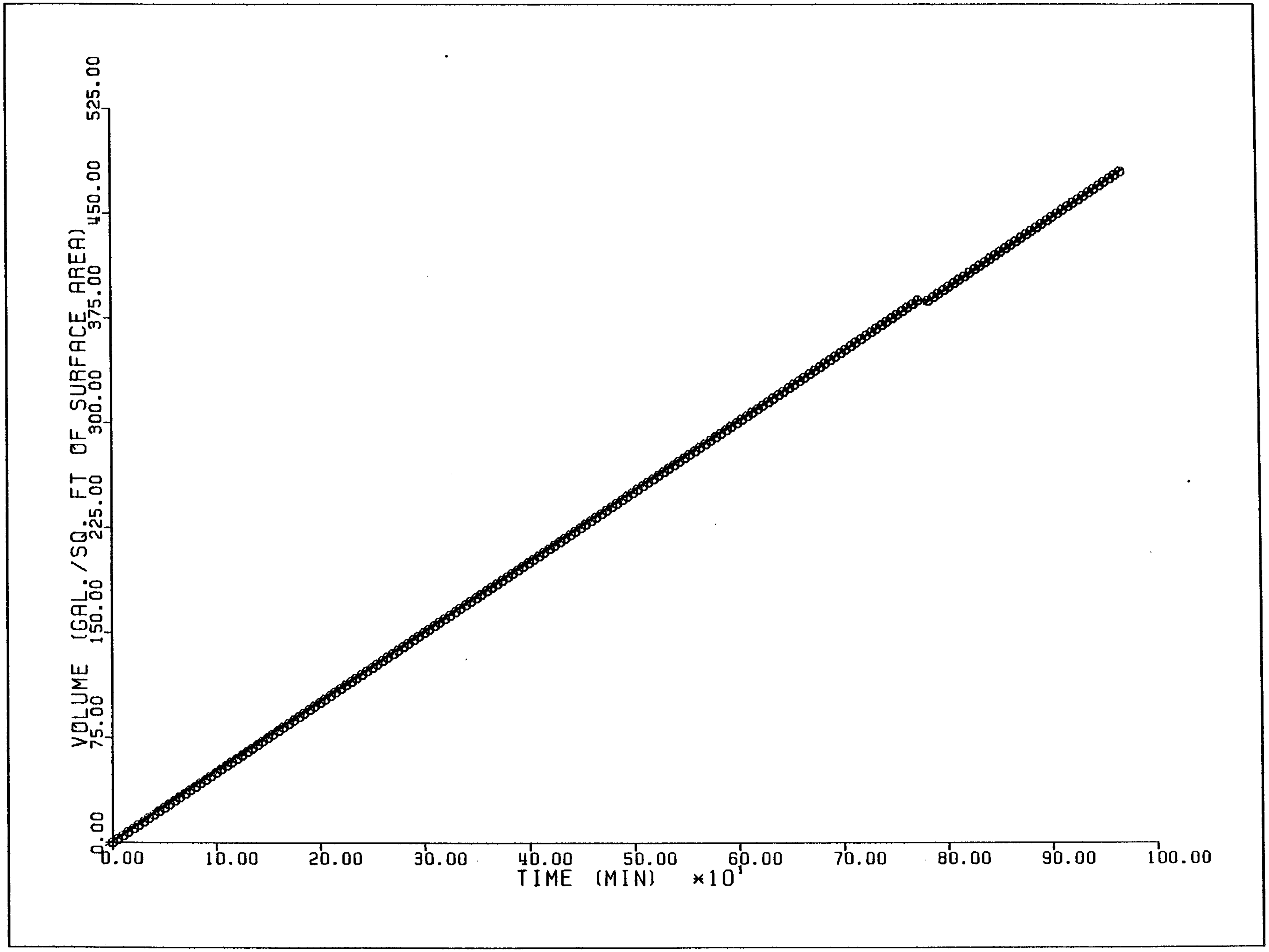


Figure A40 Flux Decline for Test 2 (first fouling test)

