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AN INVESTIGATION INTO THE REMOVAL OF ALGAE BY FINE SAND/SILT FILTRATION

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Prepared for
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ABSTRACT

A laboratory scale study was undertaken to determine the feasibility of the method of filtering *Scenedesmus quadricauda* from water using fine sand/silt as the filter media. A total of forty-six experiments were conducted with algae suspensions of varying concentrations. Five median sizes of sand (0.064 to 0.335 mm.) and four bed depths (3.2 to 12.7 mm.) were investigated in constant head experiments. Continuous measurements of flow rate, head loss, and effluent quality were collected. All media with median sizes of sand at or below 0.200 mm. gave consistently high average percent removals (98.7 percent based on chlorophyll *a*). The results suggest that the principal filtration mechanism with the fine sand/silt filtration is direct straining on the surface of the filter media. The media grain size diameter of 0.200 mm. with the bed depth of 1/8" (3.175 mm.) resulted in an average initial flow rate of 4.2 gpm/ft^2 (246 m^3/m^2-d). This combination of grain size diameter and bed depth appears to be an effective means of removing algae. An average removal of 96 percent (based on chlorophyll *a*) was obtained with the advantage of low average initial head loss (7.75 cm.). No chemical addition was required to obtain high removal levels.

INTRODUCTION

One of the problems in water and wastewater treatment is the lack of an economical technology to remove algae from eutrophic surface waters and stabilization ponds. Eutrophication can be defined as the natural or artificial addition of nutrients to water bodies and the effects of these added nutrients (Rohlich, 1969). Although eutrophication is a natural process, it is often accelerated by runoff from agricultural areas or by pollution associated with urban areas.

Although some nutrient removal does occur in waste water treatment plants, the efficiency is generally low. Approximately 5-15% removal results from primary treatment, and 30-50% of phosphorous and nitrogen is removed in conventional activated sludge process (Rohlich and Uttormark, 1972). Eutrophication problems associated with nutrient content of wastewater and treatment plant effluents has focused increased attention on development of processes to remove nutrients more effectively. Some of these processes which have been reviewed by Rohlich and Uttormark (1972) and Foehrenbach (1975) are: 1) nitrogen removal by biological growth; 2) microbial denitrification; 3) ammonia stripping; 4) ion exchange; 5) chemical precipitation; 6) demineralization; 7) granular carbon columns; and 8)algae harvesting. The last process, algae harvesting, could be accomplished by using high rate stabilization ponds (McGarry, 1971). High rate stabilization ponds, shallow in depth (15-45 cm.) with short detention times (not more than 3 days), are designed to maximize algal production. Use of stabilization ponds which provide an effective and economical method of wastewater treatment has been severely curtailed. Effluent suspended solids standards resulting from the implementation of the Federal Water Pollution Control Act Amendments (PL 92-500) cannot be met because of algae concentration in lagoon effluent (Harris, 1977).

Use of algae biomass for beneficial purposes such as protein supplement for livestock (Grau, 1957), fermentation to alchohol, or digestion to methane are limited by removal technologies. In recent years several algae separation techniques have been evaluated by investigators such as Golueke (1965), Middlebrooks (1974), and Shindala (1978). Based on consideration of economics, removal efficiencies, and maintenance problems there appears to be no technology that has achieved wide acceptance. It was concluded by Middlebrooks (1974) and Shindala (1978) that intermittent sand filtration may prove to be the best method even though it is land and labor intensive and does not produce a useable sludge. Studies by Borchardt (1961), Davis (1966) and Marshall (1974) indicate the importance of grain size in removing algae. The literature review indicated that the use of fine sand/silt had not been evaluated as a means of removing algae.

The purpose of this study was to investigate the feasibility of the method of filtering algae from water using fine sand/silt as the filter media. Effects of grain size and bed depth upon filtration efficiencies of algae laden waters was investigated.

LITERATURE REVIEW

In recent years an evaluation of the availability of algae filtration technologies have been undertaken by numerous investigators. Summaries of these techniques have been presented by Golueke (1965) and Middlebrooks (1974). Several separation techniques were considered in these papers. Based on consideration of economics, ease of operation, minimum maintenance, dependability of operation, and removal efficiencies, there appears to be no technology that has achieved wide acceptance.

Centrifugation

An evaluation of centrifugation as a method of removing algae from stabilization ponds was undertaken by Golueke, et al. (1965) and Middlebrooks, et al. (1974). These reviews indicate that this process may be an effective means of dewatering algal sludge. However, capitalization costs, power requirements and operational problems associated with the relatively sophisticated equipment makes this process impractical for application to stabilization ponds.

