MIDDLE EAST TECHNICAL UNIVERSITY
FACULTY OF ENGINEERING

SLOW SAND FILTRATION FOR SMALL COMMUNITIES AND RURAL AREAS

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AND RURAL AREAS

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ABSTRACT

In this study an attempt is made to determine the turbidity removal efficiency of a model slow sand filter and the practical use of the results obtained from the experimental study was investigated.

The first part of this study consists of the description of the filtration mechanism and the related theories, hydraulics of filtration ,important factors effecting filter performance , efficiency of slow sand filters and properties of filter bed materials but only the model filter set-up and experimental results were presented here .In the experimental part of the study emphasis is given to the effect of sand depth and influent water turbidity changes upon filtrate quality. By changing the depth of sand layer and effluent water turbidity the experimental study was performed and after three different runs the most suitable filter depth is found.At each sampling time the corresponding head loss relationships for the particular bed is obtained.

EXPERIMENTAL STUDY

Objectives of the study

The main objectives of the experimental work can be summarized under the following items :

1. Maximum turbidity removal by slow sand filters.
2. Effect of sand depth upon filtrate quality.
3. Effect of influent turbidity upon effluent quality.
4. Penetration of turbidity into the filter media and cleaning condition at different depths of the filter.
5. Head loss variation along the depth of the filter bed as related to time of operation .

Description of the experimental set up

Experimental study was performed by using a filter model consisting of a box shaped filter with dimensions 60 x60 x165 cm. The side walls of the filter is made of iron sheet plate and perspex.

The model filter had an overflow weir part where flow control is accomplished and the bottom drainage system. The drain system of the model filter consisted of a grid to support perforated bricks. A uniform withdrawal of the clarified water was possible by the use of this simple system. A slope of 1:200 was given to the filter bottom for easy removal of the effluent. A valve and a graduated metal cylinder was used for checking the effluent flow.

Against shrinkage of media and short circuiting stepping the filter walls is provided by using additional three sheet plates each of two milimeter thickness.

For head loss measurements two manometer tappings were provided, being at the bottom and near the surface layer of the media. Inside end of manometer tappings had a horizontal channel and copper wire threading to allow sufficient water passage but prevented the entrance of fine materials.

Samples were drawn by stainless steel hypodermic tubing from filter at different depths of the filter bed. For sampling, on the perspex walls, tappings were made by brass gland collars.

The biologicial film formed upon sand surface was prevented from destruction of direct water fall by an overflow weir placed after a basin with dimensions of 30 x 60 x 60 cm. At this inlet structure a levelling gage was put for precise control of the inflow.

In the preparation of turbid water a container with a mixer is utilized and this water is pumped to a constant head tank before given to the filter.The constant head tank and the filter inlet basin also were provided with two small stirrers for the homogenity of the prepared solution.

Preparation of media

In the preparation of the filter media sieve analysis is made to find out the existing sand and gravel characteristics. The effective sand size of 0.35 mm. and uniformity coefficient of 1.8 were predetermined values of the filter media.Sieve sizes used for fine aggregate analysis were 4.76,2.38,1.19, 0.59,0.297,0.149 mm. and for coarse aggregate sieve sizes used were 38.1,25.4,19.1,12.7,9.5,,4.76mm., After fifteen minutes shaking remaining material on each sieve was weighed and the obtained results were shown in the table.

Grain size analysis for fine and coarse aggregate

TABLE 1

Coarse aggregate

Sieve (Inch)	size (mm)	Remaining on each sieve (gm)	Cumulative Weight (gm)	Percentage of remaining on each sieve.	Cumulative % remaining	Cumulative % Passing
1 1/2	38.1	275	275	0.94	0.94	99.06
1	25.4	4629	4904	15.80	16.74	83.26
3/4	19.1	10938	15842	37.39	54.13	45.87
1/2	12.7	10133	25975	34.64	88.77	11.23
3/8	9.5	2690	28665	9.19	97.96	02.04
No 4	4.76	487	29152	1.70	99.65	0.35
Passing from No 4 sieve		100	29252			
Sample weight			29252			

Fine aggregate

No 4	4.76	170	170	6.56	6.56	93.44
No 8	2.38	618	788	23.86	30.42	69.58
No 16	1.19	694	1182	26.79	57.21	42.79
No 30	0.59	582	2064	22.47	79.68	20.32
No 50	0.297	370	2434	14.28	93.96	06.04
No 100	0.149	110	2544	4.24	98.20	01.80
Passing from No 100 sieve		46	2590			
Sample weight			2590			

The uniformity coefficient is given with the relationship

$$U = \frac{d_{60}}{d_{10}}$$

where d_{60} is the diameter of the grains by weight at the 60 percent finer point and d_{10} is the effective size giving the diameter of grains by weight at the 10 percent finer.

The useful part of the stock sand is determined from the formulas given by Fair and Geyer (1956) and computations are shown in figures 1 to 5 .

$$P_3 = 2(P_2 - P_1)$$

$$P_4 = P_1 - 0.1P_3$$

$$P_5 = P_4 + P_3$$

where

P_1 = The percentage of stock sand that is smaller than the desired effective size (d_{10}).

P_2 = The percentage of stock sand that is [illegible] than the desired d_{60} value.

P_3 = Calculated percentage of usuable stock sand.

P_4 = The percentage that the stock sand is too fine.

P_5 = The percentage that the stock sand is too coarse.

The sieve analysis gave for $P_3 = 0.280$, $P_4 = 0.620$ and $P_5 = 0.342$. The corresponding upper limit for sand is obtained as 0.297 mm and sand particles having a diameter greater than 1 mm are not used as fine aggregate.

The soarse aggregate is also by making use of the figure 1.

The specific gravity of sand particles are computed by γ using density bottles and the average value of three measurements was 2.63 gm./cm.^{3}.

The apparent specific gravity of s nd based on wet measurements (γ_w) with a 39.8 percent voids is computed as 1.98 gm/cm.^{3} from the following formula.

$$\gamma_w = G - f (G - \gamma_{wt})$$

G = Real specific gravity of sand particles

f = Porosity

γ_{wt} = Specific grávity of water.

The fine aggregate is obtained by mixing equal amounts of 0.297 ,0.59 ,1.19 mm sized grains but for the coarse aggregate from the bottom to sand layer , particle sizes of 25.40 ,19.10, 12.70 ,9.50 ,4.76 and 2.38 mm are used.

The prepared media was placed into the filter after washing and drying.

Preparation of Turbid Water

The amount and character of suspended material which is present in the water defines turbidity of this water. Particle size of the dispersed material is an important parameter for turbidity of a water.

Turbidity is often expressed on the so called "silica scale " and turbidity imported by one part per million of fuller 's earth is taken as unity of turbidity.

In the preparation of turbidity standards 5 gm. of local Fuller's earth is added to 1 liter of distilled water so a stock solution is obtained. By diluting this standardized stock suspension with distilled water turbidity standards were prepared.

A calibration curve is drawn by measuring deflections of different turbidity standards at spectrophotometer which is manufactured by Evans Electroselenium LTD in England ,under wave-length 410 A°.

FIGURE 1

GRAIN SIZE ANALYSIS FOR FINE & COARSE AGGREGATE

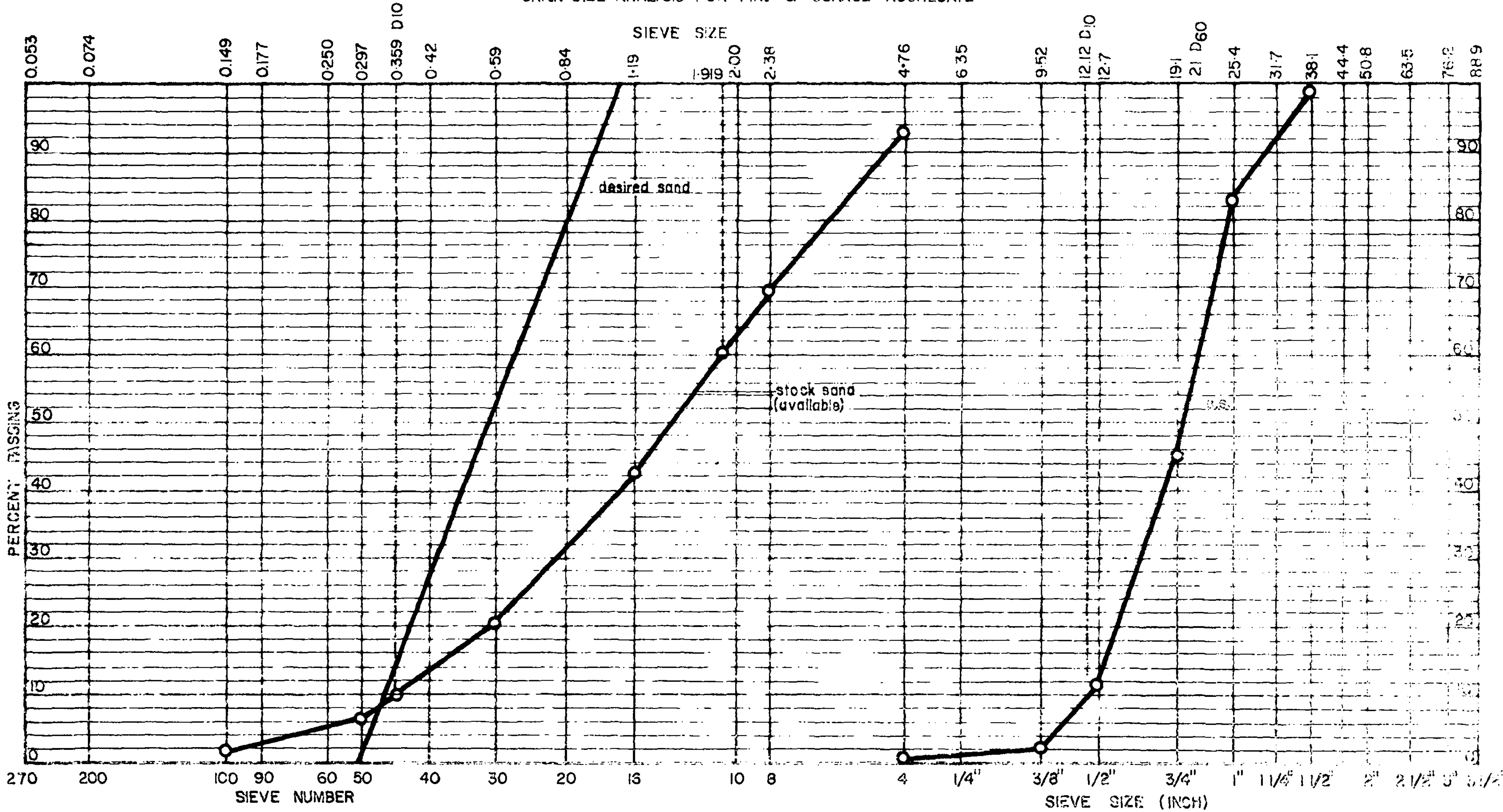


FIGURE 2

GRAIN SIZE ACCUMULATION (for fine aggregate stock sand)

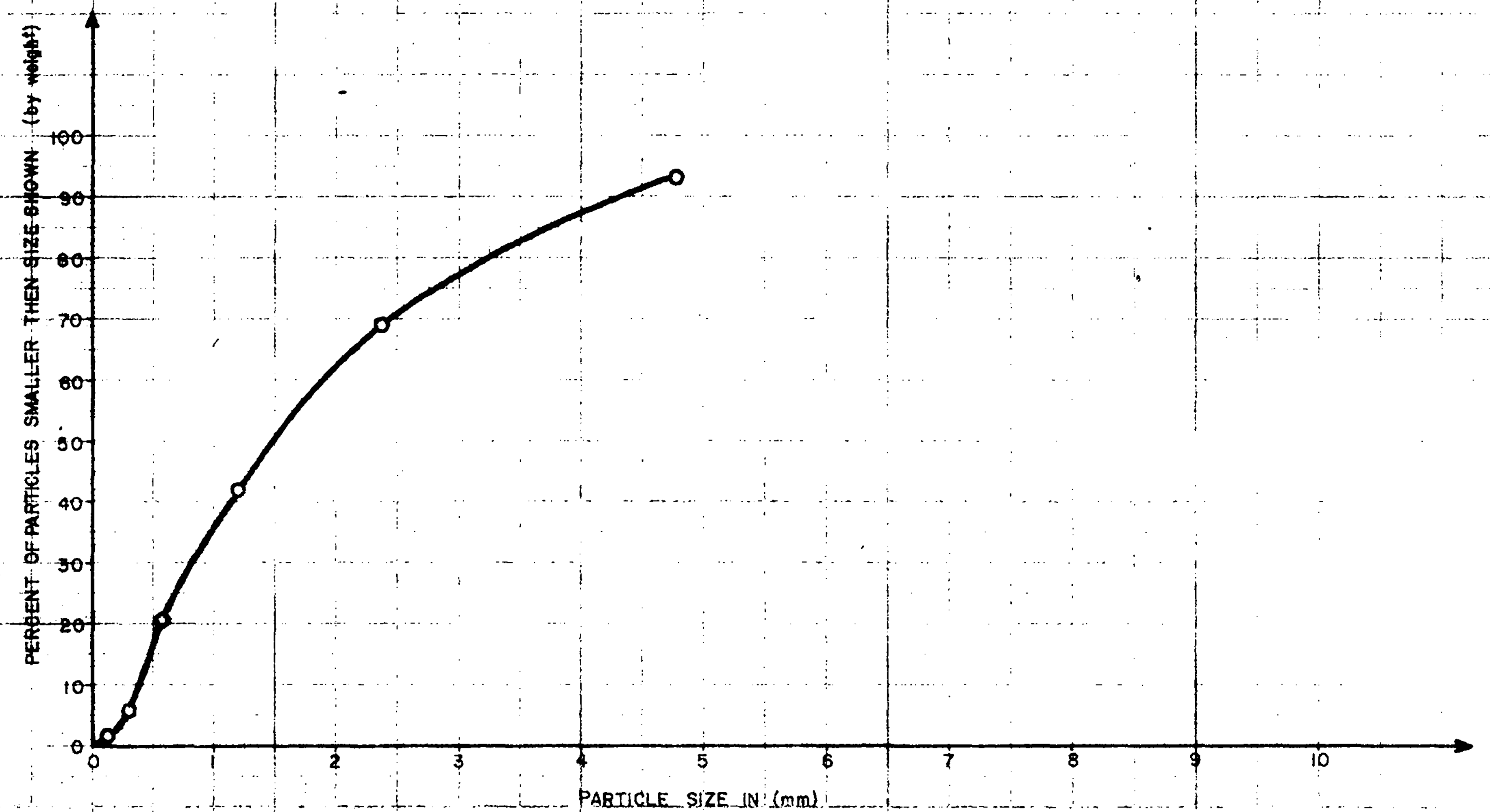


FIGURE 3

GRADATION CURVE (for fine aggregate stock sand)

