Development of a Tubular Fabric Filter Concept

by

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INTRODUCTION

Reverse Osmosis (RO) is now a commercially feasible, widely used technology. There are a number of commercial plans which use RO to treat secondary sewage effluents for reclamation. Prominent among these is Water Factory 21 operated by the Orange County Water District (1).

In spite of the commercialization of RO technology, there exists a continuing need for process improvement. Energy cost associated with the high pressure needed to obtain practicable membrane fluxes is the major operating cost and also the major impediment to widespread use.

There are a number of approaches to minimizing energy costs. New, low pressure membranes are being developed and this approach is promising, but commercialization of new membranes may not occur soon. Energy recovery devices are also being developed to recover energy contained in the high pressure brine. An alternate approach which can be quickly developed on a site-specific basis is improved pretreatment. Pretreatment can minimize the flux decline due to fouling or scaling of membranes.

Pretreatment systems include filtration, activated carbon adsorption, softening, coagulation, and biological treatment. Water Factory 21 (1) has used all of these methods with varying degrees of success. Additionally, the senior author (2) has conducted extensive studies of various filtration and coagulation methods. Conventional pretreatment systems have been optimized to operate in fixed locations and have also been developed to minimize energy and chemical requirements. Although land area requirements are an important aspect of pretreatment system design, few pretreatment systems have been designed to operate with minimum space. Consequently most pretreatment systems are bulky, heavy and have little application for portable operation.

Sand filters or mixed-media filters are a good case in point. They are very effective for RO pretreatment and also serve as polishing filters for secondary effluents. They have modest land requirements (3 to 5 GPM/ft^2) and require a number of ancillary facilities including pumps and backwash storage tanks. The filter media usually has a specific gravity in excess of 1.5 which means that sand filters are quite heavy. For example, a typical sand filter or mixed-media filter contains 30 inches of filter media, or 80 lb/GPM/ft^2 of filter capacity (calculated at 3 GPM/ft^2). It is obvious that sand filters cannot really be considered unless they can be transported without sand.

There are alternative methods of filtration, but none have been used on a wide-scale basis for water treatment. Diatomaceous earth filters have been used with sucesss for potable water treatment in small size applications; however, they are bulky and heavy and do not overcome the sand filter's primary disadvantage. Cloth media filters have been developed for specific application, and might be adapted to RO pretreatment.

A controlled investigation of cloth or fabric media filtration for RO pretreatment, to the best of our knowledge, has never been conducted. It is the objective of this work to evaluate the suitability of fabric filtration for RO pretreatment. An important aspect of this work is the development of effective back washing techniques. The development of an effective fabric filter could aid in the development of portable units.

EXPERIMENTAL DESIGN

To evaluate fabric filtration an experimental apparatus was obtained from the Naval Civil Engineering Laboratories in Port Heuneme, California. The unit consisted of an eight-inch diameter plexiglass column which housed one to four fabric filters. The fabric filters were one-inch diameter tubes which were cut into four-foot long sections, each tube containing 1.0 ft^2 of superficial surface area.

Fabric Types

Three fabric types were evaluated. The simplest type of fabric was a polyester material which was woven coarsely. The webbing was easily visible, but holes through the webbing were not. This fabric type will be referred to as Type I. The Type I fabric was woven into a tubular shape without a seam. The second type of fabric was woven very finely with a barely perceptible webbing. The material was stitched and glued to form a tube. This type of fabric will be referred to as Type II. The third type of fabric was a thick fabric coated internally with a micro porous membrane. The membrane provided the surface used in filtration. This type of fabric will be referred to as Type III.

The fabrics were supplied to UCLA by Naval Civil Engineering Laboratory personnel. They were selected in the hope of providing varying degrees of treatment, with Type I being the least efficient, and Type III being the most efficient.

Apparatus Description

The apparatus obtained from the Naval labs was modified to accommodate different modes of filtration and backwashing. The apparatus is shown in

Figures 1 and 2. The apparatus is completely contained on a single, rolling platform, with the exception of the feed tank reservoir. Figure 3 is a schematic diagram of the unit.

To operate the filter tap water is introduced into the feed reservoir to a convenient volume. Tap water is then pumped by the main feed pump (a Viking gear pump with variable speed DC motor) through a calibrated rotometer and check valve into the mixing tee. Detergent solution and AC Road Dust is also injected into the tee, using a variable speed Masterflex peristolic pump. The concentration of contaminants introduced into the feed water can be controlled by the Masterflex pump speed or by the concentration in the contaminant reservoir. Normally the 87.89 grams of AC road dirt and 380.57 grams of military detergent were added to 40 liters of tap water to make "stock" contaminant solution. This synthetic wastewater flows through a second, larger rotometer to the top of the column. The wastewater can be injected into the center of the fabric tubes or to the column. The flow split is required in order to evaluate normal (into the center of the fabric tubes) and reverse flow operation.

Backwash water is introduced into the feed stream prior to the large rotometer. Therefore the large rotometer indicates total flow to the filter, including backwash or cross flow.

The fabric tubes are attached to a header constructed of a four-inch PVC pipe cap and 4-inch PVC pipe plug. Four filter positions were originally provided. Each filter attached to a one-inch PVC nipple which was glued to the manifold. Later in the study the one-inch PVC nipples were replaced with ribbed hose adapters. This change was made as a convenience

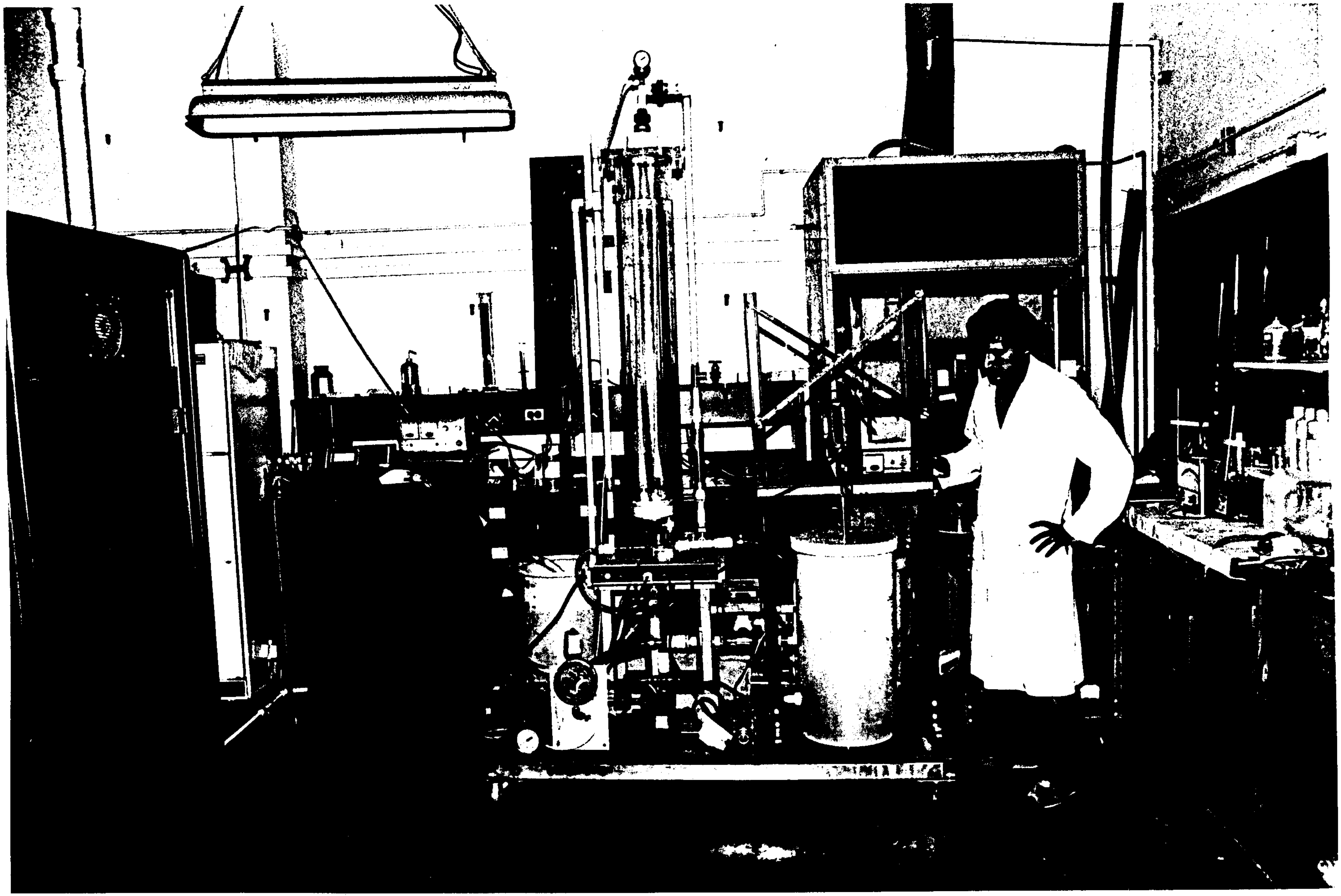

Figure 1. Front View of the Filter Apparatus

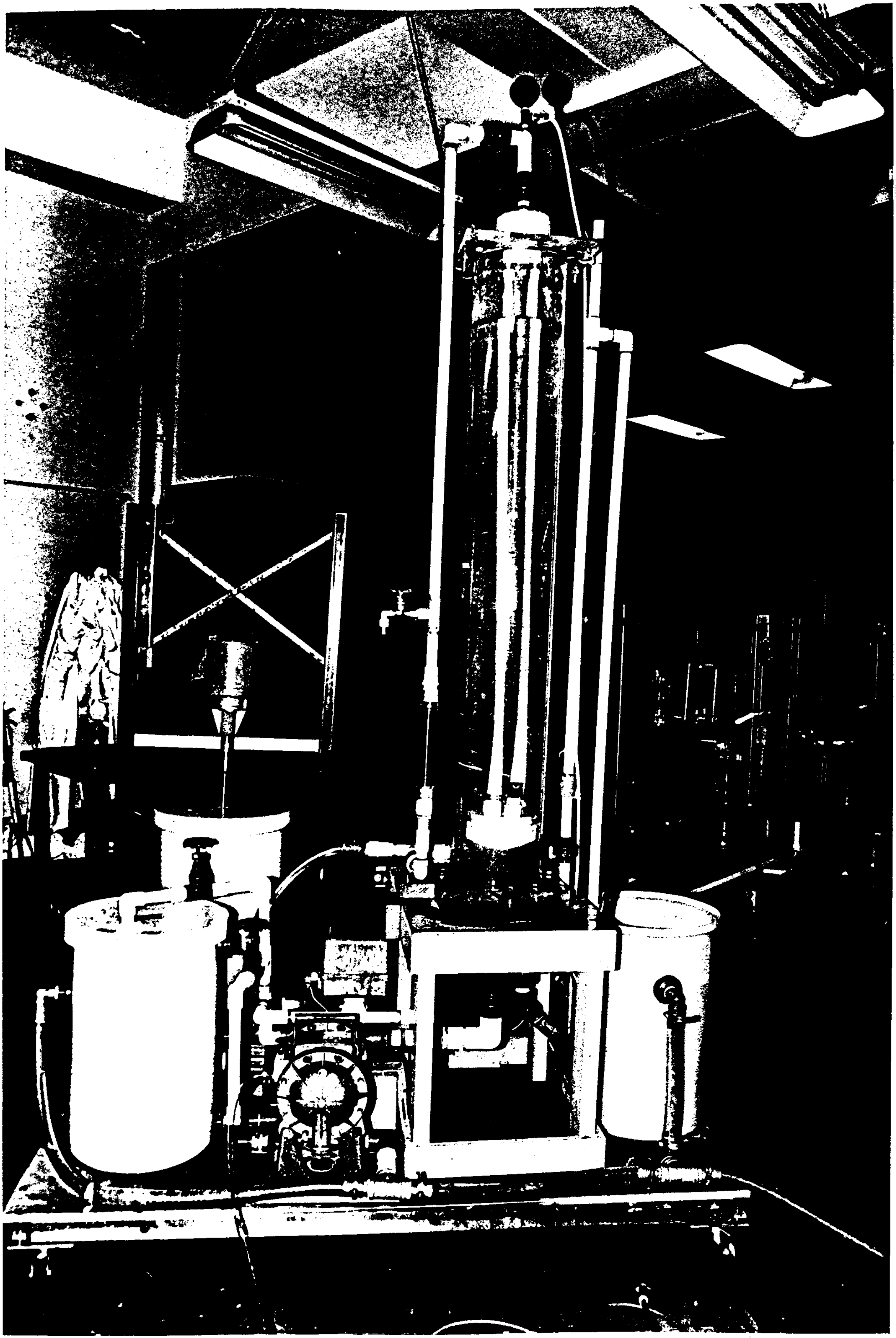

Figure 2. Back View of the Filter Apparatus

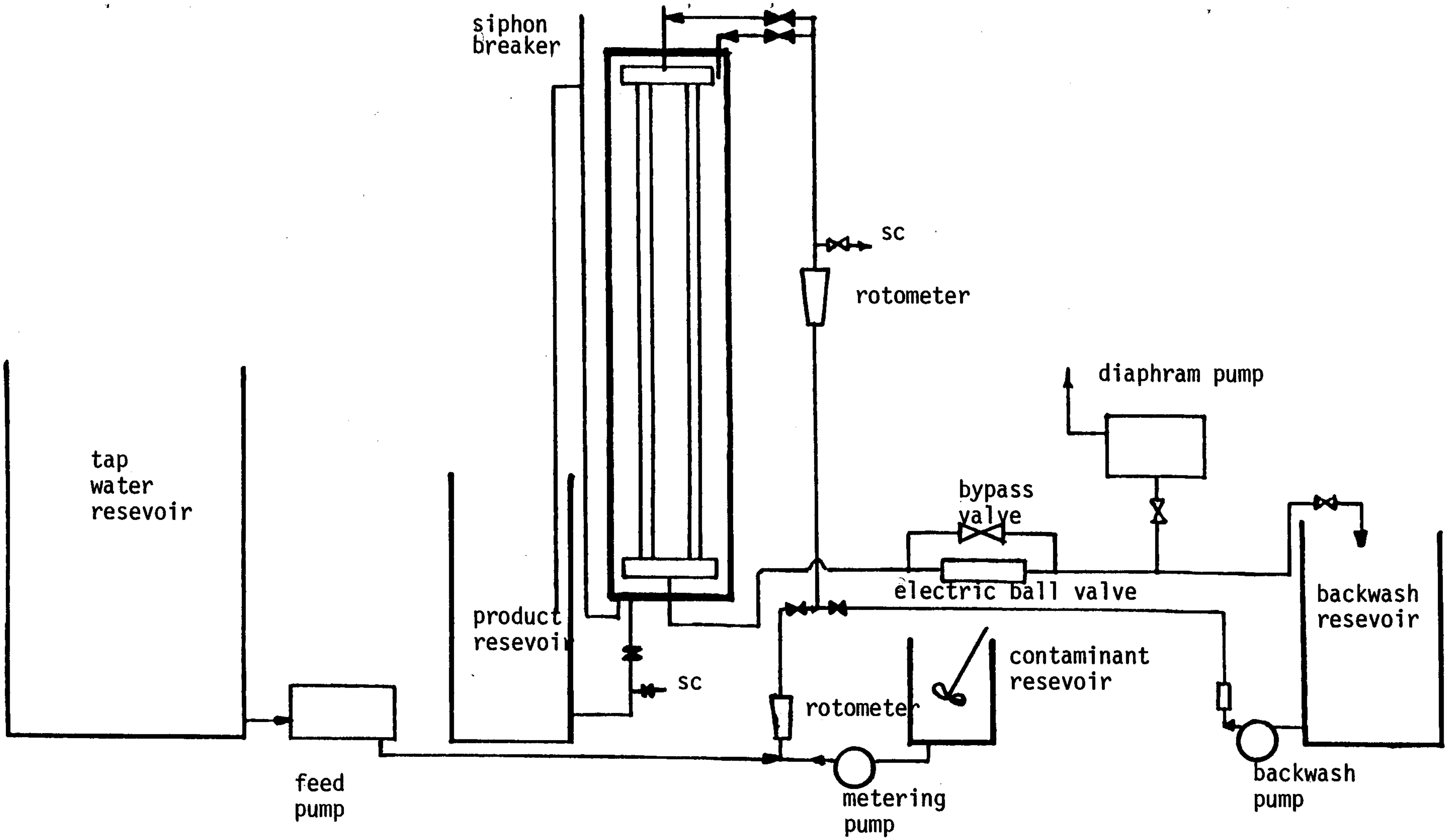

Figure 3. Schematic Diagram

when the top header was reconstructed; however, it was later determined that the one-inch PVC nipples allowed leakage to occur.

The bottom header was connected to a 1 1/2-inch PVC electrically operated ball valve. The valve was also equipped with a 3/4-inch manual bypass valve. The discharge side of the ball valve was connected to a backwash collection reservoir and also to a pneumatic Sandpiper diaphram pump. The diaphram pump was used for backwashing and also for reverse flow operation. The filtered product water was drained from the column using an overflow device which kept the liquid level above the level of the filters.

Analytical Methods

The basic analytic method used during all testing was turbidity. The turbidity was orginally measured using a Hach model 2100 turbidity meter, but later in the study a Fischer model was used. Surface tension measurements (du Nouy method) were also made, but the surface tension of the liquid was virtually unchanged during filtration. Also the TOC was unchanged by filtration. Flow rates and pressure drops were measured during each test.

Modes of Operation

The filter was operated in three different modes. The first mode is called "closed-end" which means that both the electrically operated ball valve and the bypass valve are closed. The entire influent must flow through the filters. The second mode of operation is called "cross flow." A portion of the influent flow is allowed to flow past the fabric and into the backwash container. The cross flow rate is controlled by opening the bypass valve. Additionally, very high cross flow rates can be obtained by using the backwash pump. The third method of operation is called "reverse flow."

In this technique, the influent is introduced to the column outside the filters and is sucked through the filters by the diaphram pump.

Modes of Backwashing

The filter was operated with three different backwashing techniques. The first technique was to cross wash the filter with very high cross flows in the hopes of scouring filtered material from the internal surface of the tubes. To achieve high cross flow rates the 1 1/2 inch ball valve was opened. The cross flow backwash was used with the filtration modes of operation referred to as the "closed end" and "cross flow". The second type of backwash (also used with the above operational modes) was to use the diaphram pump to suck effluent back through the fabric in the hope that filtered material would be removed from the internal area of the tubes.

The third type of backwash was used only with "reverse flow" operation. With "reverse flow" operation the tubes are backwashed by pressurizing the internal part of the tube. Backwashing can be achieved by simply reversing the valves which direct influent to the internal or external parts of the tubes.

Other types of backwashing or cleaning procedures were used on a trial basis. For example, flow surging and manual cleaning were periodically tried.

RESULTS AND DISCUSSION

The three modes of filtering and the three modes of backwashing were examined in a systematic way through a series of experiments changing one operating parameter at a time. When it became apparent that one operating mode was of little value, that mode of operation was abandoned. Also many of the experiments had to be performed first on a trial basis in order to adjust flow rates and determine appropriate operating pressures. Since all the pumps were manually controlled, the experiment had to be monitored throughout the period of operation. Quite frequently vessels overflowed or pressure drops became too high, negating experimental results.

The entire sequence of experiments is reported in Table 1 and a list of data, including turbidity, pressure drops, and flow rates is included in the Appendix. Table 1 shows the test number which corresponds with the test number on the graphs and tables in the Appendix.

Cross Flow Operation

Experiments 1, 4, 5, 6 and 8 were cross flow experiments using different flow rates and cross flow backwash rates. The cross flow method removed approximately 70 percent of the inlet turbidity and no trend of removal efficiency with respect to flow rate or cross flow rate can be determined. Experiment 1 shows very high effluent turbidity but this is due to the high inlet turbidity.

The filter typically started operation by producing large quantities of product water. The production rate gradually declined as the fabric began to plug and eventually both the influent and cross flow were being

Table 1. Selected Test Summaries

Test No.	Filter Type	Mode of Operation	Mode of Backwash	Flow (GPM/ft^2)	Inlet Turbidity	Approximate Vol. & Time to Plugging (Gal/Min)	Avg. Eff. Turbidity (NTU)
1	1 (New)	Cross Flow	Cross Flow C 3.5 GPM/ft^2	0.5	20	32/52	7.7
2	1 (New)	Closed End	Cross Flow 3.0 GPM/ft^2	2.0	10	72/32	2.9
3	1 (New)	Closed End	Vacuum	2.0	10	44/24	2.4
4	1 (Old)	Cross Flow	Cross Flow C 3.2 GPM/ft^2	2.0	14	11/30	2.8
5	1 (Old)	Cross Flow	Cross Flow C 2.5 GPM/ft^2	0.5	11	6.7/26	4.3
6	1 (Old)	Cross Flow	Cross Flow 4.0 GPM/ft^2	2.0	9.0	24/43	1.95
7	1 (New)	Closed End	Vacuum	2.0	10	40/20	2.5
8	1 (Old)	Cross Flow	Cross Flow 2.5 GPM/ft^2	2.0	10	11/20	2.5
9	1 (New)	Closed End	Cross Flow 3.5 GPM/ft^2	0.5	10	62/72	4.6
10	2 (New)	Closed End	Cross Flow 4.0 GPM/ft^2	0.5	13	54/76	8.5
11	3 (New)	Closed End	Cross Flow 3.5 GPM/ft^2	0.5	12	19/30	11.6
12	1 (New)	Closed End	Cross Flow 2.0 GPM/ft^2	2.0	12	58/24	5.7
13	1 (New)	Closed End	Cross Flow 3.5 GPM/ft^2	0.5	12	59/62	5.1
14	1 (Old)	Reverse Flow	Closed End 1.0 GPM/ft^2	1.0	12		6.2

directed to the backwash storage vessel. The pressure generally increased to about 5 PSIG, but this pressure was controlled by the position of the bypass valve and the backwash pump control valve. For successful cross flow operation it will be necessary to use an automatic flow controller in order to make the system pressure rise and force more of the influent through the filters. The use of flow controllers is not warranted at this time since the cross flow did not keep the fabric clean.

Closed End Operation

Closed end operation allowed the system pressure to rise to any desired value, since the entire influent was forced through the fabric. Operating pressures of up to 20 PSIG were tested; however, pressures above 10 PSIG resulted in rapid deterioration of the fabric. Type I filters developed small pin holes which allowed the influent to shoot out in a small jet stream. The seams of Types II and III failed at high pressures. Therefore, most of the experiments were restricted to pressures of 10 PSIG or less.

Experiments 2, 3, 7, 9, 10, 11, 12, and 13 were conducted in the closed end mode. In general the closed end mode of operation produced more filtrate than cross flow operation, but plugging still occurred. Cross washing was used to clean the fabric, but was only marginally effective. The inside of the fabric (Type I) is shown in Figure 4. The right end of the fabric shows the filter as it appeared after removal. The left end of the filter, which appears much cleaner, was manually worked to determine if the dirt particles could be removed. As seen from the figure, the manual washing was only partiallly successful. Eventually the closed end operation was abandoned.

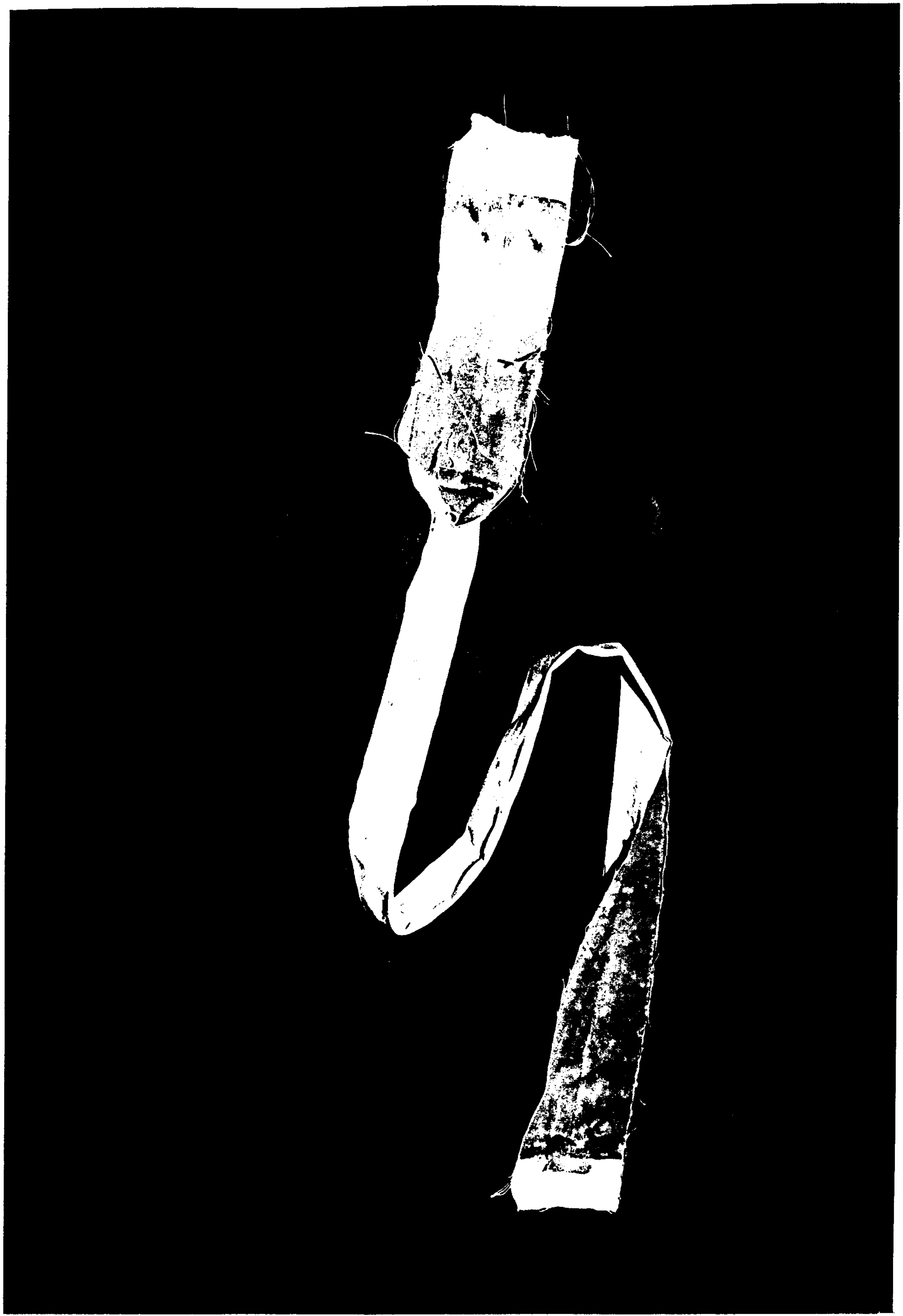

Figure 4. Fabric Type I, Showing Dirt on Internal Fabric

Backwashing

Both cross flow backwashing and vacuum backwashing showed little promise. The vacuum backwashing was shown to clean the filter better than cross washing, but the volumes of water required are quite high,

Reverse Flow Operation

Reverse flow operation was next tried. Reverse flow operation proved to be very difficult to control since the filter apparatus was not designed to pressurize the external side of the tubes. Therefore, the diaphram pump was used to suck water through the membranes. Precise flow regulation was required, or the filter vessel would overflow. It was also found necessary to add an additional check valve to the diaphram pump in order to maintain the needed vacuum.