Microstrainers

Use of microstrainers for removing algae was evaluated by investigators such as Shindala, et al. (1978), Berry (1961), and Kormanik, et al. (1979). Microstrainers were found to be an effective means of removing algae from stabilization ponds by Berry and Kormanik. These findings are contradicted by Shindala. Shindala concluded that microstrainers were not feasible for upgrading lagoon effluents due to poor effluent quality and inconsistent performance. The major limitation of microstrainers is that the small species of algae can pass through the normal micro-mesh (23-60 microns). Another problem associated with microstrainers is the build-up of bacterial and algal slime on the micro-fiber (Middlebrooks, et al. 1974).

Coagulation-flocculation-sedimentation

This method is extensively used for the removal of colloidal and suspended material in water treatment. Feasibility of this method for removing algae has been investigated by Friedman, et al. (1975), McGarry (1970), Tenney, et al. (1969), Van Vuuren, et al. (1965), and Al-Layla, et al. (1974). However, the effectiveness of this process depends on the type of coagulants used (Van Vuuren), pH levels (Tenney and Friedman), and the type and physiological state of the cells (Middlebrooks, 1974). Operating cost of coagulation-floculation process is usually high because it requires large quantities of coagulants and trained operating personnel. The amount of coagulants required is influenced by the initial algal solids concentration. McGarry indicated that this process was uneconomical for algal solids concentrations below 30 mg/l. Also a large volume of sludge is produced in this process. This sludge contains high concentration of chemicals which may have toxic effects on livestock when used as a feed stuff. Addition of coagulants is costly and significantly increases the volume of sludge. The high volume of sludge produced requires sludge handling facilities and also creates sludge disposal problems. Coagulants normally used for this process are alum, synthetic polyelectrolytes or the combination of both.

Dissolved Air Floatation

Use of dissolved air floatation as a method of removing algae has been evaluated by Bare, et al. (1975), Parker, et al. (1973), Stone, et al. (1975), and Shell, et al. (1971). A comprehensive study of this process by Bare indicates that addition of coagulants is necessary for successful algae removal. Acid dosage (for example, H_2SO_4) in order to achieve optimum pH levels for flocculation is frequently necessary for effective algae removal (Stone). This process is relatively expensive, requires chemical addition (alum or synthetic polyelectrolytes) and considerable maintenance (Middlebrooks, et al. 1974). A combination of chemical flocculation with autoflotation was evaluated by Lincoln and Hill (1980). This method was proved to be an effective harvesting technique that recovered up to 48.6 kg/day of algal solids from $800m^2$ of culture area. Addition of coagulants is costly and significantly increases the volume of sludge. Recovery of algae as a feed stuff, depending on the coagulants used, is prevented due to toxic effects on livestock.

In-Pond Chemical Precipitation

Precipitation of algae may be accomplished by adding chemicals, such as alum, which bring about the formation of settleable insoluble hydroxide particles in which algae are enmeshed. In-pond chemical precipitation has been evaluated by Friedman, et al. (1975) and Golueke, et al. (1965). Both Friedman and Golueke concluded that this process appears to be feasible for algae removal. The review of this process by Middlebrooks, et al. (1974) indicate that the addition of chemicals immensely increases the sludge build-up in the pond. Thus, sludge handling facilities would be required. Cost of chemicals used and capital and maintenance costs of sludge handling facilities make this process costly for small applications.

Rapid Sand Filters

Sand filtration is a unit operation in which solid particles are removed from solution through the use of a sand media. The filter medium consists of 45 to 75 cm. of sand supported by a layer of gravel. Generally, the effective size of the sand media ranges from 0.45 to 0.55 mm. Filtration rate can range from 2 to 5 gpm/ft.^{2} (117 to 293 m^3/m^2-d) for removing colloidal suspensions (Middlebrooks, et al. 1974). Rapid sand filtration as a means for removing algae was studied by Shindala, et al. (1978), Folkman and Wachs (1970), Borchardt and O'Melia (1961), and Davis and Borchardt (1966). Borchardt found that the algal cells from a mixed culture are capable of passing through sand filters. A comprehensive study of rapid sand filtration by Shindala concluded that rapid sand filters require chemical flocculation for efficient algae removal. Shindala also indicates that this operation is not feasible for upgrading lagoon effluent averaging 100 mg/l suspended solids or more. Addition of coagulants has the disadvantages of excessive chemical cost, short filter runs. Addition of coagulants also generates problems associated with backwash (Shindala, et al. 1978).