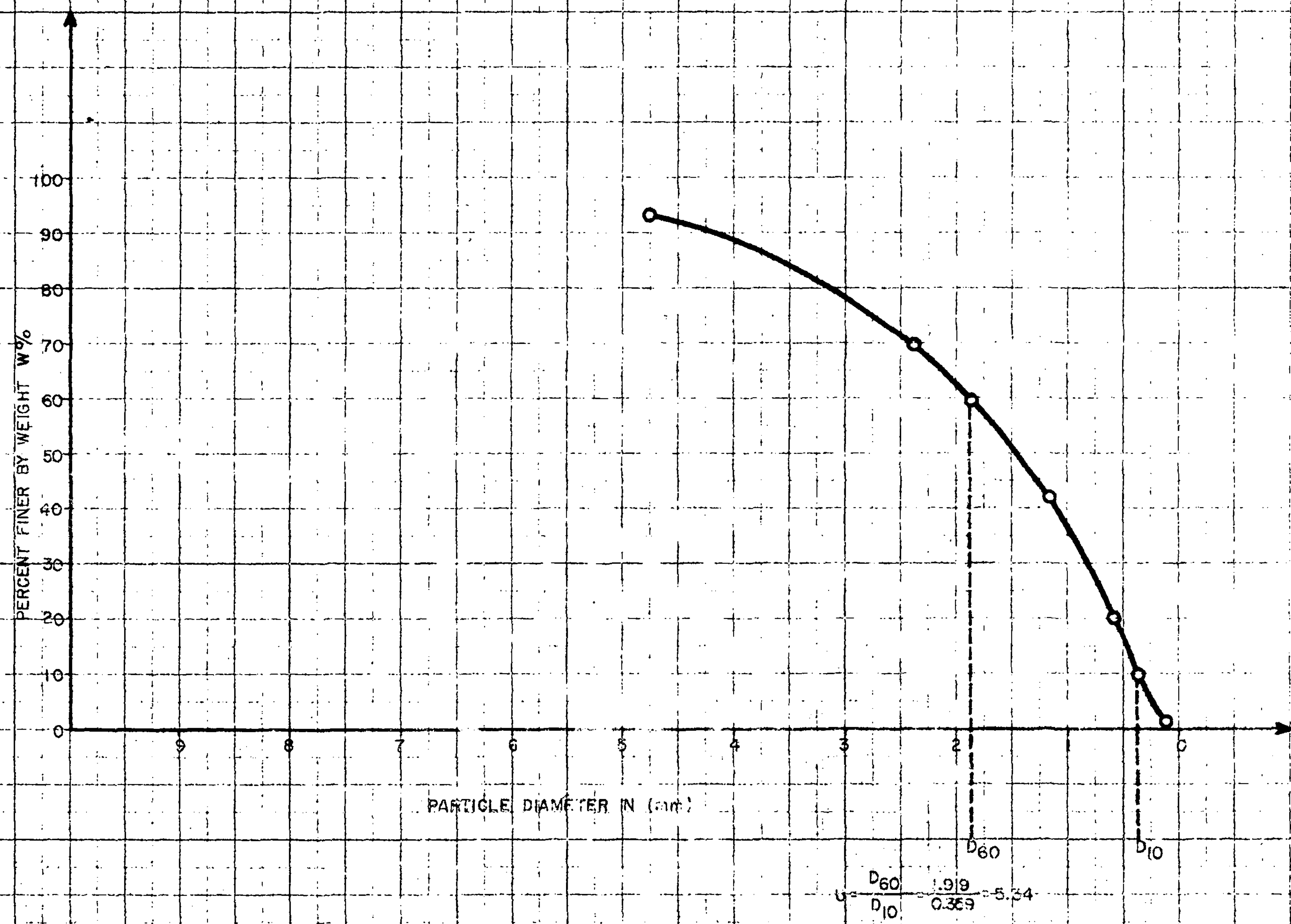


FIGURE 4

GRAIN SIZE ACCUMULATION CURVE (coarse aggregate stock gravel)

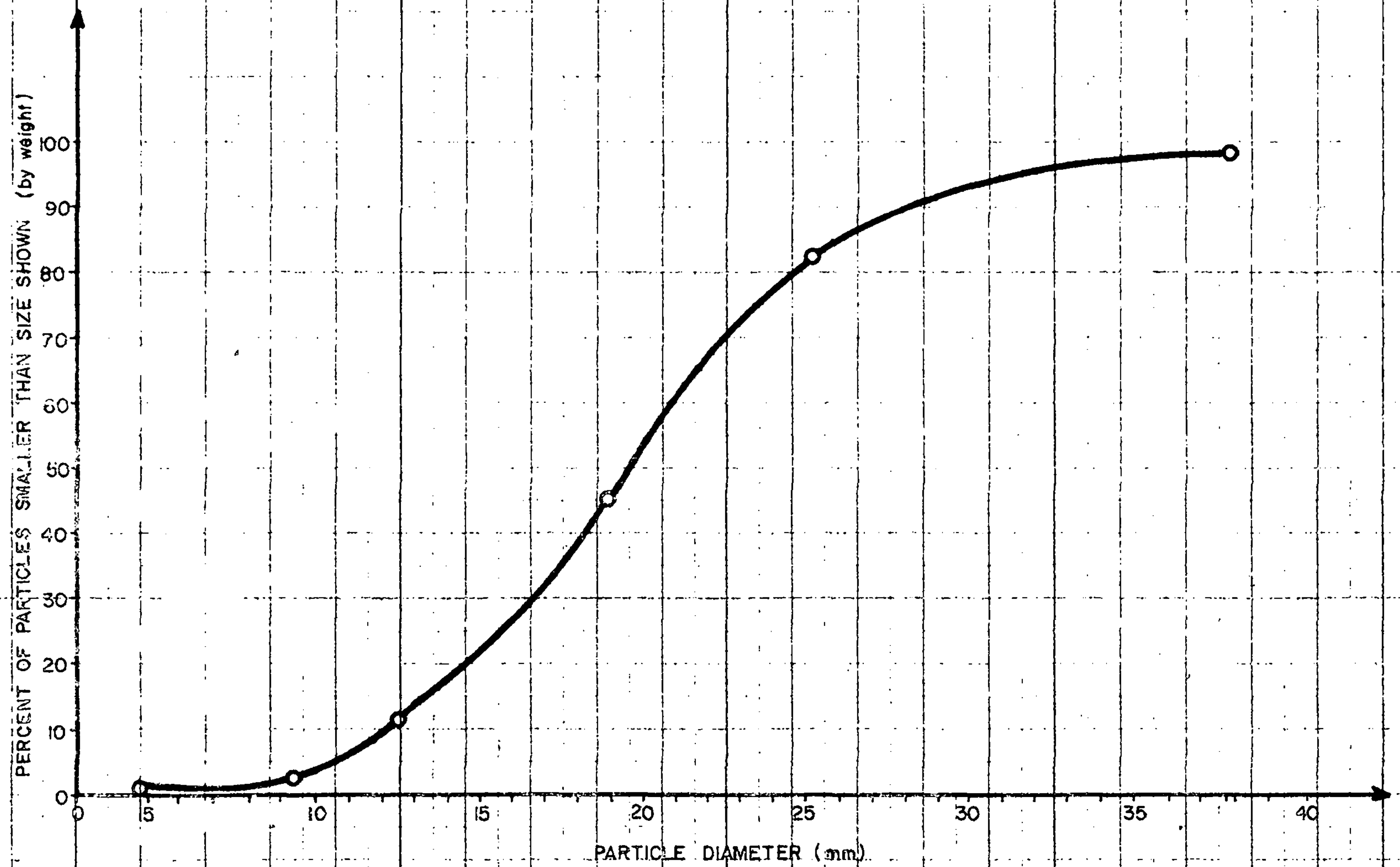
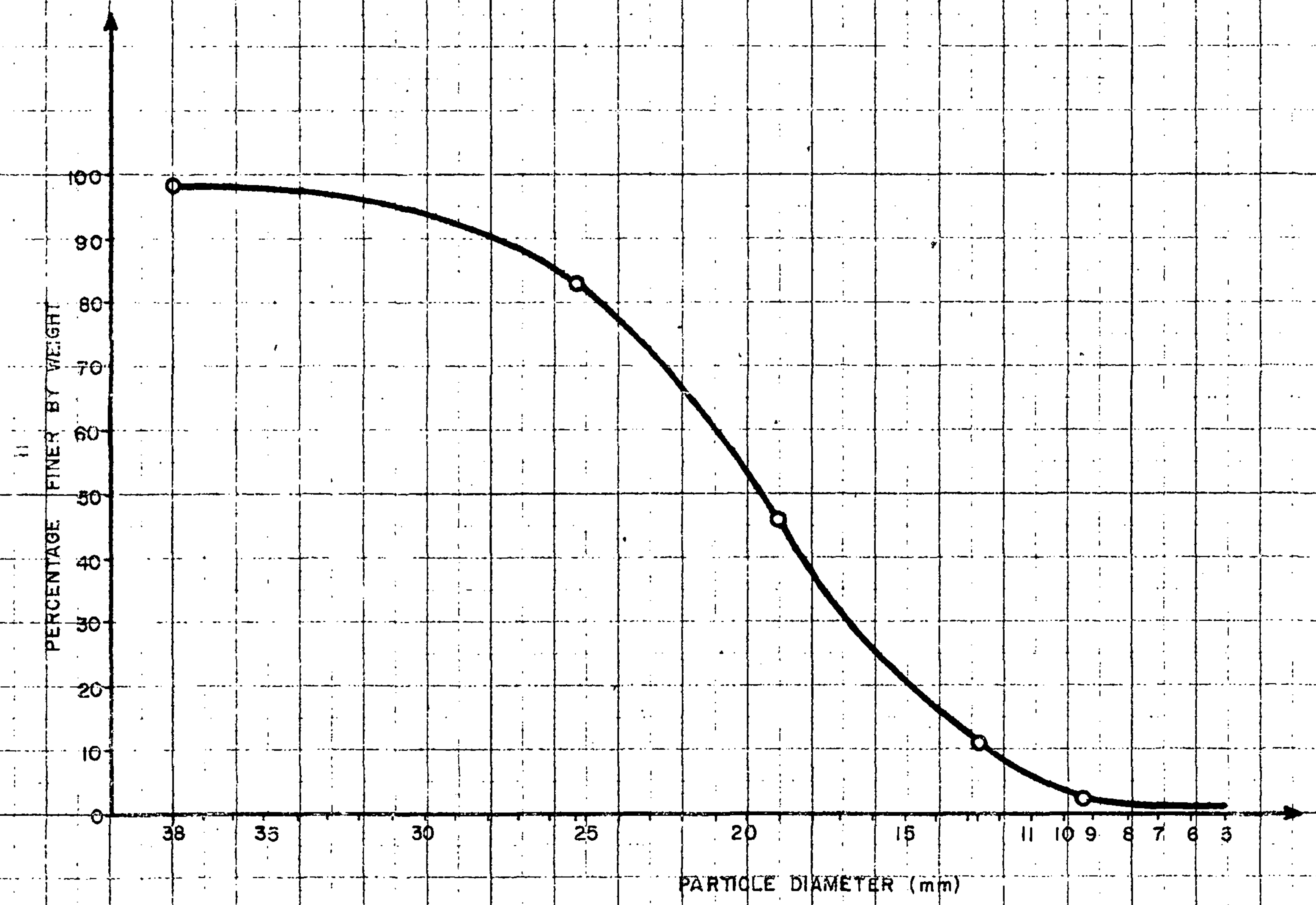


FIGURE: 5

GRADATION CURVE (Coarse aggregate - stock gravel)



Experiments conducted

During the experiment filtration rate is taken as 0.159 gpm/sq-ft and corresponds to a flow of 2.3 lt/min in the experimental filter. This flow rate is maintained by a levelling gage which had an initiall height 35.93 cm. and controlled by an influent needle pointer. The height of water level above the weir is calculated by using formula (Water Measurement Manual, 1953)

$$Q = 3.33\, H^{3/2}\,(L - 0.2\, H)$$

where

Q = Discharge (cu-ft/sec)

L = Weir length (ft)

H = Height of water above weir (ft)

By trial and error the height of water above the weir is taken as H = 0.1 cm.

The uniformity of flow is closely checked by use of the inlet and outlet controls. In the first week of the experimentation a lower flow rate, 1.15 lt/min is given to the filter to form a good bacteria rich layer of schmutzdecke.

A constant head of 40 cm. water is provided over the top surface of filter bed and destruction of the formed mud layer is prevented.

Experiments were conducted in two different media arrangements. In the first part a sand layer of 30 cm. and a gravel layer of 30 cm is used. During the second and the third part of the experiments sand layer depth was increased to 60 cm.

The prepared turbid water consisted of a mixture of local Fuller's earth and tap water with a turbidity of 40 units (silica scale) in the first and the second part of the experiments. In the third part turbidity was 60 units. Daily filter runs took eight hours. During the first and the second part of the experiment 1120 liters and in the last part 1680 liters of turbid water were filtered.

In each filter run samples were drawn from different layers of the media for turbidity measurements. During the first run of the experimentation samples were collected with one hour intervals but in the second and the third runs samples were collected with two hours intervals.

The head loss is also recorded by using a manometer attachment. The filtration was continued until a filtrate turbidity of 19.5 units was reached. This took about 200 hours of operation with a head loss of 8 cm.

After the first part of experiments the upper layer of the sand was discarded then the remaining sand layer is removed and washed throughly. The gravel layer is washed in place. The new sand is mixed with the old one and put into the filter. Attention was given to avoid the stratification of the newly placed sand.

Second part of the experiments with 60 cm depth of sand took approximately 280 hours of operation. This part of experiments was completed when effluent turbidity was 19.5 units. At the beginning of the second part of the experiments initial head loss was 4 cms. and at the end of it final head loss was 24 cms.

In the third run with 60 units influent turbidity and 60 cms. depth of sand, was completed when a filtrate turbidity of 20 units was reached. Length of the run was 184 hours and the maximum head loss obtained was 7.5 cms.

In three runs of the experiment, temperature and pH values of influent water were recorded at each sampling time.

Evaluation ofrthults

The first experimental run :

During the first week of filtration flow rate was very low ,only the maturation of filter was achieved and turbidity removal was very limited.Obtained maximum removal of turbidity was 40 percent.

After formation of the schmutzdecke layer effluent turbidity was nearly 20 units.Removal efficiency was 86.25 percent after 44 hours working period.The maximum removal observed was 96.25 percent.Percent removal of turbidity versus operation time curve tends down after 96 hours of operation fig.6. At the end of 132 hours working period percent removal of turbidity dropped to 86.25After that time turbidity removal decreased with a slower rate.The beginning turbid water conditions was attained in the effluent at the end of 200 hours working period.

When the figure (7) for the first experimental run was examined it is seen that minimum effluent turbidity was 1.5 units. To have such a lower turbidity 80 hours filtration was required.This maximum efficiency value continued for a period of 16 hours figure(7).

Variation of head loss with time is shown in figure (8),

The significant increase in head loss was seen after 96 hours of operation.Nearly 75 percent of the head loss was developed during the last 72 hours.In the first 80 hours of the filtration head loss development was almost 8 to 10 percent of the maximum value.