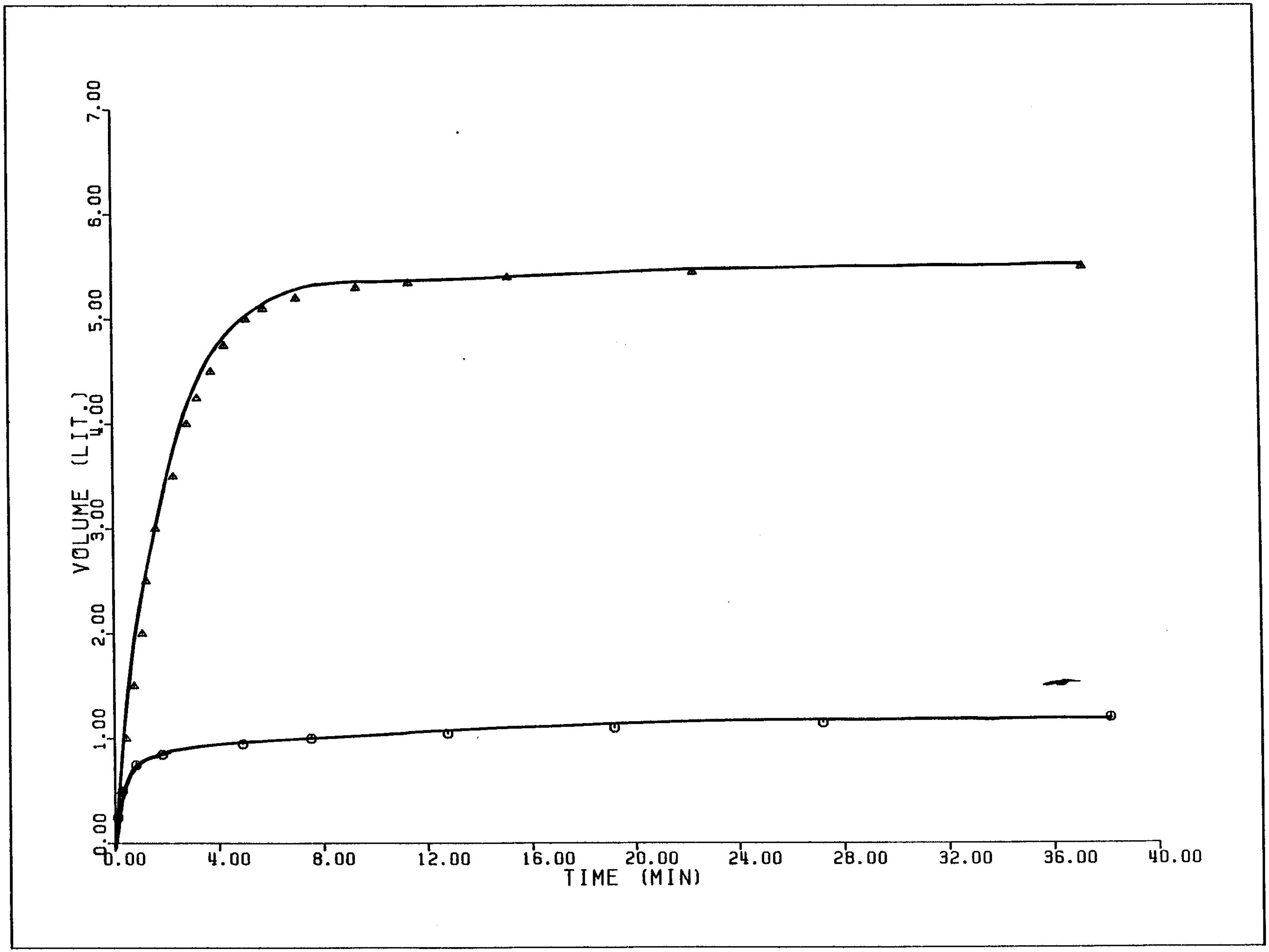


Figure A41 Flux Decline for Test 2 (second fouling test)

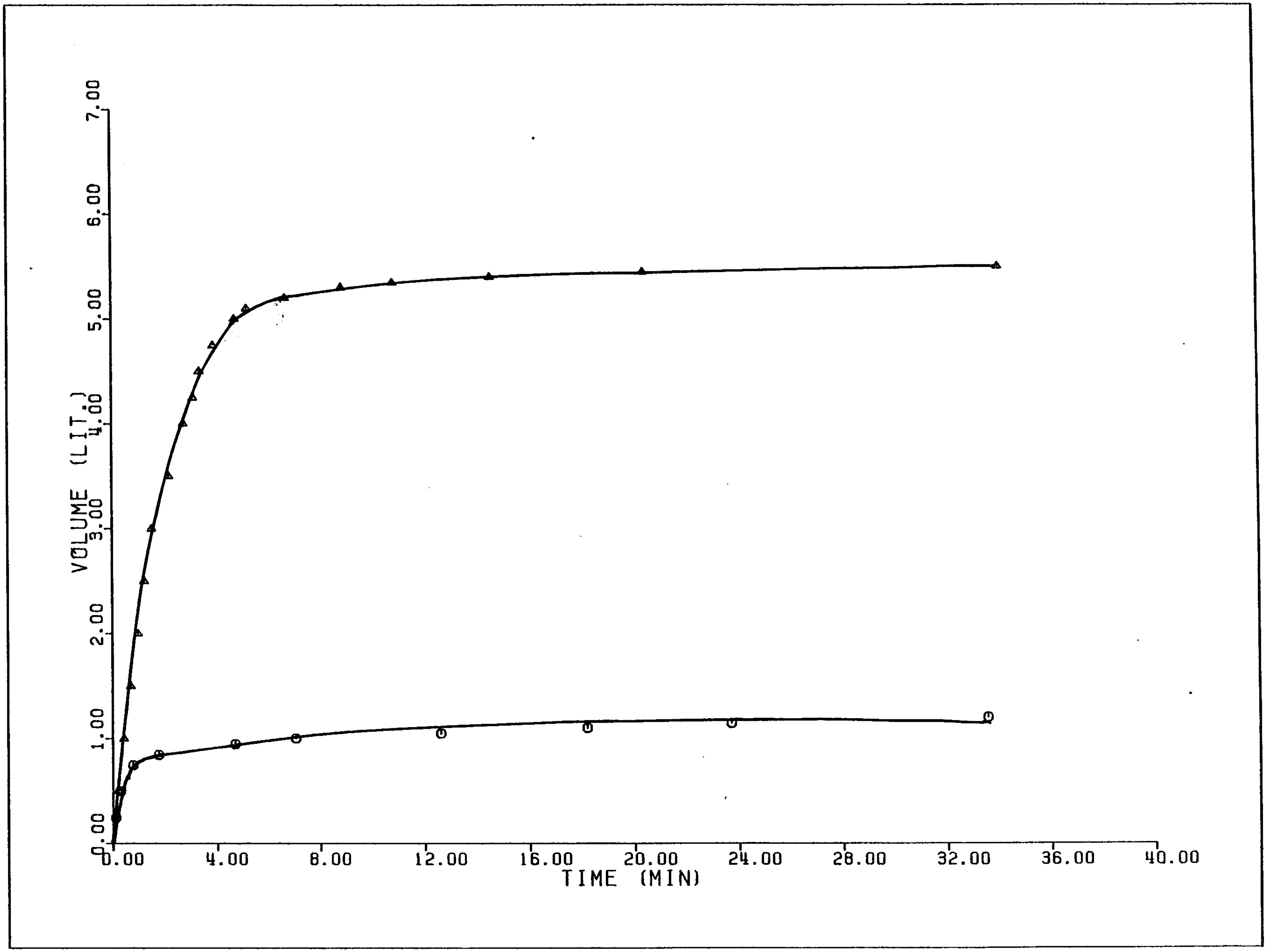


Figure A42 Flux Decline for Test 4 (first fouling test)