Intermittent Sand Filters

An intermittent filter is a slow sand filter to which pond effluent is applied on a periodic or intermittent basis. Filter sand is placed on the gravel at a depth that varies from 60 cm. to 150 cm. (Marshall, et al. 1974). The effective grain size diameter normally used ranges from 0.2 to 0.5 mm (Shindala, et al. 1978). Loading rates of 1.5 to approximately 3 million gallons per day per acre (2297.7 to 4595.4 m^3/

hectare-day) are commonly reported (Marshall). Comprehensive studies by Marshall, Harris, et al. (1977), Hill, et al. (1977), and Shindala, et al. (1978) indicate that intermittent sand filtration produces a high quality effluent. Results by these investigators indicate that this technique may have high potential as an upgrading alternative for oxidation ponds. The reason that intermittent sand filtration is not widely used today is because it requires a low loading rate (Middlebrooks, et al. 1974). This process is also land and labor intensive.

Fine Sand /Silt Filters

The literature review did not reveal any investigations of the feasibility of fine sand/silt filtration for algae removal. Sand filtration of algae by Borchardt (1961) and Davis (1966) indicate the importance of grain size in removing algae. Smaller effective size sand resulted in a better removal efficiency. Davis used Selenastrum Gracile and distinguished the diminishing effectiveness of coarser sand sizes at increasing filtration rates. Furthermore, a decreasing removal efficiency was associated with increasing size of media at any one flow rate. Results of studies by Davis for filtration rate of 0.97 $gpm/ft.^2$ ($56.91\ m^3/m^2$-d) and by Borchardt for filtration rate of 1 $gpm/ft.^2$ ($58.67\ m^3/m^2$-d) are illustrated in Figure 1. In the results presented in this figure algal genus Scenedesmus (four and eight-cell packets) were used by Borchardt. The smallest size of sand used by Borchardt and Davis was 0.275 mm. Borchardt also found that the algal cells from a mixed culture are capable of passing through the sand filters. Marshall (1974) indicates that effect of sand size becomes greater at higher algae concentrations. Andrews (1968), and Folkman (1970) indicate that retention of algae occurred mostly at the upper part of the sand columns.