During the first and final days of the experimentation turbidity removal was very low.Minimum turbidity obtained below the schmutzdecke layer was 5.5 units after 104 hours working period.Maximum value of turb of turbidity was determined as 23.5 units at the beginning houes of operation period. A similar trend was observed at other

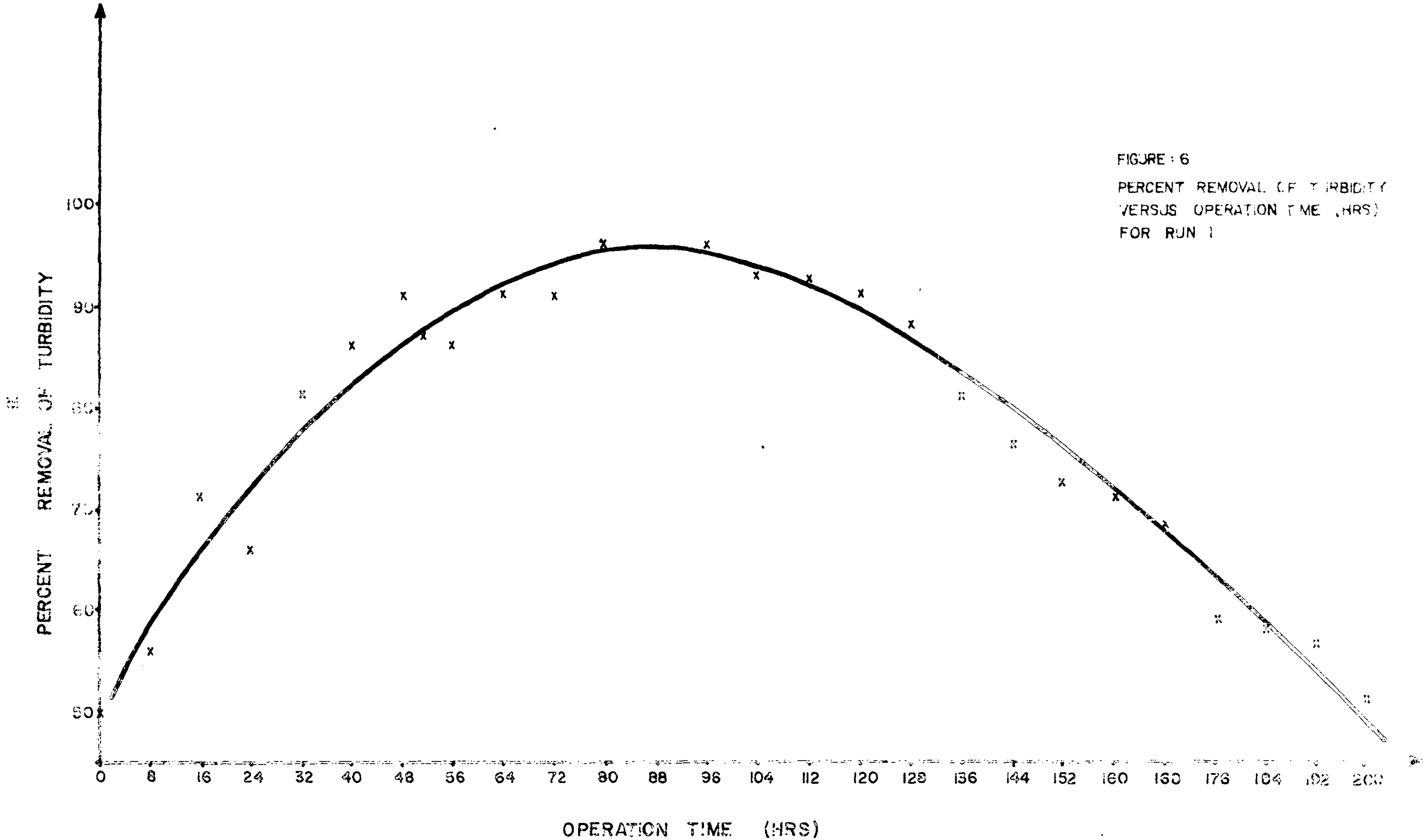
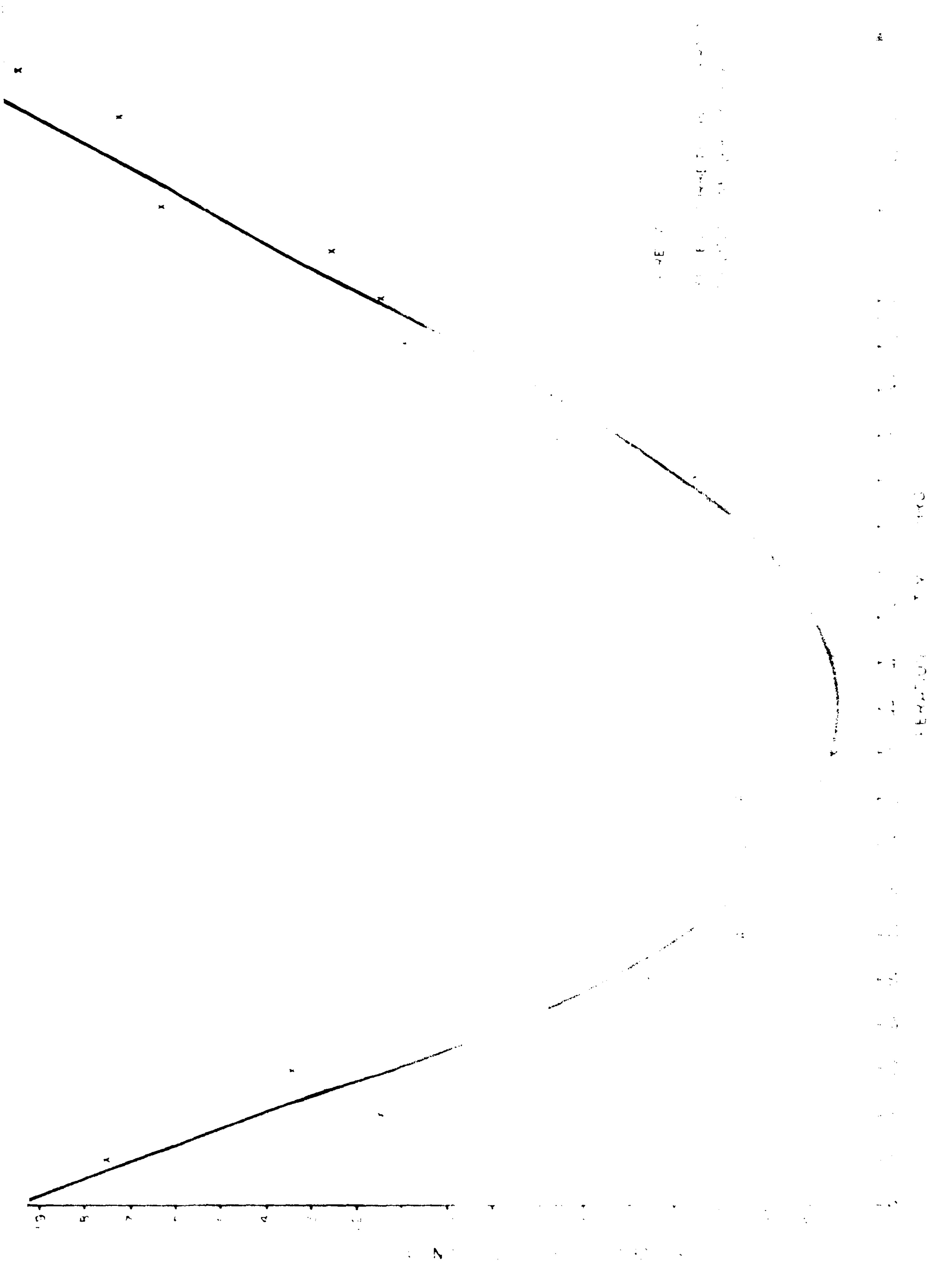
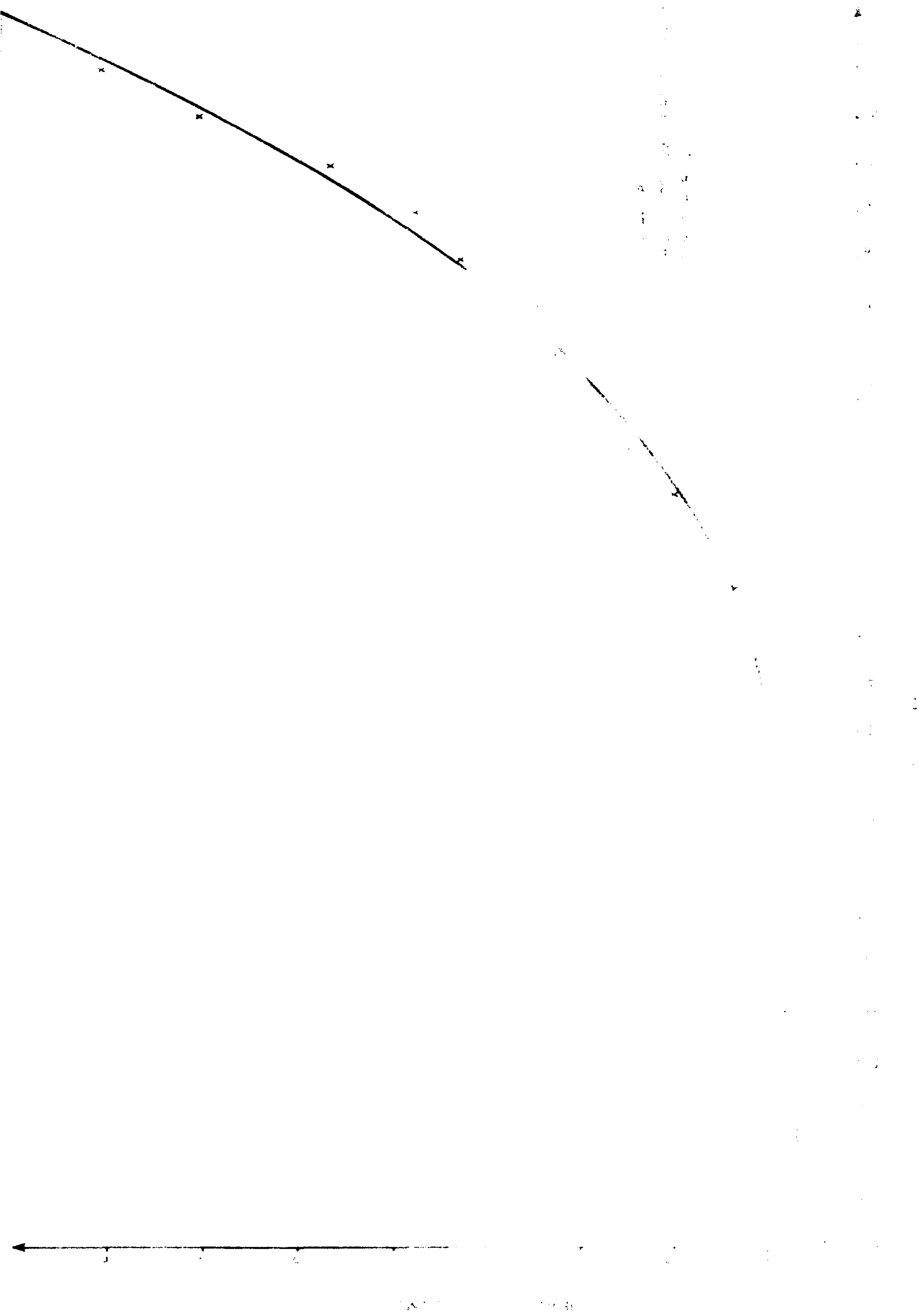


FIGURE : 6
PERCENT REMOVAL OF TURBIDITY VERSUS OPERATION TIME (HRS) FOR RUN 1





sampling depths .By examining the turbidity values of the fourth sampling point a removal efficiency particular to the gravel layer can be estimated.Turbidity removal within the gravel layer changed from 0 to 6 units and most of the time an average of 2 units removal was observed.

The second experimental run :

The filter was operated at a very low rate for three days at the start of experimentation as described in the first run.

At the begining and at the end of the filtration period 50 percent removal of turbidity was observed.After 64 hours filter operation period,the removal efficiency reached was 86.5 percent which corresponds to an effluent turbidity of 5.5 units .The maximum removal of turbidity was 96.25 percent and this value was attained between the 120 th. and the 185 th. hours of operation.While filter was clogging a decrease of percent removal of turbidity was observed.A 86.25 percent removal of turbidity was reached at the end of 200 hours of operation.(Figure 9).Table (2) Appendix.

The minimum filtrate turbidity was 1.5 units and the value was obtained between 120 and 185 hours .Increasing rate of removal of turbidity was nearly equal to the declining rate of turbidity removal fig.10.The maximum turbidity was 19.5 units and this value was determined at the beginning of the filtration period.Also a similar turbidity value was observed at the end of the operation period.The filtrate turbidity values equal or below to 5.5 units were obtained from samples which were collected between 64 th. and 232nd. hours of operation.