The reverse flow operation proved to be very successful and a total of three experiments were made. Two were trial experiments and the final experiment is shown in Table 1 as experiment 14. The tubes used in experiment 14 were old and were used in the two trial reverse flow experiments. The figures in the Appendix show that the tubes were successfully backwashed twice restoring high filtration rate. In actuality, the tubes used for experiment 14 had been backwashed three times in preceding experiments. The reverse flow operation has the advantage that the feed pump can also be used for backwash. It is also fortuitous that the backwashing rate needs to be only as high as the feed flowrate.

The success of the reverse flow operation is possibly due to the expansion properties of the fabric tubes. In closed end operation, the tubes were pressurized and were vissibly stretched. The stretching increased the pores and void spaces in the fabric, allowing particles to penetrate deep into the fabric. During backwashing or cross washing, the pressure was reduced allowing the tube to shrink. The shrinking could tightly bind the particles, and present effective backwashing.

Reverse flow operation is exactly opposite with respect to expanding and shrinking. Filtration occurs when the tube is pressurized from the outside, causing it to shrink around the inner supports shown in Figure 5. During backwashing the tube is exapnded, allowing the pores and voids to expand, promoting cleaning.

The reverse flow operation was slightly less efficient in removing turbidity, removing only about 50 percent of the turbidity. This reduction may only be an artifact since only one complete test was documented. However, it should be noted that the diaphram pump operates in a pulsating fashion, causing spikes in the velocity of water through the fabric. These velocity spikes could attribute to reduced efficiency. Further testing needs to be performed in a pressure vessel without pulsating flow characteristics.

Fabric Types

The effects of fabric type on filter performance is not yet clear. The trial experiments with the Type II membrane showed poor results primarily due to leakage at the seams. Experiment 17 with the micro porous membrane coated fabric (Type III) showed the poorest results, and this was surprising since it should have produced the best results. It was later learned that the end connections of the tubes were poor and that leakage occurred around the worm gear hose clamps which held the tubes to the PVC nipples. The leakage was determined by accident when the experiment was repeated with the rebuilt manifold, containing ribbed tubing adapters. It

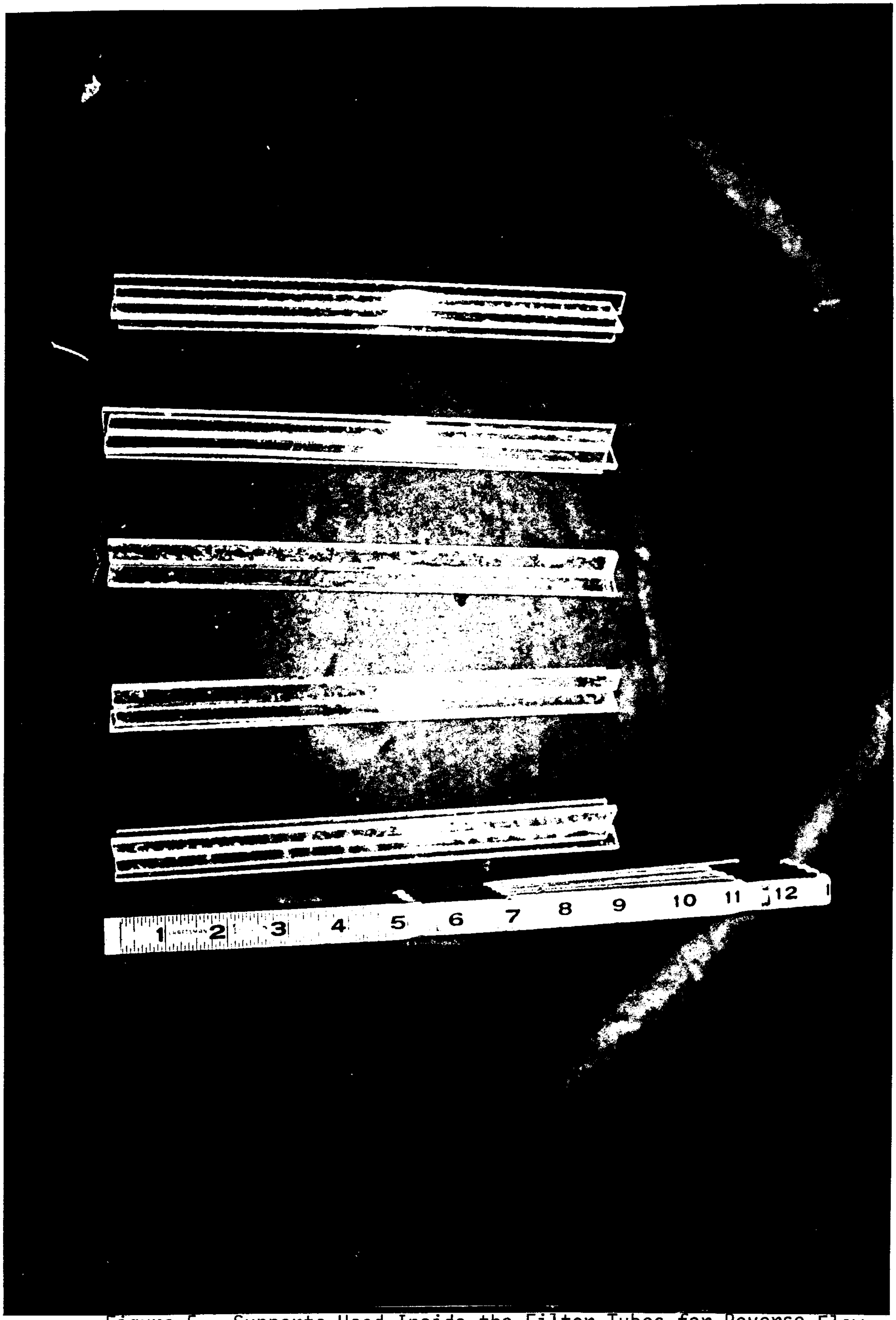

Figure 5. Supports Used Inside the Filter Tubes for Reverse Flow

was later determined that the static pressure drop through the Type III fabrics was approximately 20 PSIG at 1.0 GPM/ft^2. The pressures obtained in experiment 11 were never higher than 15 PSIG.

Spongeball Cleaning

It was observed in the tests with the Type III fabric that a coating of dirt collected on the surface of the filter. This coating could be removed by gently wiping with a soft cloth or sponge. Therefore, it was postulated that spongeball cleaning could possibly be used to restore filter flux. Spongeball cleaning has been used frequently with tube-style RO membranes. The filter header was rebuilt in order to allow spongeball cleaning. In rebuilding the filter header it was discovered that leakage had occurred in the previous task with the Type III fabric.

The spongeball cleaning tests are inconclusive due to the ruptures of the membranes which occurred at the high pressures (>20 PSIG). The seams on the filters quickly rupture at the high pressure, allowing unfiltered water to escape into the effluent. The cleaning technique appeared to clean the inside of the tubes, due to the removal of a dirt film which was collected as the spongeball was removed. A new series of experiments will have to be performed at reduced flow rates, or with redesigned tubes before a conclusive evaluation can be made.

Flux Decline Tests

In order to determine the improvement that fabric filtration provides for RO, flux decline tests were performed. This test is a modified form of the "fouling factor" test used frequently to evaluate pretreatment techniques.

The test is quite simple and uses Millipore or Gilman 0.45 micron filters in a vacuum filtration apparatus. Samples of both influent and effluent are collected and filtered. The samples are filtered individually and the volume filter as a function of time is recorded. High throughput is an indication of low fouling tendency and has been correlated to RO performance.

Figure 6 shows the results of a flux decline test using effluent collected during reverse flow filtration with fabric Type I. The lower line in the figure is for influent and it plugs the 0.45 micro filter after approximately 450 ml have been filtered. The effluent, however, shows only moderate plugging after 1100 ml have been filtered. The difference is dramatic.

PLOT OF VOLUME VS. TIME FOR INFLUENT AND EFFLUENT

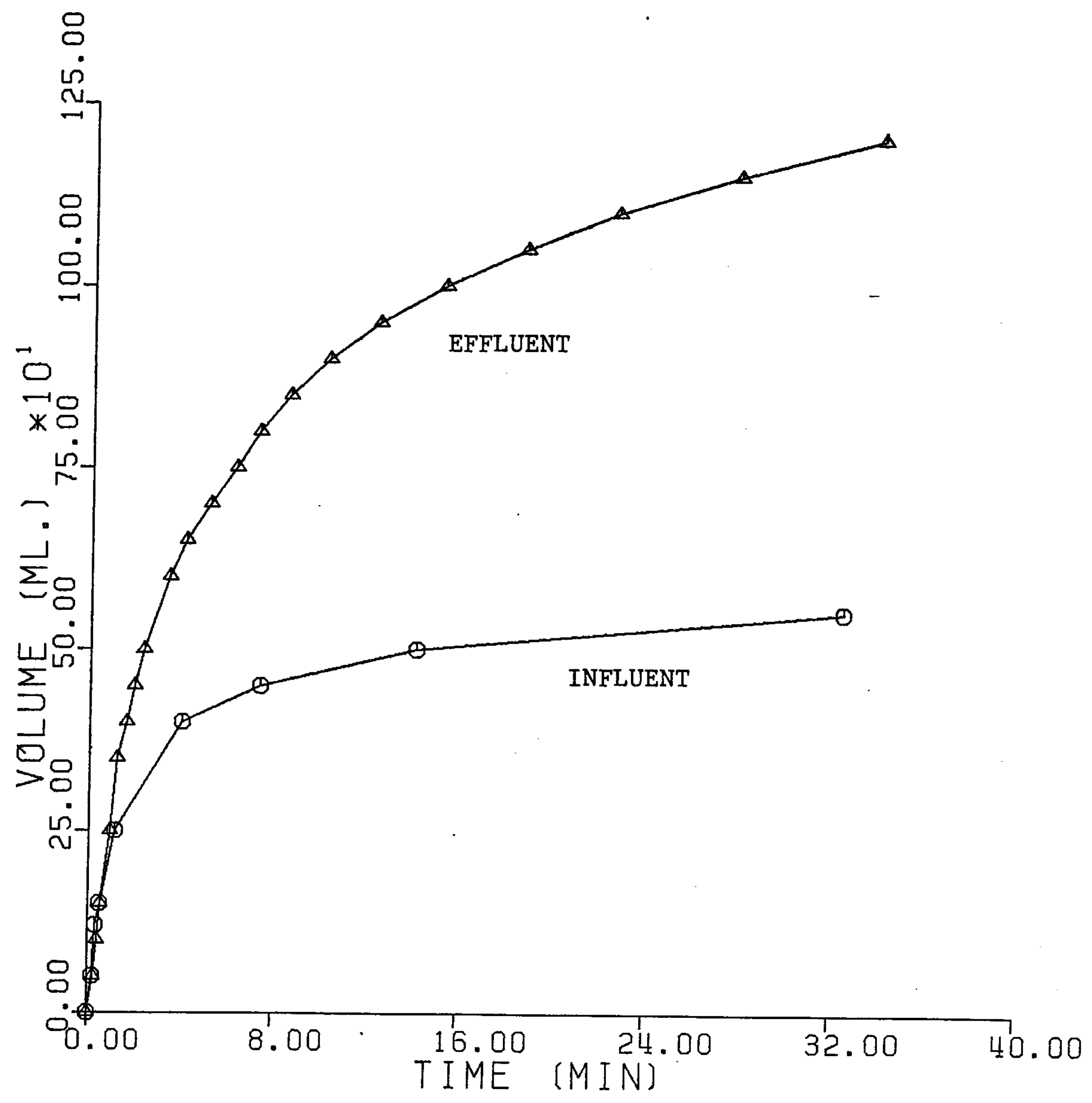

Figure 6. Flux Decline Tests

CONCLUSIONS AND RECOMMENDATIONS

The short investigation described in this report has shown that tubular fabric filtration holds promise for development using the reverse flow techniques. Although only a few successful tests were performed, a series of reverse flow tests demonstrated that the fabric could be successfully backwashed. The fabric filters removed over 1/2 of the turbidity and better efficiency may be possible with uniform filtration rates.

The promise for fabric filtration is even more promising when one considers the tremendous area and weight savings offered by fabric filters. To show the potential savings a series of calculations are presented. These calculations are based on using a fabric filter with 36 one-inch filters per square foot of superficial filter area, corresponding to a center-to-center tube spacing of two inches. At this spacing it is necessary to use a filtration rate of only 0.139 GPM/ft^2 in the fabric filter to correspond to 5 GPM/ft^2 with a mixed media filter. To further illustrate the area savings of the tubular fabric filter over a sand or mixed-media filter, Table 2 shows a series of typical sand filter flows and the equivalent flow needed in the tubular fabric filter to utilize the same superficial area. For example the superficial area used in a sand filter at 3.0 GPM/ft^2 could be used to produce the same net flow with a tubular fabric flow at 0.056 GPM/ft^2 of fabric. Also it is useful to compare area savings of tubular fabric filters operating at specific flow rates to sand filters operating at different, specific flow rates. Table 3 shows these ratios.

Table 2. Required Flow Rate for Sand and Tubular Fabric Filters Occupying the Same Superficial Area

Sand on Mixed-Media Filter GPM/ft^2	Tubular Fabric Filter GPM/tube = GPM/ft^2
1.0	0.028
1.5	0.042
2.0	0.056
3.0	0.056
4.0	0.111
5.0	0.139
6.0	0.167
10.0	0.278
15.0	0.417

Table 3. Ratio of Areas of Sand Filters and Tubular Filters with Different Flow Rates

$\frac{GPM}{ft^2}$	GPM/Filter ~~GRANULAR FILTRATION RATE (GPM/ft²)~~	TUBULAR FILTER RATE ~~FLOW~~ (GPM/ft²)						
		0.025	0.050	0.1	0.2	0.5	1.0	2.0
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SAND FILTER FLOW	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
	4.5	0.50	1.0	2.0	4.0	10	20	40
	5.0	0.45	0.90	1.8	3.6	9	18	36
	5.5	0.40	0.80	1.6	3.2	8	16	32
	6.0	0.38	0.76	1.5	3.0	7.6	15	30

Numbers represent ratios of the superficial areas of the tubular filter to superficial area of the sand filter. Numbers greater than unity show an area savings for the tubular filter.

For example a sand filter operating at 1.0 GPM/ft^2 would require 180 times the superficial surface of a tubular fabric filter operating at 2.0 GPM/ft^2. Volume savings are also realized because of the area savings and also because of the depth of a fabric filter is less than the required depth of sand filters. The sand filter requires more depth due to bed expansion in backwash. The ratios of volume savings are shown in Table 4 in a fashion similar to the area ratios in Table 3.

To develop the tubular fabric filter into a commercial process, further development is needed. What is specifically needed are several long-term tests to evaluate fabric life. To perform these tests it will be necessary to design a new filter apparatus which can be conveniently and automatically operated in the reverse flow mode. Also the Type III membranes should be re-evaluated at reduced flow rates with spongeball cleaning. It is possible that two levels of treatment efficiency could be developed: one using the Type I fabric operating at medium removal efficiency but at high flowrate, and the second using Type III fabric at high efficiency and low flow.

Table 4. Ratio of Volumes of Sand Filters and Tubular Fabric Filters with Different Flow Rates

GPM/Filter

SAND FILTER FLOW $\frac{GPM}{ft^2}$	TUBULAR FILTER FLOW						
	0.025	0.05	0.1	0.2	0.5	1.0	2.0
1.0	0.9	1.8	3.6	7.2	18	36	72
1.5	0.6	1.2	2.4	4.8	12	24	48
2.0	0.45	0.9	1.8	3.6	9	18	36
2.5	0.36	0.72	1.4	2.9	7.2	14	29
3.0	0.30	0.60	1.2	2.4	6.0	12	24
3.5	0.26	0.51	1.0	2.1	5.1	10	21
4.0	0.225	0.45	0.90	5.1	4.5	9	16
4.5	0.20	0.40	0.80	1.6	4.0	8	16
5.0	0.18	0.36	1.4	3.6	7.2	7.2	14
5.5	0.16	0.33	0.65	1.3	3.3	6.5	13
6.0	0.15	0.30	0.6	1.2	3.0	6.0	12

Numbers represent ratios of the volume of the tubular fabric filters to the volume of sand filters (48" tall). Numbers greater than unity favor the sand filter.

REFERENCES

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2. Stenstrom, M. K., et al., "Improvement of Reverse Osmosis Through Pretreatment," to be published in the January 1982 JWPCF.

APPENDIX

TEST 1

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 OBS    TIME    PRESSURE    TURB    VOLUME

   1      0       0.60       9.7      0.00
   2      1       1.50        .       1.56
   3      2       1.75        .        .
   4      3       1.90        .        .
   5      4       1.95       9.0       .
   6      5       1.95        .        .
   7      6       1.95        .        .
   8      7       2.00        .        .
   9      8       2.10       8.0       .
  10      9       2.10        .        .
  11     10       2.20        .        .
  12     11       2.20        .        .
  13     12       2.25       9.7     18.18
  14     13       2.25        .        .
  15     14       2.30        .        .
  16     15       2.35        .        .
  17     16       3.25       8.0       .
  18     17       3.45        .        .
  19     18       3.45        .        .
  20     19       3.45        .        .
  21     20       3.45       7.0       .
  22     21       3.40        .        .
  23     22       3.40        .        .
  24     23       3.50        .        .
  25     24       3.50       7.0     25.98
  26     25       3.90        .        .
  27     26       3.90        .        .
  28     27       4.00        .        .
  29     28       4.00       7.5       .
  30     29       4.10        .        .
  31     30       4.10        .      29.37
  32     31       4.10        .        .
  33     32       4.10       6.5       .
  34     33       4.10        .        .
  35     34       4.00        .        .
  36     35       3.90        .        .
  37     36       3.80       7.5       .
  38     37       3.75        .        .
  39     38       3.70        .        .
  40     39       3.65        .      31.22
  41     40       3.65       7.0       .
  42     41       3.65        .        .
  43     42       3.60        .        .
  44     43       3.60        .        .
  45     44       3.60       7.0       .
  46     45       3.60        .        .
  47     46       3.50        .        .
  48     47       3.50        .        .
  49     48       3.50       7.0       .
  50     49       3.50        .        .
  51     50       3.50        .        .
  52     51       3.60        .        .
  53     52       3.50       7.5     32.45
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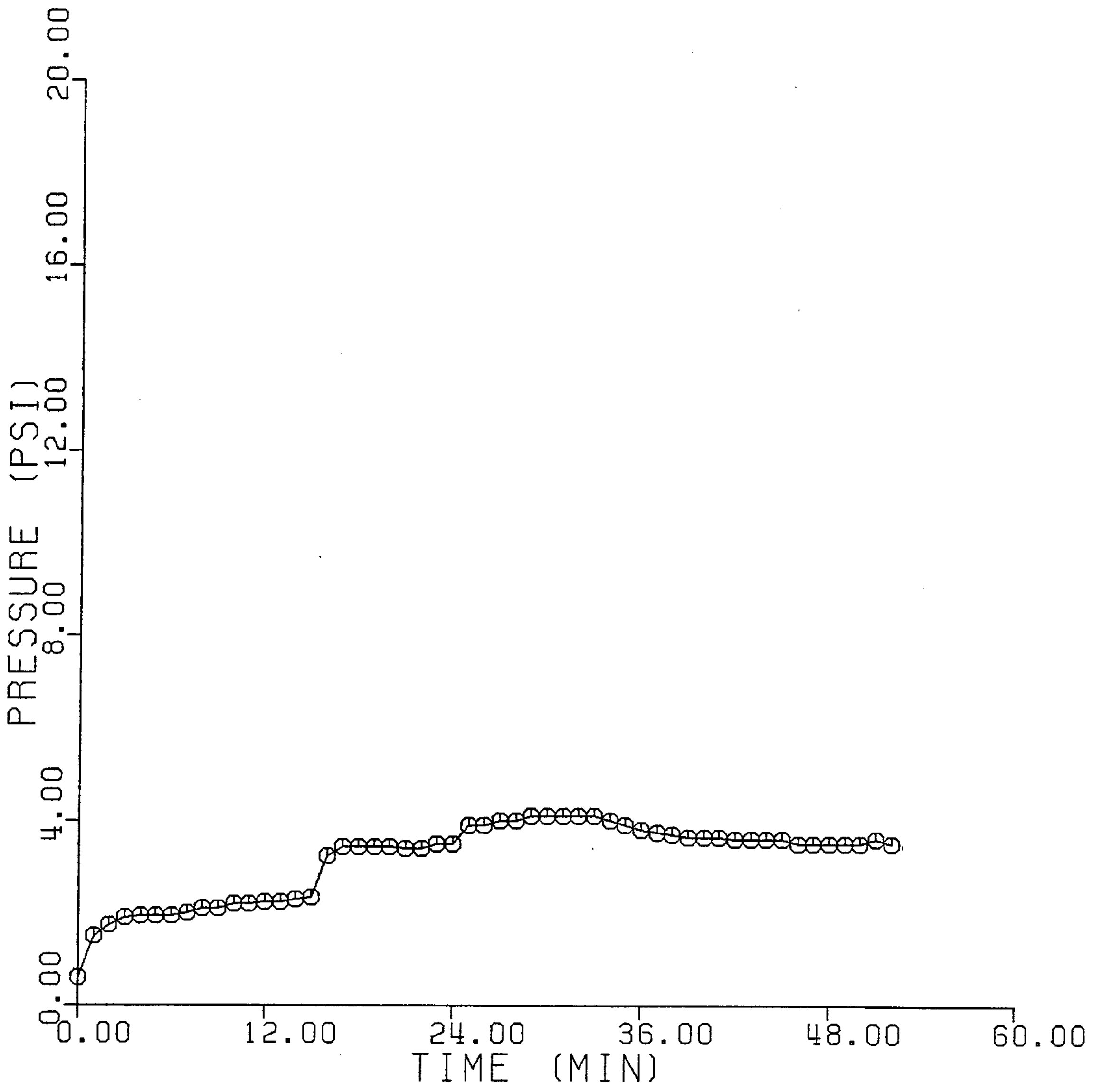
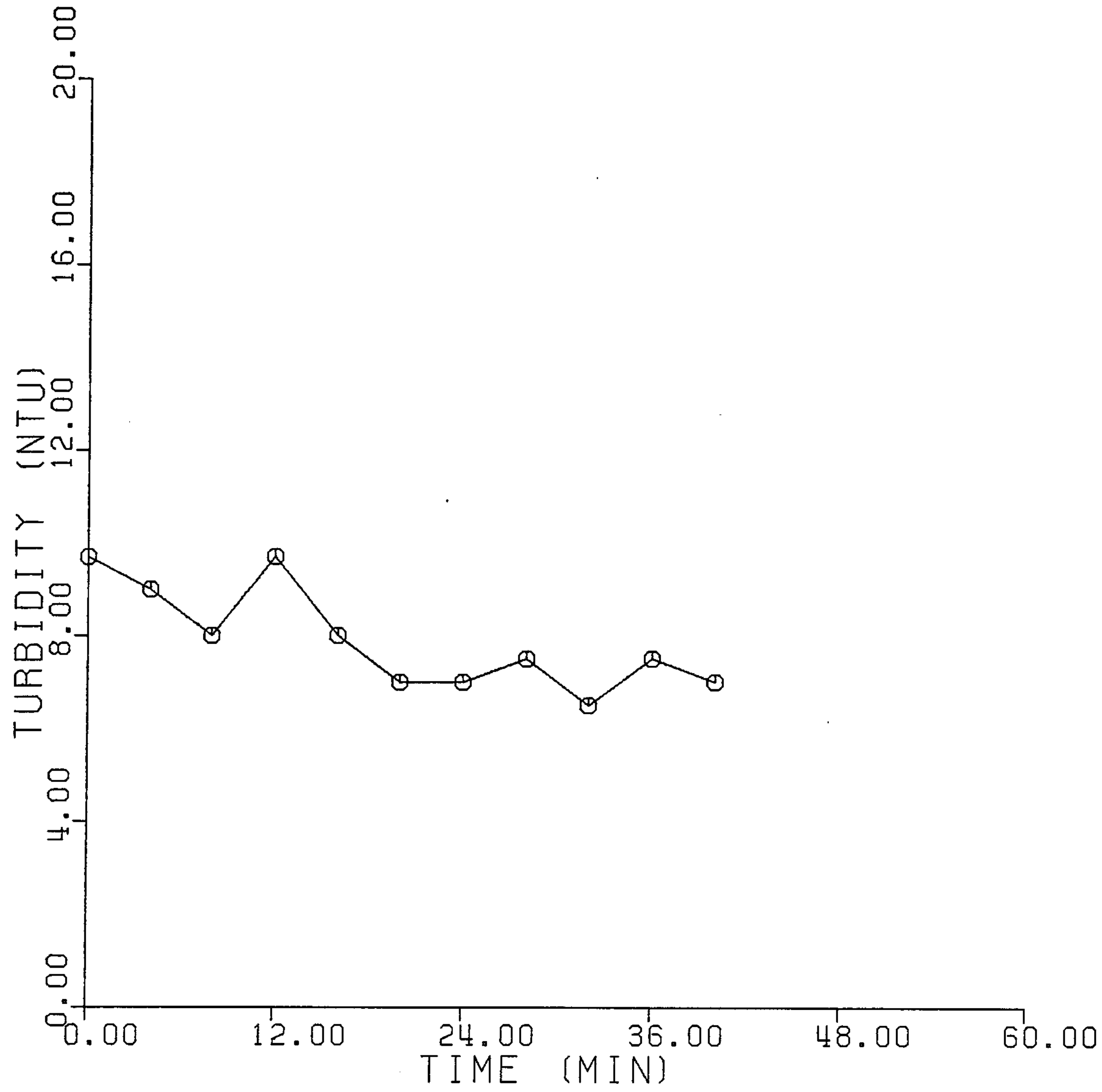
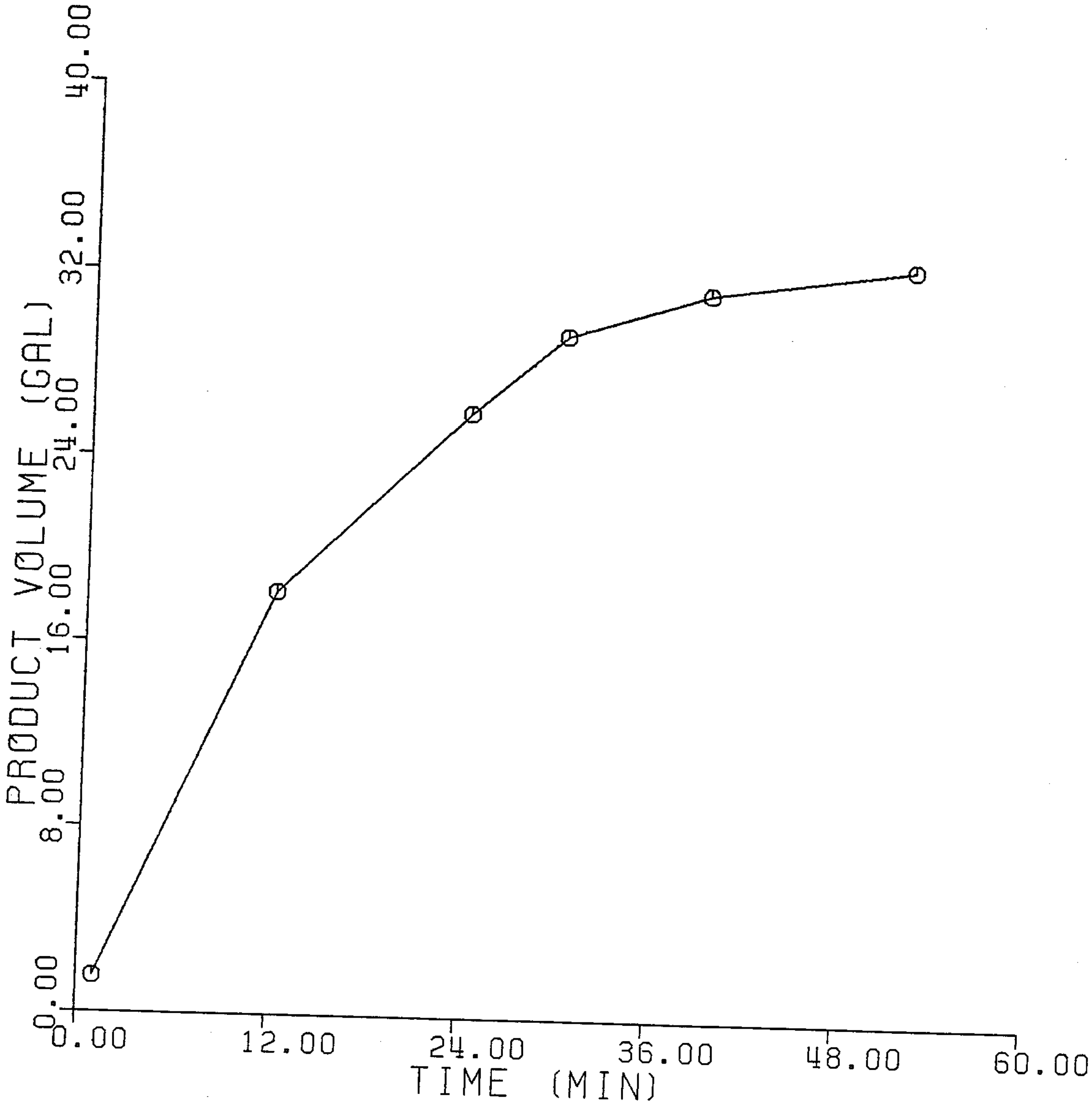
PLOT OF PRESSURE VS. TIME FOR CROSS FLOW OPERATION AT 1.0 GPM #1