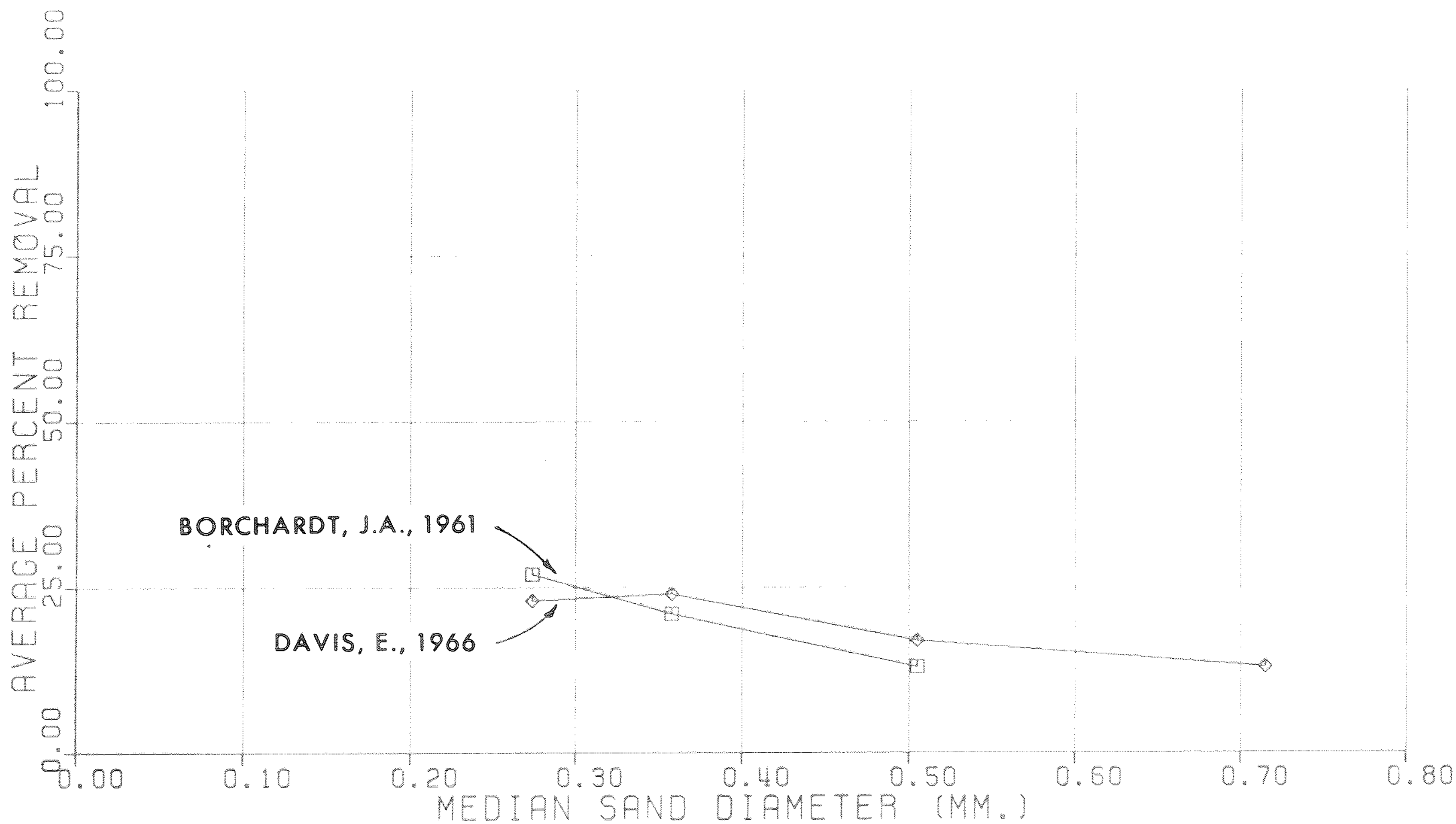


FIGURE 1. EFFECT OF GRAIN SIZE DIAMETER ON REMOVAL EFFICIENCY IN STUDIES BY DAVIS E. (1966, p. 52) AND BORCHARDT, J.A. (1961, p. 1496)

THEORY OF SAND FILTRATION

Sand filtration is employed in water treatment for removal of suspended solids present in surface waters. The most common types of filters used are deep granular filters (sand, dual-medium, and multimedia) and precoat filters (diatomaceous earth). The mechanisms of suspended solids removal these filters are relatively complex. Many investigators such as Camp (1964) and O'Melia and Stumm (1967) have discussed the various factors which may play important roles in suspended solids removal. The dominant mechanisms depend on the physical and chemical characteristics of the suspended solids and the filter media, the rate of filtration, and the physical and chemical properties of the water.

Precoat filters remove solids at the surface primarily by forming a cake of solids on top of the filter media, probably by the simple mechanism of mechanical straining. In deep granular filters of coarse material, removal is primarily within the filter bed, commonly referred to as depth filtration. Some solids may be removed by the mechanical process of interstitial straining. Removal of other solids depends on two types of mechanisms. First, transport mechanism (gravitational settling, diffusion and interception) which brings the small particles from the bulk of the fluid within the interstices close to the surface of the media. Second, attachment mechanism in which the small particles are retained by the surface of the medium or previously deposited solids. The attachment mechanism may involve electrostatic interactions, specific adsorption, or chemical bridging. In deep granular filters, removal may result from a combination of surface cake removal and depth removal simultaneously.

Hydraulics of flow through sand filters is dominated by flow control pattern and development of head loss. Flow control may be accomplished using constant-head, constant-rate, or declining-rate filtration (Shindala, et al. 1978). In a constant-head filtration, the total available pressure drop is applied to the filter throughout the filter run. At the beginning of the filter run, high permeability of the filter results in high filtration rate. As the filter clogs with solids, filter permeability decreases, and since the pressure drop remains constant, the flow rate decreases. In constant-rate filtration, a constant pressure drop is maintained across the filter bed; the filter rate is held constant by means of automatic or manual flow control valves. Declining rate filtration operates in a manner intermediate to constant-head and constant-rate operation. The filter influent enters the operating filters through a common influent header. As the filters served by a common influent header become fouled the flow through the dirtiest filters decreases, automatically causing the cleaner filters to pick up the capacity lost by the dirtier filters. This method of operation causes a gradual decline of flow rate near the end of filter run. Flow of water through the clean sand bed is assumed to laminar.