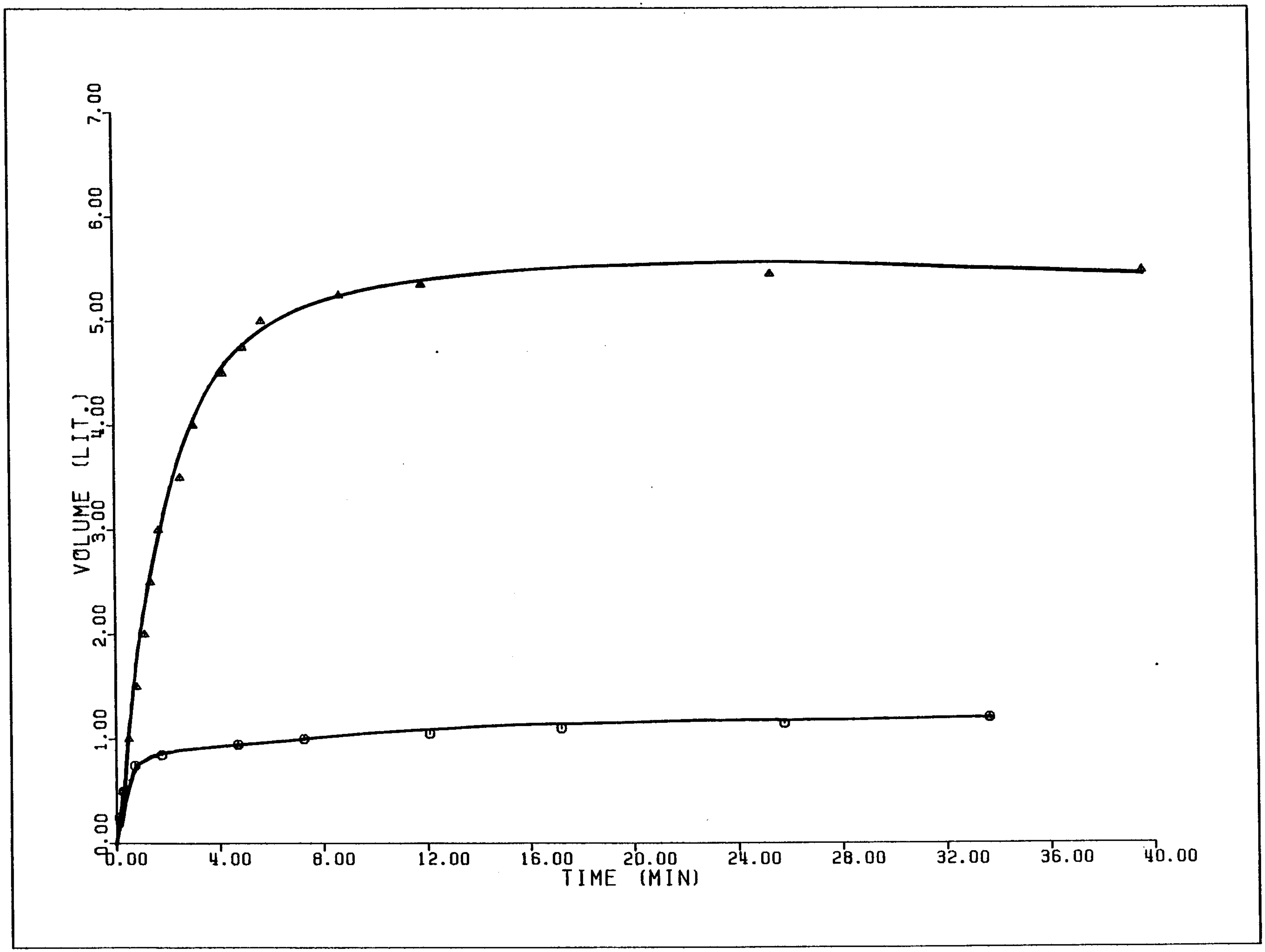


Figure A43 Flux Decline for Test 4 (second fouling test)