PLOT OF TURBIDITY VS. TIME FOR CROSS FLOW OPERATION AT 1.0 GPM #1



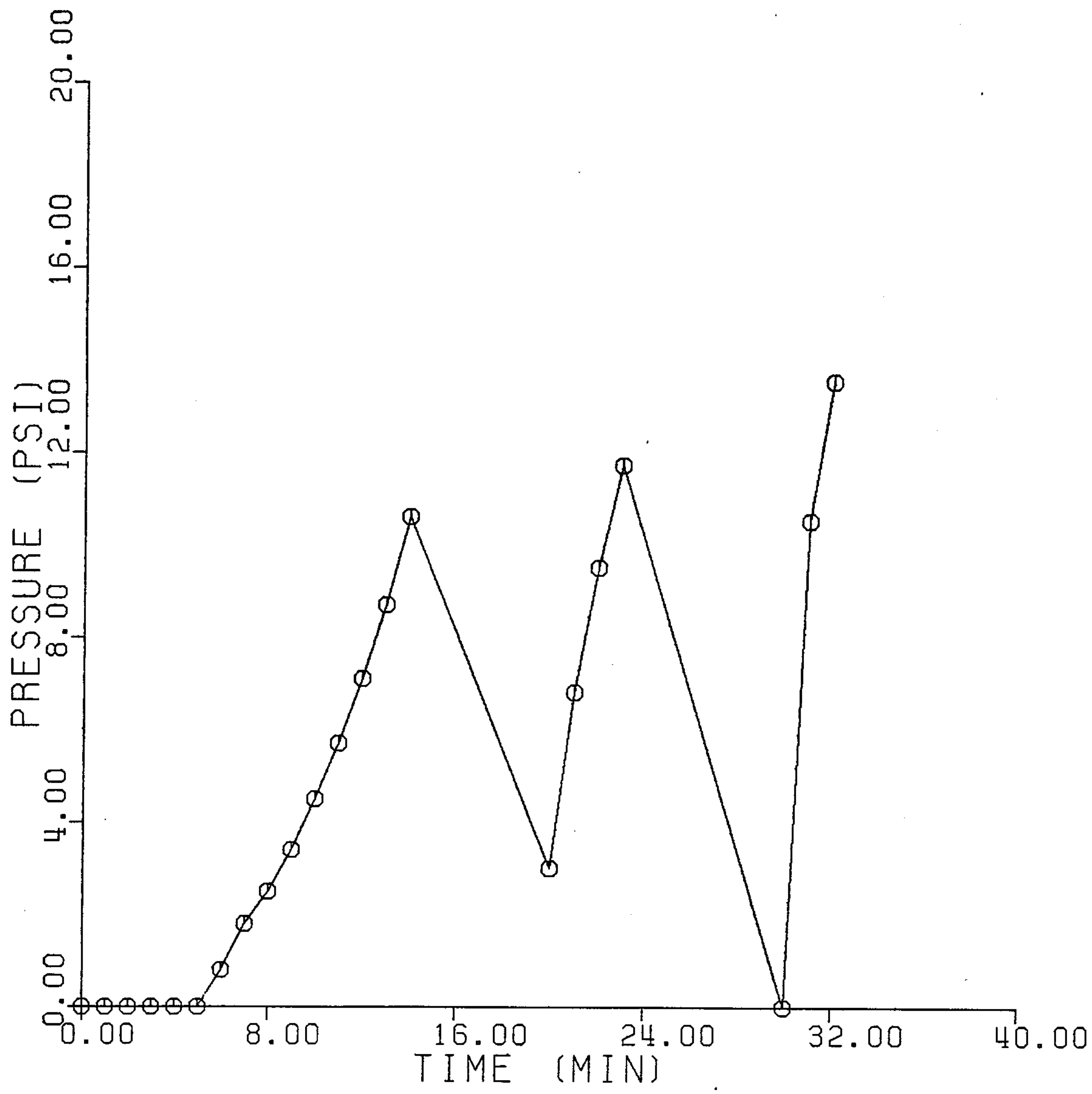
PLOT OF TOTAL PRODUCT VOLUME FOR CROSS FLOW OPERATION AT 1.0 GPM #1



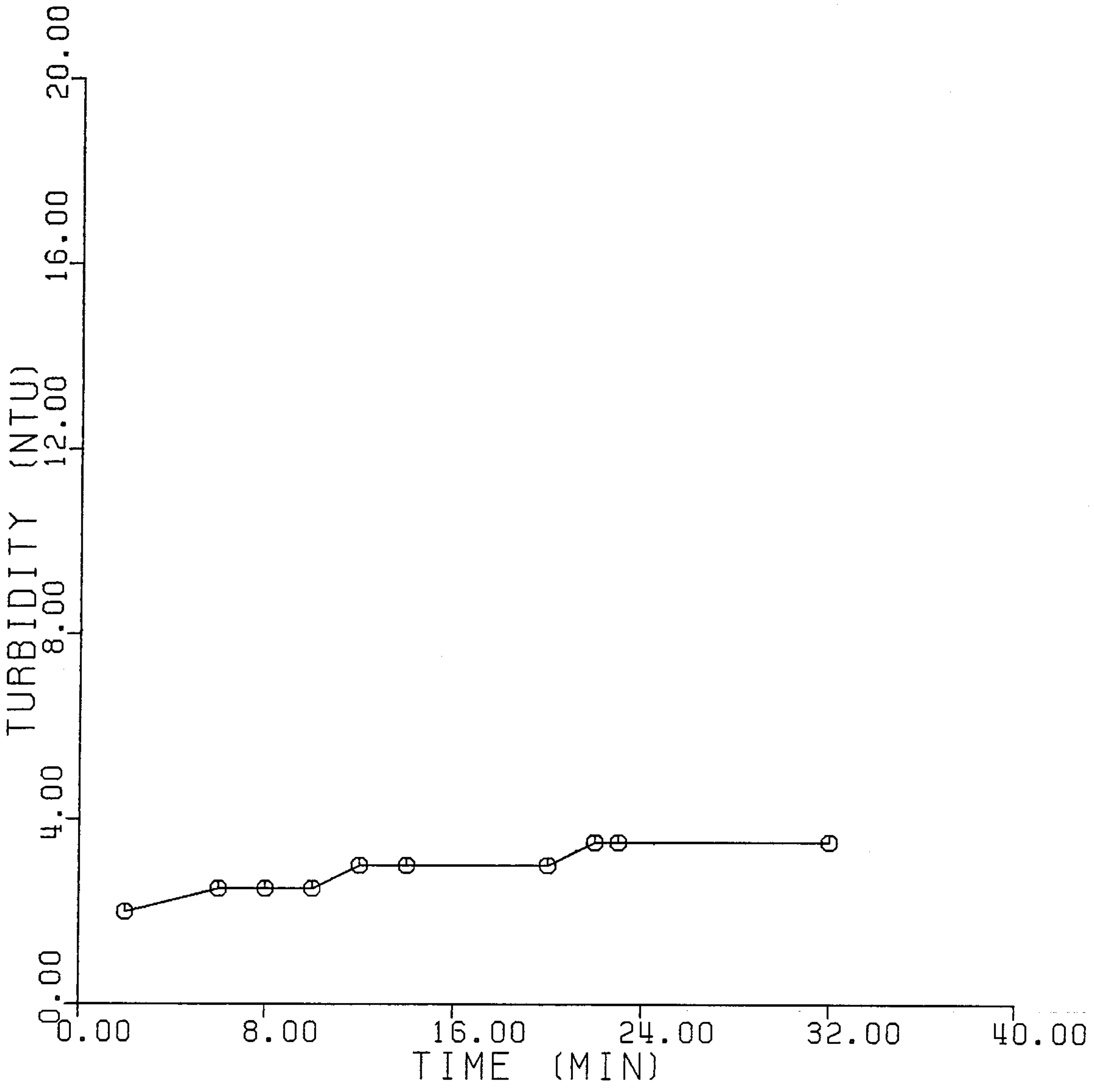
TEST 2

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	.	0
2	1	0.0	.	4
3	2	0.0	2.0	.
4	3	0.0	.	.
5	4	0.0	.	16
6	5	0.0	.	.
7	6	0.8	2.5	.
8	7	1.8	.	.
9	8	2.5	2.5	32
10	9	3.4	.	.
11	10	4.5	2.5	.
12	11	5.7	.	44
13	12	7.1	3.0	.
14	13	8.7	.	.
15	14	10.6	3.0	56
16	20	3.0	3.0	56
17	21	6.8	.	.
18	22	9.5	3.5	.
19	23	11.7	3.5	68
20	30	0.0	.	68
21	31	10.5	.	.
22	32	13.5	3.5	72

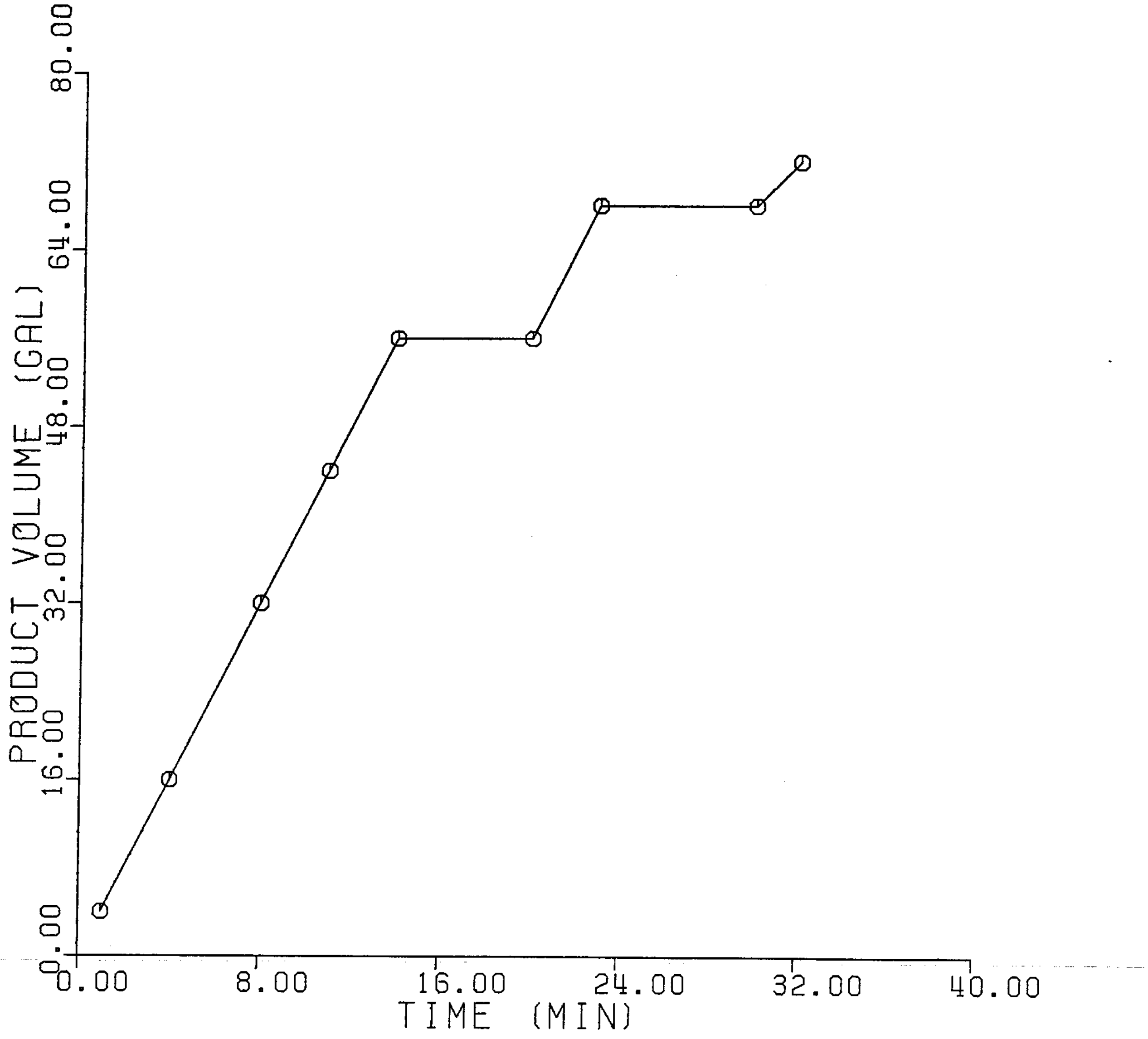
PLOT OF PRESSURE VS. TIME FOR CLOSED END OPERATION AT 4.0 GPM #2



PLOT OF TURBIDITY VS. TIME FOR CLOSED END OPERATION AT 4.0 GPM #2



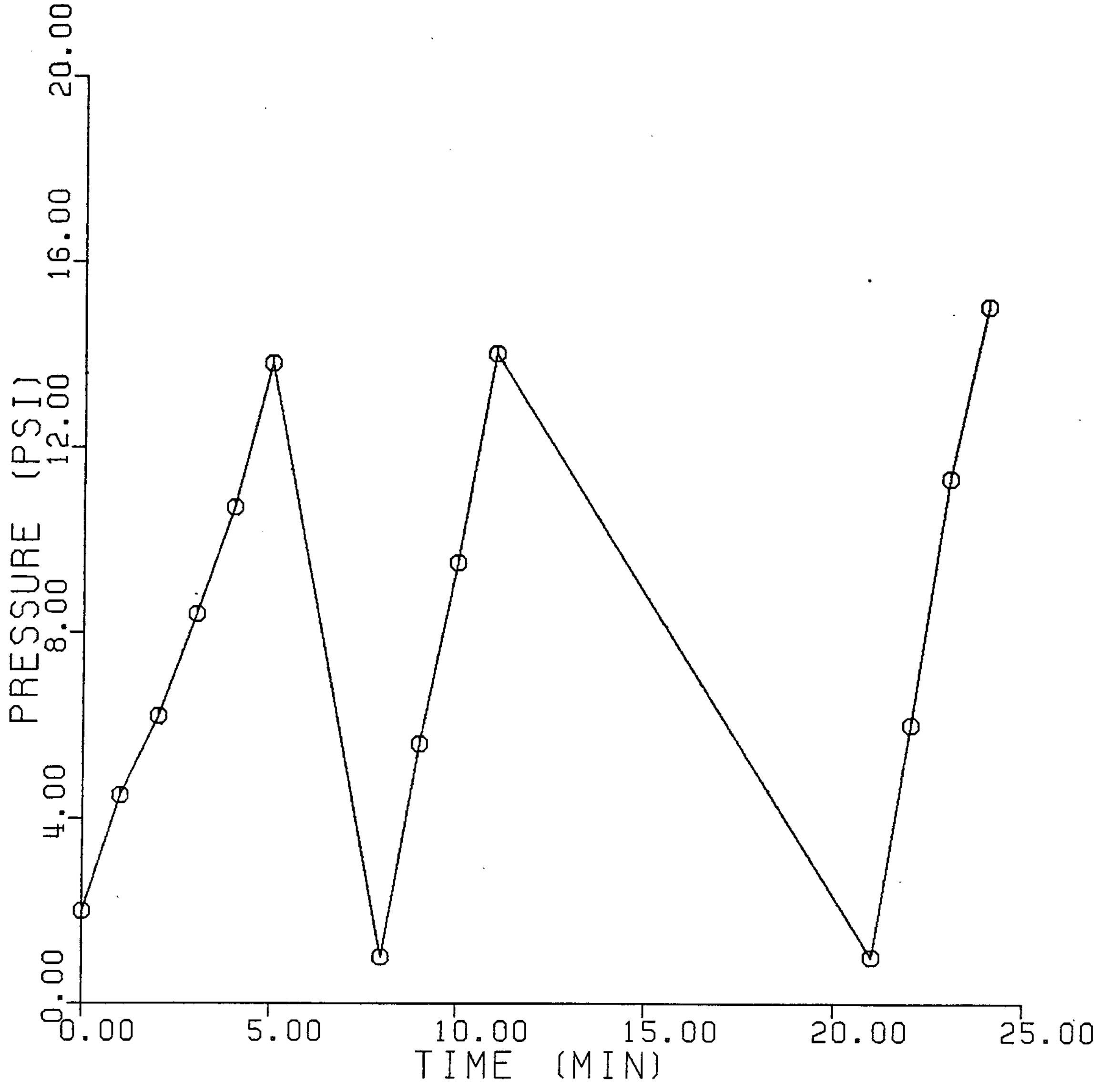
PLOT OF TOTAL PRODUCT VOLUME FOR CLOSED END OPERATION AT 4.0 GPM #2



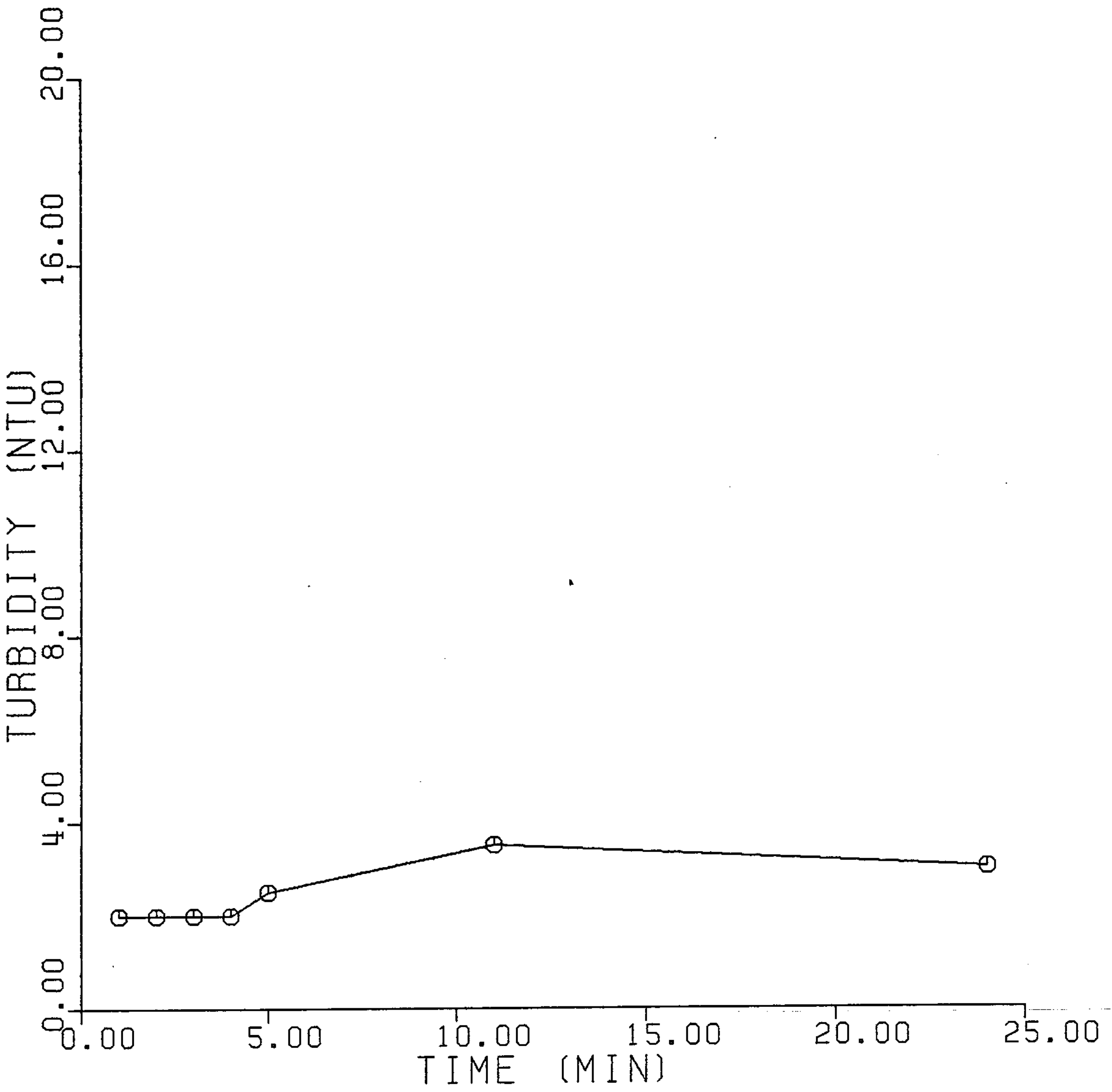
TEST 3

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	2.0	.	0
2	1	4.5	2.0	4
3	2	6.2	2.0	.
4	3	8.4	2.0	12
5	4	10.7	2.0	.
6	5	13.8	2.5	20
7	8	1.0	.	20
8	9	5.6	.	.
9	10	9.5	.	.
10	11	14.0	3.5	32
11	21	1.0	.	32
12	22	6.0	.	.
13	23	11.3	.	.
14	24	15.0	3.0	44