Several equations have been developed for the head loss through the sand media. From the Carman-Kozeny equation, the head loss, H, caused by flow at a face velocity, v, through a porous bed of thickness, L, and porisity, E, is

$$H = f \, \frac{L\,(1 - E)\,S}{dE^3} \, \frac{v^2}{g} \qquad (1)$$

where f is the friction factor, S the particle shape factor, d the effective particle size, and g the gravity constant. Experimentally the friction factor has been found to be

$$f = J \frac{M}{P} \frac{(1 - E)}{v} \frac{S}{d} \qquad (2)$$

where J is a constant, M and P are absolute viscosity and mass density of the suspension. Substitution of Equation (1) for f in Equation (2) gives

$$H = [J \frac{(1 - E)^2 \quad S^2}{E^3}] \quad \frac{M}{P} \quad L \quad \frac{V}{g} \quad \frac{1}{d^2} \qquad (e)$$

The face velocity is the flow rate through the filter divided by the total filter surface area, or

$$v = \frac{1}{A} \quad \frac{dV}{dt} \qquad (4)$$

where V is the filtrate volume. Substitution of Equation (4) into Equation (3) gives

$$H = [J \frac{(1 - E)^2 \quad S^2}{E^3}] \quad \frac{M}{P} \quad \frac{dV}{A \quad dt} \quad \frac{L}{d^2} \quad \frac{1}{g} \qquad (5)$$

The variable quantities within the bracket in Equation (5) depend only on the properties of the sand and may be called R, for convenience.

$$H = R \quad \frac{M}{P} \quad \frac{dV}{A\ dt} \quad \frac{L}{d^2} \quad \frac{1}{g} \qquad (6)$$

The coefficient R should be determined experimentally for a filtration system. This could be done by measuring flow rate and head loss and solving for R in Equation (6). This coefficient, R, is dimensionless.

METHODOLOGY

Process Formulation and Experimental Design

The literature review indicated that the design parameters for algae removal techniques were head loss, rate of flow, and quality of effluent. Therefore, this process was designed to measure these filtration variables.

The literature review also indicated the importance of grain size diameter in removing algae (Davis, 1966 and Borchardt, 1961). Andrews (1968) and Folkman (1970) indicated that retention of algae occurred mostly at the upper part of the sand columns. These findings proposed the idea of utilizing thin layers (less than 13mm.) of fine sand/silt as the filtration bed. One of the most influential factors in the operation of sand filters was found to be the influent solids concentrations (Marshall, 1974). The amount of suspended matter in the influent directly influences the length of filter run. To evaluate the effects of influent solids concentration, influent solids concentrations were varied randomly.

Description of Apparatus

A batch filtration apparatus, without backwash considerations, with a constant head flow control pattern was designed and constructed for this investigation. The apparatus is shown schematically in Figure 2. Filtration unit was made of 2" (5.08 cm.) I.D. x 2½" (6.35 cm.) O.D. x 8" (20.32 cm.) acrylic tubing with a support bed 3" (7.5 cm.) from the bottom and a manometer tap directly below the support bed. The filter