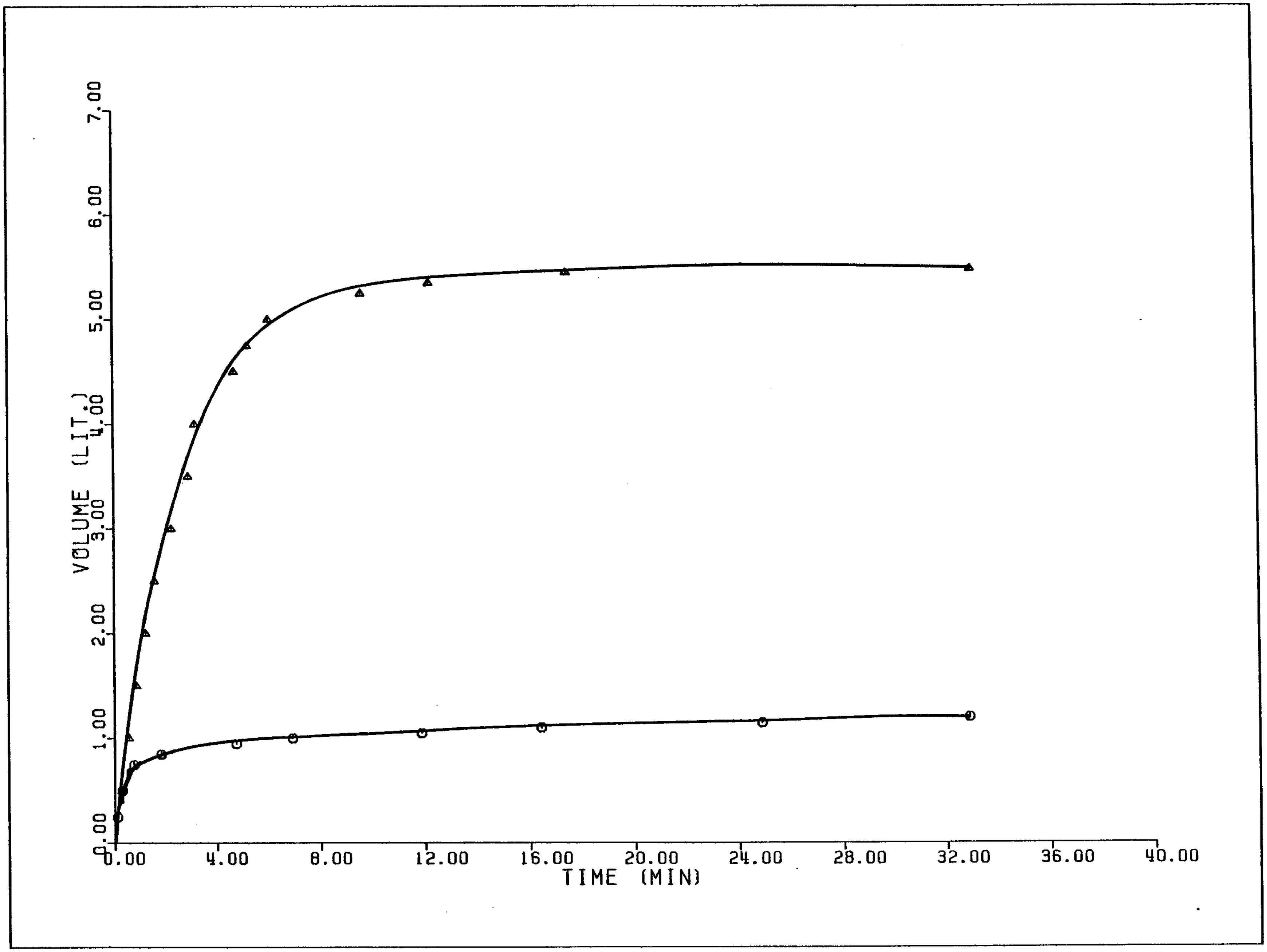


Figure A44 Flux Decline for Test 5 (first fouling test)

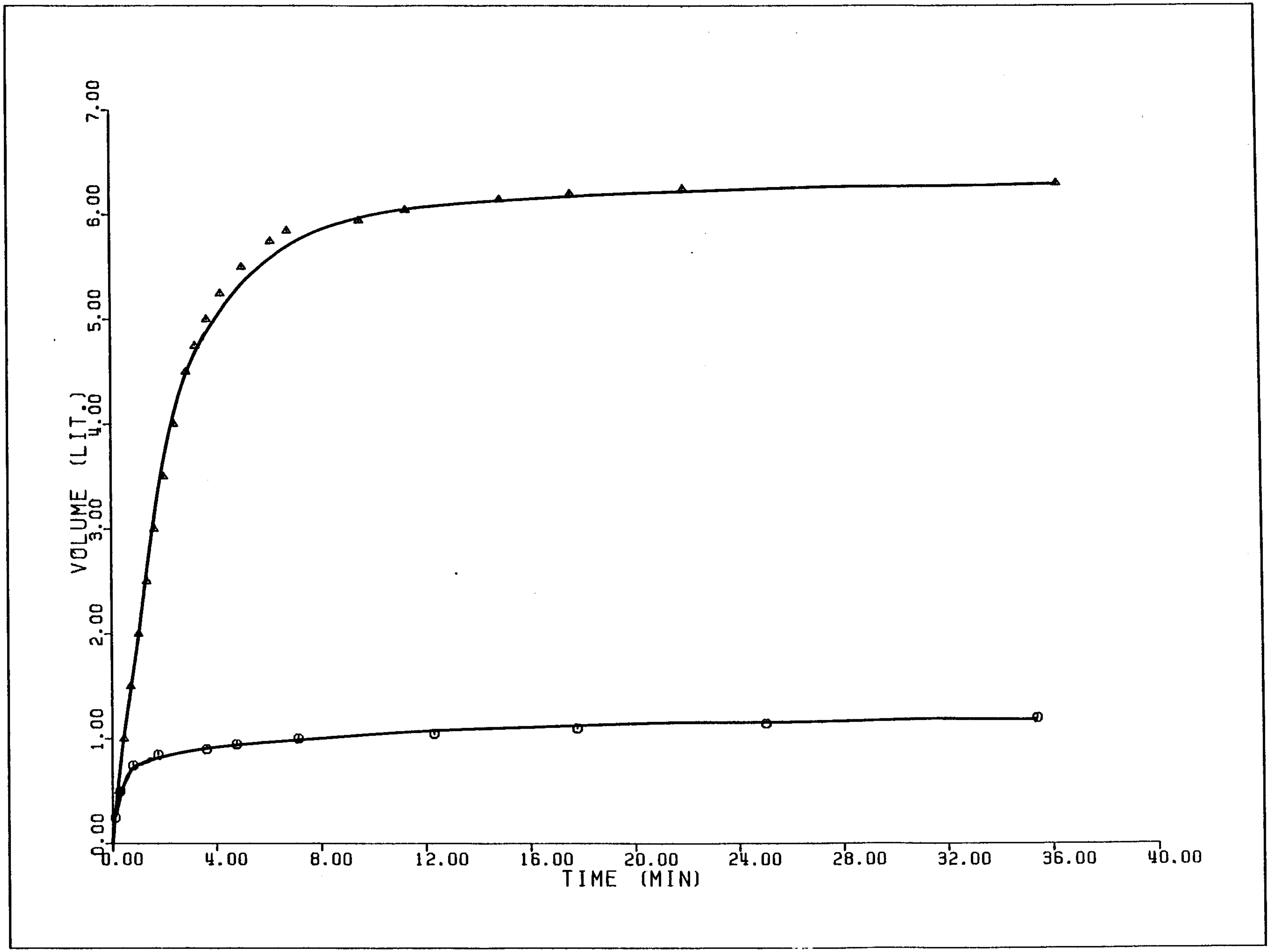


Figure A45 Flux Decline for Test 5 (second fouling test)