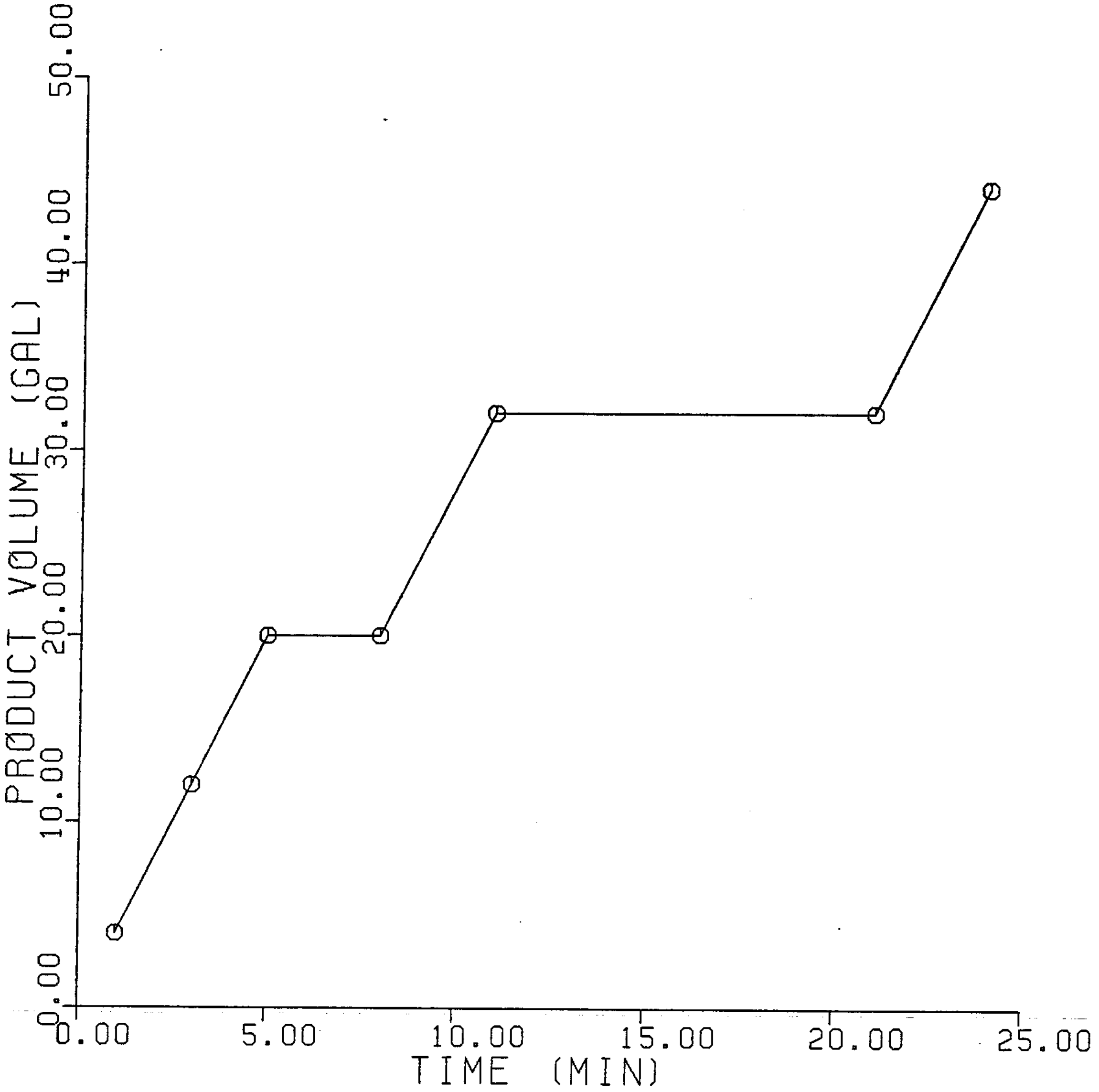
PLOT OF PRESSURE VS. TIME FOR CLOSED END OPERATION AT 4.0 GPM #3



PLOT OF TURBIDITY VS. TIME FOR CLOSED END OPERATION AT 4.0 GPM #3



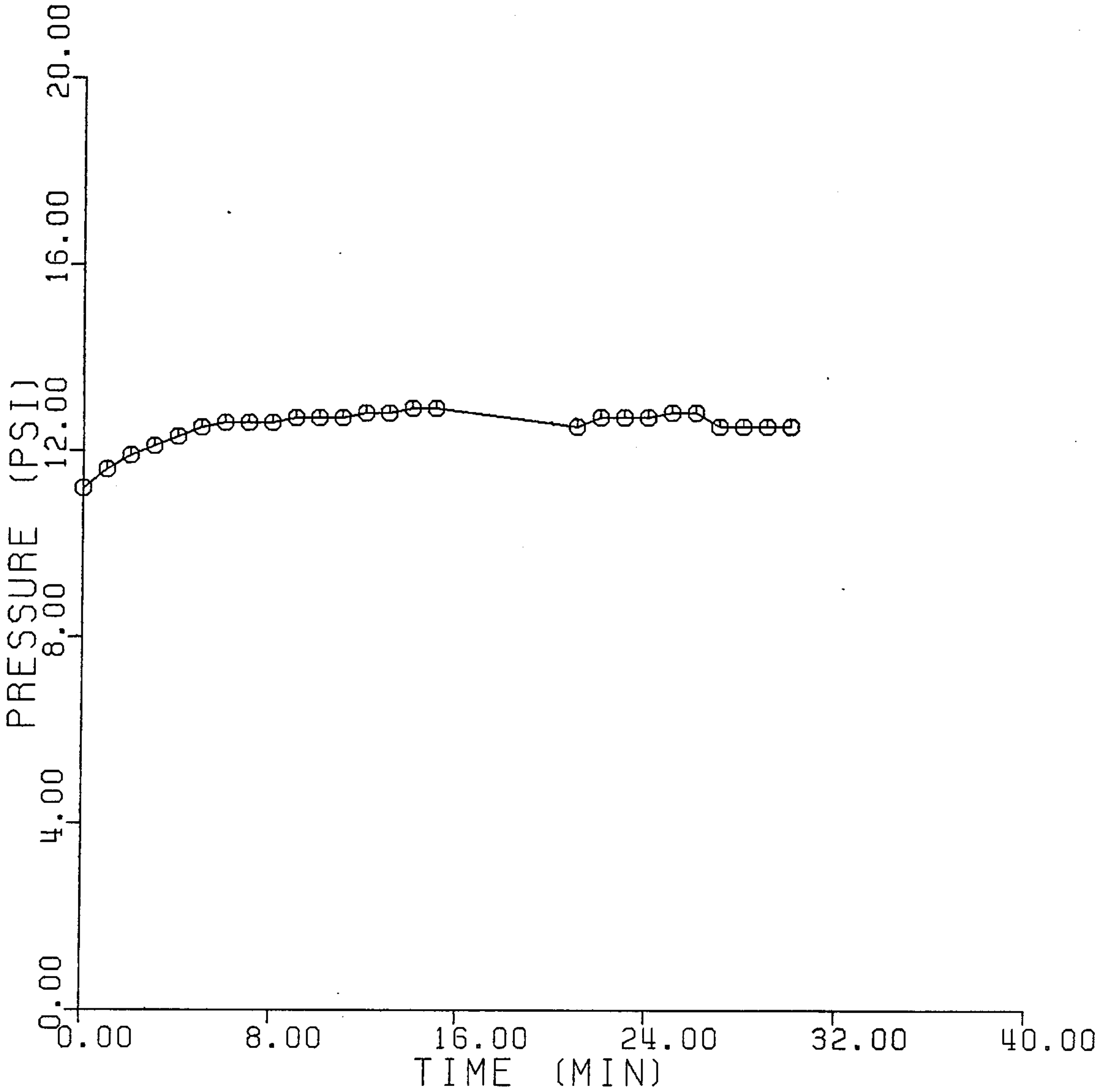
PLOT OF TOTAL PRODUCT VOLUME FOR CLOSED END OPERATION AT 4.0 GPM #3



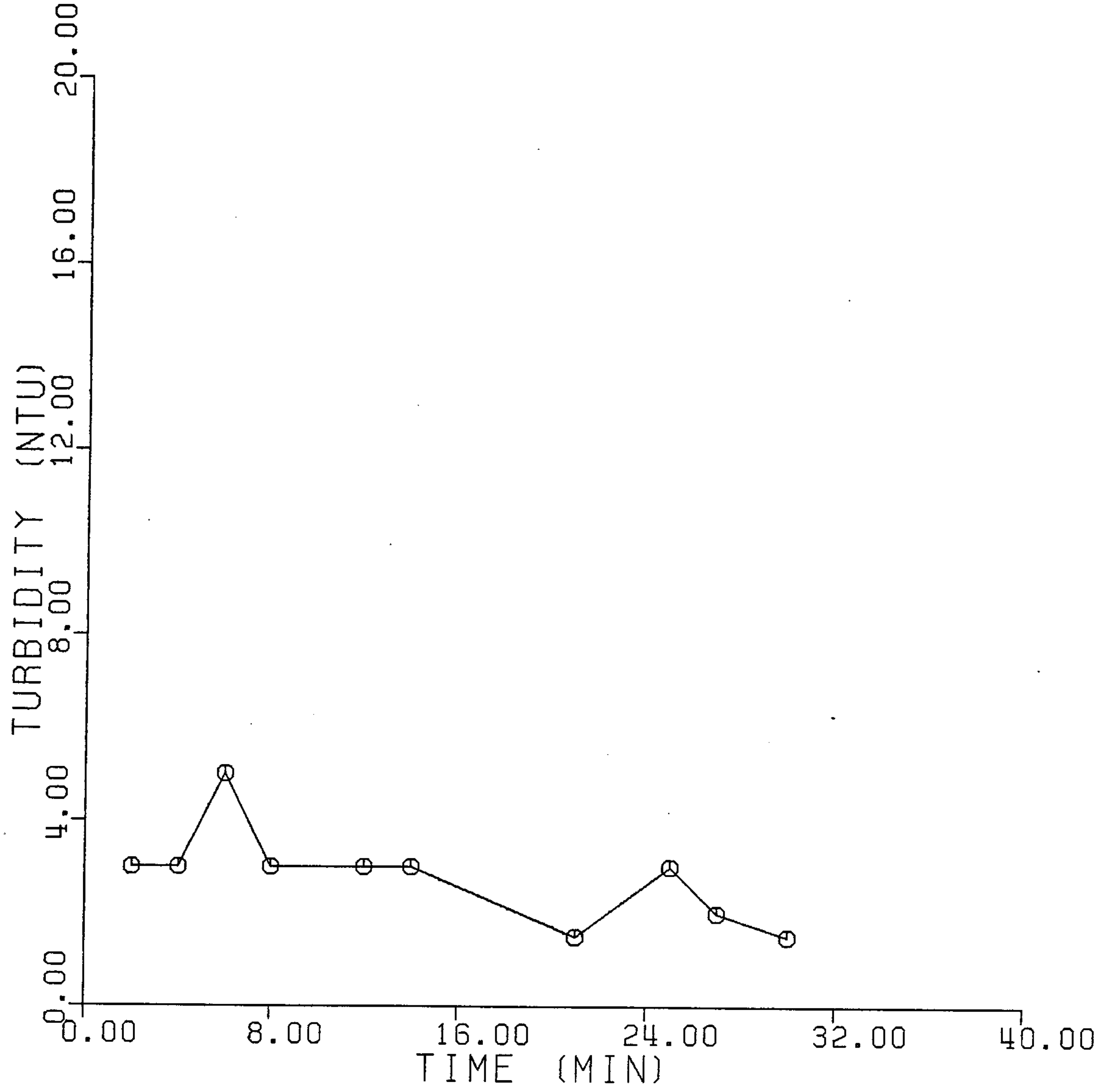
TEST 4

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	11.2	.	.
2	1	11.6	.	1.35
3	2	11.9	3.0	.
4	3	12.1	.	4.04
5	4	12.3	3.0	.
6	5	12.5	.	.
7	6	12.6	5.0	6.16
8	7	12.6	.	.
9	8	12.6	3.0	.
10	9	12.7	.	7.44
11	10	12.7	.	.
12	11	12.7	.	.
13	12	12.8	3.0	.
14	13	12.8	.	8.72
15	14	12.9	3.0	.
16	15	12.9	.	9.20
17	21	12.5	1.5	9.20
18	22	12.7	.	9.42
19	23	12.7	.	.
20	24	12.7	.	.
21	25	12.8	3.0	.
22	26	12.8	.	.
23	27	12.5	2.0	.
24	28	12.5	.	10.41
25	29	12.5	.	.
26	30	12.5	1.5	10.65

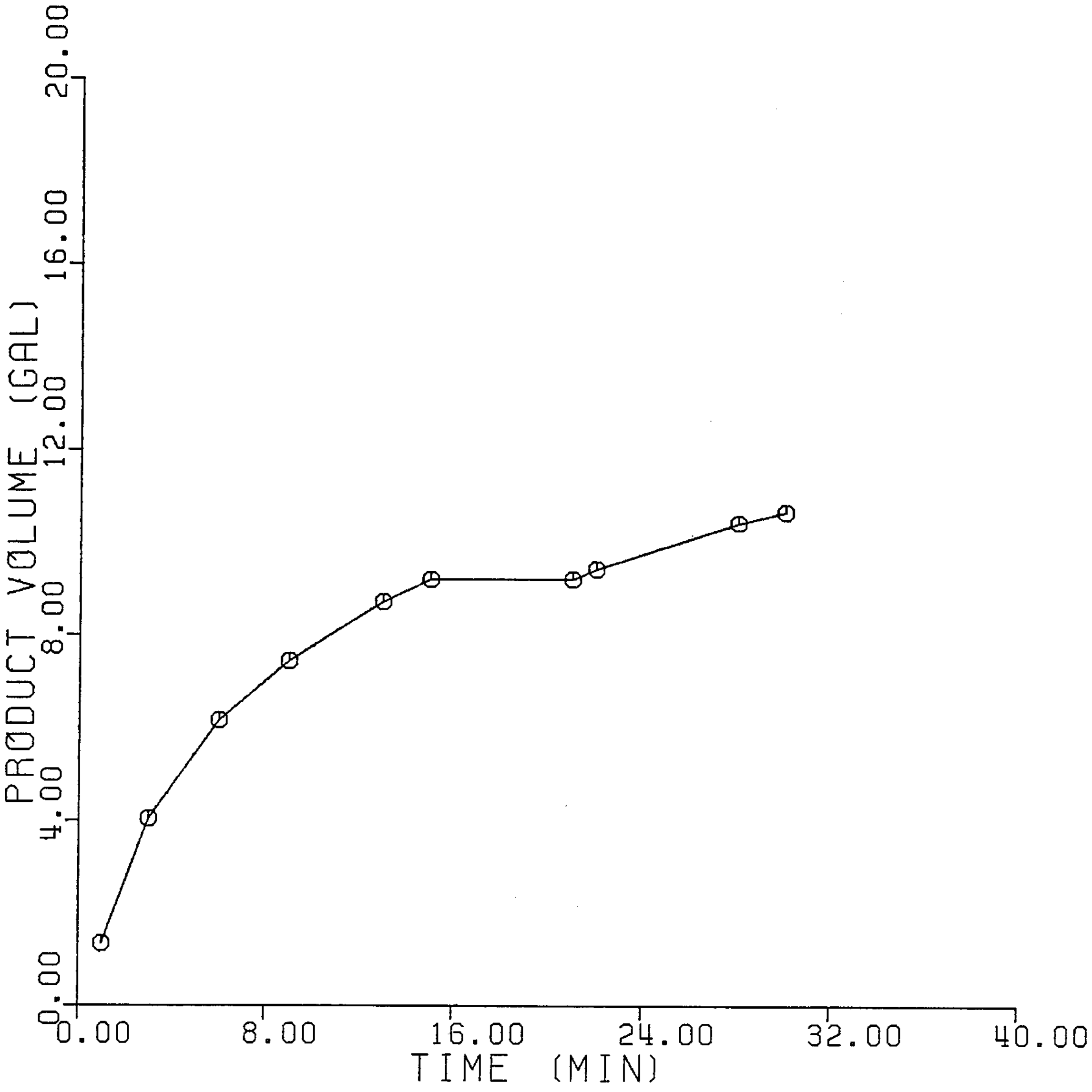
PLOT OF PRESSURE VS. TIME FOR CROSS FLOW OPERATION AT 4.0 GPM #4



PLOT OF TURBIDITY VS. TIME FOR CROSS FLOW OPERATION AT 4.0 GPM #4



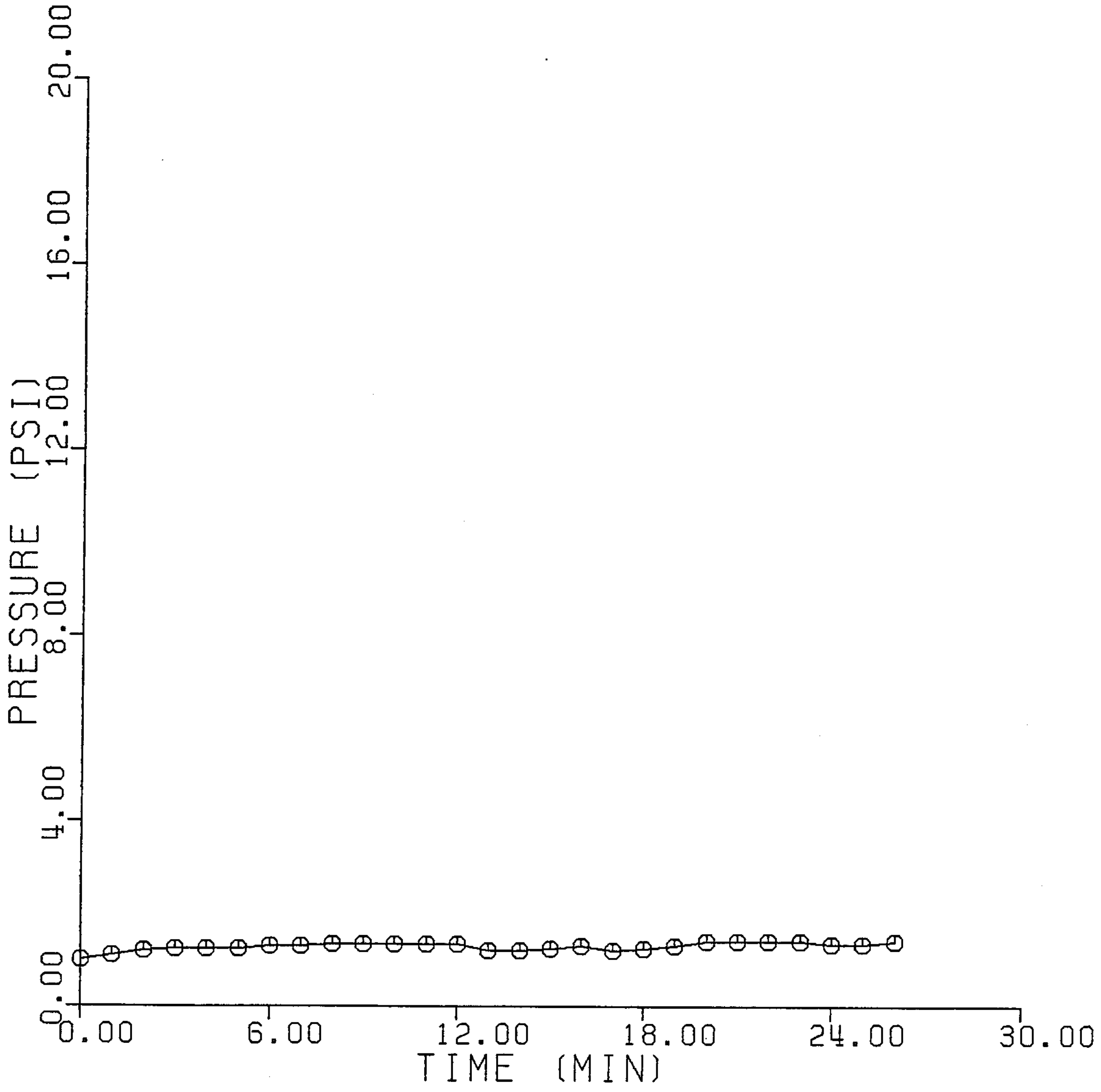
PLOT OF TOTAL PRODUCT VOLUME FOR CROSS FLOW OPERATION AT 4.0 GPM #4



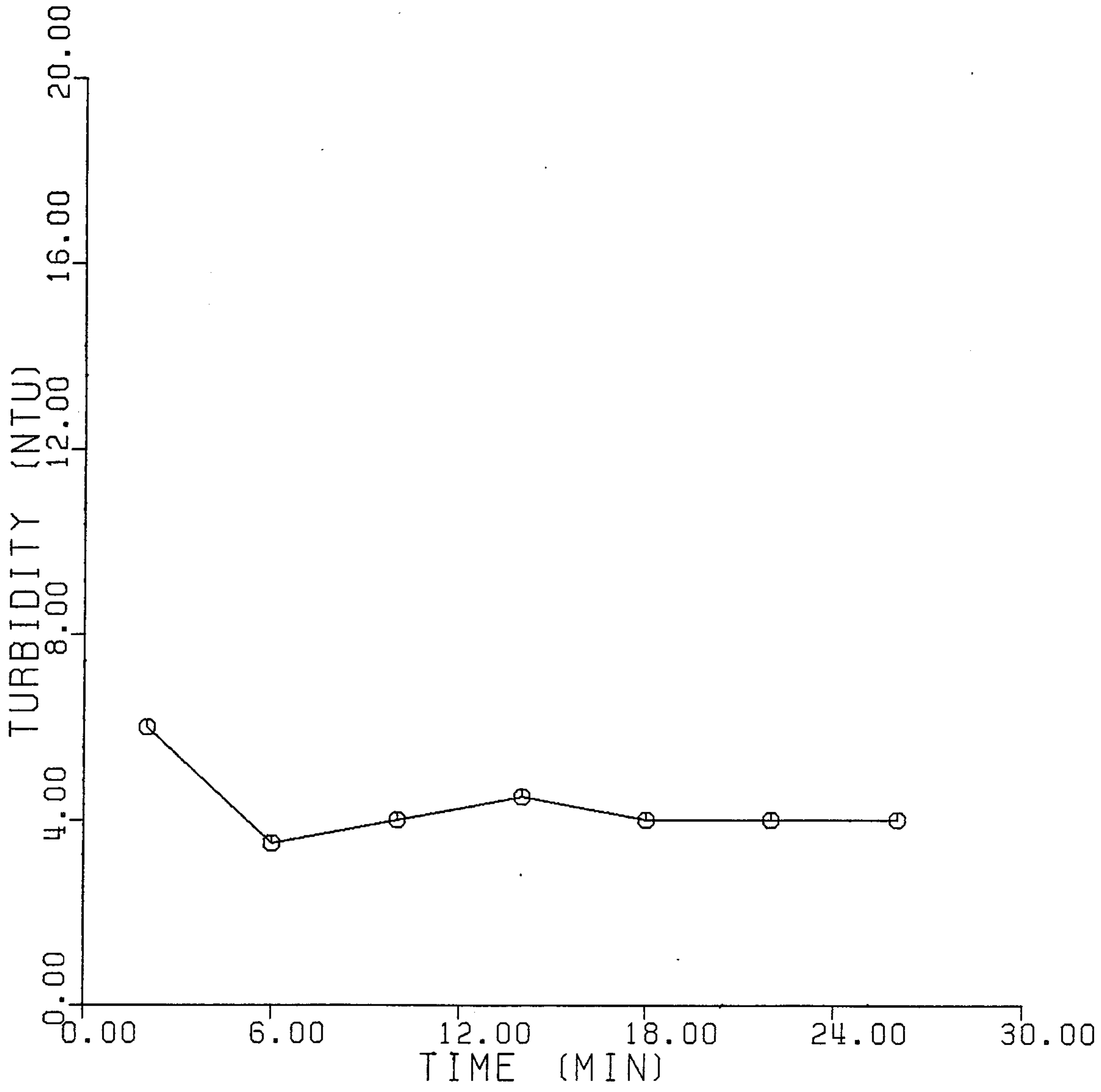
TEST 5

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	1.00	0.0	0.00
2	1	1.10	.	0.48
3	2	1.20	6.0	.
4	3	1.25	.	.
5	4	1.25	.	1.92
6	5	1.25	.	.
7	6	1.30	3.5	.
8	7	1.30	.	.
9	8	1.35	.	3.41
10	9	1.35	.	.
11	10	1.35	4.0	.
12	11	1.35	.	.
13	12	1.35	.	4.43
14	13	1.20	.	.
15	14	1.20	4.5	.
16	15	1.25	.	.
17	16	1.30	.	5.16
18	17	1.20	.	.
19	18	1.25	4.0	.
20	19	1.30	.	.
21	20	1.40	.	5.85
22	21	1.40	.	.
23	22	1.40	4.0	.
24	23	1.40	.	.
25	24	1.35	.	6.46
26	25	1.35	.	.
27	26	1.40	4.0	6.70