The head loss increased gradually from the beginning of the experimentation to 184 th.hour and during the remaining part of the filtration a rapid increase was seen figure 11.The turbidity removal at different depths of the filter bed is shown in figures(12-18).The minimum turbidity observed just below the schmutzdecke was 9.5 units and this was maintained between the 112 th.and 192 nd. hours

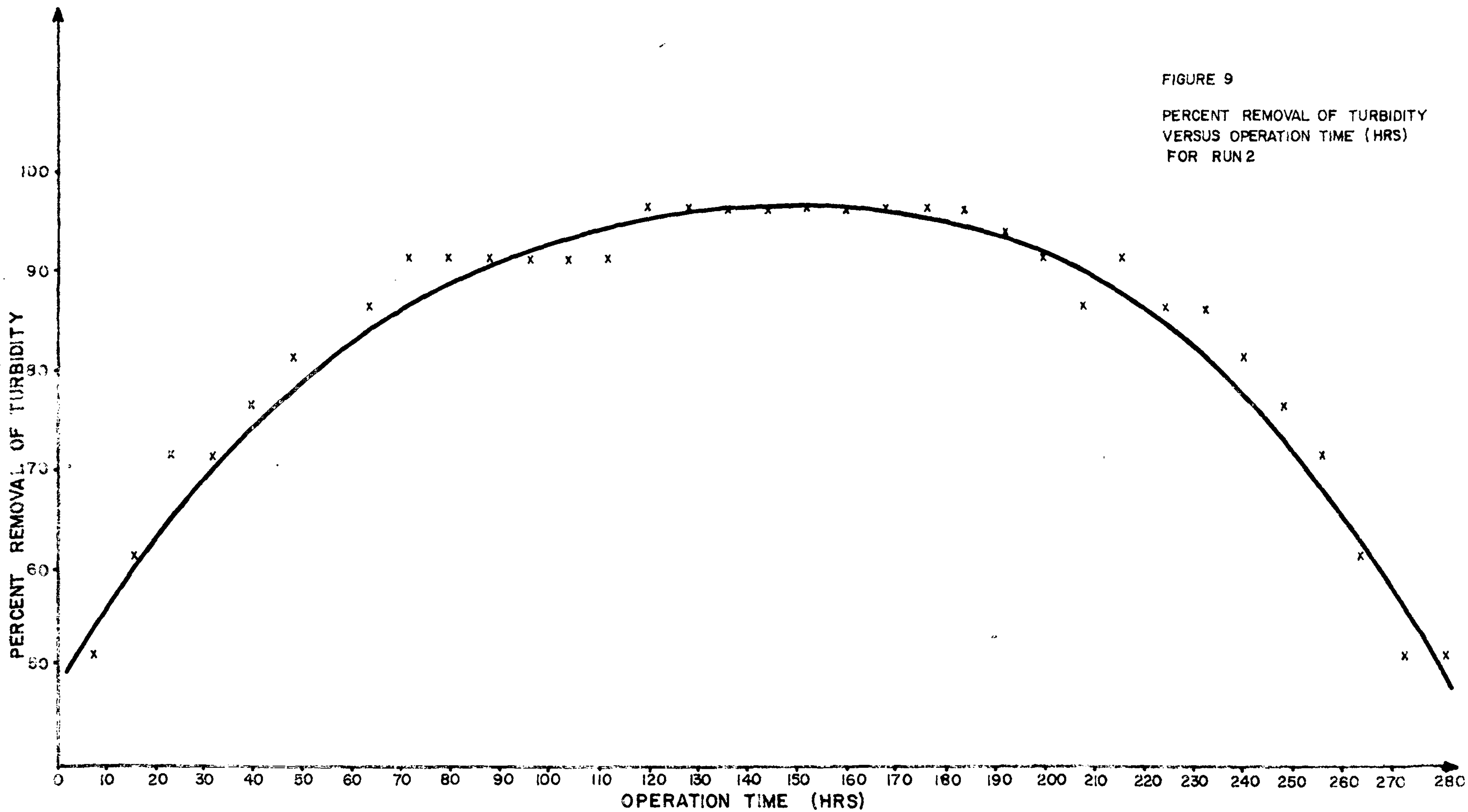


FIGURE 9

PERCENT REMOVAL OF TURBIDITY
VERSUS OPERATION TIME (HRS)
FOR RUN 2

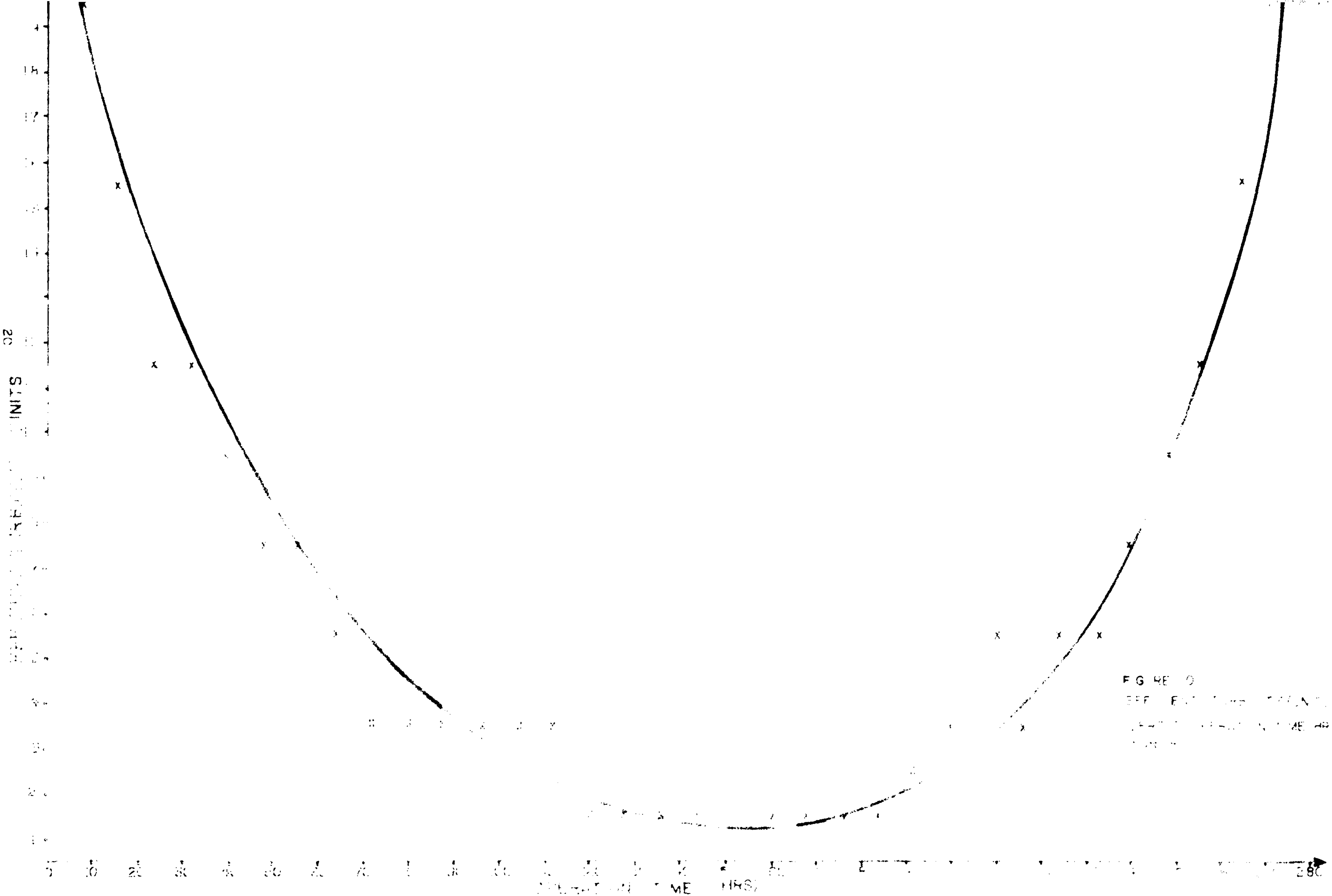
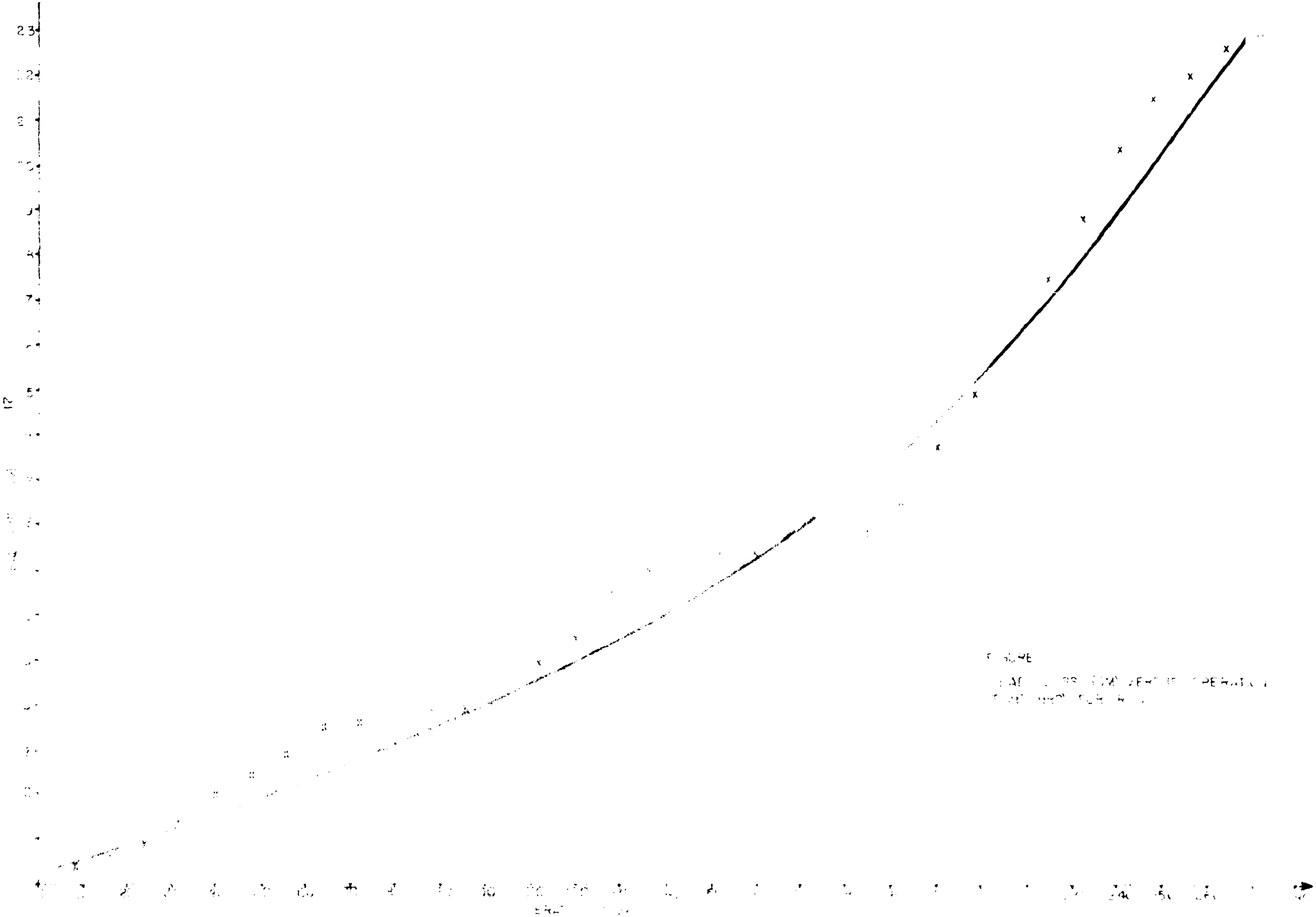
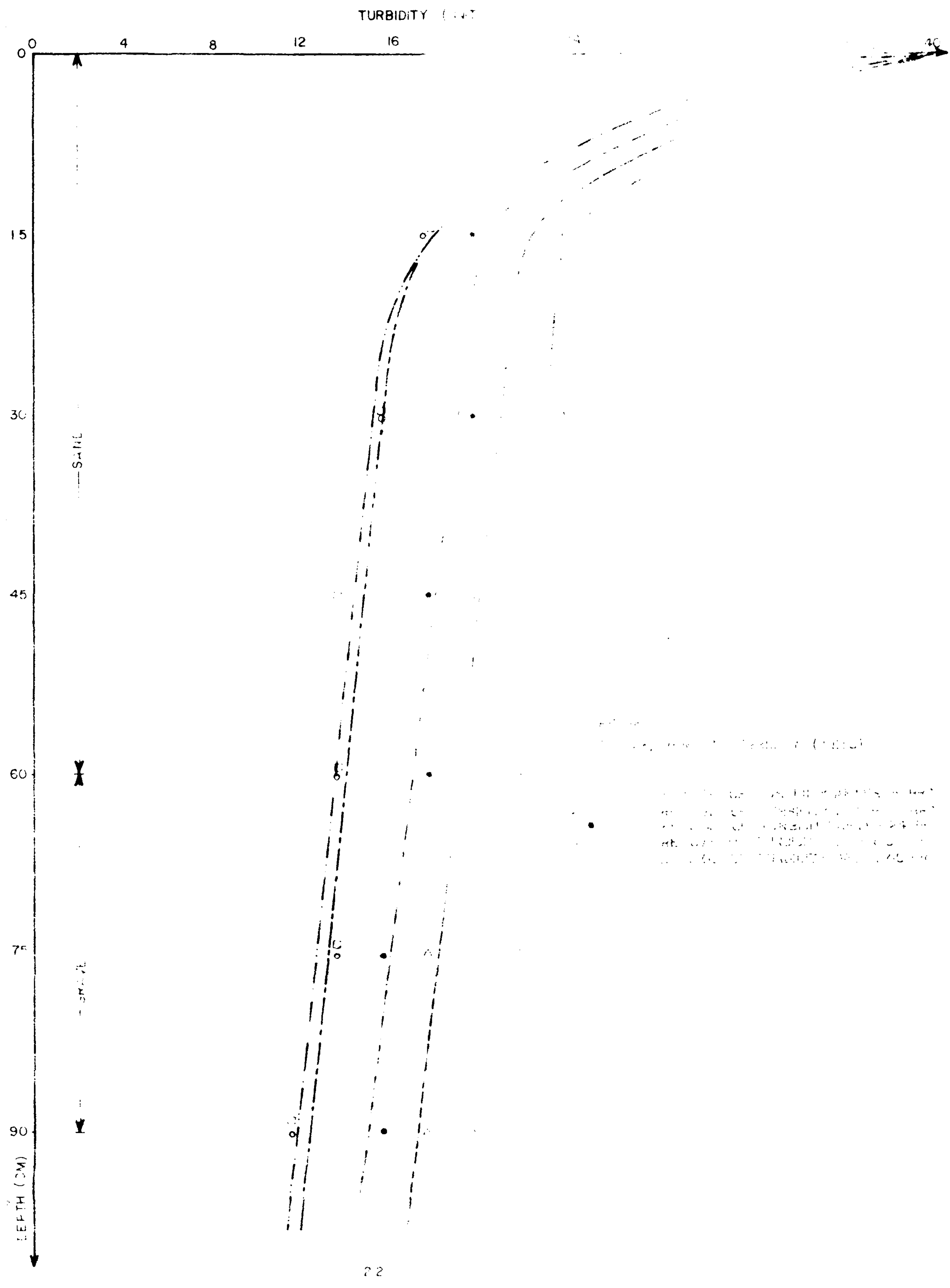


FIGURE [illegible]