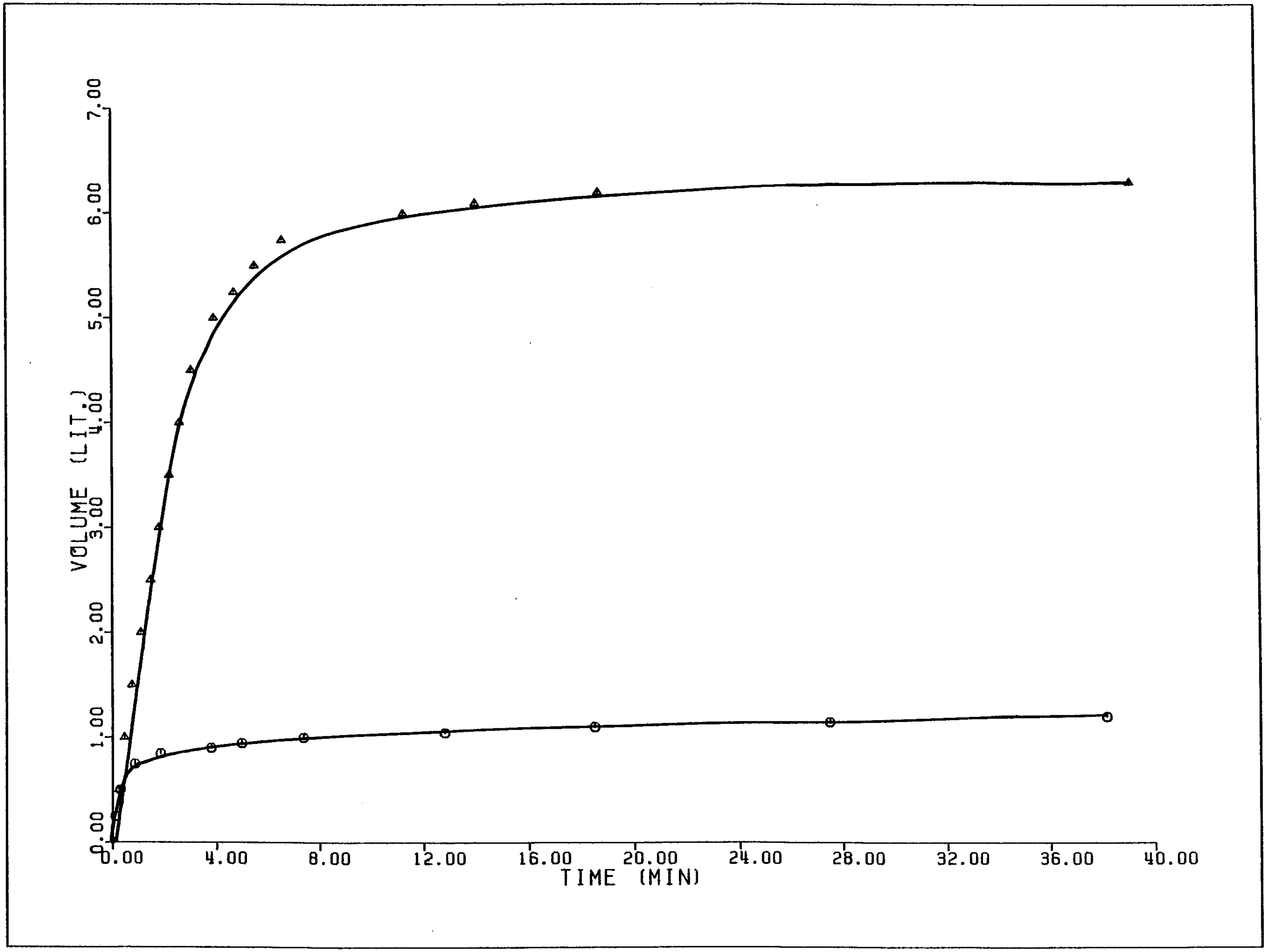


Figure A46 Flux Decline for Test 5 (third fouling test)