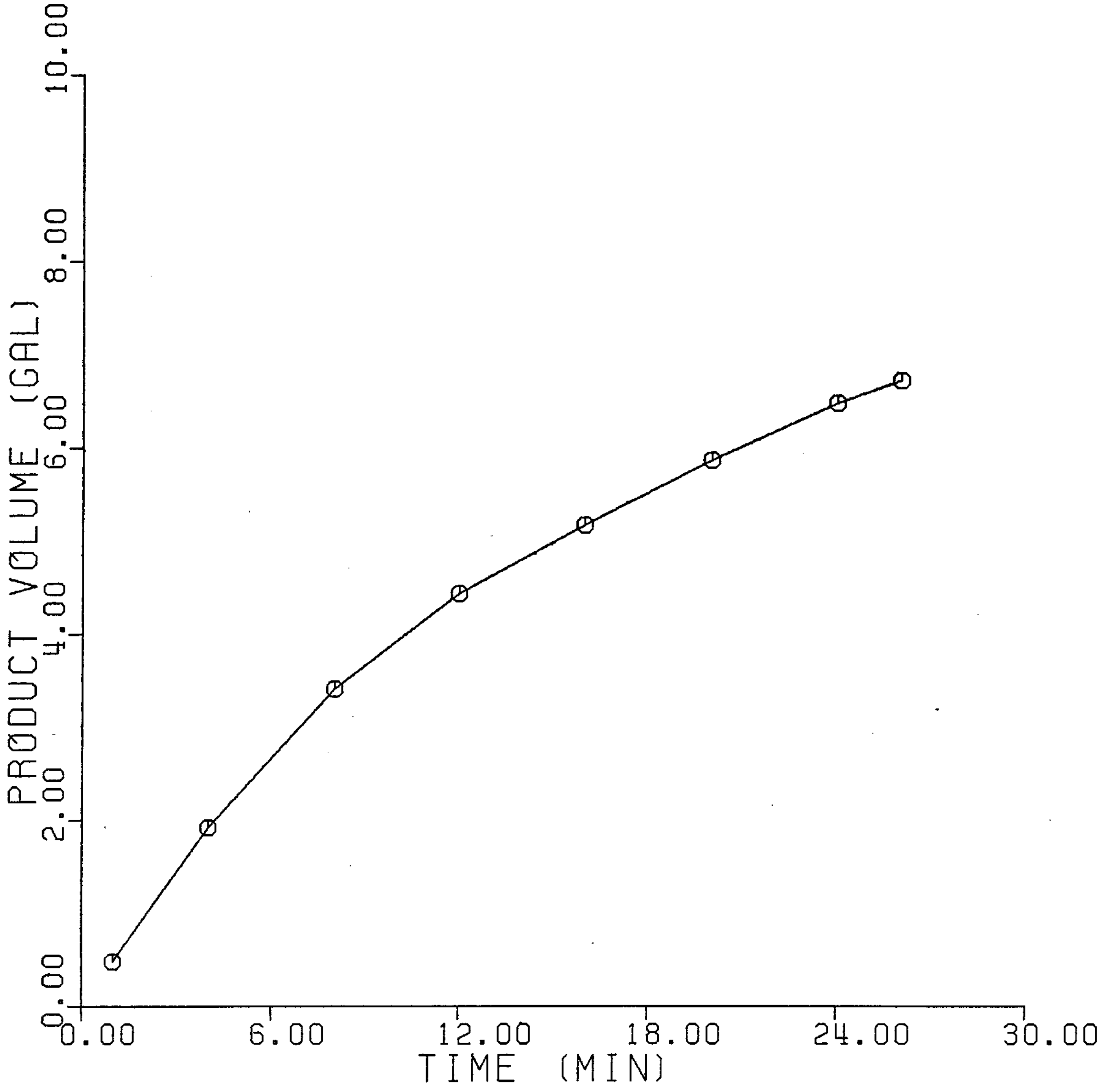
PLOT OF PRESSURE VS. TIME FOR CROSS FLOW OPERATION AT 1.0 GPM #5



PLOT OF TURBIDITY VS. TIME FOR CROSS FLOW OPERATION AT 1.0 GPM #5



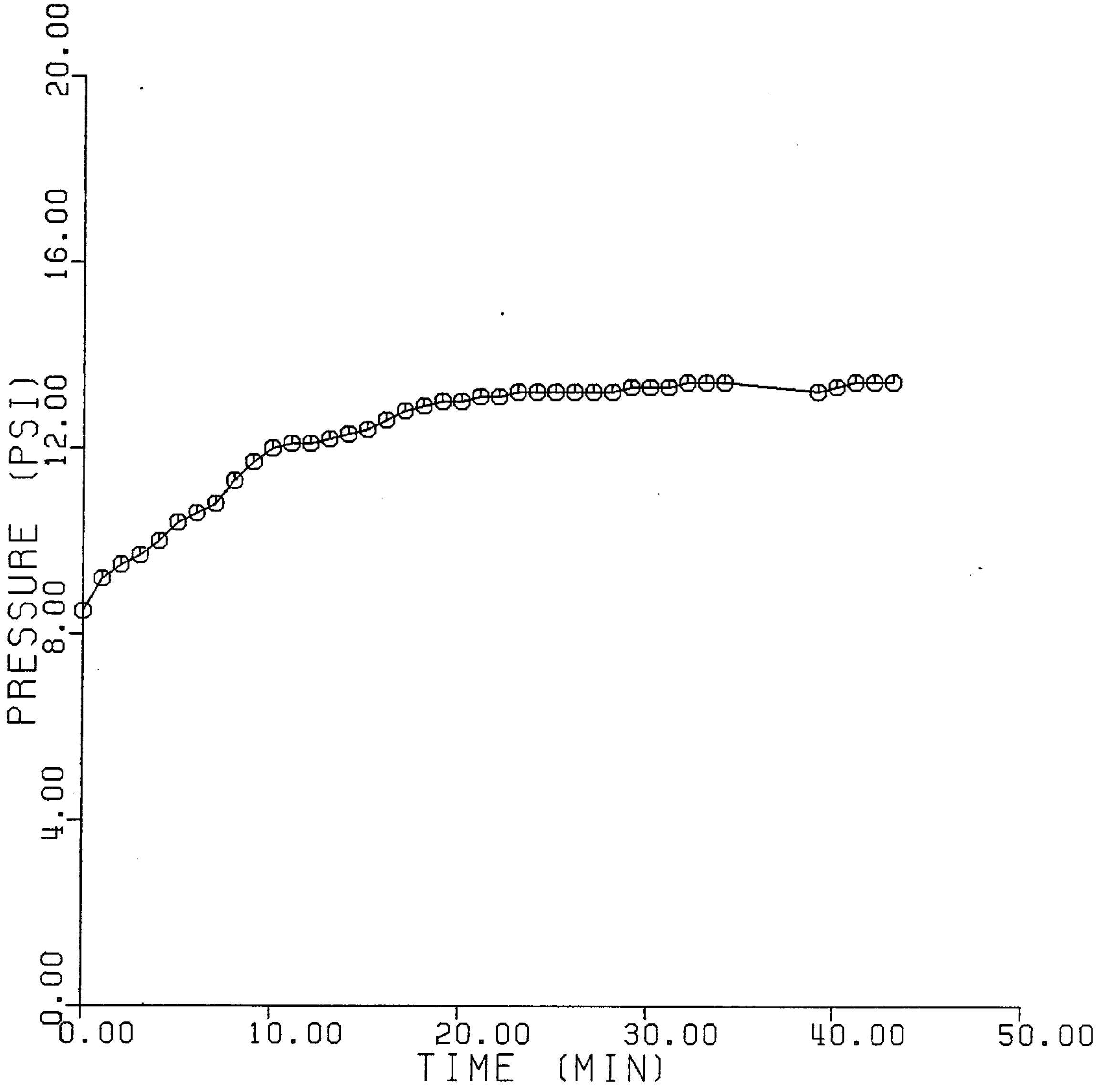
PLOT OF TOTAL PRODUCT VOLUME FOR CROSS FLOW OPERATION AT 1.0 GPM #5



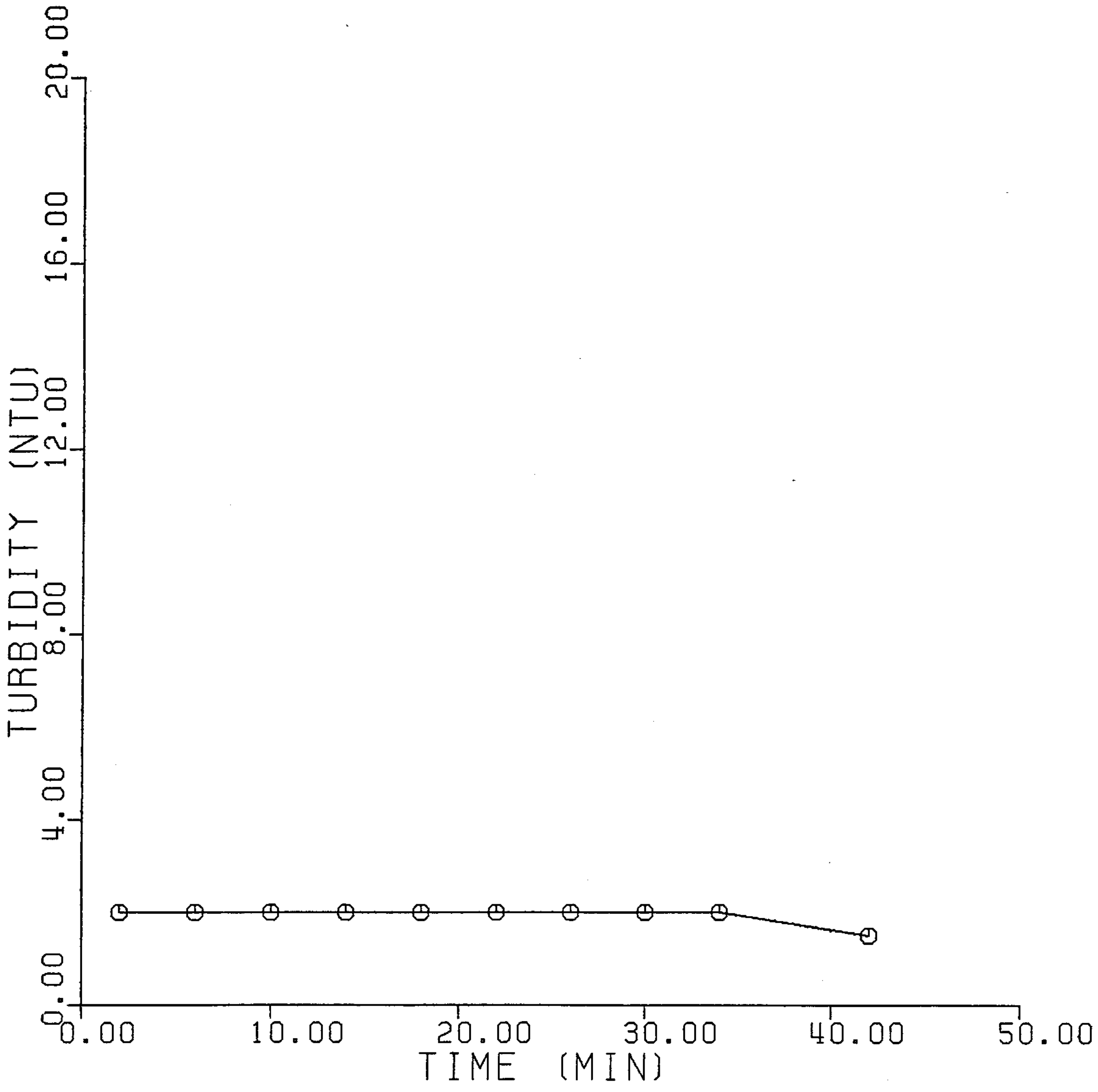
TEST 6

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	8.5	.	0.00
2	1	9.2	.	1.20
3	2	9.5	2.0	.
4	3	9.7	.	4.80
5	4	10.0	.	.
6	5	10.4	.	.
7	6	10.6	2.0	.
8	7	10.8	.	.
9	8	11.3	.	11.24
10	9	11.7	.	.
11	10	12.0	2.0	.
12	11	12.1	.	.
13	12	12.1	.	14.95
14	13	12.2	.	.
15	14	12.3	2.0	.
16	15	12.4	.	.
17	16	12.6	.	17.52
18	17	12.8	.	.
19	18	12.9	2.0	.
20	19	13.0	.	.
21	20	13.0	.	19.43
22	21	13.1	.	.
23	22	13.1	2.0	.
24	23	13.2	.	.
25	24	13.2	.	20.84
26	25	13.2	.	.
27	26	13.2	2.0	.
28	27	13.2	.	.
29	28	13.2	.	21.96
30	29	13.3	.	.
31	30	13.3	2.0	.
32	31	13.3	.	.
33	32	13.4	.	22.85
34	33	13.4	.	.
35	34	13.4	2.0	23.28
36	39	13.2	.	23.28
37	40	13.3	.	23.47
38	41	13.4	.	.
39	42	13.4	1.5	.
40	43	13.4	.	24.00

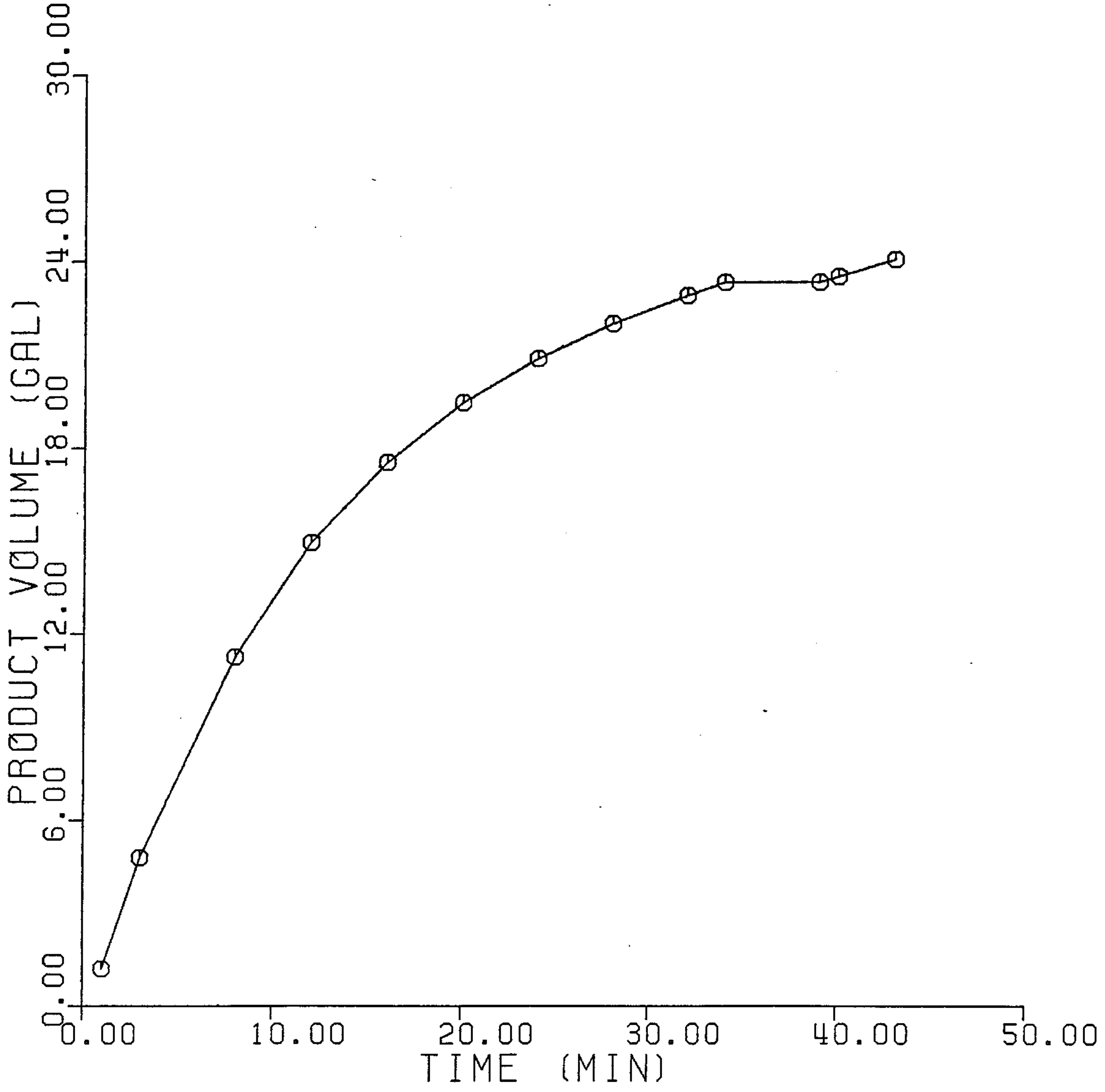
PLOT OF PRESSURE VS. TIME FOR CROSS FLOW OPERATION AT 4.0 GPM #6



PLOT OF TURBIDITY VS. TIME FOR CROSS FLOW OPERATION AT 4.0 GPM #6



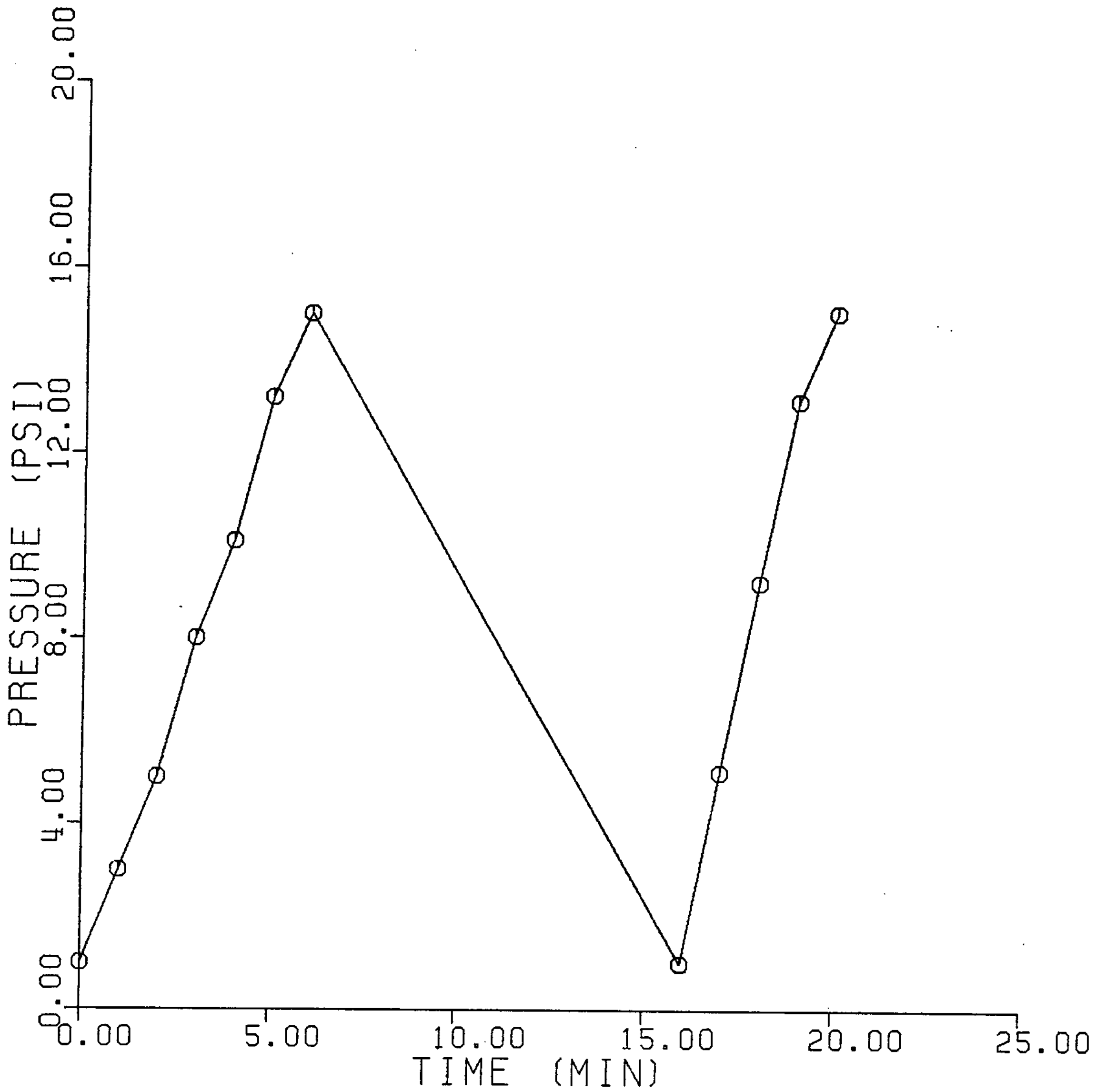
PLOT OF TOTAL PRODUCT VOLUME FOR CROSS FLOW OPERATION AT 4.0 GPM #6



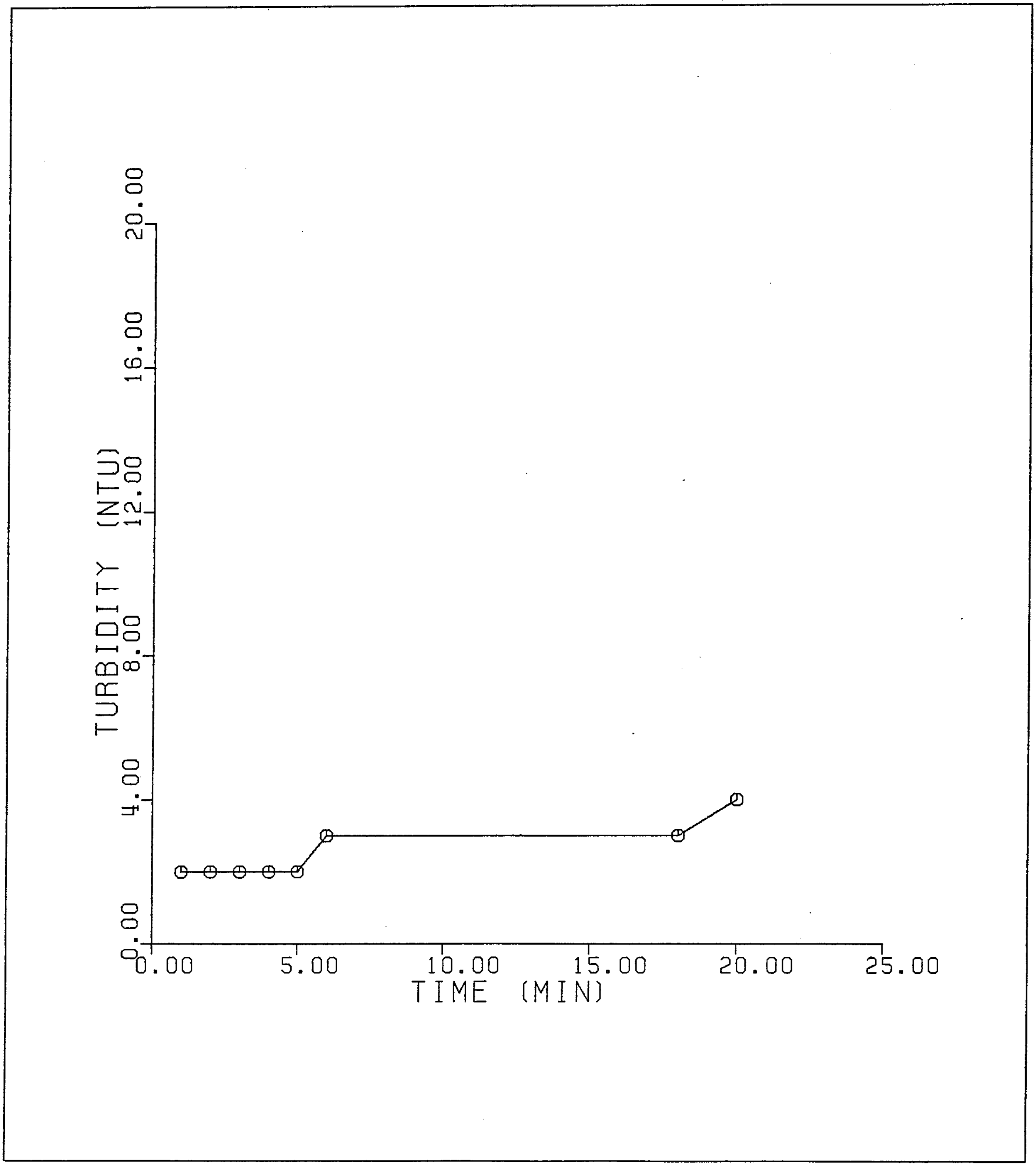
TEST 7

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	1.0	.	0
2	1	3.0	2	4
3	2	5.0	2	.
4	3	8.0	2	.
5	4	10.1	2	16
6	5	13.2	2	.
7	6	15.0	3	24
8	16	1.0	.	24
9	17	5.1	.	.
10	18	9.2	3	32
11	19	13.1	.	.
12	20	15.0	4	40