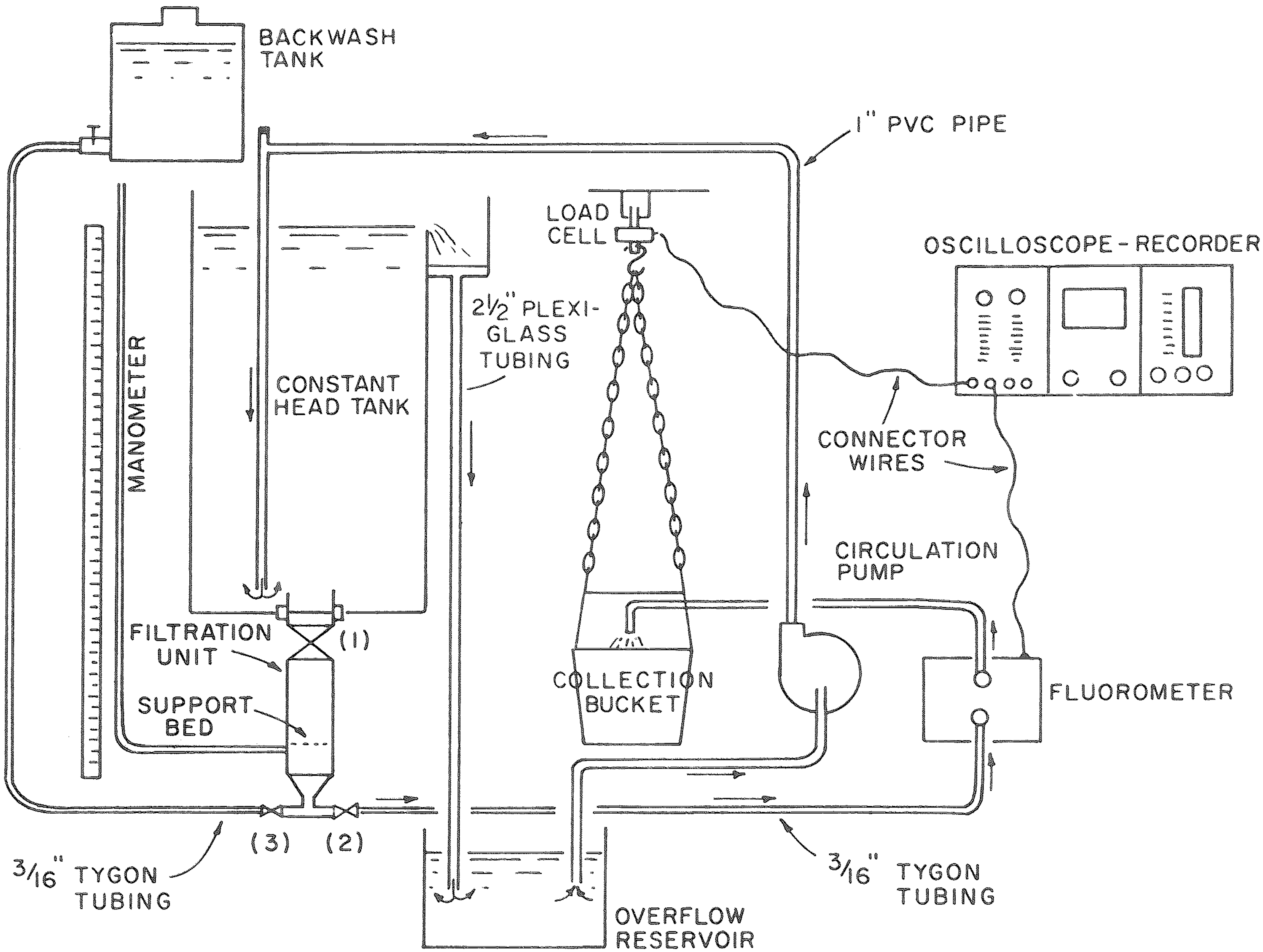


FIGURE 2. SCHEMATIC FLOW DIAGRAM OF FILTRATION APPARATUS

media was supported by a stainless steel wire cloth (#325 mesh). To measure the rate of flow, a load cell connected to a recorder was used. The cumulative volume of the filtrate was measured and then differentiated to determine the flow rate. The use of an Oscilloscope-recorder with the ability to provide digitized data points at 1 second intervals made the differentiation of volume of filtrate a practical way of determining the flow rate. The head on the filter was kept constant (91 cm.) by utilizing a constant head tank and the rate of flow was allowed to drop as the head loss was increased due to accumulation of algae on the filter bed. The head loss was measured manually using a manometer. Concentration of algae in the effluent was measured by using a fluorometer. Fluorometry has been found to be an effective means of direct measurement of algae populations (Fitzgerald, 1975 and Turner, 1973).

A Turner fluorometer (Model #111) with continuous flow attachment was used to measure the quality of the effluent. Blue Lamp (Turner #110-853) was used as the light source in the fluorometer with the aperture setting on 3X. Combination of 50 and 10 percent neutral density filters was used in addition to primary (Turner #110-922) and secondary (Turner #110-921) filters. A load cell (Model #3397), with a total capacity of 25 pounds (11.34 kg.), manufactured by Lebow Inc. with a recorder connected was employed to measure the volume of the filtrate. To provide continuous measurements of volume and quality of the filtrate, the fluorometer and load cell were connected to an oscilloscope-recorder manufactured by Nicolet Instrument Corporation. The range setting on the recorder was 20 millivolts each millivolt being equivalent to 0.9865 pounds (0.4475 kg.) of load exerted on the load cell. The range setting for the fluorometer was 1000 millivolts to a full scale of 100 fluorescence units.