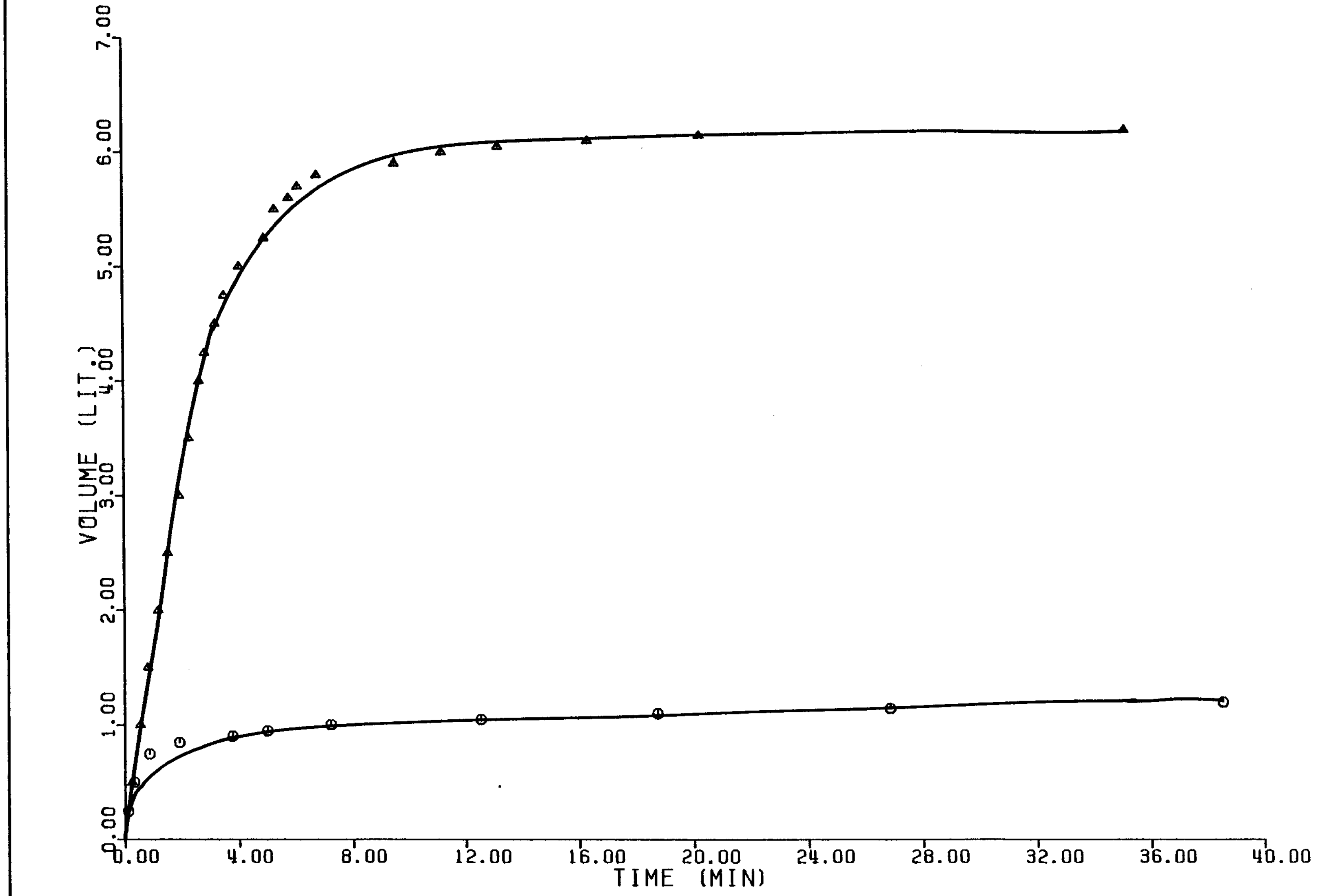


Figure A47 Flux Decline for Test 9 (first fouling test)

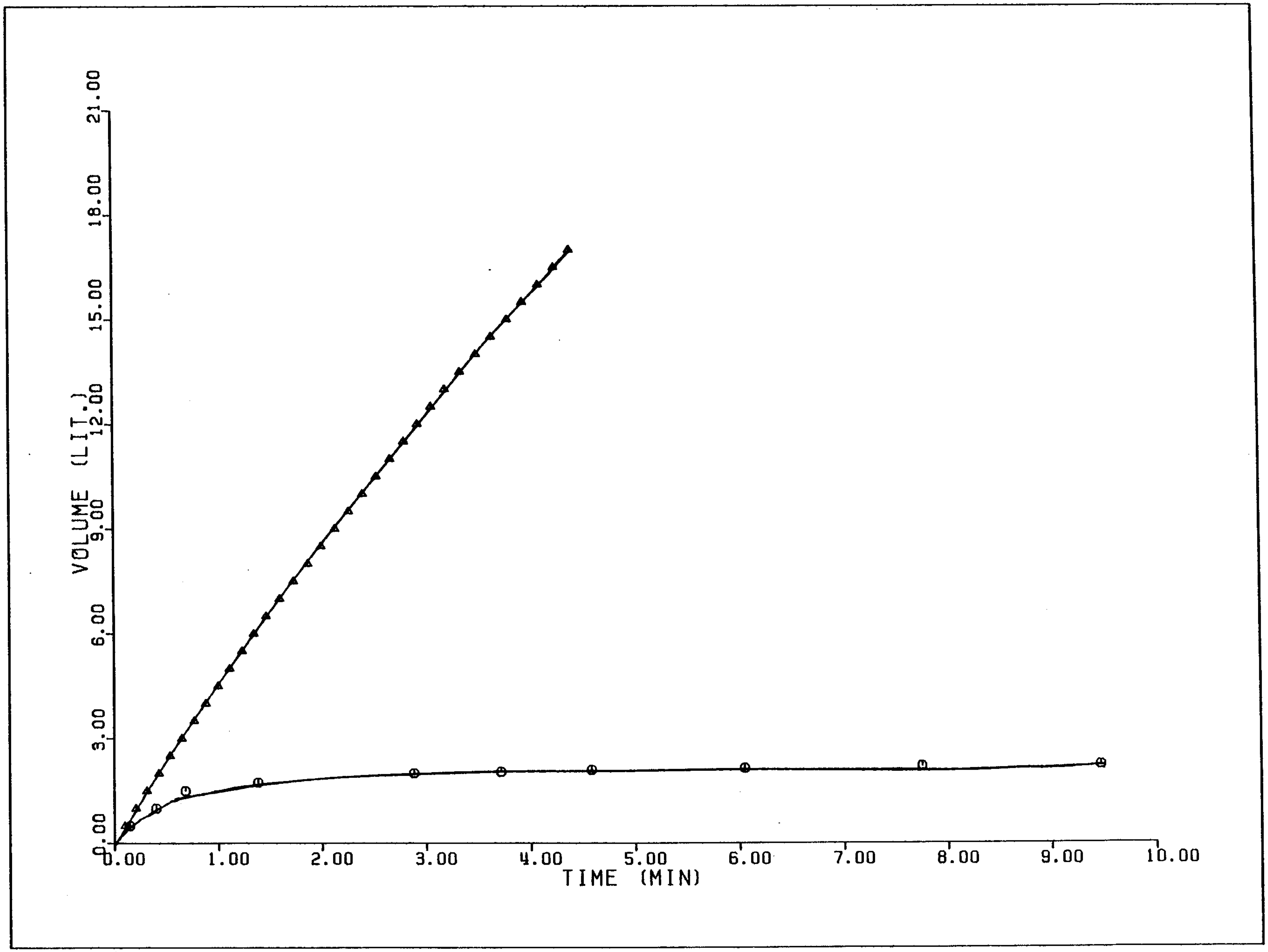


Figure A48 Flux Decline for Test 9 (second fouling test)