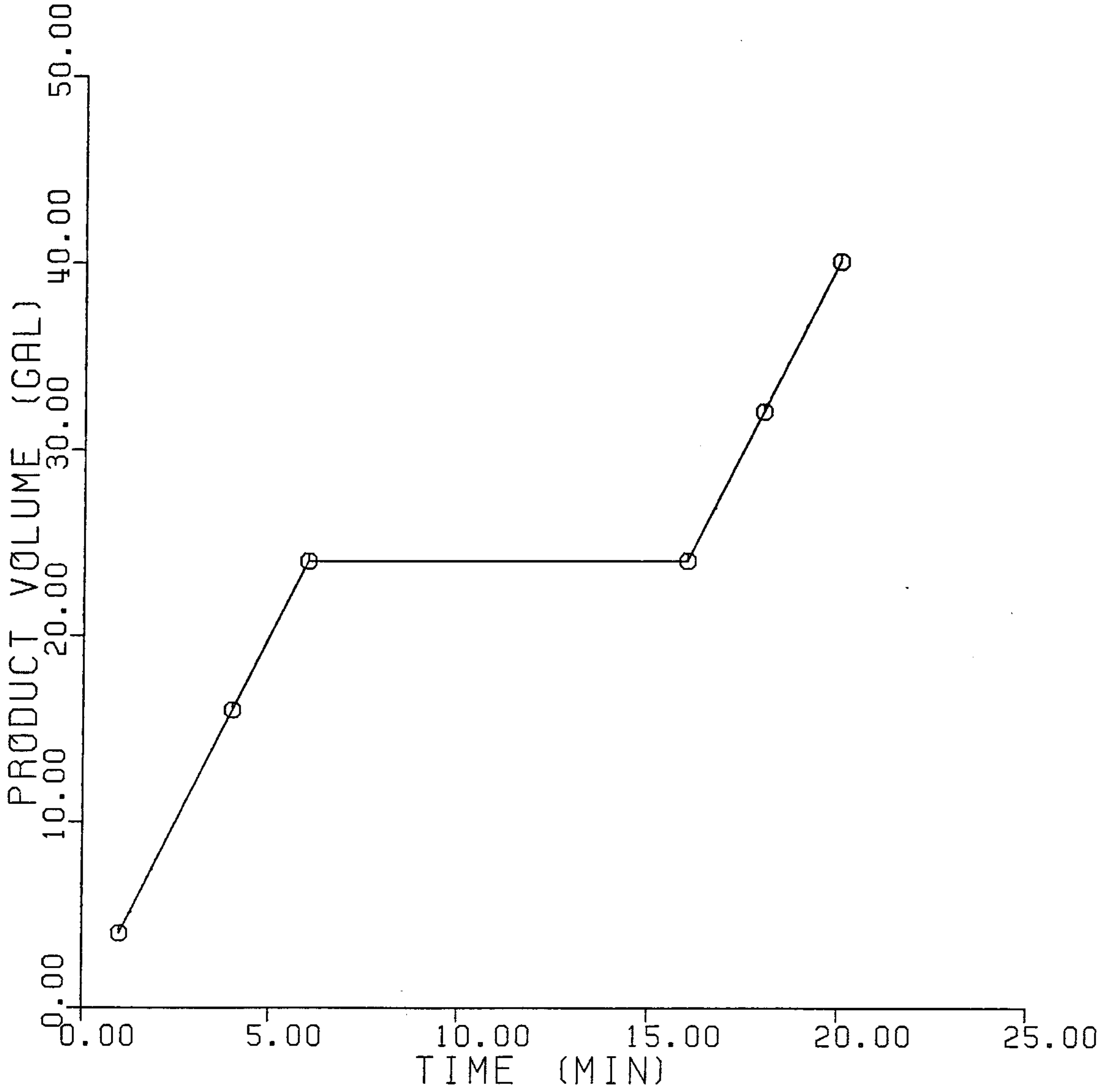
PLOT OF PRESSURE VS. TIME FOR CLOSED END OPERATION AT 4.0 GPM #7



PLOT OF TURBIDITY VS. TIME FOR CLOSED END OPERATION AT 4.0 GPM #7



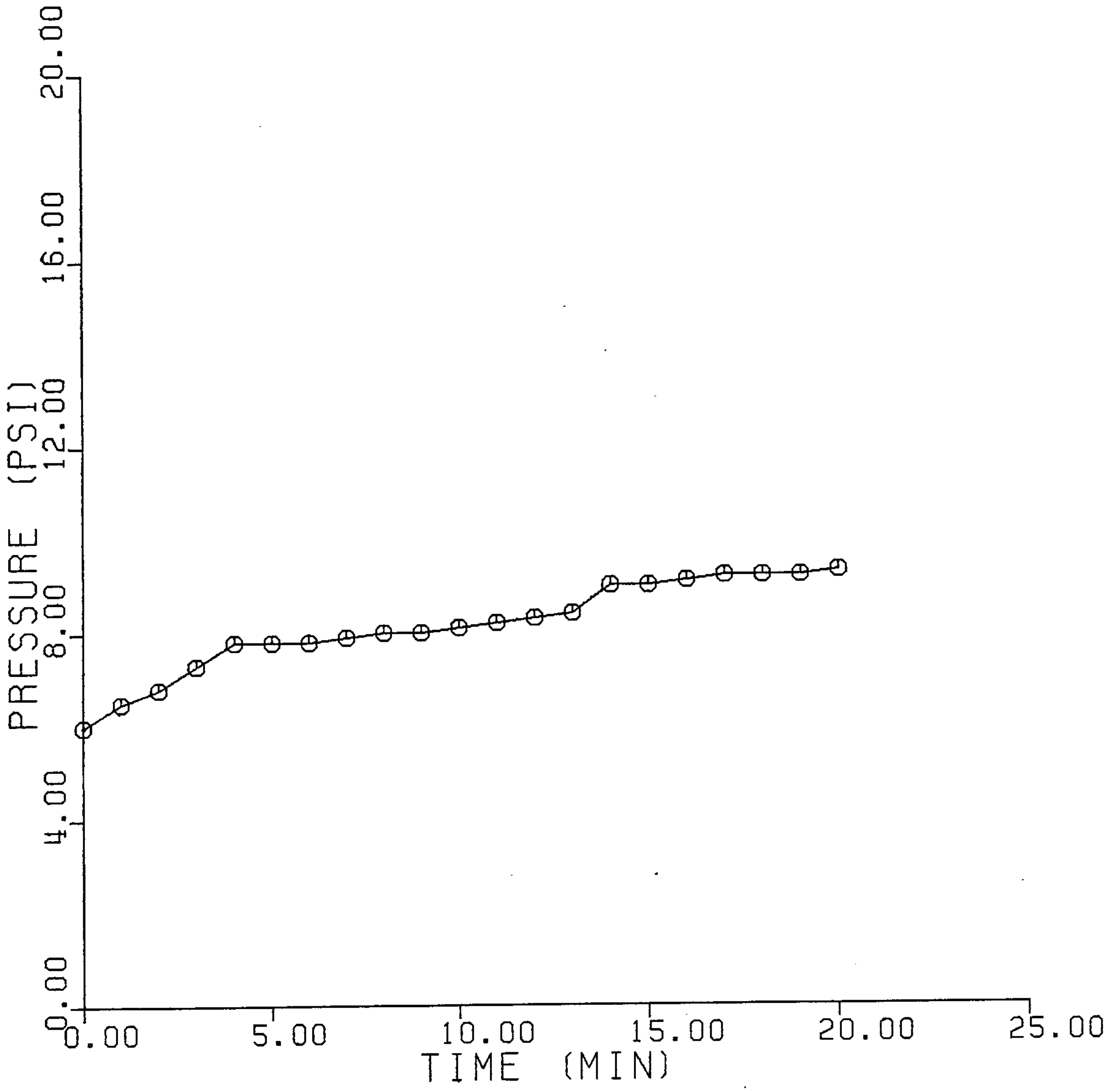
PLOT OF TOTAL PRODUCT VOLUME FOR CLOSED END OPERATION AT 4.0 GPM #7



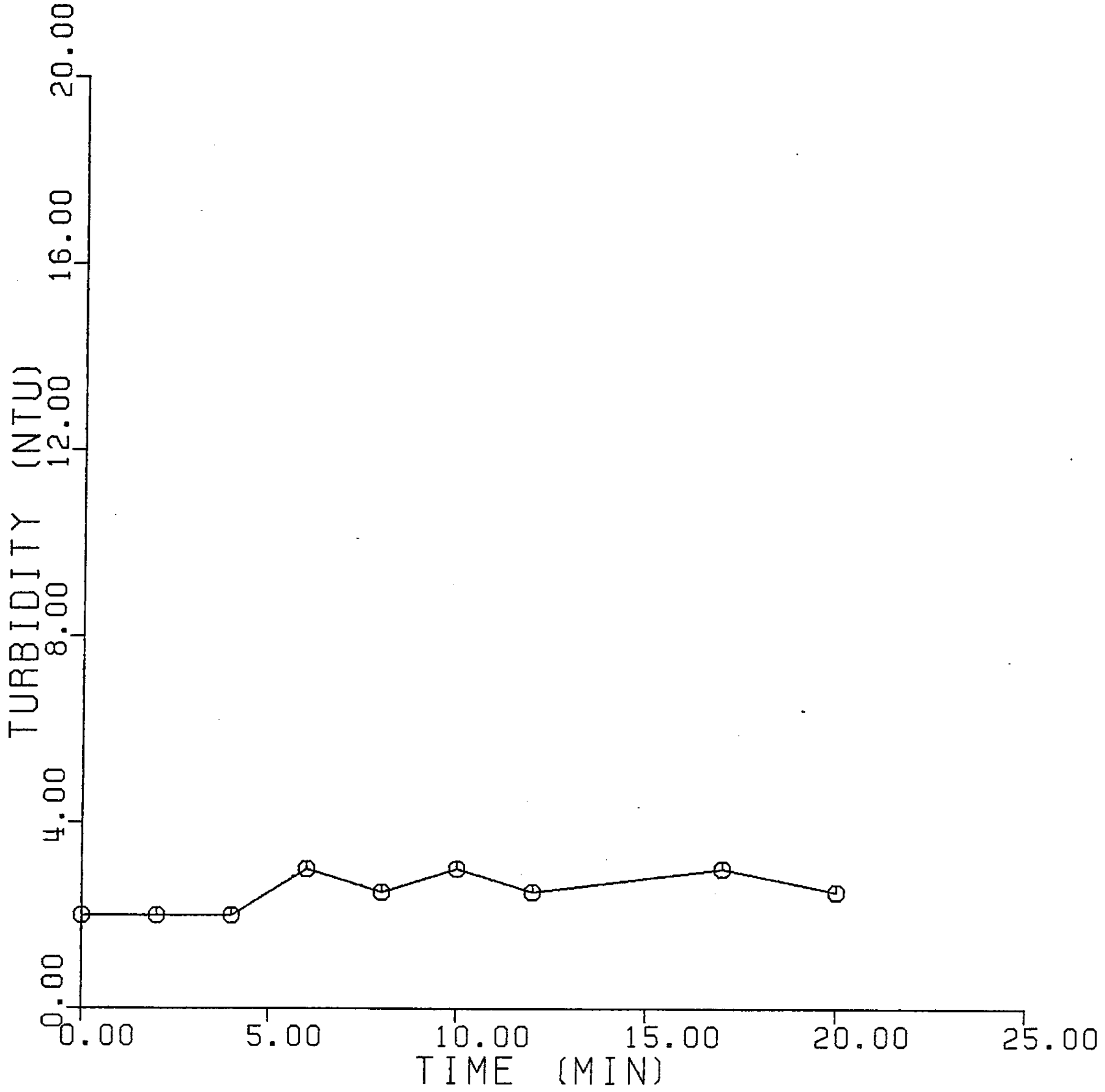
TEST 8

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	6.0	2.0	0.00
2	1	6.5	.	0.75
3	2	6.8	2.0	.
4	3	7.3	.	.
5	4	7.8	2.0	.
6	5	7.8	.	3.41
7	6	7.8	3.0	.
8	7	7.9	.	.
9	8	8.0	2.5	.
10	9	8.0	.	5.59
11	10	8.1	3.0	.
12	11	8.2	.	.
13	12	8.3	2.5	.
14	13	8.4	.	7.49
15	14	9.0	.	.
16	15	9.0	.	.
17	16	9.1	.	8.86
18	17	9.2	3.0	.
19	18	9.2	.	.
20	19	9.2	.	.
21	20	9.3	2.5	10.54

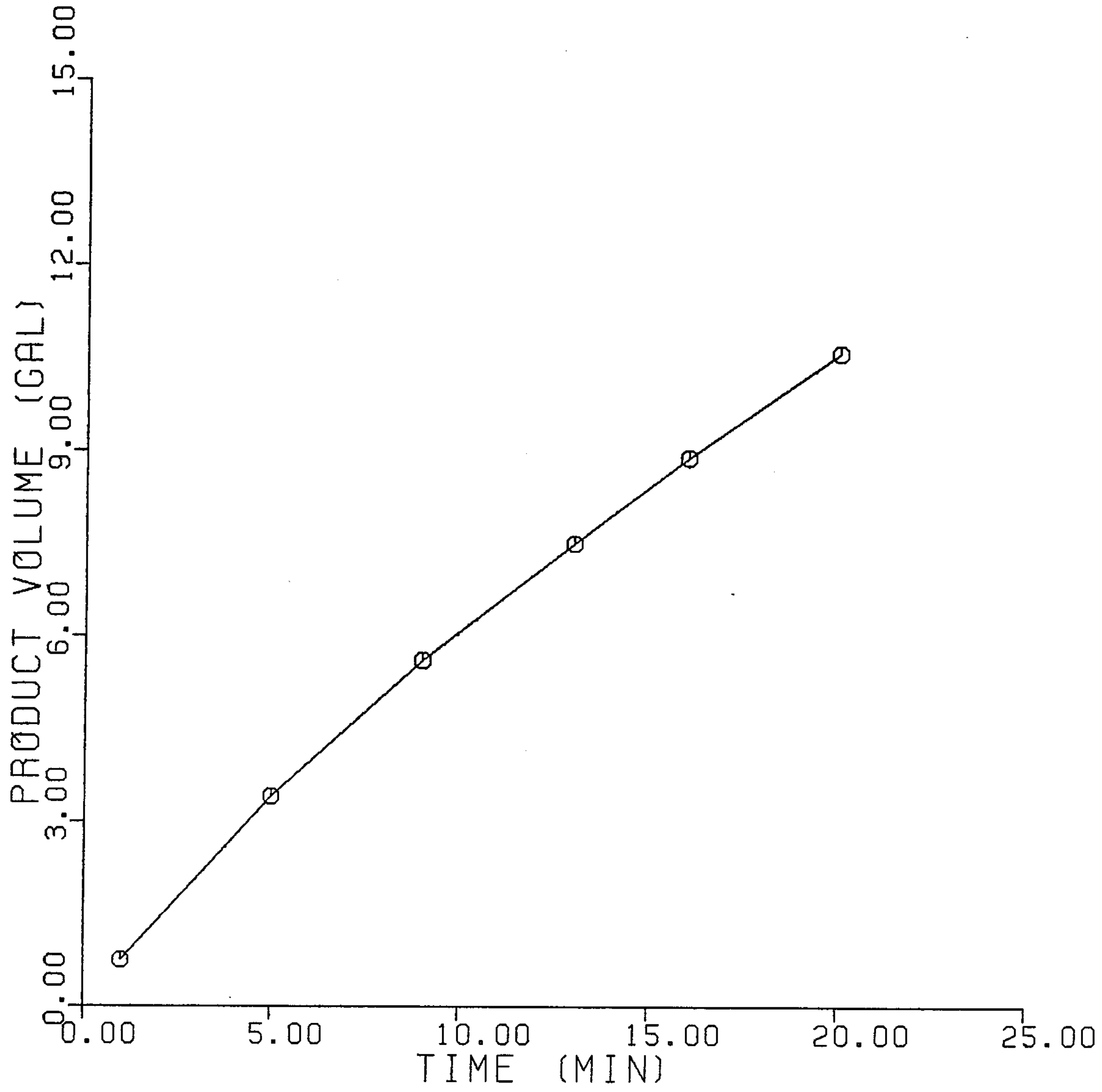
PLOT OF PRESSURE VS. TIME FOR CROSS FLOW OPERATION AT 4.0 GPM #8



PLOT OF TURBIDITY VS. TIME FOR CROSS FLOW OPERATION AT 4.0 GPM #8



PLOT OF TOTAL PRODUCT VOLUME FOR CROSS FLOW OPERATION AT 4.0 GPM #8



TEST 9

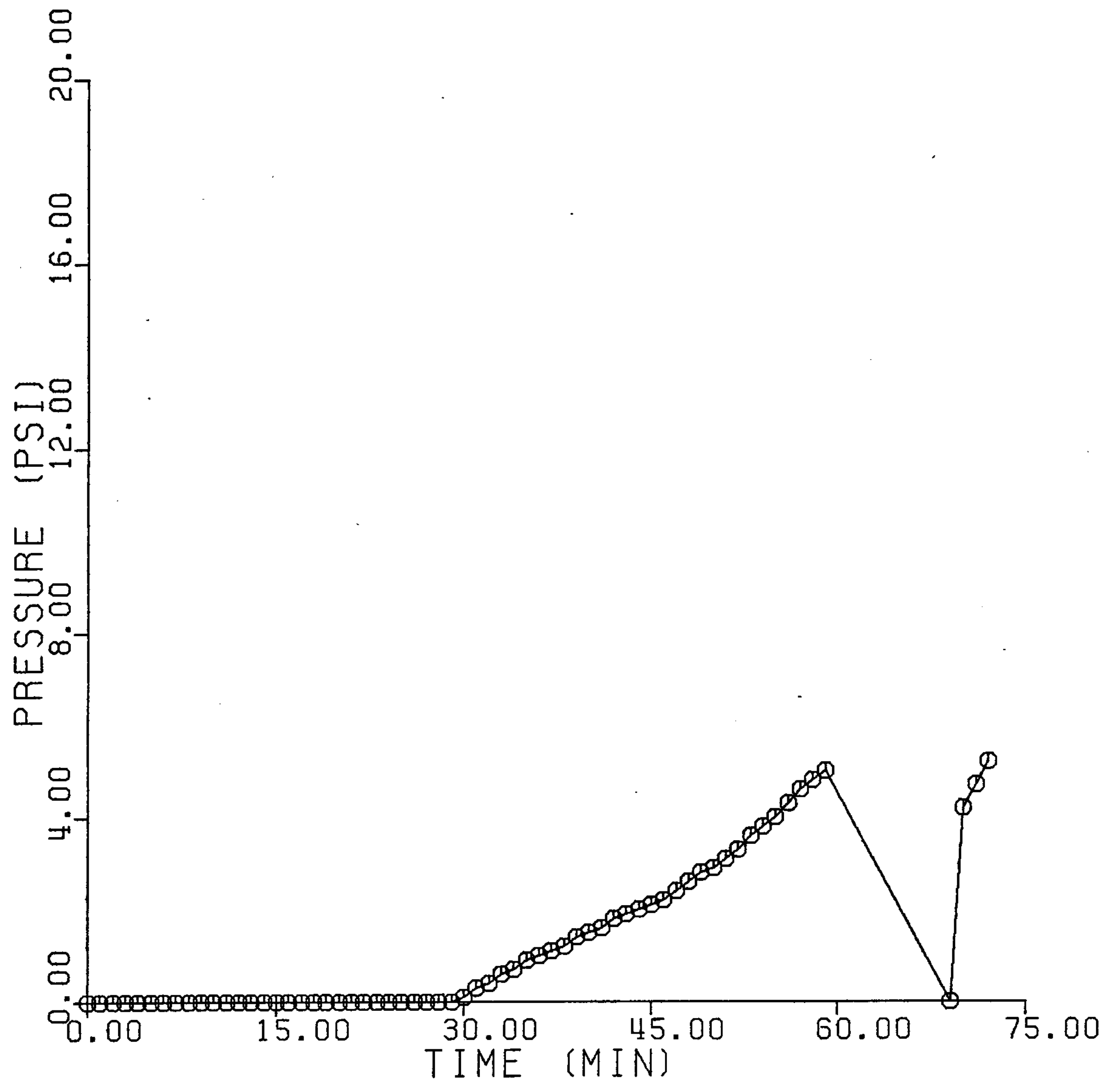
```
OBS    TIME    PRESSURE    TURB    VOLUME

  1      0       0.0        .         .
  2      1       0.0       5.0        1
  3      2       0.0        .         .
  4      3       0.0        .         .
  5      4       0.0        .         .
  6      5       0.0        .         .
  7      6       0.0       5.0        6
  8      7       0.0        .         .
  9      8       0.0        .         .
 10      9       0.0        .         .
 11     10       0.0       5.0        .
 12     11       0.0        .         .
 13     12       0.0        .        12
 14     13       0.0        .         .
 15     14       0.0       5.0        .
 16     15       0.0        .         .
 17     16       0.0        .         .
 18     17       0.0        .         .
 19     18       0.0       4.5       18
 20     19       0.0        .         .
 21     20       0.0        .         .
 22     21       0.0        .         .
 23     22       0.0        .         .
 24     23       0.0        .         .
 25     24       0.0       4.0       24
 26     25       0.0        .         .
 27     26       0.0        .         .
 28     27       0.0        .         .
 29     28       0.0        .         .
 30     29       0.0        .         .
 31     30       0.1        .        30
 32     31       0.3       4.5        .
 33     32       0.4        .         .
 34     33       0.6        .         .
 35     34       0.7        .         .
 36     35       0.9        .         .
 37     36       1.0       4.5       36
 38     37       1.1        .         .
 39     38       1.2        .         .
 40     39       1.4        .         .
 41     40       1.5        .         .
 42     41       1.6        .         .
 43     42       1.8       4.5       42
 44     43       1.9        .         .
 45     44       2.0        .         .
 46     45       2.1        .         .
 47     46       2.2        .         .
 48     47       2.4        .         .
 49     48       2.6       4.5       48
 50     49       2.8        .         .
 51     50       2.9        .         .
 52     51       3.1        .         .
 53     52       3.3        .         .
```

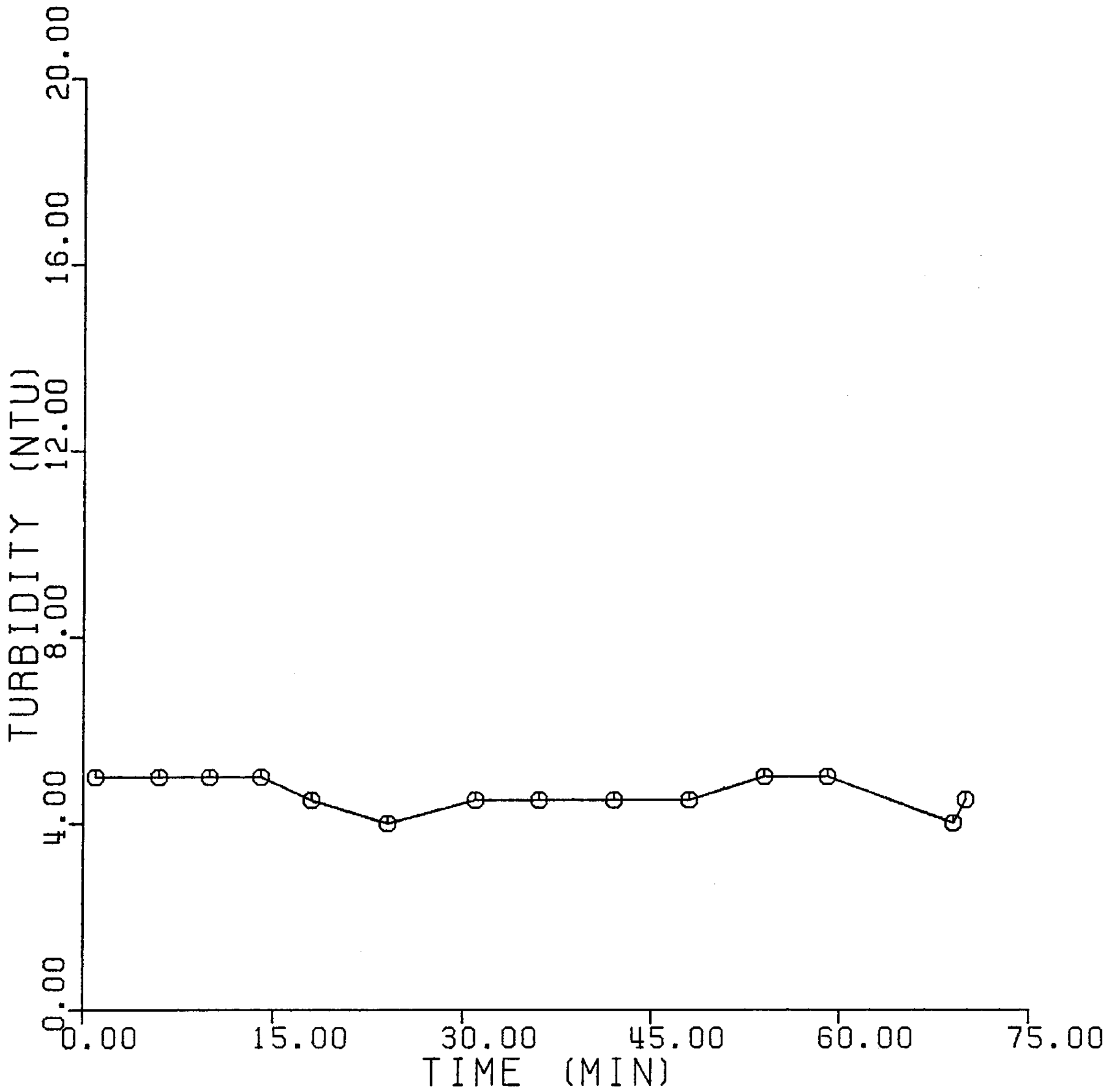
TEST 9 cont

OBS	TIME	PRESSURE	TURB	VOLUME
54	53	3.6	.	.
55	54	3.8	5.0	54
56	55	4.0	.	.
57	56	4.3	.	.
58	57	4.6	.	.
59	58	4.8	.	.
60	59	5.0	5.0	59
61	69	0.0	4.0	59
62	70	4.2	4.5	.
63	71	4.7	.	.
64	72	5.2	.	62