TURBIDITY
0
4
8
12
16
15
30
45
60
75
90
DEPTH (CM)
SAND

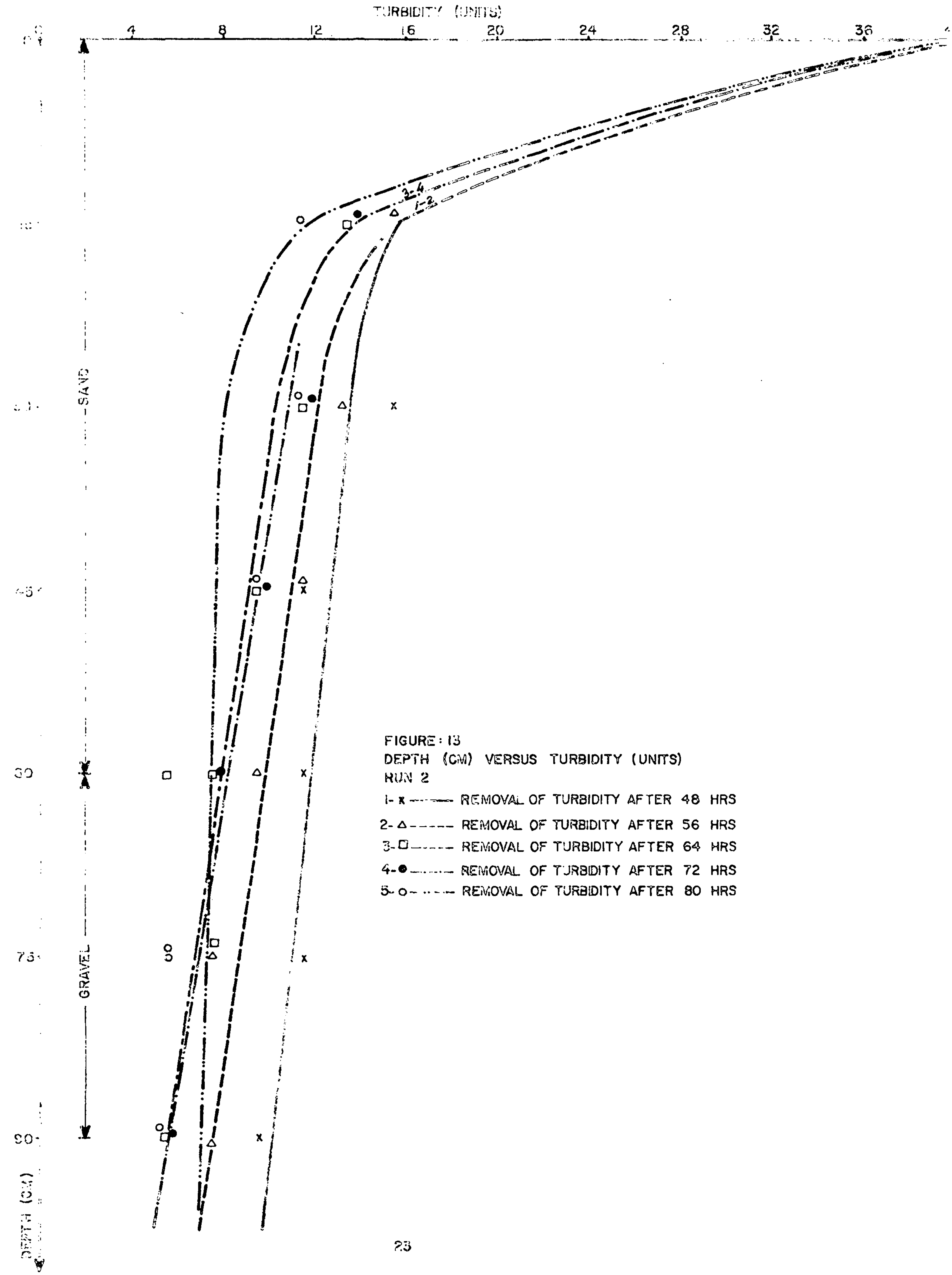


FIGURE: 13
DEPTH (CM) VERSUS TURBIDITY (UNITS)
RUN 2
1- x ——— REMOVAL OF TURBIDITY AFTER 48 HRS
2- △ ----- REMOVAL OF TURBIDITY AFTER 56 HRS
3- □ ----- REMOVAL OF TURBIDITY AFTER 64 HRS
4- ● ------ REMOVAL OF TURBIDITY AFTER 72 HRS
5- o ------ REMOVAL OF TURBIDITY AFTER 80 HRS

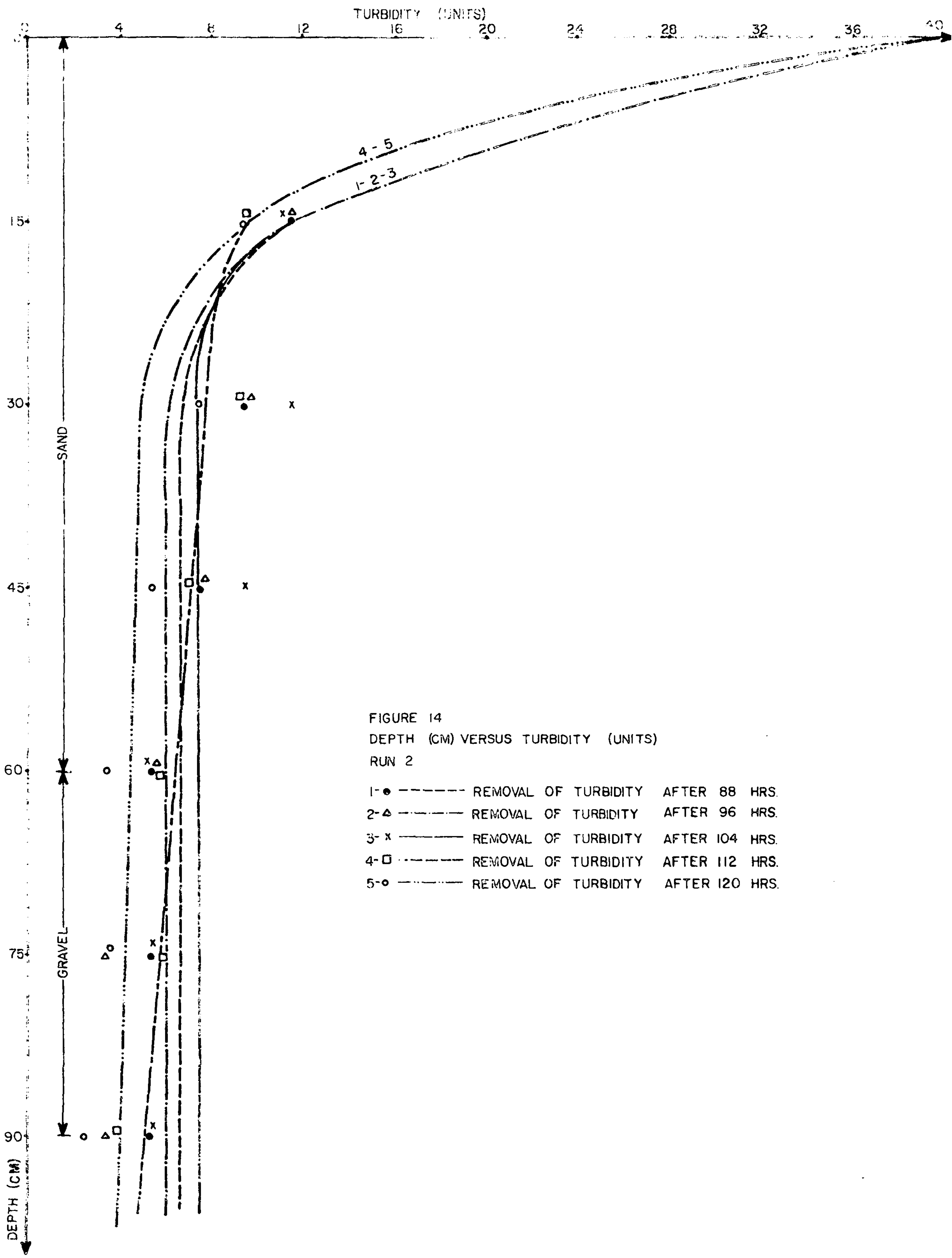


FIGURE 14
DEPTH (CM) VERSUS TURBIDITY (UNITS)
RUN 2

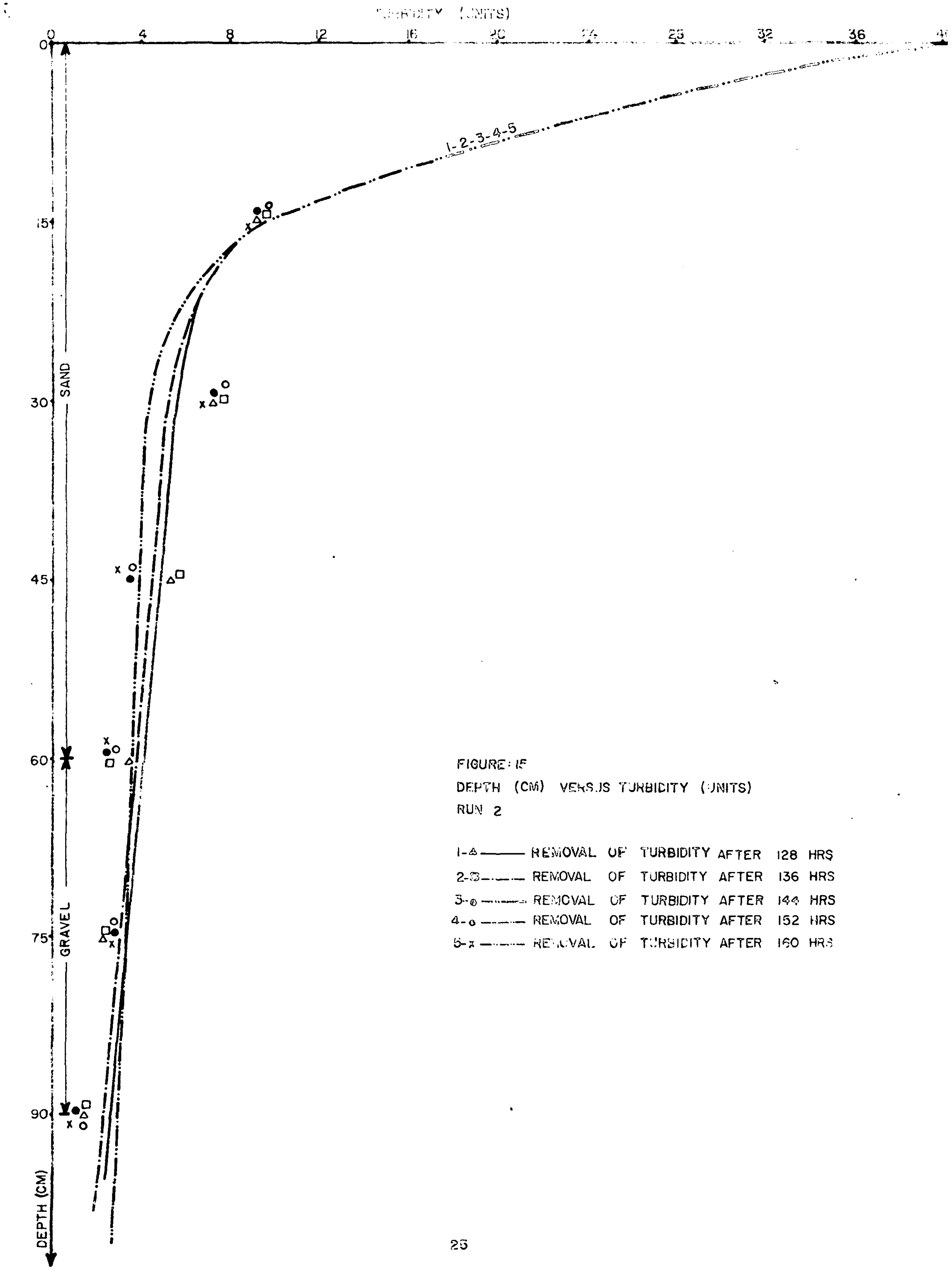


FIGURE: 1F
DEPTH (CM) VERSUS TURBIDITY (UNITS)
RUN 2

1-△ ——— REMOVAL OF TURBIDITY AFTER 128 HRS
2-□ — — — REMOVAL OF TURBIDITY AFTER 136 HRS
3-● —··— REMOVAL OF TURBIDITY AFTER 144 HRS
4-o —·—·— REMOVAL OF TURBIDITY AFTER 152 HRS
5-x —···— REMOVAL OF TURBIDITY AFTER 160 HRS