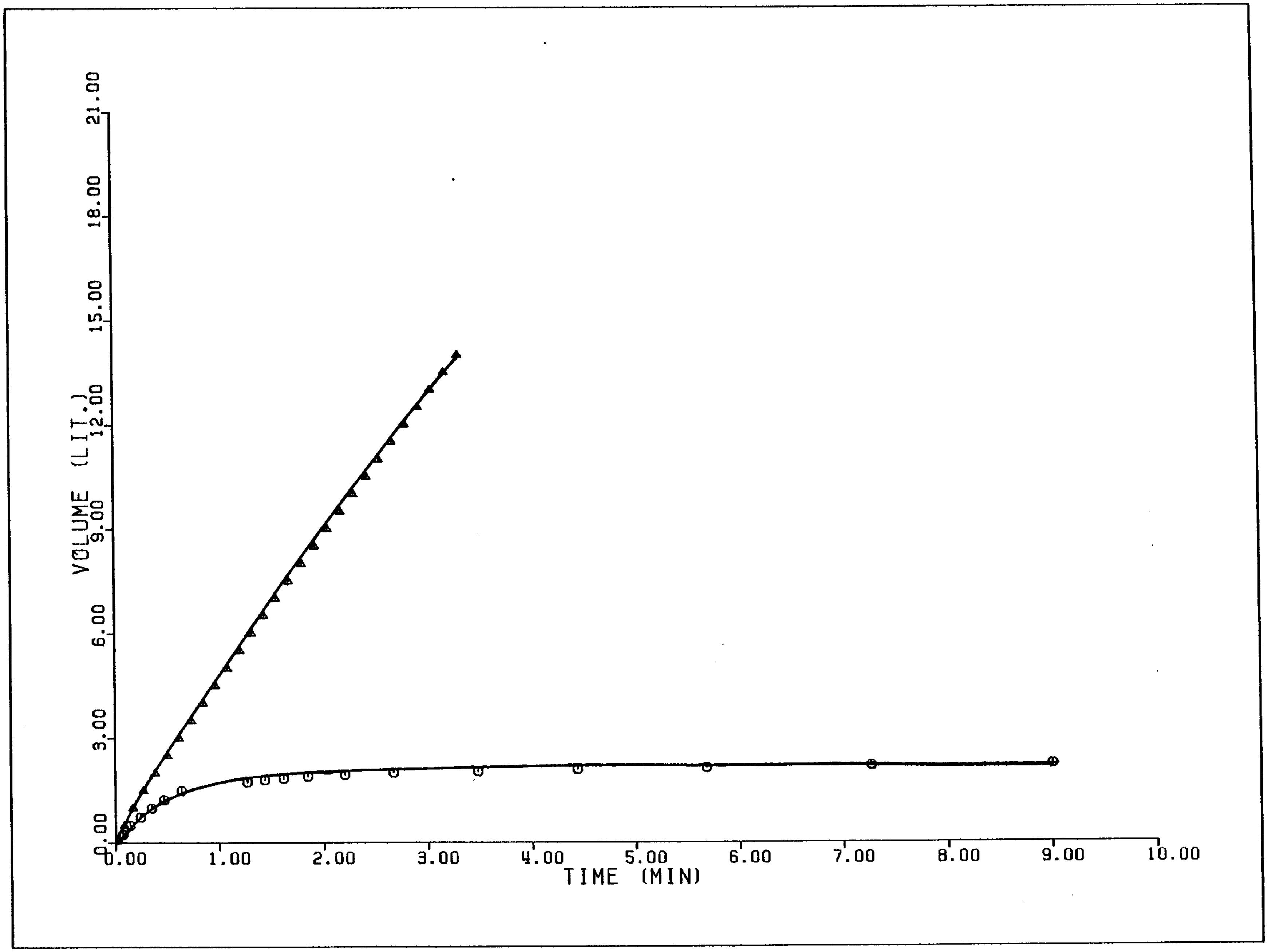


Figure A49 Flux Decline for Test 9 (third fouling test)