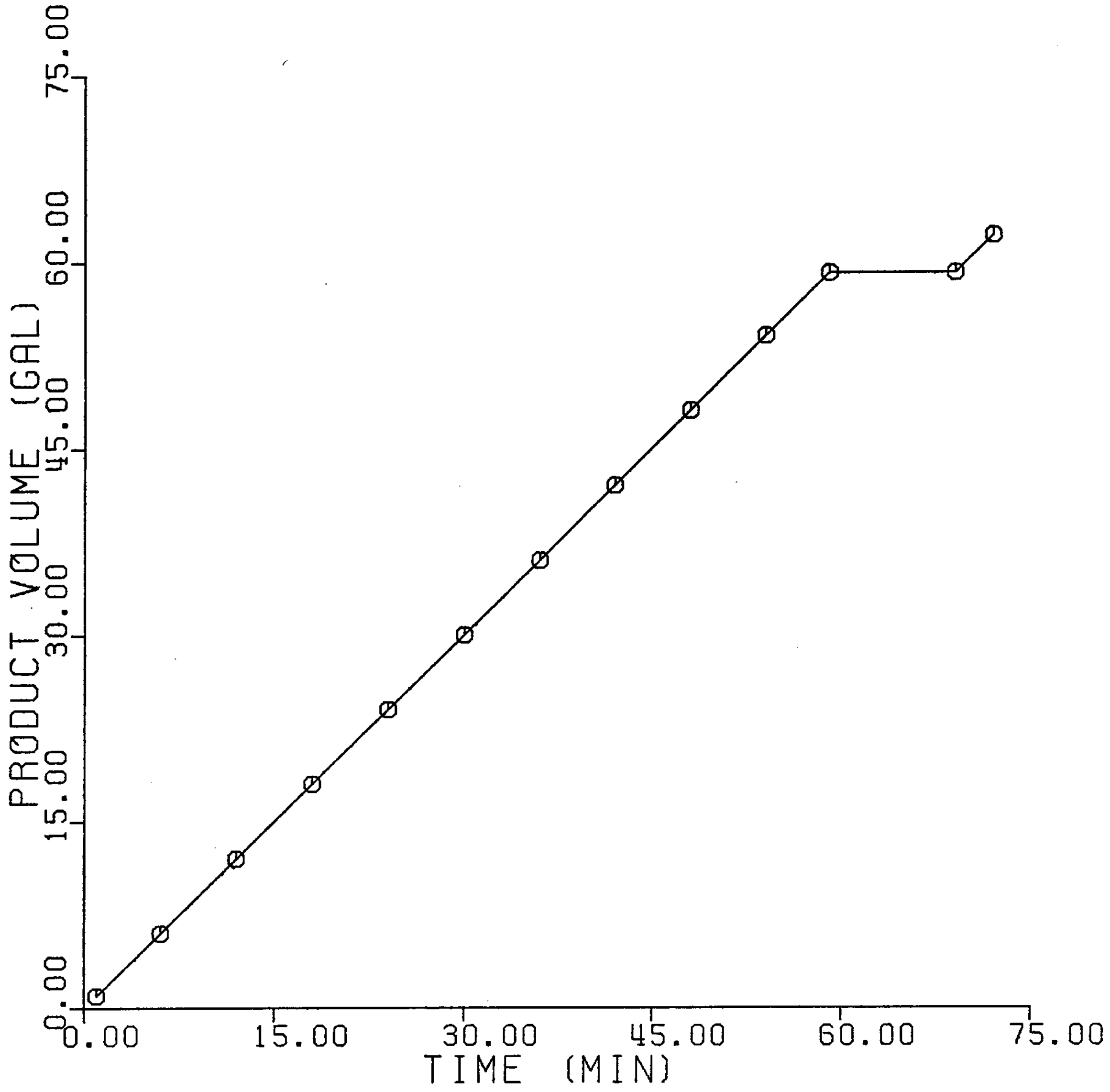
PLOT OF PRESSURE VS. TIME FOR CLOSED END OPERATION AT 1.0 GPM #9



PLOT OF TURBIDITY VS. TIME FOR CLOSED END OPERATION AT 1.0 GPM #9



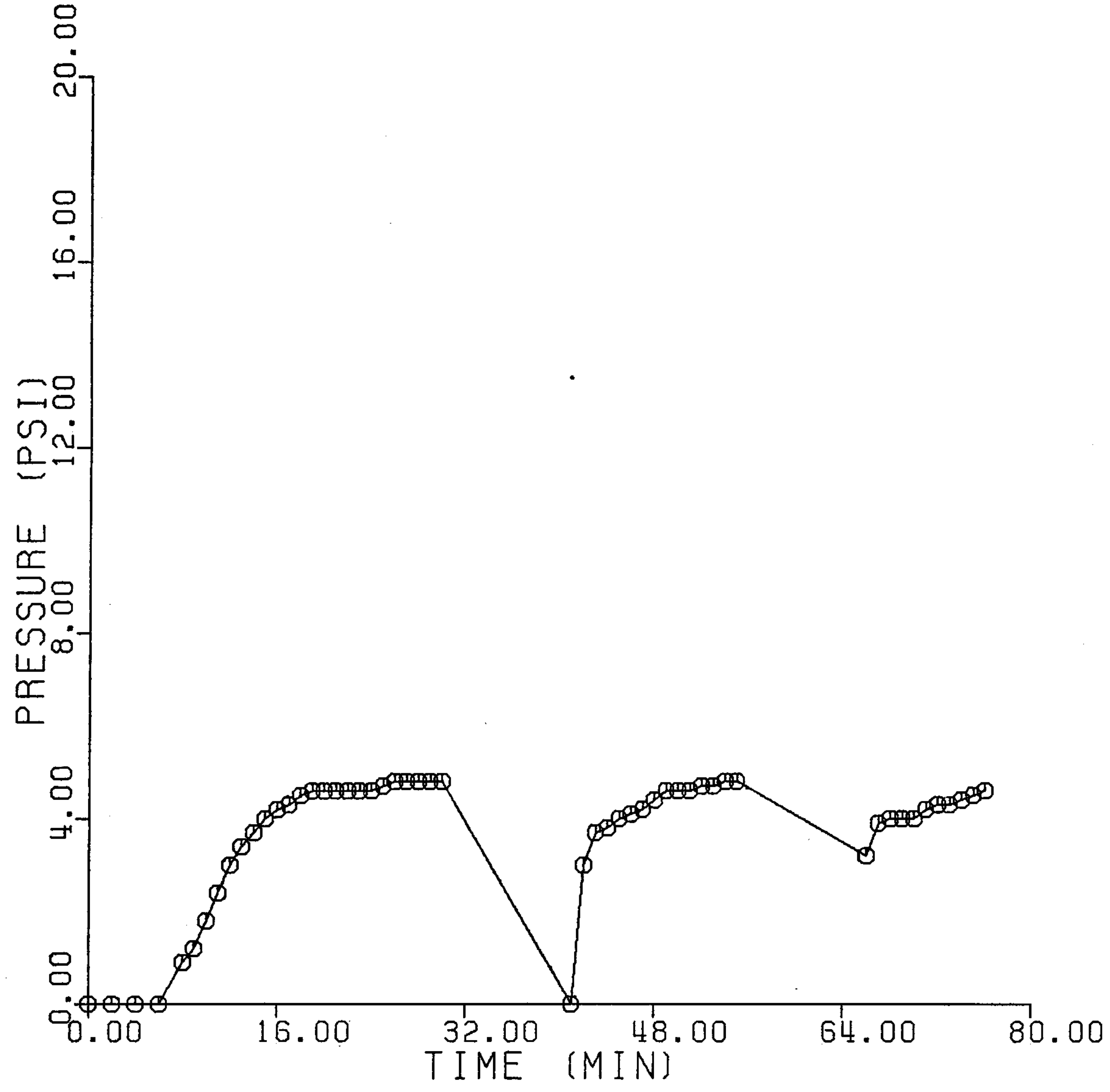
PLOT OF TOTAL PRODUCT VOLUME FOR CLOSED END OPERATION AT 1.0 GPM #9



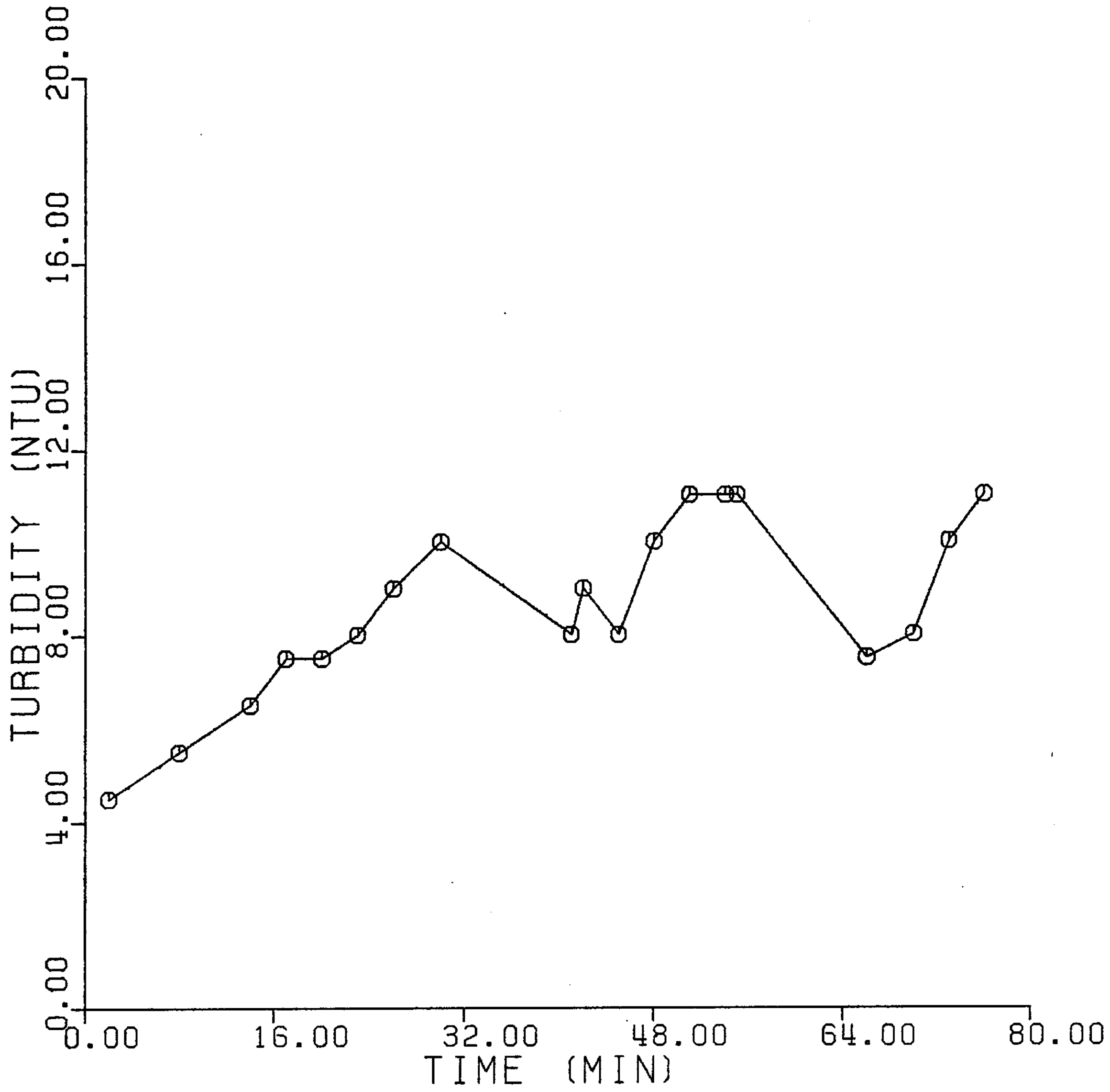
TEST 10

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.0	.	.
2	2	0.0	4.5	2
3	4	0.0	.	.
4	6	0.0	.	.
5	8	0.9	5.5	8
6	9	1.2	.	.
7	10	1.8	.	.
8	11	2.4	.	.
9	12	3.0	.	12
10	13	3.4	.	.
11	14	3.7	6.5	.
12	15	4.0	.	.
13	16	4.2	.	16
14	17	4.3	7.5	.
15	18	4.5	.	.
16	19	4.6	.	.
17	20	4.6	7.5	20
18	21	4.6	.	.
19	22	4.6	.	.
20	23	4.6	8.0	.
21	24	4.6	.	24
22	25	4.7	.	.
23	26	4.8	9.0	.
24	27	4.8	.	27
25	28	4.8	.	.
26	29	4.8	.	.
27	30	4.8	10.0	30
28	41	0.0	8.0	30
29	42	3.0	9.0	.
30	43	3.7	.	.
31	44	3.8	.	.
32	45	4.0	8.0	34
33	46	4.1	.	.
34	47	4.2	.	.
35	48	4.4	10.0	.
36	49	4.6	.	38
37	50	4.6	.	.
38	51	4.6	11.0	.
39	52	4.7	.	41
40	53	4.7	.	.
41	54	4.8	11.0	.
42	55	4.8	11.0	44
43	66	3.2	7.5	44
44	67	3.9	.	.
45	68	4.0	.	.
46	69	4.0	.	47
47	70	4.0	8.0	.
48	71	4.2	.	.
49	72	4.3	.	50
50	73	4.3	10.0	.
51	74	4.4	.	.
52	75	4.5	.	.
53	76	4.6	11.0	54

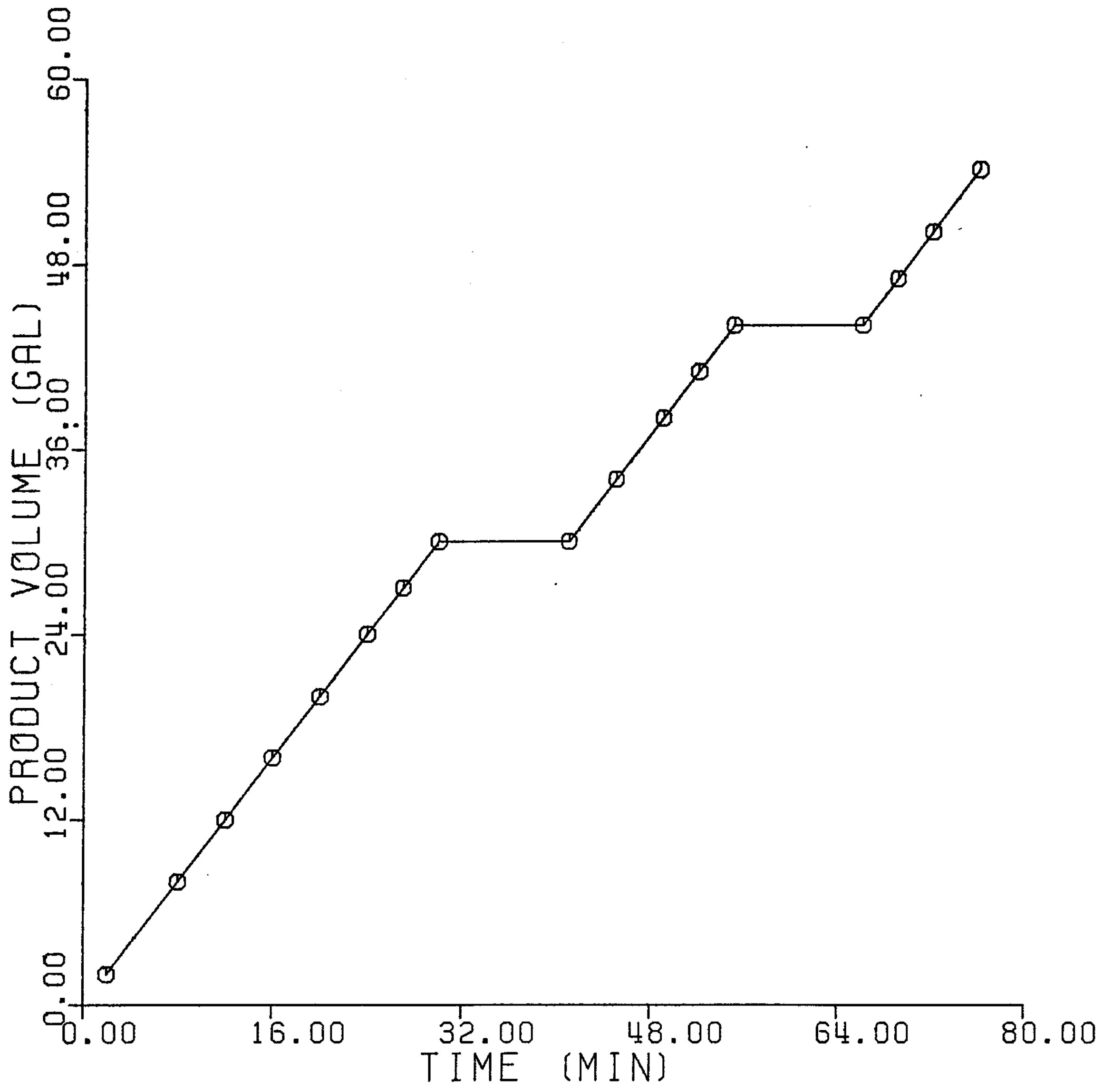
PLOT OF PRESSURE VS. TIME FOR CLOSED END OPERATION AT 1.0 GPM #10



PLOT OF TURBIDITY VS. TIME FOR CLOSED END OPERATION AT 1.0 GPM #10



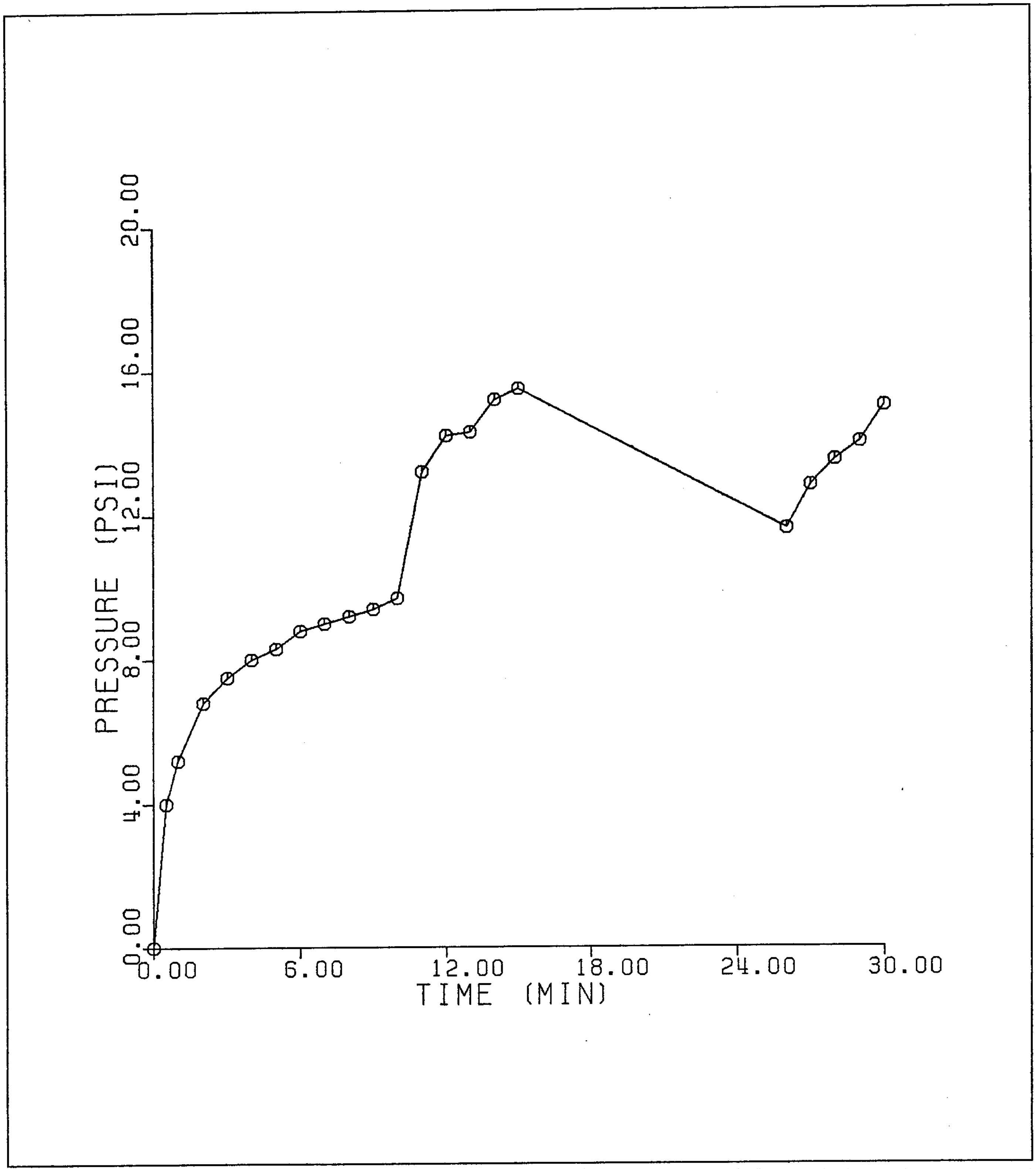
PLOT OF TOTAL PRODUCT VOLUME FOR CLOSED END OPERATION AT 1.0 GPM #10



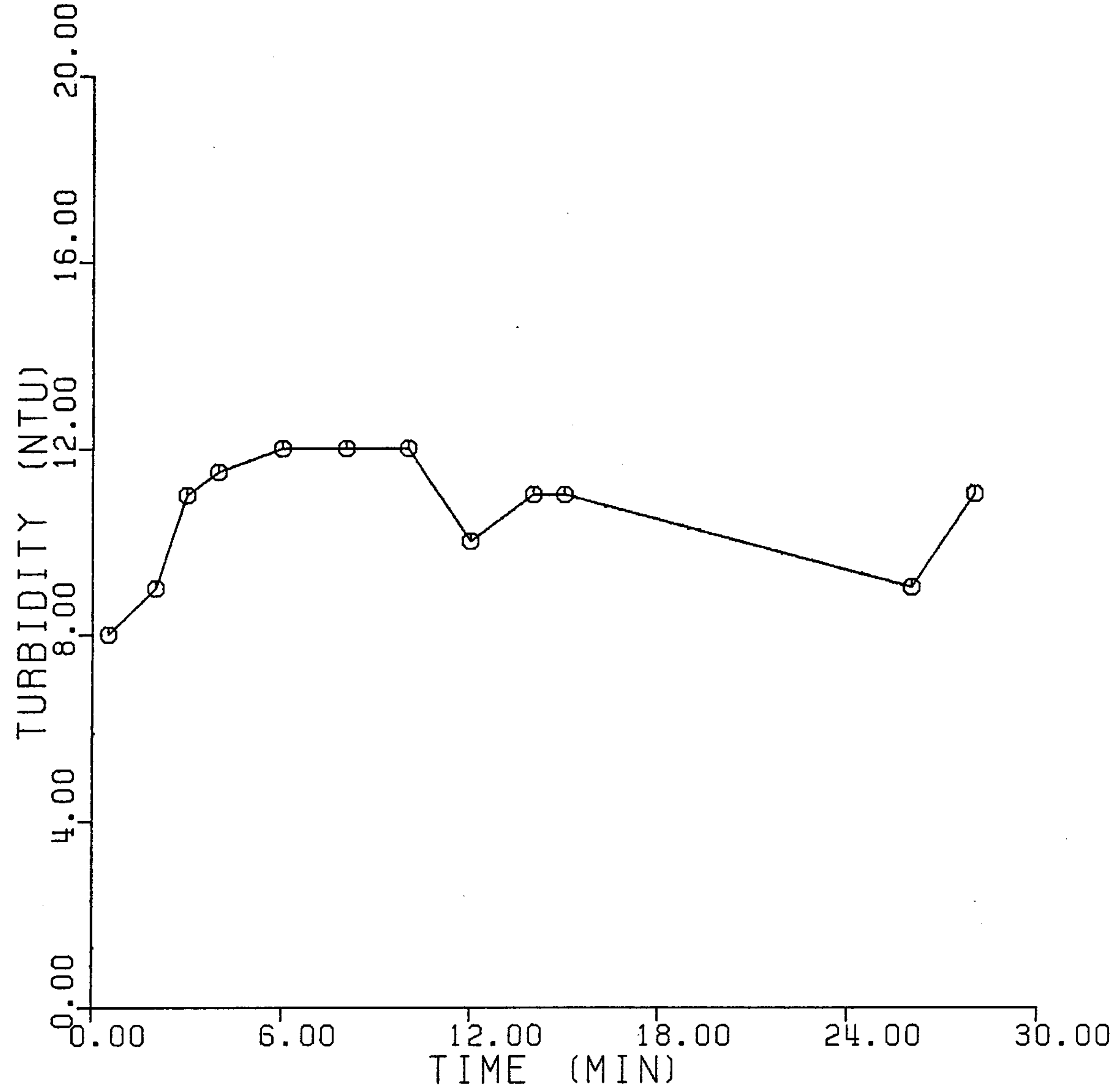
TEST 11

OBS	TIME	PRESSURE	TURB	VOLUME
1	0.0	0.0	0.0	.
2	0.5	4.0	8.0	0.5
3	1.0	5.2	.	.
4	2.0	6.8	9.0	.
5	3.0	7.5	11.0	3.0
6	4.0	8.0	11.5	.
7	5.0	8.3	.	.
8	6.0	8.8	12.0	6.0
9	7.0	9.0	.	.
10	8.0	9.2	12.0	.
11	9.0	9.4	.	9.0
12	10.0	9.7	12.0	.
13	11.0	13.2	.	.
14	12.0	14.2	10.0	12.0
15	13.0	14.3	.	.
16	14.0	15.2	11.0	.
17	15.0	15.5	11.0	15.0
18	26.0	11.6	9.0	15.0
19	27.0	12.8	.	.
20	28.0	13.5	11.0	17.0
21	29.0	14.0	.	.
22	30.0	15.0	.	19.0

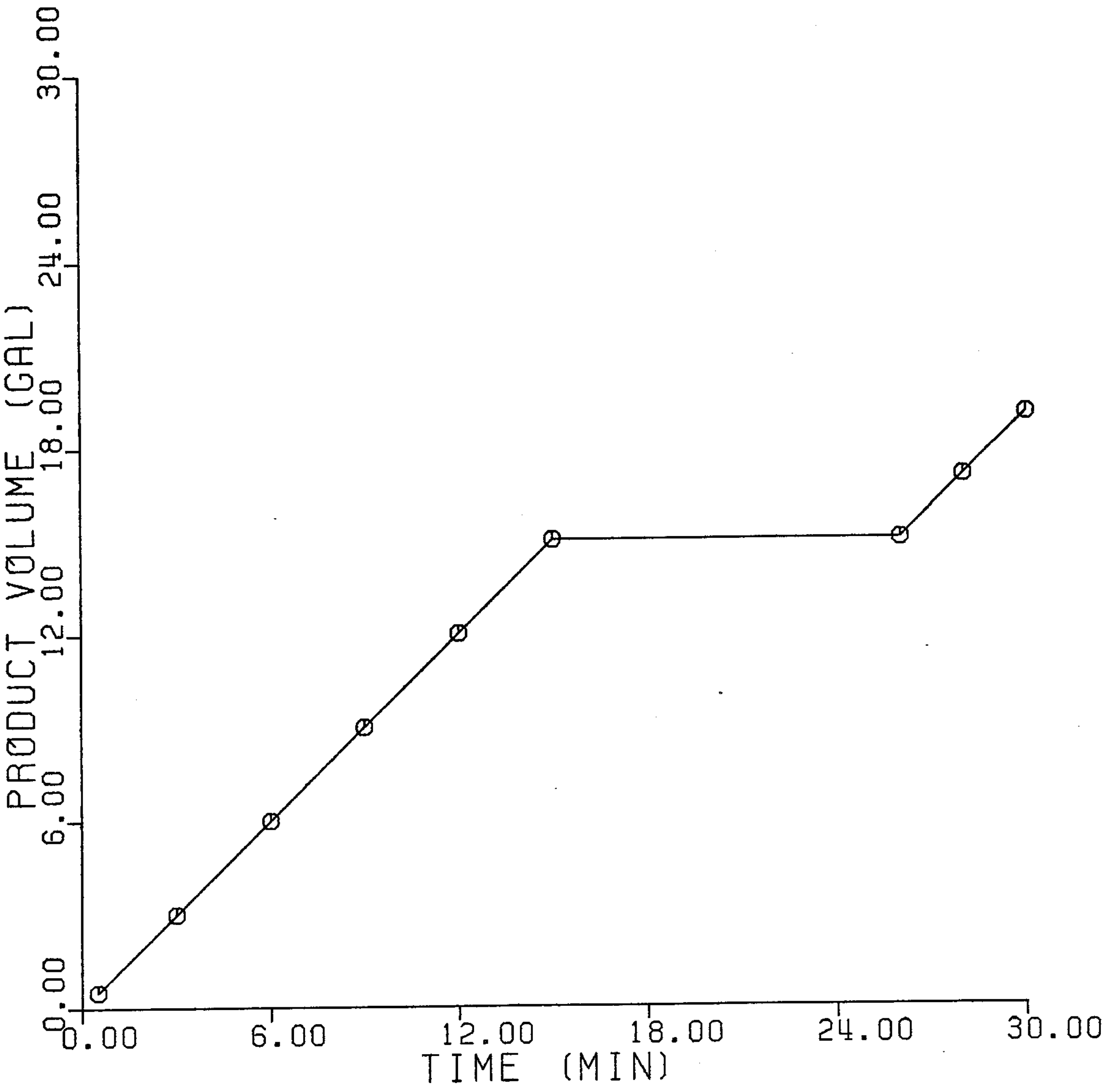
PLOT OF PRESSURE VS. TIME FOR CLOSED END OPERATION AT 1.0 GPM #11



PLOT OF TURBIDITY VS. TIME FOR CLOSED END OPERATION AT 1.0 GPM #11



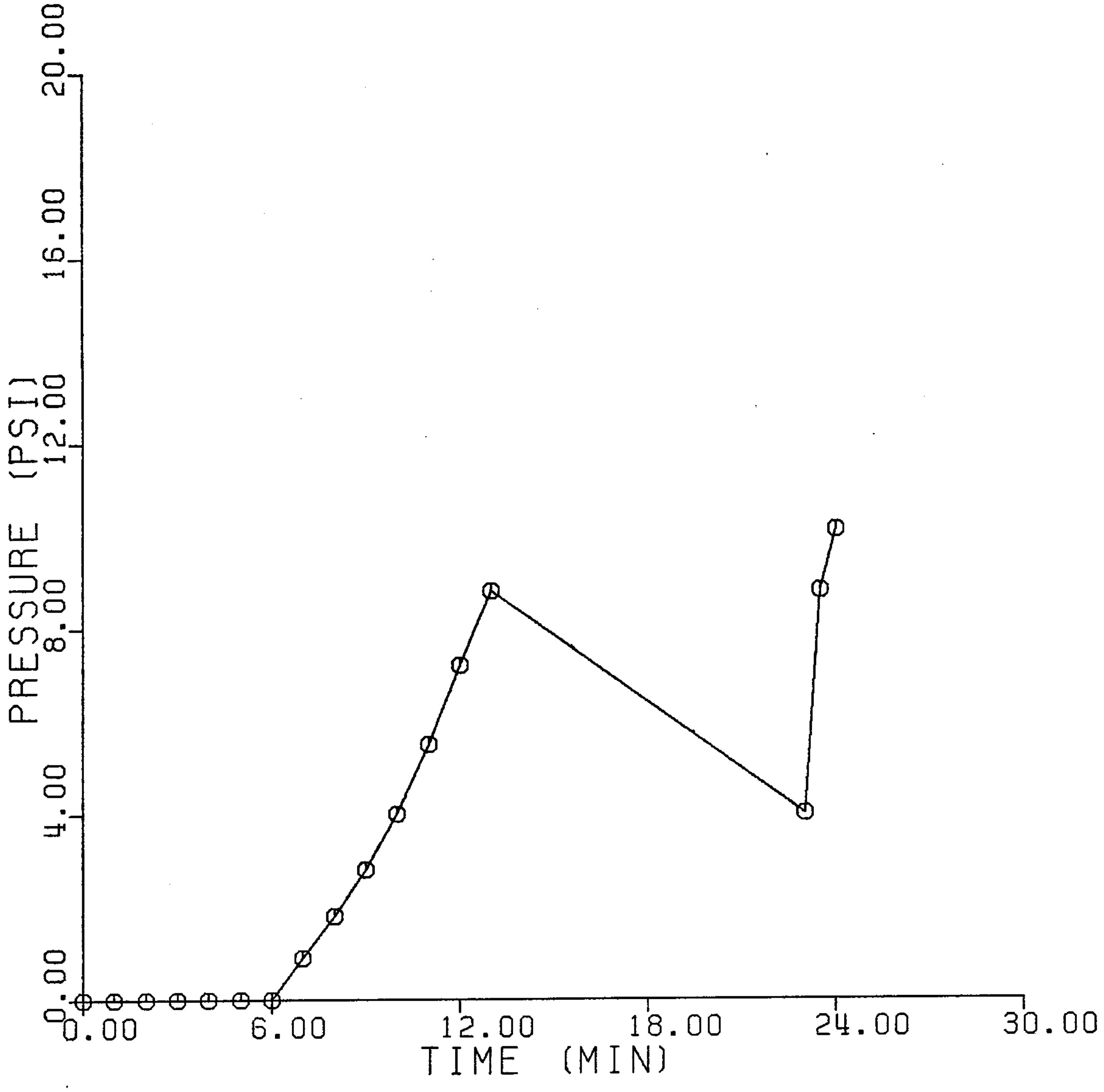
PLOT OF TOTAL PRODUCT VOLUME FOR CLOSED END OPERATION AT 1.0 GPM #11



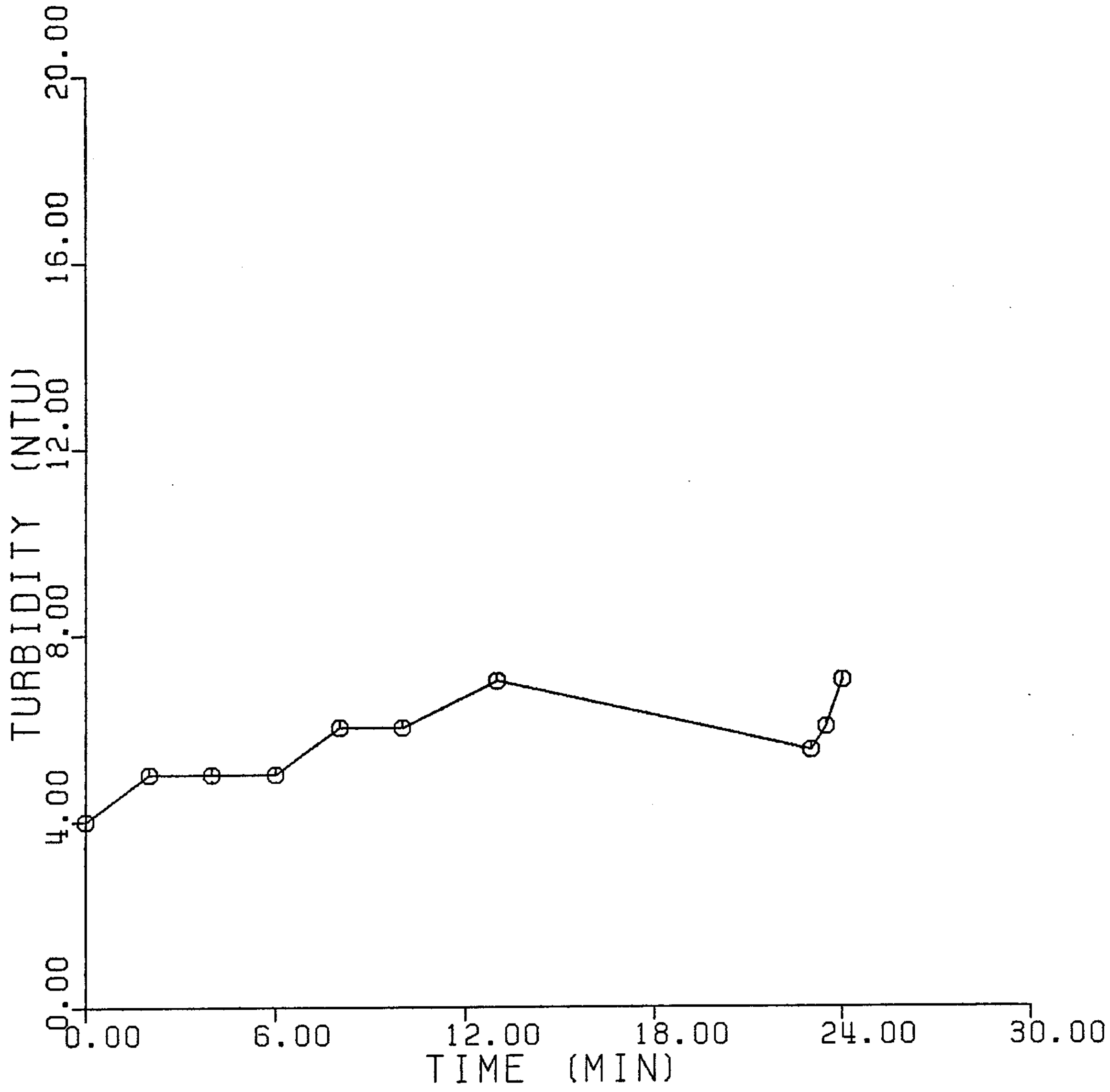
TEST 12

OBS	TIME	PRESSURE	TURB	VOLUME
1	0.0	0.0	4.0	0
2	1.0	0.0	.	4
3	2.0	0.0	5.0	.
4	3.0	0.0	.	12
5	4.0	0.0	5.0	.
6	5.0	0.0	.	.
7	6.0	0.0	5.0	24
8	7.0	0.9	.	.
9	8.0	1.8	6.0	.
10	9.0	2.8	.	36
11	10.0	4.0	6.0	.
12	11.0	5.5	.	.
13	12.0	7.2	.	48
14	13.0	8.8	7.0	52
15	23.0	4.0	5.5	52
16	23.5	8.8	6.0	54
17	24.0	10.1	7.0	58