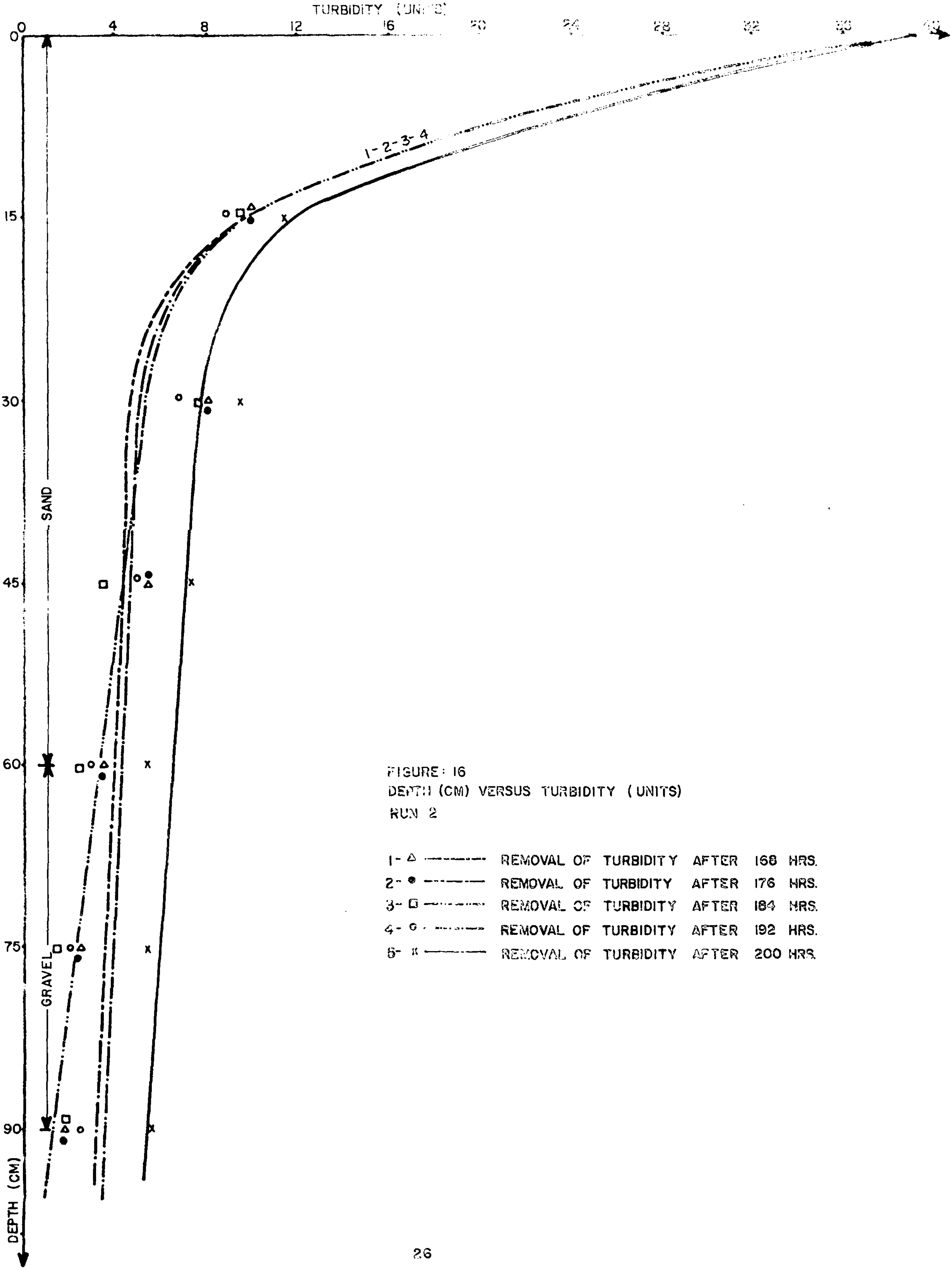


FIGURE: 16
DEPTH (CM) VERSUS TURBIDITY (UNITS)
RUN 2

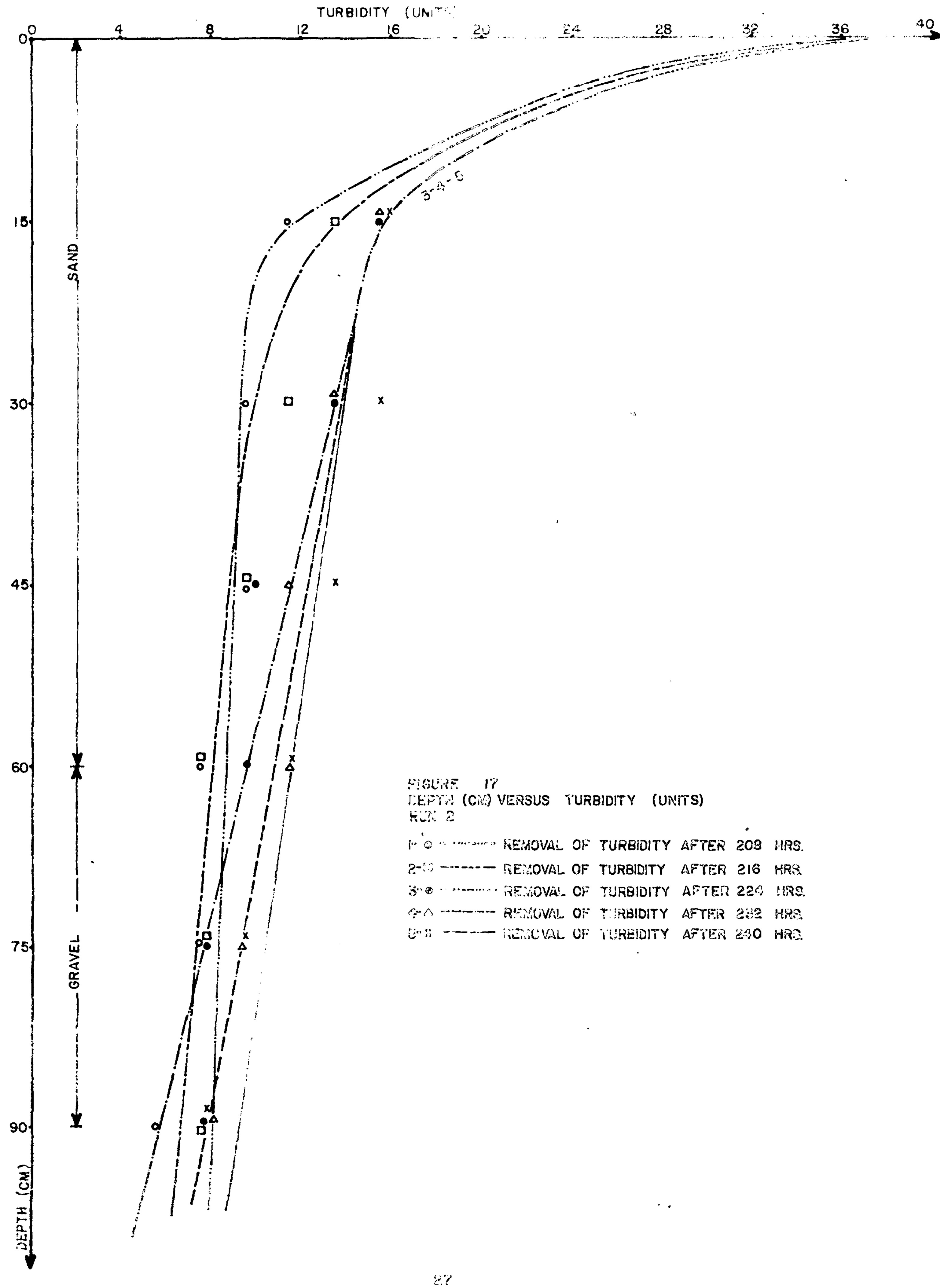


FIGURE 17
DEPTH (CM) VERSUS TURBIDITY (UNITS)
RUN 2

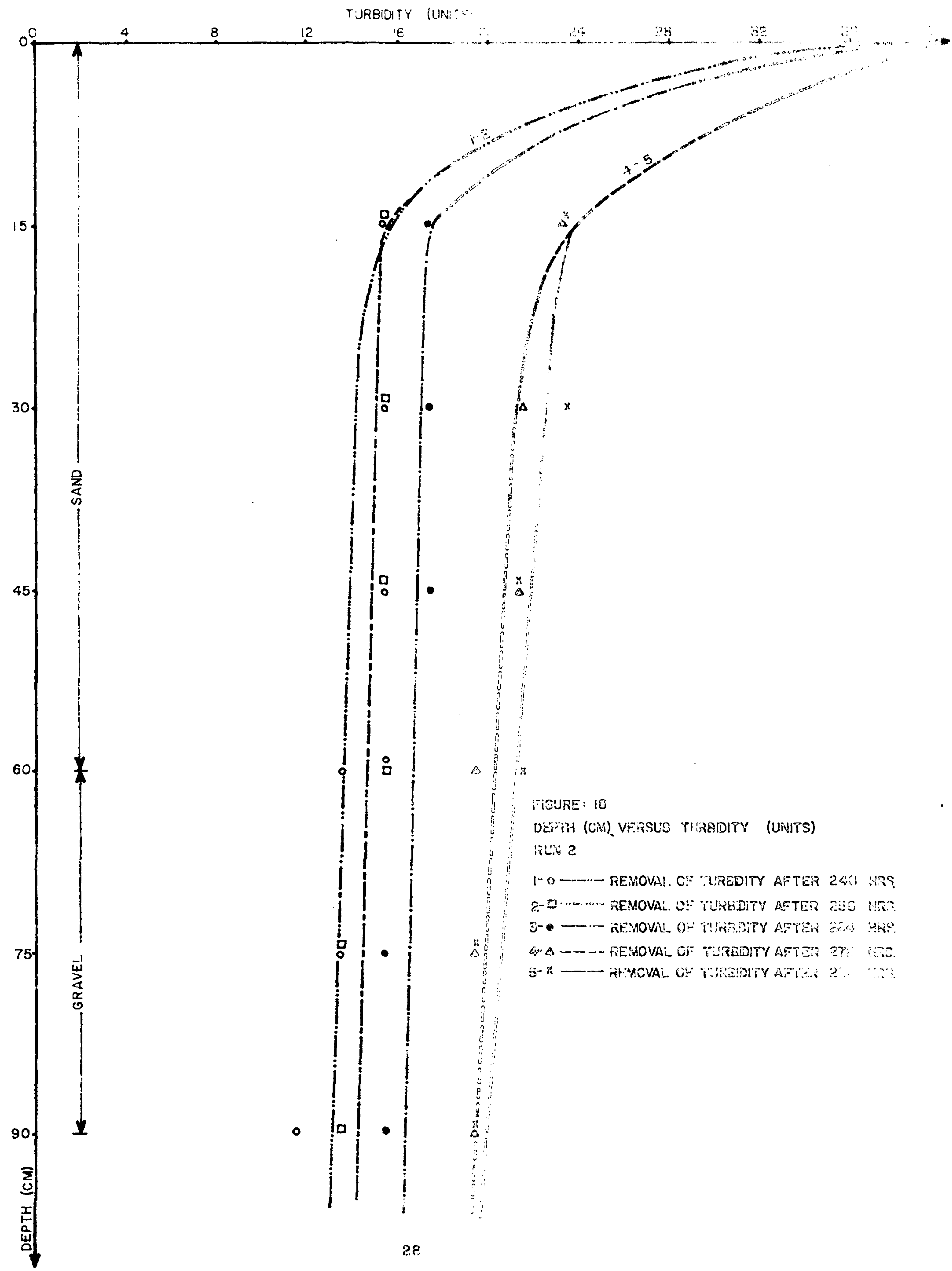


FIGURE: 18
DEPTH (CM) VERSUS TURBIDITY (UNITS)
RUN 2

of the operation time. The maximum value of this turbidity was 23.5 [illegible] units and it was observed during the first 8 hours and the last 12 [illegible] 12 hours of the filtration period.

In a few samples only 4 units removal of turbidity in the gravel layer was determinedand in most of the time removal of turbidity within the gravel layer changed from 0 to 2 units.

The third experimental run :

After the second run of the filtration 2.5 cm of the upper sand layer was removed and the remaining sand was washed in place and cleaning of filter was completed. A three days of ripening period was used at a very small filtration rate.

The effluent turbidity at the beginning of the experimentation was 7 units and the corresponding removal efficiency was 55 percent. When filtrate turbidity was 5.5 units the turbidity removal as percent was 90.83 fig(19). This value was obtained at the end of the 112 hours working period. The maximum removal of turbidity was 94.16 percent with a 3.5 units of effluent turbidity. After 144 th. hour of operation period efficiency of the filter declined rapidly and filtrate turbidities became higher than 5.5 units. 20 units of filtrate turbidity was observed at the end of the 184 th. hour working period fig. (20). The related percent remov l of turbidity was 66.66. fig(19).

In this part of the experimental study head losses were measured at each sampling point depth and six head loss versus operation time curves were obtained fig. 21.

The lowest curve in figure (21) show the head loss change with operation time at the depth of first sampling point. The rate of increase of head loss was very small and total change of it was 1.5 cm. At the second sampling depth the head loss development was higher than the first one and its value varied from 2 cm. to 4.1 cm. The gradual increase of head losses were observed upto the fourth curve and the last two curves tended upward rapidly. The maximum change of head loss thorugh the various depths of the filter was observed at the last sampling depth and the difference between the final and the initial head loss values was 5 cm.

After the first day of the experimentation 50 percent removal of turbidity was obtained in the schmutzdecke had a minimum turbidity of 16 units. This value was obtained between the 88 th and 96 th. hours of operation. At the end of the operation time observed turbidity below the upper sandlayer was 29 units.