Operation

Data obtained included head loss across the bed, volume of the filtrate, and the quality of the filtrate. For a typical run the following steps were undertaken. Initially, the sand was placed in the filtration unit. With valves No. 1 and 2 closed, distilled water was used to backwash the media in order to obtain a uniform filter bed. Then with valve No. 3 closed, and valves No. 1 and 2 open, data was collected. Head loss was recorded manually at 30-second intervals after the initial drop (1-5 seconds) due to clean filter media. Volume and quality of the effluent were recorded automatically every second for a period of 16 minutes. The quality of the effluent was recorded in fluorescence units. Suspended solids data (Standard Methods, 1976) on various algal concentrations was utilized to develop a correlation curve between suspended solids and Fluorescence units (Figure 3). Simple linear regression procedure (SAS, 1979) was used to develop this correlation model (R - Square = 0.957) which is illustrated as a straight line in Figure 3. Lag volume between the filter bed and the fluorometer was measured, by dye analysis, to be 104.33 milliliters. Therefore the fluorometer readings were lagged for this value of filtrate volume. Data was recorded on floppy disks and then was transferred on a computer tape. A program developed by Recep Yilmaz (1981) was modified and used for this transfer. A program was also developed for calculations and plotting of data. A listing of these programs can be found in Appendix A.

Filter Media

Five sizes of sand were used as filter media in this investigation. Fine sand/silt was obtained by grinding a larger size of sand (#40) in a

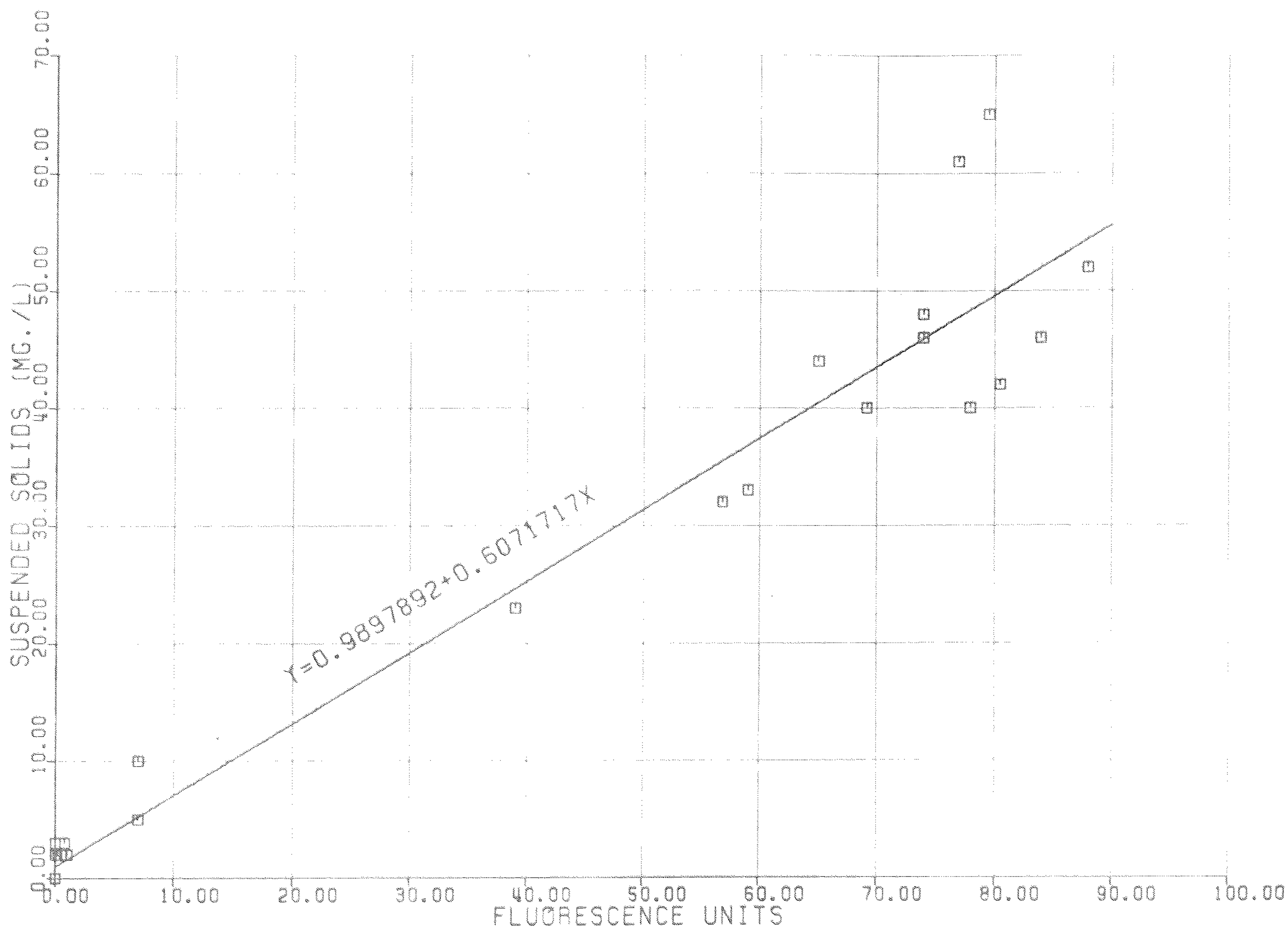


FIGURE 3. CORRELATION BETWEEN SUSPENDED SOLIDS AND FLOURESCENCE UNITS

laboratory sand grinder. The standard sieve analysis was conducted and results are found in Table 1.