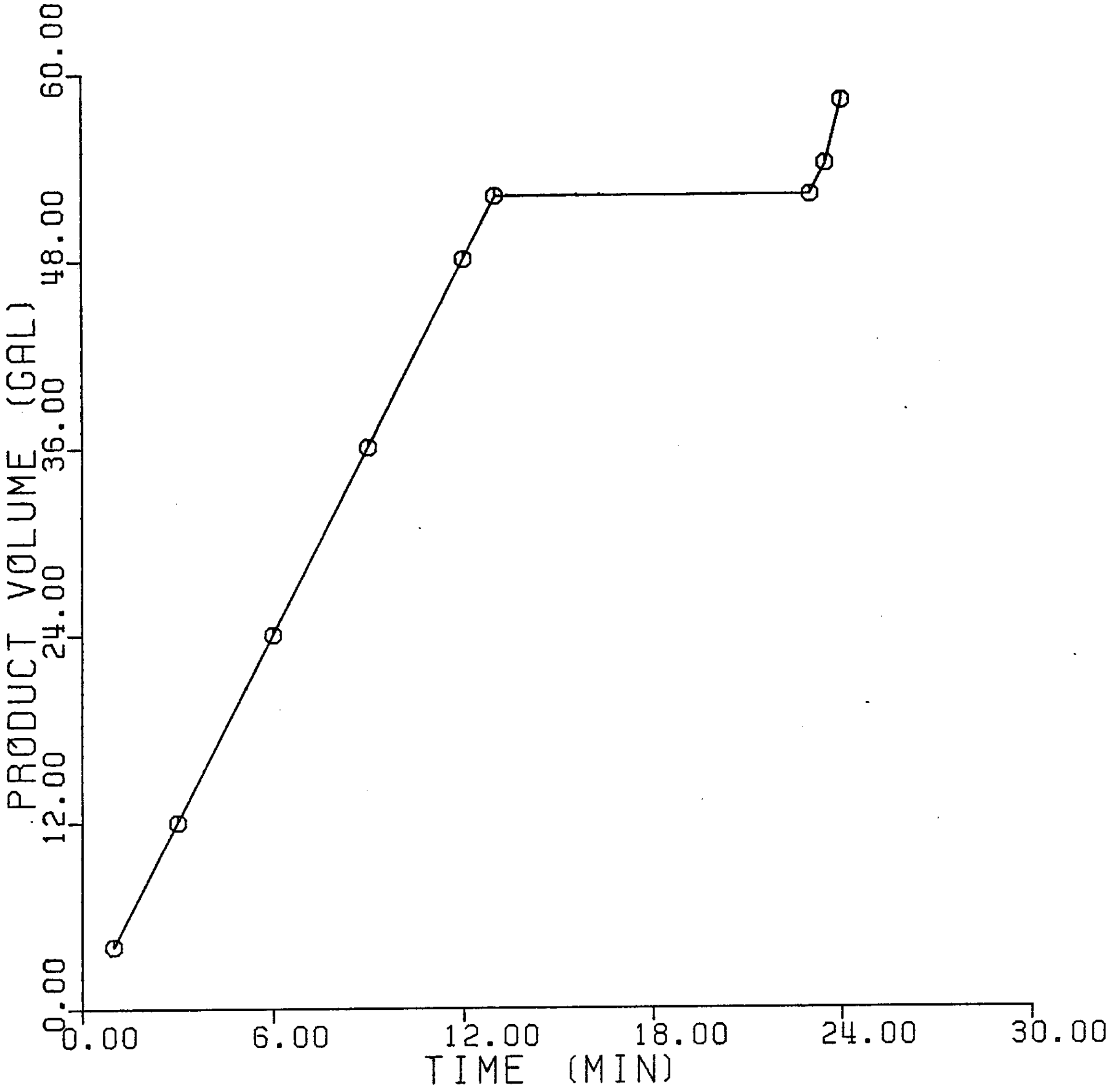
PLOT OF PRESSURE VS. TIME FOR CLOSED END OPERATION AT 4.0 GPM #12



PLOT OF TURBIDITY VS. TIME FOR CLOSED END OPERATION AT 4.0 GPM #12



PLOT OF TOTAL PRODUCT VOLUME FOR CLOSED END OPERATION AT 4.0 GPM #12



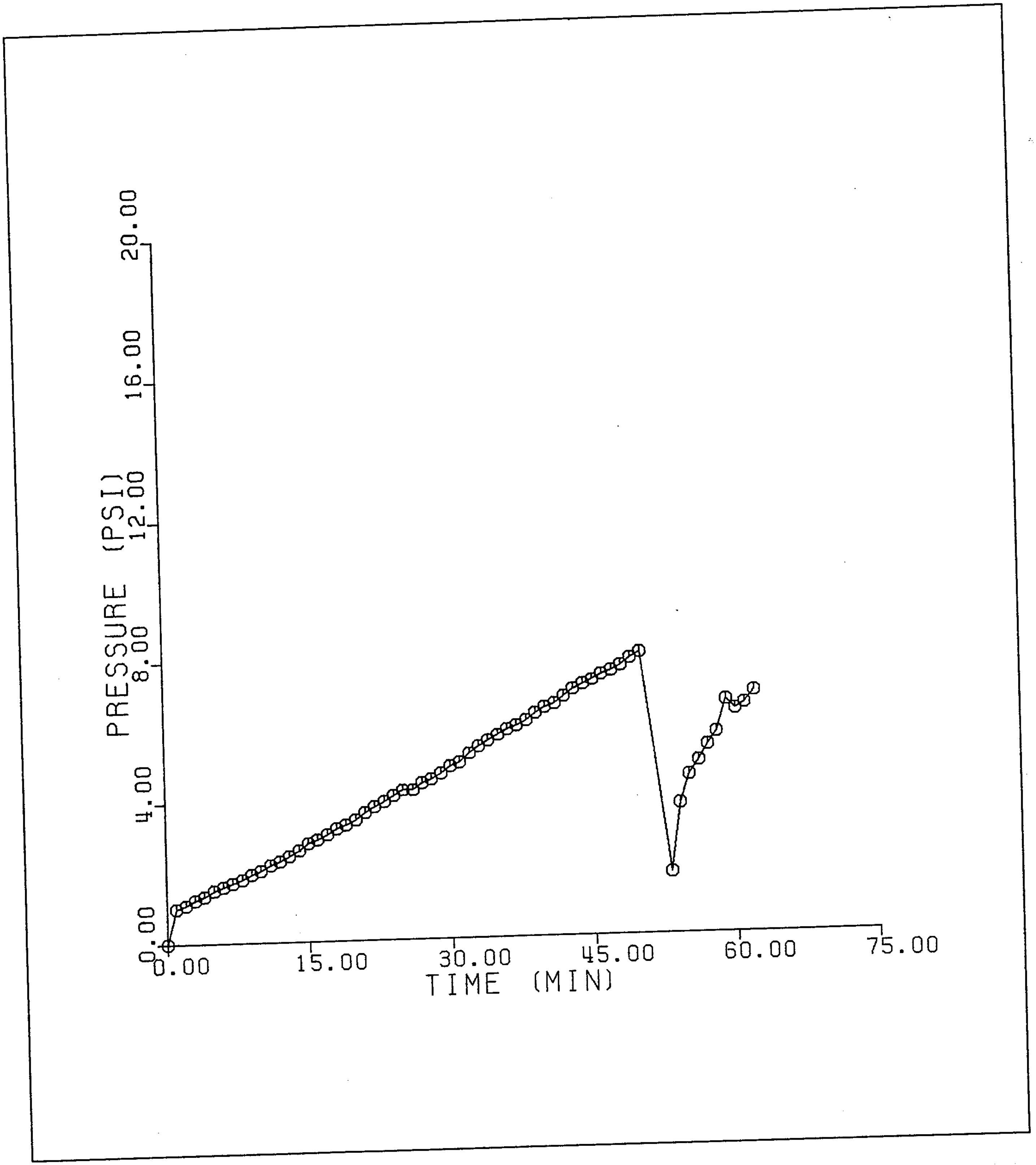
TEST 13

OBS	TIME	PRESSURE	TURB	VOLUME
1	0	0.00	4.0	0
2	1	1.00	.	1
3	2	1.10	4.5	.
4	3	1.25	.	.
5	4	1.35	5.0	.
6	5	1.50	.	.
7	6	1.60	5.0	.
8	7	1.70	.	.
9	8	1.80	5.0	8
10	9	1.95	.	.
11	10	2.05	.	.
12	11	2.20	.	.
13	12	2.30	5.0	.
14	13	2.45	.	.
15	14	2.60	.	14
16	15	2.80	.	.
17	16	2.90	5.0	.
18	17	3.05	.	.
19	18	3.20	.	.
20	19	3.30	.	.
21	20	3.45	5.0	20
22	21	3.65	.	.
23	22	3.80	.	.
24	23	3.95	.	.
25	24	4.10	5.0	.
26	25	4.25	.	.
27	26	4.25	.	26
28	27	4.45	.	.
29	28	4.55	.	.
30	29	4.70	.	.
31	30	4.90	.	.
32	31	5.00	.	.
33	32	5.25	.	32
34	33	5.45	5.5	.
35	34	5.60	.	.
36	35	5.75	.	.
37	36	5.90	.	.
38	37	6.00	.	.
39	38	6.15	5.0	38
40	39	6.35	.	.
41	40	6.50	.	.
42	41	6.60	.	.
43	42	6.80	5.0	.
44	43	7.00	.	.
45	44	7.15	.	44
46	45	7.25	.	.
47	46	7.40	6.0	.
48	47	7.50	.	.
49	48	7.65	.	.
50	49	7.85	.	.
51	50	8.00	6.0	50
52	53	1.75	5.0	50
53	54	3.70	5.0	.

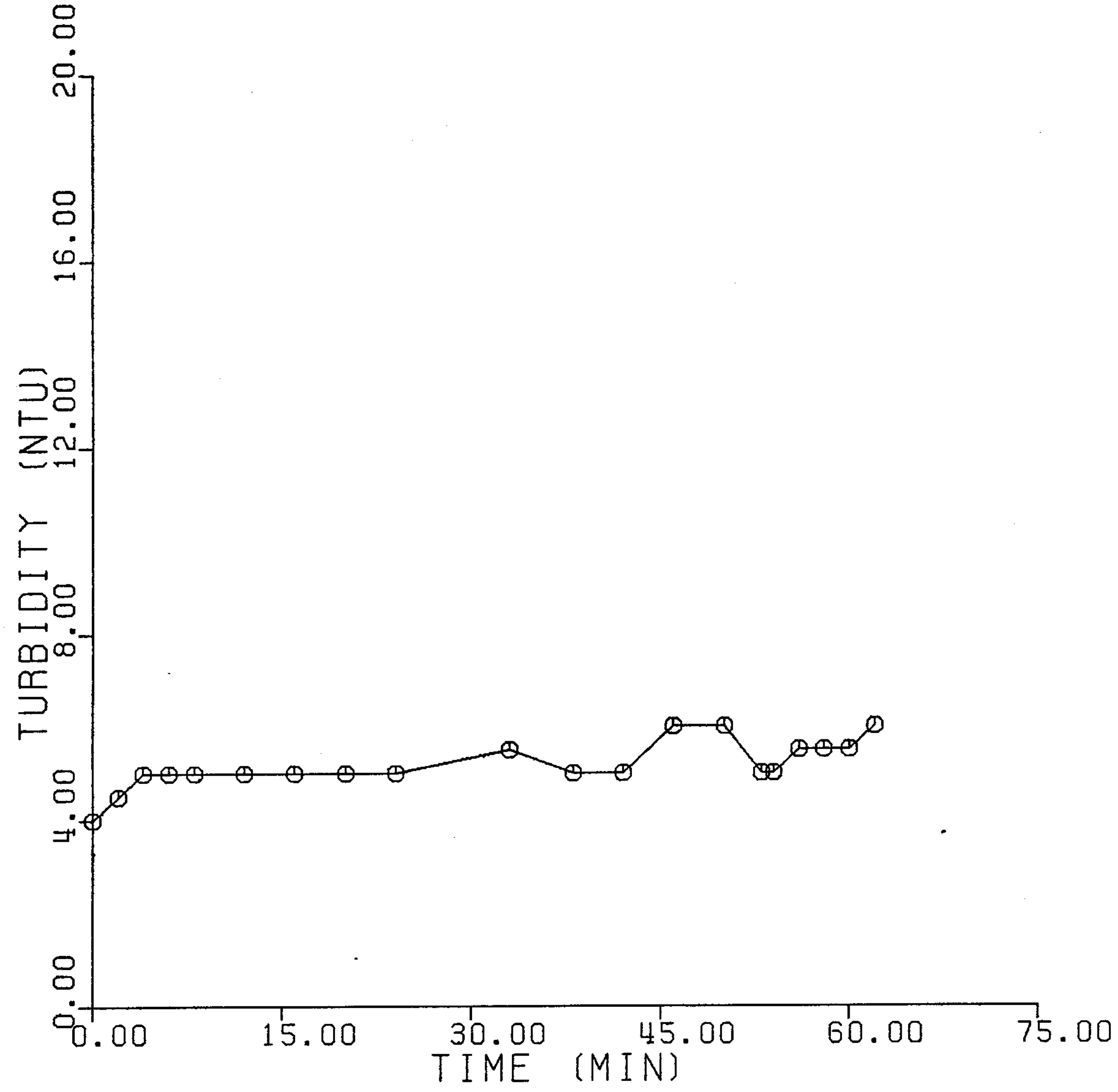
TEST 13

OBS	TIME	PRESSURE	TURB	VOLUME
54	55	4.50	.	.
55	56	4.90	5.5	53
56	57	5.35	.	.
57	58	5.70	5.5	.
58	59	6.60	.	.
59	60	6.35	5.5	.
60	61	6.50	.	.
61	62	6.85	6.0	59

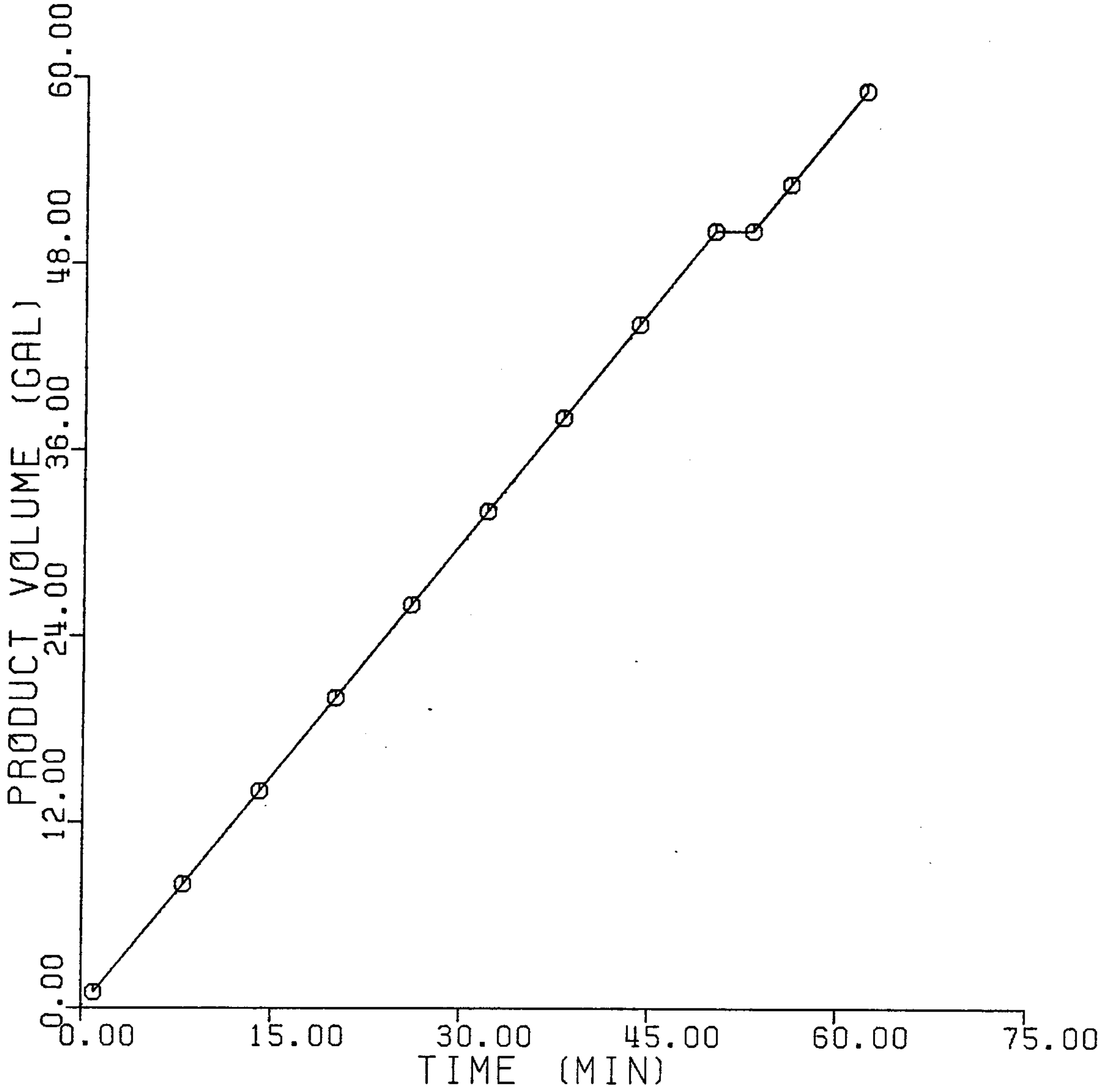
PLOT OF PRESSURE VS. TIME FOR CLOSED END OPERATION AT 1.0 GPM #13



PLOT OF TURBIDITY VS. TIME FOR CLOSED END OPERATION AT 1.0 GPM #13



PLØT ØF TØTAL PRØDUCT VØLUME FØR CLØSED END ØPERATIØN AT 1.0 GPM #13



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TEST 14

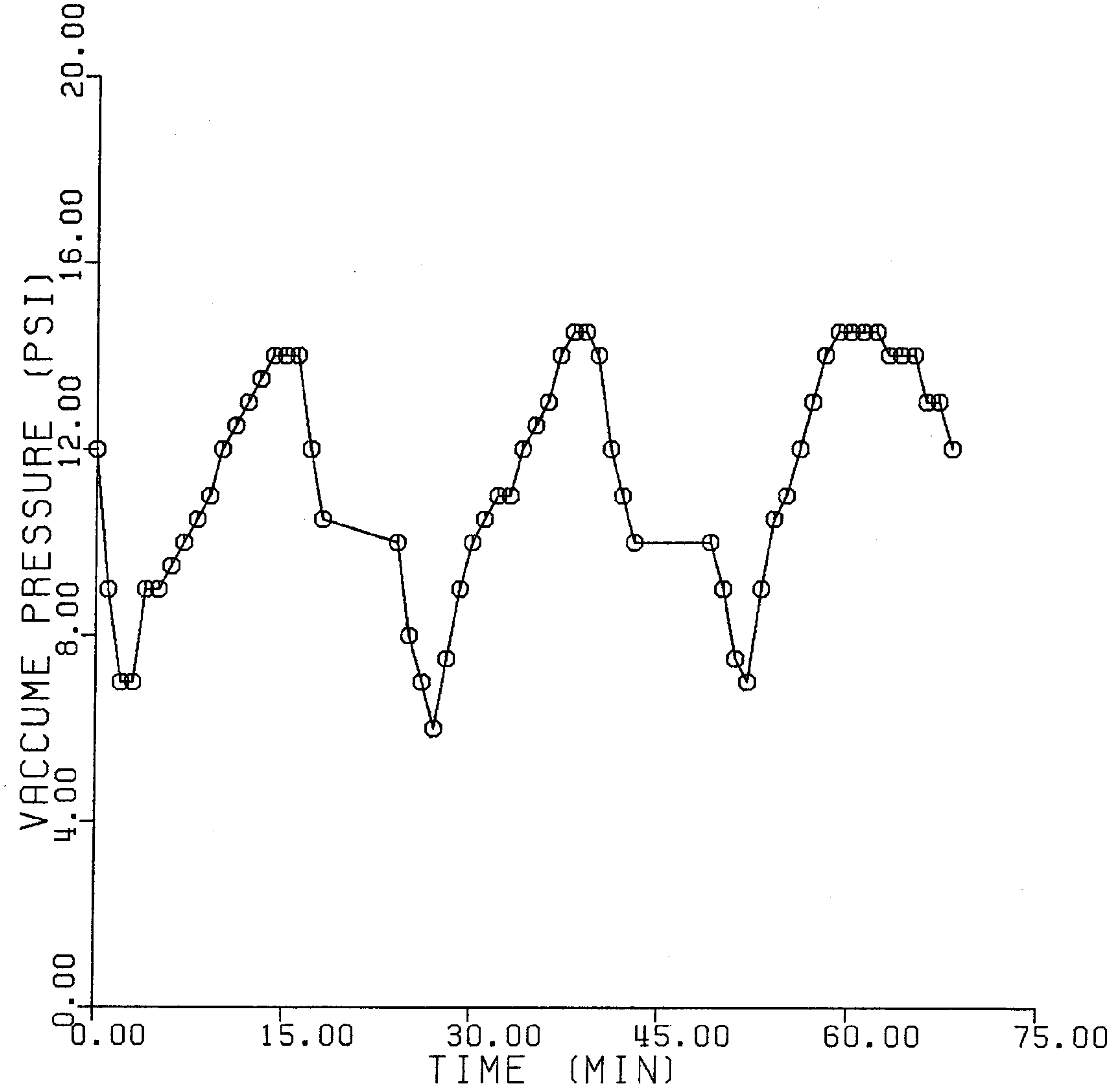
 OBS   TIME    VACCUME    TURB    VOLUME

   1      0       12.0      .       0.00
   2      1        9.0     5.0      2.64
   3      2        7.0      .        .
   4      3        7.0      .       6.13
   5      4        9.0     5.0       .
   6      5        9.0      .        .
   7      6        9.5      .       9.65
   8      7       10.0     5.0       .
   9      8       10.5      .        .
  10      9       11.0      .      12.83
  11     10       12.0     6.0       .
  12     11       12.5      .        .
  13     12       13.0      .      15.51
  14     13       13.5     7.0       .
  15     14       14.0      .        .
  16     15       14.0      .      17.38
  17     16       14.0     6.0       .
  18     17       12.0      .        .
  19     18       10.5      .      18.49
  20     24       10.0     5.0     18.49
  21     25        8.0     5.5     20.54
  22     26        7.0      .        .
  23     27        6.0      .        .
  24     28        7.5     6.5     25.49
  25     29        9.0      .        .
  26     30       10.0      .        .
  27     31       10.5     7.0     29.46
  28     32       11.0      .        .
  29     33       11.0      .        .
  30     34       12.0      .        .
  31     35       12.5     8.0     33.86
  32     36       13.0      .        .
  33     37       14.0      .        .
  34     38       14.5     6.5     36.26
  35     39       14.5      .        .
  36     40       14.0      .        .
  37     41       12.0     6.5     37.94
  38     42       11.0      .        .
  39     43       10.0     6.5     38.60
  40     49       10.0     6.0     38.60
  41     50        9.0      .        .
  42     51        7.5     7.0     42.02
  43     52        7.0      .        .
  44     53        9.0      .        .
  45     54       10.5     6.0     46.01
  46     55       11.0      .        .
  47     56       12.0      .        .
  48     57       13.0     7.0     49.54
  49     58       14.0      .        .
  50     59       14.5      .        .
  51     60       14.5     7.5     52.43
  52     61       14.5      .        .
  53     62       14.5      .        .
```

TEST 14 cont

OBS	TIME	VACCUME	TURB	VOLUME
54	63	14.0	6.0	54.32
55	64	14.0	.	.
56	65	14	.	.
57	66	13	5.5	55.38
58	67	13	.	.
59	68	12	.	.

PLOT OF PRESSURE VS. TIME FOR REVERSE FLOW OPERATION AT 2.0 GPM #14



PLOT OF TURBIDITY VS. TIME FOR REVERSE FLOW OPERATION AT 2.0 GPM #14