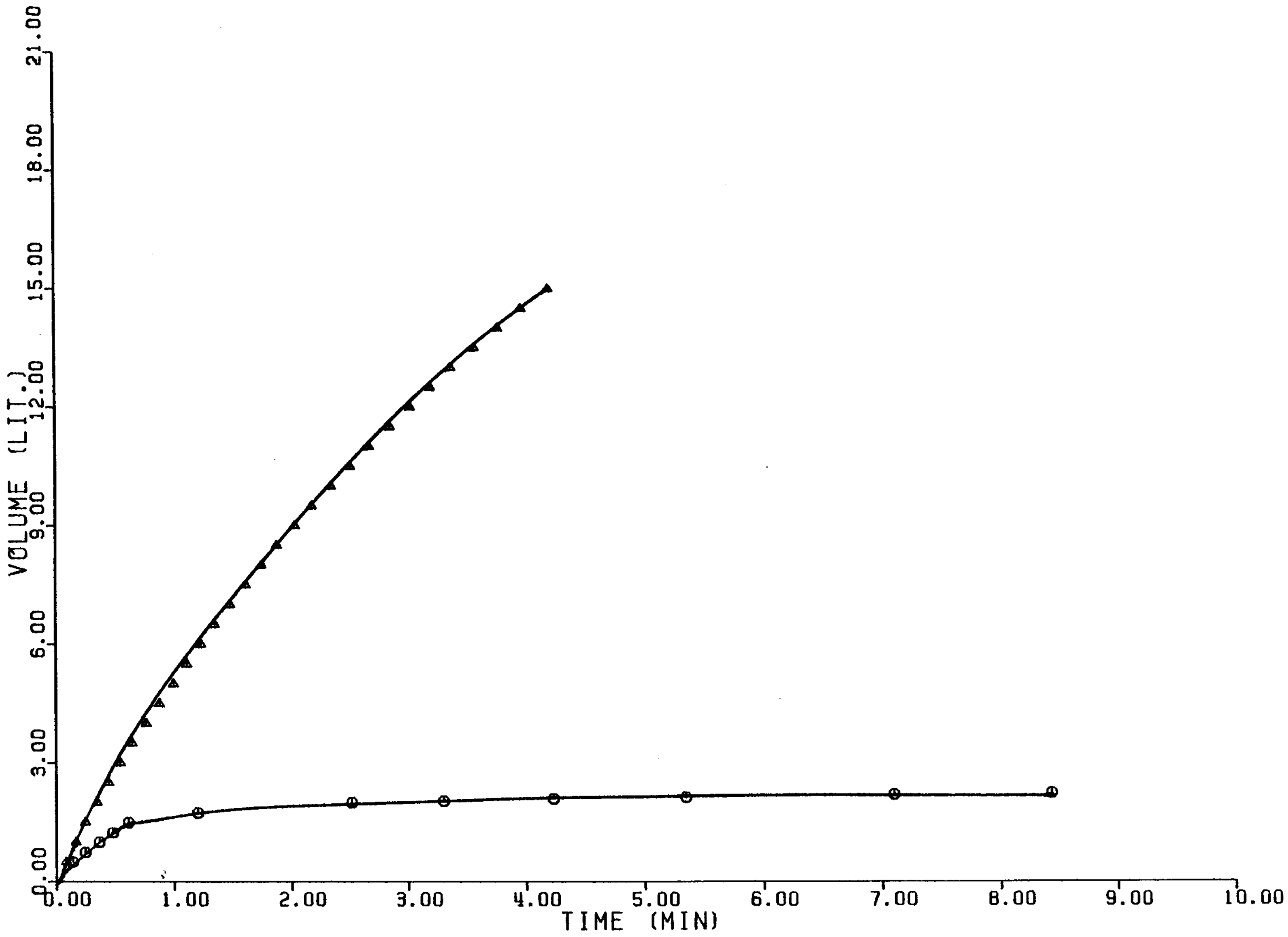


Figure A50 Flux Decline for Test 11 (first fouling test)

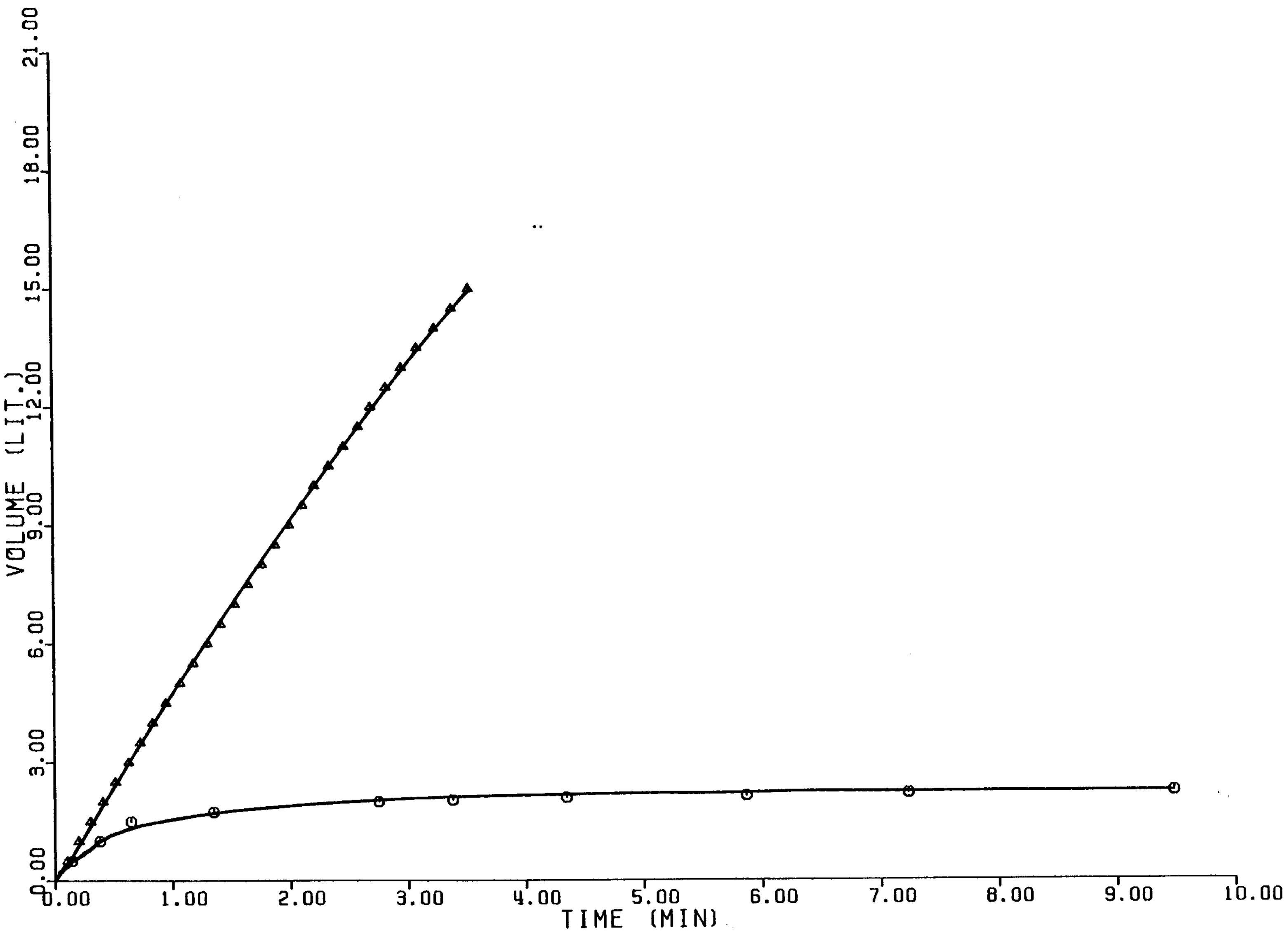


Figure A51 Flux Decline for Test 12 (second fouling test)