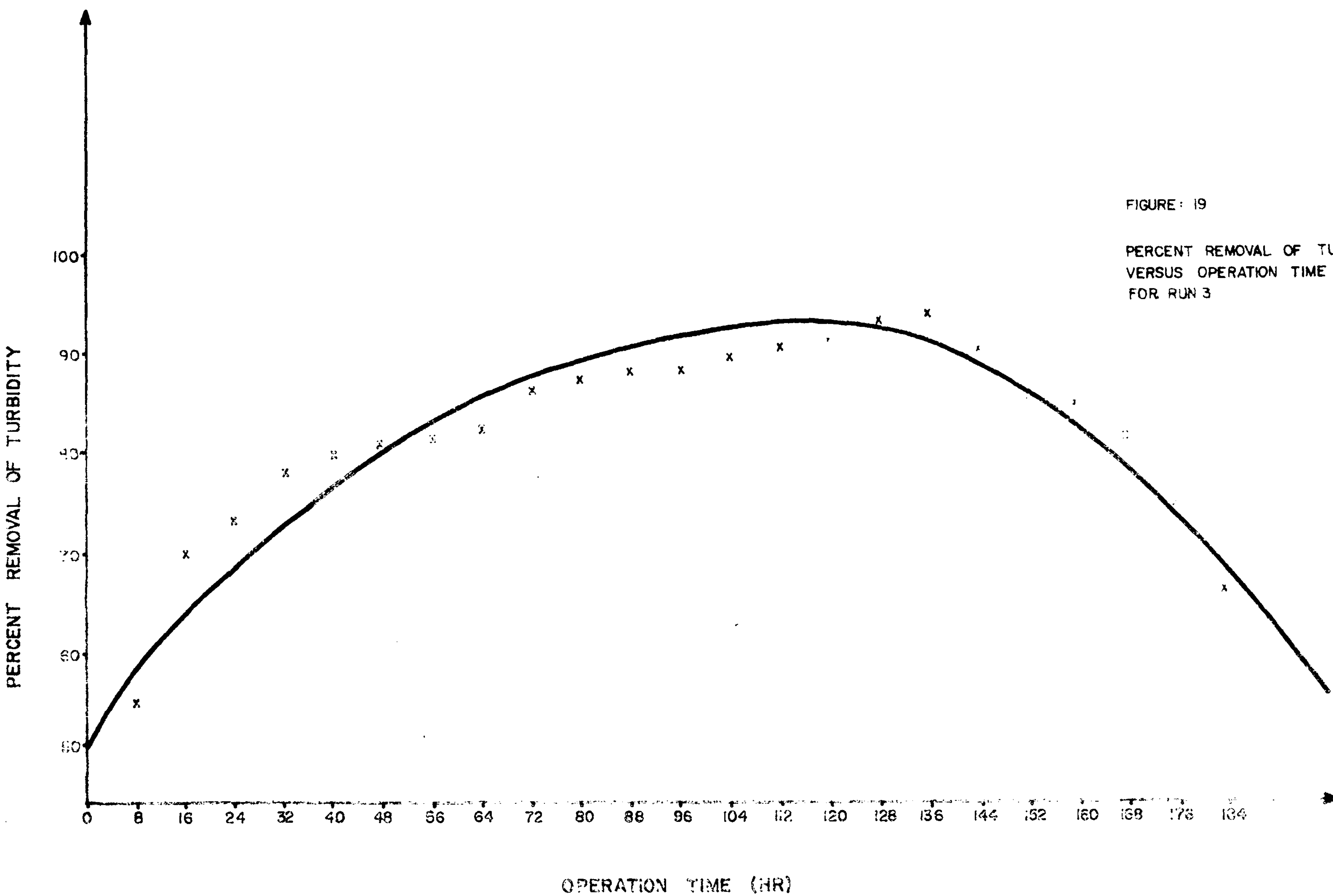


FIGURE: 19

PERCENT REMOVAL OF TURBIDITY VERSUS OPERATION TIME (HRS) FOR RUN 3

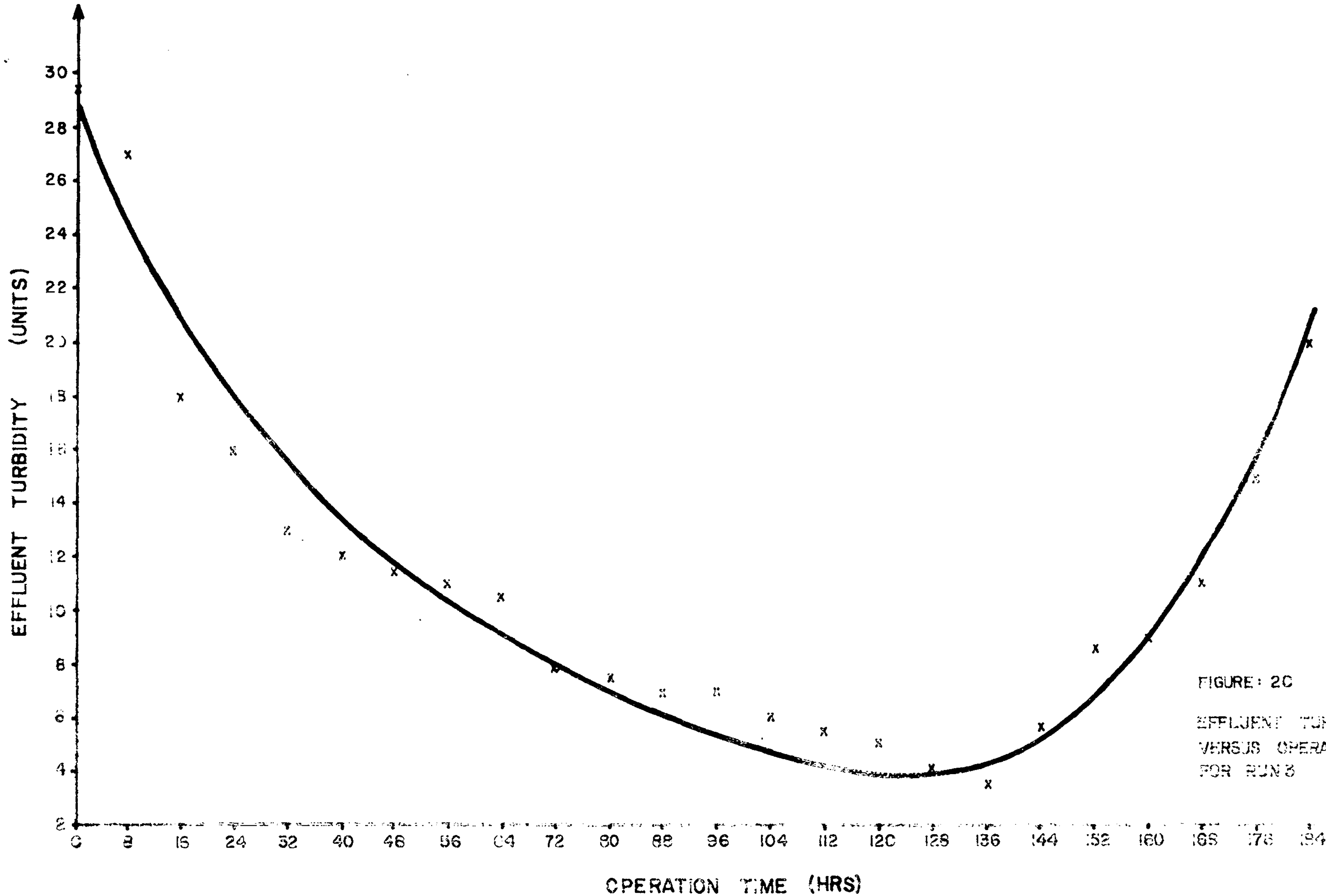


FIGURE: 2C

EFFLUENT TURBIDITY (UNITS) VERSUS OPERATION TIME (HRS) FOR RUN 3

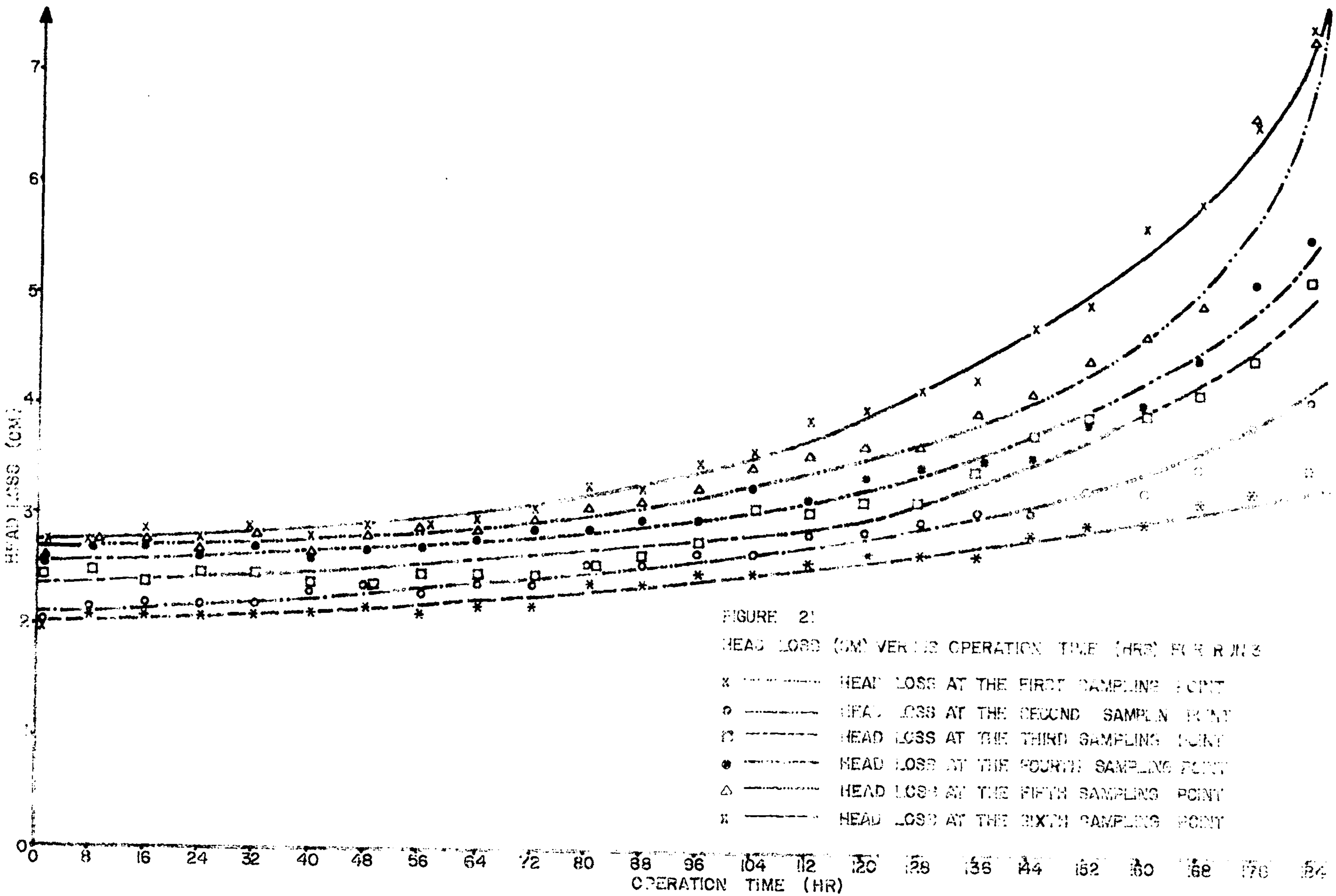


FIGURE 21

HEAD LOSS (CM) VERSUS OPERATION TIME (HRS) FOR RUN 3

CONCLUSION

In the experimental part of this study by using a filter set-up ,slow sand filtration performance was investigated as related to the filter bed depth and influent water turbidity changes.

The maximum turbidity removal in the slow sand filter set - up was 96.25 % ,which indicated a very high efficiency. Between the three experimental runs the best cleaning of the raw water is achieved in the second run when the influent turbidity was 40 units and the filter bed depth was 90 cms. The turbidity removal efficiency reduction was observed when the raw water turbidity was 60 units and the filter bed depth was 60 cms. Therefore it can be recommended that the minimum sand depth should be 60 cms and the turbidity of raw water must be equal or lower than 40 units for such filters. In order to increase the efficiency of the filter in presence of high raw water turbidities some pretreatment is required. The plain sedimentation ,storage and if necessary for algea removal micro-straining combination can be recommended.

Also by taking samples at different depths of the filter bed and measuring the head losses at the corresponding depths , it is determined that the impurities in the infulent do not penetrate into the lower layers of the filter bed as being an advantage of such slow sand filters.

Since in practice the sand layer depth preferably is around one meter so several times scraping of the upper sand surface can be done .When the filter effluent turbidity passes beyond the maximum permissible limit of the drinking water standards (TS 266) the upper sand layer should be scraped out. Experimental results

(TS 266) : Turkish Drinking Water Standards.

indicates that this procedure can be repeated until the remaining sand depth becomes 60 cm for the common turbidity ranges of raw water .At this time removed sand layer must be replaced by the clean and washed one.

When the filter is continuously operated ,according to the second experimental run's results, it will be working efficiently for 12 or 13 days. If the filter sand depth is taken as 105 cms, at every 13 days by scraping of 2.5 cm of the upper sand layer ,washing and replacement of the total filter media will be necessary after seven or eight months of operation time. It is seen that the used wash water quantity is less if compared to pressure or rapid sand filters.Also it can be easily concluded from the experimental study that ,when the raw water turbidity is less than 40 units, washing and replacement interval of sand will be longer than seven or eight months. It can be recommended that some pretreatment must be applied to raw water if it's turbidity is high or it is the flood time.

During the experimentation due to sun light there was some algae growth upon the sand surface and on the side walls of the filter. This algea formation did not produce any color or odor in the effluent water. Therefore it is proved that certain amount of algae growth do not bring any deleterious effect at slow sand filtration process.

The author suggests that for rural areas and communities slow sand filtration is a very convenient water treatment method. Because in most parts of the country filter bed materials are available and less skillfull operation and less close supervision are needed during operation than for rapid sand filters. Low labour and land costs are being another advantage of slow sand filter applications for rural areas in this country.

The ddsign details of the slow sand filters are much less critical than the other type of filters so the minimum skilled supervision is required during construction period.Also this reasoning supports the application of slow sand filters for small communities.

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LIST OF REFERENCES

Baylis,J.R.(1954), Washing and Maintenance of Filters.
J.Am Wat.Wks.Ass.,46,176.

Biological or Slow Sand Filters(1970).
Tech.Rep.Ser.Wld.Hlth.Org.

Cleasby,J.L.,Baumann,E.R.(1961).Selection of Optimum Filtration Rates for Sand Filters.
Progress Report,Iowa State University,Ames.

Deb,A.K.(1959).Theory of Sand Filtration.
Proc.Am.Soc.Civ.Engrs.95,411.

Fair,G.M.Geyer,J.C.(1956).Elements of Water Supply and Waste Water Disposal ,1st.Edn.,p.373,N.Y.,John Wiley and Sons.

Fox,D.M.,Cleasby,J.L.(1966).Experimental Evaluation of Sand Filtration Theory.Proc.Am.Soc.Civ.Engrs.92,61.

Huisman,L.(1972).Slow Sand Filtration 1.st.Edn.Delft University of Tecnnology,Netherlands.

Ives,K.J.(1960).Rational Design of Filters.
Proc.Am.Soc.Civ.Engrs.,16.189.

Ives,K.J.Sholji,I.(1965).Research on Variables Affecting Filtration. Proc.Am.Soc.Civ.Engrs.91,1.

Lewin,J.(1961) .Mechanization of Slow Sand and Secondary Filter Bed Cleaning.J.Inst.Wat.Engrs.15.15.

Progress Toward a Filterability Index Test (1959).Task Group Report.J.Am.Wat.Wks.Ass.51,1539.

Standard Methods for the Examination of Water and Wastewater.(1965)
12.th.Edn.,APHA.AWWA.WPCF.

Wagner,E.G.,Lanoix,J.N.(1959).Water Supply for Rural Areas and Small Communities WHO ,Genevo.

A P P E N D I X

TABLE 2. TURBIDITY-HEAT LOSS-TIME RELATIONSHIPS FOR RUN 2

Time (hr)	Head-loss (cm)	Sampling point 1 turbidity (unit)	Sampling point 2 turbidity (unit)	Sampling point 3 turbidity (unit)	Sampling point 4 turbidity (unit)	Sampling point 5 turbidity (unit)	Sampling point 6 turbidity (unit)	Effluent turbidity (unit)	Percent removal	Temp. °C.
3-8-1971										
2	4.00	23.5	23.5	23.5	21.5	21.5	19.5	19.5	51.25	18.0
4	4.30	23.5	23.5	23.5	21.5	21.5	19.5	19.5	51.25	18.0
6	4.30	23.5	23.5	23.5	21.5	19.5	19.5	19.5	51.25	17.8
8	4.50	23.5	23.5	23.5	21.5	21.5	19.5	19.5	51.25	17.8
26.10.1971										
2	4.50	21.5	21.5	21.5	19.5	21.5	17.5	17.5	56.25	17.8
4	4.50	21.5	21.5	19.5	19.5	19.5	17.5	17.5	56.25	17.6
6	4.50	21.5	21.5	19.5	19.5	17.5	17.5	15.5	61.25	17.6
8	4.60	21.5	21.5	19.5	19.5	17.5	17.5	15.5	61.25	17.6
29.10.1971										
2	4.90	21.5	21.5	19.5	17.5	15.5	15.5	15.5	61.25	17.5
4	4.90	21.5	19.5	19.5	17.5	15.5	15.5	13.5	66.25	17.5
6	4.90	21.5	19.5	19.5	17.5	15.5	15.5	13.5	66.25	17.5
8	4.90	19.5	19.5	17.5	17.5	15.5	15.5	11.5	71.25	17.4
30.10.1971										
2	5.10	17.5	17.5	15.5	15.5	15.5	13.5	11.5	71.25	17.4
4	5.30	17.5	17.5	15.5	15.5	15.5	13.5	11.5	71.25	17.5

TABLE 2 (continue)

Time (hr)	Headloss (cm)	Sampling point 1 turbidity unit	Sampling point 2 turbidity unit	Sampling point 3 turbidity unit	Sampling point 4 turbidity unit	Sampling point 5 turbidity unit	Sampling point 6 turbidity unit	Effluent turbidity	Percent removal	Temp. °C.	pH
6	5.40	17.5	17.5	15.5	13.5	13.5	13.5	11.5	71.25	17.5	8.1
8	5.40	15.5	15.5	15.5	13.5	13.5	11.5	11.5	71.25	17.4	8.1
1.11.1971											
2	5.70	17.5	15.5	15.5	13.5	13.5	13.5	11.5	71.25	17.4	8.0
4	5.70	17.5	15.5	13.5	13.5	13.5	11.5	9.5	76.25	17.4	8.0
6	5.70	17.5	15.5	13.5	13.5	13.5	11.5	9.5	76.25	17.3	8.0
8	6.00	17.5	15.5	13.5	13.5	13.5	11.5	9.5	76.25	17.5	8.1
2.11.1971											
2	6.20	17.5	15.5	13.5	13.5	11.5	9.5	9.5	76.25	17.4	8.1
4	6.20	17.5	15.5	13.5	13.5	11.5	9.5	7.5	81.25	17.4	8.1
6	6.40	15.5	15.5	13.5	13.5	11.5	9.5	7.5	81.25	17.4	8.1
8	6.40	15.5	15.5	11.5	11.5	11.5	9.5	7.5	81.25	17.4	8.2
3.11.1971											
2	6.50	15.5	15.5	11.5	9.5	9.5	7.5	7.5	81.25	17.2	8.0
4	6.80	15.5	15.5	11.5	9.5	9.5	7.5	7.5	81.25	17.2	8.0
6	6.90	15.5	13.5	11.5	9.5	9.5	7.5	7.5	81.25	17.2	8.0
8	6.90	15.5	13.5	11.5	9.5	7.5	7.5	7.5	81.25	17.2	8.0
6.11.1971											
2	7.20	13.5	13.5	11.5	9.5	7.5	7.5	5.5	86.25	17.1	8.0
4	7.30	13.5	11.5	11.5	7.5	7.5	7.5	5.5	86.25	17.1	8.1
6	7.30	13.5	11.5	9.5	7.5	7.5	7.5	5.5	86.25	17.1	8.1
8	7.50	13.5	11.5	9.5	7.5	7.5	5.5	5.5	86.25	17.2	8.1

TABLE 2 (continue)

Time (hr)	Head loss (cm)	Sampling point 1 turbidity (unit)	Sampling point 2 turbidity (unit)	Sampling point 3 turbidity (unit)	Sampling point 4 turbidity (unit)	Sampling point 5 turbidity (unit)	Sampling point 6 turbidity (unit)	Effluent turbidity unit	Percent removal	Temp. °C	pH
7.11.1971											
2	7.50	13.5	11.5	9.5	7.5	5.5	5.5	5.5	86.25	17.2	8.2
4	7.50	13.5	11.5	9.5	7.5	7.5	5.5	5.5	86.25	17.2	8.1
6	7.50	13.5	11.5	9.5	7.5	5.5	5.5	5.5	86.25	17.2	8.1
8	7.60	13.5	11.5	9.5	7.5	5.5	5.5	3.5	91.25	17.2	8.1
8.11.1971											
2	7.60	13.5	11.5	9.5	7.5	5.5	5.5	3.5	91.25	17.2	8.0
4	7.60	11.5	11.5	9.5	5.5	5.5	5.5	3.5	91.25	17.2	8.0
6	7.60	11.5	11.5	9.5	5.5	5.5	5.5	3.5	91.25	17.0	8.0
8	7.70	11.5	11.5	9.5	5.5	5.5	5.5	3.5	91.25	17.0	8.0
9.11.1971											
2	7.70	11.5	9.5	9.5	5.5	5.5	5.5	3.5	91.25	17.0	8.0
4	7.70	11.5	9.5	9.5	5.5	5.5	5.5	3.5	91.25	17.0	7.9
6	7.70	11.5	9.5	9.5	5.5	5.5	5.5	3.5	91.25	17.1	7.9
8	7.90	11.5	9.5	7.5	5.5	5.5	5.5	3.5	91.25	17.0	7.9
10.11.1971											
2	7.90	11.5	9.5	7.5	5.5	5.5	3.5	3.5	91.25	16.9	7.8
4	7.90	11.5	9.5	7.5	5.5	5.5	3.5	3.5	91.25	16.9	7.7
6	7.90	11.5	9.5	7.5	5.5	5.5	3.5	3.5	91.25	16.9	7.7
8	7.90	11.5	9.5	7.5	5.5	3.5	3.5	3.6	91.25	16.9	7.7

TABLE 2 (continue)

Time hr	Head loss cm	Sampling point 1 turbidity unit	Sampling point 2 turbidity unit	Sampling point 3 turbidity unit	Sampling point 4 turbidity unit	Sampling point 5 turbidity unit	Sampling point 6 turbidity unit	Effluent turbidity unit	Percent removal	Temp. C.	pH
13.11.1971											
2	8.00	11.5	9.5	7.5	5.5	3.5	3.5	2.5	93.74	17.0	7.7
4	8.00	13.5	11.5	9.5	7.5	5.5	5.5	5.5	86.25	17.0	7.9
6	8.10	11.5	11.5	9.5	7.5	5.5	5.5	3.5	91.25	17.1	7.9
8	8.20	11.5	11.5	9.5	5.5	5.5	5.5	3.5	91.25	17.1	7.9
14.11.1971											
2	8.50	11.5	11.5	7.5	5.5	5.5	3.5	3.5	91.25	17.2	7.8
4	8.80	11.5	9.5	7.5	5.5	5.5	3.5	3.5	91.25	17.2	7.8
6	8.90	11.5	9.5	7.5	5.5	5.5	3.5	3.5	91.25	17.2	7.7
8	8.90	9.5	9.5	7.5	5.5	5.5	3.5	3.5	91.25	17.2	7.7
15.11.1971											
2	9.00	9.5	7.5	5.5	5.5	3.5	3.5	3.5	91.25	17.0	7.7
4	9.30	9.5	7.5	5.5	5.5	3.5	3.5	2.5	93.75	17.0	7.7
6	9.50	9.5	7.5	5.5	5.5	3.5	3.5	2.5	93.75	17.0	7.7
8	9.50	9.5	7.5	5.5	3.5	3.5	2.5	1.5	96.25	17.1	7.8
16.11.1971											
2	9.90	9.5	7.5	5.5	3.5	3.5	2.5	1.5	96.25	17.2	7.8
4	10.00	9.5	7.5	5.5	3.5	2.5	2.5	1.5	96.25	17.2	7.8
6	10.40	9.5	7.5	5.5	3.5	2.5	2.5	1.5	96.25	17.2	7.9
8	10.50	9.5	7.5	5.5	3.5	2.5	1.5	1.5	96.25	17.1	7.9

TABLE 2 (continue)

Time hr	Headloss cm	Sampling point 1 turbidity unit	Sampling point 2 turbidity unit	Sampling point 3 turbidity unit	Sampling point 4 turbidity unit	Sampling point 5 turbidity unit	Sampling point 6 turbidity unit	Effluent turbidity unit	Percent removal	Temp. °C	pH
17.11.1971											
2	10.90	9.5	7.5	5.5	3.5	2.5	1.5	1.5	96.25	17.1	7.9
4	11.00	9.5	7.5	5.5	2.5	2.5	1.5	1.5	96.25	17.1	7.9
6	11.00	9.5	7.5	5.5	2.5	2.5	1.5	1.5	96.25	17.1	7.9
8	11.00	9.5	7.5	5.5	2.5	2.5	1.5	1.5	96.25	17.1	7.9
20.11.1971											
2	11.00	9.5	7.5	5.5	2.5	2.5	1.5	1.5	96.25	17.1	8.0
4	11.00	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.1	7.9
6	11.2	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.1	7.9
8	11.2	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.0	7.8
21.11.1971											
2	11.2	9.5	7.5	5.5	2.5	2.5	1.5	1.5	96.25	17.0	7.8
4	11.4	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.0	8.0
6	11.4	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.1	8.0
8	11.4	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.1	8.0
27.11.1971											
2	11.4	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.0	8.1
4	11.4	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.0	8.1
6	11.4	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.0	8.1
8	11.4	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.0	8.1

TABLE 2 (continue)

Time hr	Headloss cm	Sampling point 1 turbidity unit	Sampling point 2 turbidity unit	Sampling point 3 turbidity unit	Sampling point 4 turbidity unit	Sampling point 5 turbidity unit	Sampling point 6 turbidity unit	Effluent turbidity unit	Percent removal	Temp. °C	pH
23.11.1971											
2	11.4	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.0	8.1
4	11.5	9.5	7.5	5.5	2.5	2.5	1.5	1.5	96.25	17.0	8.1
6	11.5	9.5	7.5	5.5	3.5	2.5	1.5	1.5	96.25	17.0	8.1
8	11.5	9.5	7.5	5.5	3.5	2.5	1.5	1.5	96.25	17.0	8.0
24.11.1971											
2	11.5	9.5	7.5	5.5	3.5	2.5	1.5	1.5	96.25	16.8	8.0
4	11.5	9.5	7.5	5.5	3.5	2.5	1.5	1.5	96.25	16.8	8.0
6	11.7	9.5	7.5	5.5	3.5	2.5	1.5	1.5	96.25	16.8	8.0
8	11.7	9.5	7.5	5.5	3.5	2.5	1.5	1.5	96.25	16.9	8.0
27.11.1971											
2	11.7	9.5	7.5	5.5	2.5	2.5	1.5	1.5	96.25	16.9	8.1
4	11.8	9.5	7.5	5.5	2.5	2.5	1.5	1.5	96.25	16.9	8.2
6	11.8	9.5	7.5	3.5	2.5	2.5	1.5	1.5	96.25	17.0	8.2
8	11.8	9.5	7.5	3.5	2.5	1.5	1.5	1.5	96.25	17.0	8.2
28.11.1971											
2	12.0	9.5	7.5	5.5	3.5	2.5	2.5	1.5	96.25	17.0	8.2
4	12.2	9.5	7.5	5.5	3.5	2.5	2.5	1.5	96.25	17.0	8.2
6	12.5	9.5	7.5	5.5	3.5	2.5	2.5	2.5	93.75	17.0	8.2
8	12.5	9.5	7.5	5.5	3.5	2.5	2.5	2.5	93.75	17.0	8.2
29.11.1971											
2	12.8	9.5	7.5	5.5	5.5	3.5	2 5	2.5	93.75	16.5	8.1
4	13.1	11.5	9.5	7.5	5.5	3.5	3.5	2.5	93.75	16.5	8.1

TABLE 2 (continue)

Time hr	Headloss cm	Sampling point 1 turbidity unit	Sampling point 2 turbidity unit	Sampling point 3 turbidity unit	Sampling point 4 turbidity unit	Sampling point 5 turbidity unit	Sampling point 6 turbidity unit	Effluent turbidity unit	Percent removal	Temp. °C	pH
6	13.5	11.5	9.5	7.5	5.5	5.5	5.5	3.5	91.25	16.4	8.1
8	13.7	11.5	9.5	7.5	5.5	5.5	5.5	3.5	91.25	16.4	8.1
3.1.1972											
2	14.5	11.5	9.5	7.5	7.5	5.5	5.5	3.5	91.25	16.4	8.0
4	14.5	11.5	9.5	7.5	7.5	5.5	5.5	3.5	91.25	16.4	7.8
6	14.9	11.5	9.5	9.5	7.5	7.5	5.5	3.5	91.25	16.5	7.8
8	14.9	11.5	9.5	9.5	7.5	7.5	5.5	5.5	86.25	16.5	8.0
4.1.1972											
2	15.3	11.5	9.5	9.5	7.5	7.5	5.5	5.5	86.25	16.7	8.4
4	15.4	11.5	9.5	9.5	7.5	7.5	5.5	5.5	86.25	16.7	8.4
6	15.8	11.5	9.5	9.5	7.5	7.5	5.5	3.5	91.25	16.7	8.4
8	16.1	13.5	11.5	9.5	7.5	7.5	7.5	3.5	91.25	16.5	8.4
5.1.1972											
2	16.5	13.5	11.5	9.5	9.5	7.5	7.5	3.5	91.25	16.7	8.3
4	16.9	13.5	11.5	9.5	9.5	9.5	7.5	3.5	91.25	16.7	8.3
6	17.1	15.5	11.5	9.5	9.5	3.5	3.5	3.5	91.25	16.6	8.3
8	17.4	15.5	13.5	9.5	9.5	7.5	7.5	5.5	86.25	16.6	8.3

TABLE 2 (continue)

Time hr	Headloss cm.	Sampling point 1 turbidity (unit)	Sampling point 2 turbidity (unit)	Sampling point 3 turbidity (unit)	Sampling point 4 turbidity (Unit)	Sampling point 5 turbidity (unit)	Sampling point 6 turbidity (unit)	Effluent turbidity (unit)	Percent removal	Temp. °C	pH
6.1.1972											
2	17.7	15.5	13.5	11.5	9.5	7.5	7.5	5.5	86.25	16.5	8.2
4	18.3	15.5	13.5	11.5	9.5	7.5	7.5	5.5	86.25	16.5	8.2
6	18.5	15.5	13.5	11.5	9.5	9.5	7.5	5.5	86.25	16.5	8.1
8	18.8	15.5	13.5	11.5	11.5	9.5	7.5	5.5	86.25	16.6	8.1
7.1.1972											
2	19.4	15.5	13.5	11.5	11.5	9.5	7.5	5.5	86.25	16.5	8.2
4	19.5	15.5	15.5	13.5	11.5	9.5	7.5	5.5	86.25	16.5	8.2
6	19.9	15.5	15.5	13.5	11.5	9.5	7.5	5.5	86.25	16.5	8.1
8	20.3	15.5	15.5	13.5	11.5	9.5	7.5	7.5	81.25	16.5	8.1
10.1.1972											
2	20.8	15.5	15.5	13.5	11.5	9.5	9.5	7.5	81.25	16.7	8.1
4	21.0	15.5	15.5	13.5	11.5	9.5	9.5	7.5	81.25	16.7	8.2
6	21.4	15.5	15.5	13.5	13.5	11.5	9.5	9.5	76.25	16.7	8.1
8	21.5	15.5	15.5	13.5	13.5	11.5	11.5	9.5	76.25	16.7	8.1
11.1.1972											
2	21.5	15.5	15.5	15.5	13.5	13.5	13.5	11.5	71.25	16.5	8.0
4	22.0	15.5	15.5	15.5	15.5	13.5	13.5	11.5	71.25	16.6	8.0
6	22.0	15.5	15.5	15.5	15.5	13.5	13.5	11.5	71.25	16.6	8.1

TABLE 2 (continue)

Time hr	Headloss cm	Sampling point 1 turbidity (unit)	Sampling point 2 turbidity (unit)	Sampling point 3 turbidity (unit)	Sampling point 4 turbidity (unit)	Sampling point 5 turbidity (unit)	Sampling point 6 turbidity (unit)	Effluent turbidity (unit)	Percent removal	Temp. °C	pH
8	22.0	15.5	15.5	15 .5	15.5	13.5	13.5	11.5	71.25	16.6	8.1
12.1.1972											
2	22.5	17.5	15.5	15.5	15.5	13.5	13.5	13.5	66.25	16.7	8.1
4	22.5	17.5	15.5	15.5	15.5	13.5	13.5	13.5	66.25	16.7	8.2
6	22.6	17.5	15.5	15.5	15.5	15.5	15.5	15.5	61.25	16.5	8.2
8	22.6	17.5	17.5	17.5	17.5	15.5	15.5	15.5	61.25	16.5	8.0
17.1.1972											
2	22.9	21.5	19.5	19.5	17.5	17.5	17.5	17.5	56.25	16.6	8.0
4	23.0	21.5	21.5	19.5	19.5	17.5	17.5	17.5	56.25	16.6	8.0
6	23.0	23.5	21.5	21.5	19.5	19.5	19.5	19.5	51.25	16.6	8.0
8	23.0	23.5	21.5	21.5	19.5	19.5	19.5	19.5	51.25	16.6	7.9
18.1.1972											
2	23.4	23.5	21.5	21.5	21.5	19.5	19.5	19.5	51.25	16.5	8.0
4	23.4	23.5	21.5	21.5	19.5	19.5	19.5	19.5	51.25	16.6	8.0
6	24.0	23.5	23.5	21.5	21.5	19.	19.5	19.5	51.25	16.6	8.1
8	24.0	23.5	23.5	21.5	21.5	19.5	19.5	19.5	51.25	16.6	8.1