The five sand sizes were compared at different depths. The bed depths investigated were 1/8" (3.175 mm.), 1/4" (6.35 mm.), 3/8" (9.525 mm.), and 1/2" (12.7 mm.).

	U.S. Bureau of Standard Sieve No		Median Sand Diameter (mm.)
Media 1	- 40	+ 60	0.335
Media 2	- 60	+100	0.200
Media 3	-100	+140	0.127
Media 4	-140	+200	0.090
Media 5	-200	+270	0.064

TABLE 1 - Results of sieve analysis.

Algae Cultures

Algae are unicellular or multicellular, autotrophic, photosynthetic microorganisms. The process of photosynthesis is illustrated by the equation

$$CO_2 + 2H_2O \xrightarrow{\text{sun light}} \text{new algae cells} + O_2 + H_2O.$$

The overall effect of this reaction is to produce new plant life, thereby increasing the number of algae cells. Algae are autotrophic, using carbon dioxide or bicarbonates in the solution as a source of carbon. The inorganic nutrients of phosphorus and nitrogen are necessary for algal growth. In addition, certain trace elements, such as iron, magnesium, sulfur, boron, cobalt, molybdenum, potassium, calcium, manganese, zinc, and copper are also required.

Algae are undersirable in water supplies because they produce bad tastes and odors. In water treatment plants, the presence of algae will shorten filter runs. The green color of most species also lowers the aesthetic value of the water. Algae which grow unattached in the water are referred to as "phytoplankton".

Studies by Bare (1975), Abeliovich (1975), Bush (1961), Dryden (1968), and Goldman (1974) indicated that *Scenedesmus* was the predominant algae in stabilization ponds. Therefore, *Scenedesmus quadricauda* was selected for use in this study. *Scenedesmus quadricauda* is seldom known as a taste and odor or filter clogging algae (Palmer, 1962). *Scenedesmus quadricauda* is often known as a pollution tolerant algae (Palmer, 1969) with capability of passing through filter media because of its small size (4-6 microns). Use of *Senedesmus quadricauda* has the advantages of ease of culturing and availability of literature on its physiology and biochemistry. A unialgal culture of *Scendesmus quadricauda* was obtained from the University of Texas at Austin (Starr, 1978). This algae was cultured under laboratory conditions in covered 10 gallon aquariums. A bank of "Cool-White" fluorescent lights (30 watts) above the aquariums provided a constant light source to support algal growth. An approximately 1.5 strength synthetic algal nutrient medium used by Miller (1978) was prepared and utilized to grow algae. Cultures were periodically observed under the microscope to ensure the purity of cultures.

RESULTS AND DISCUSSION

A total of 46 useable filter runs were obtained with algae suspensions of varying concentration. The two filter variables were bed depth and the grain size diameter of the filter media. Head loss was manually recorded every 30 seconds while effluent quality and the filtrate volume were automatically recorded at one second intervals. Head loss, effluent quality and filtrate volume data at 30-second intervals are summarized in the tables in Appendix B. Plots of corresponding data sets are also presented in Appendix B. Figure 4 represents a group of plots for a typical run. This group of plots consists of 4 plots. Quality of effluent in fluorescence units, Head loss (cm.), Filtrate volume (ml.), and Flow rate (ml./sec.) are plotted versus time (min.). These plots allow direct reading of these variables at any time at the duration of the experiment. A non-linear regression procedure (SAS, 1979) was utilized to fit an exponential model for the filtrate volume. Filtrate volume equations are presented in data tables in Appendix B and are illustrated in the plots of filtrate volume versus time (see Figure 4) as a line. Recorded values of filtrate volume for 30-second intervals are also illustrated as square symbols on the same plot. It should be noted that this curve fitting might have had a smoothing effect on the values computed using filtrate volume. However, since good fits were obtained for all the runs, this smoothing effect seems to be insignificant.

Filtrate volume equation was then differentiated with respect to time to allow determination of flow rate. Flow rate is normally used in

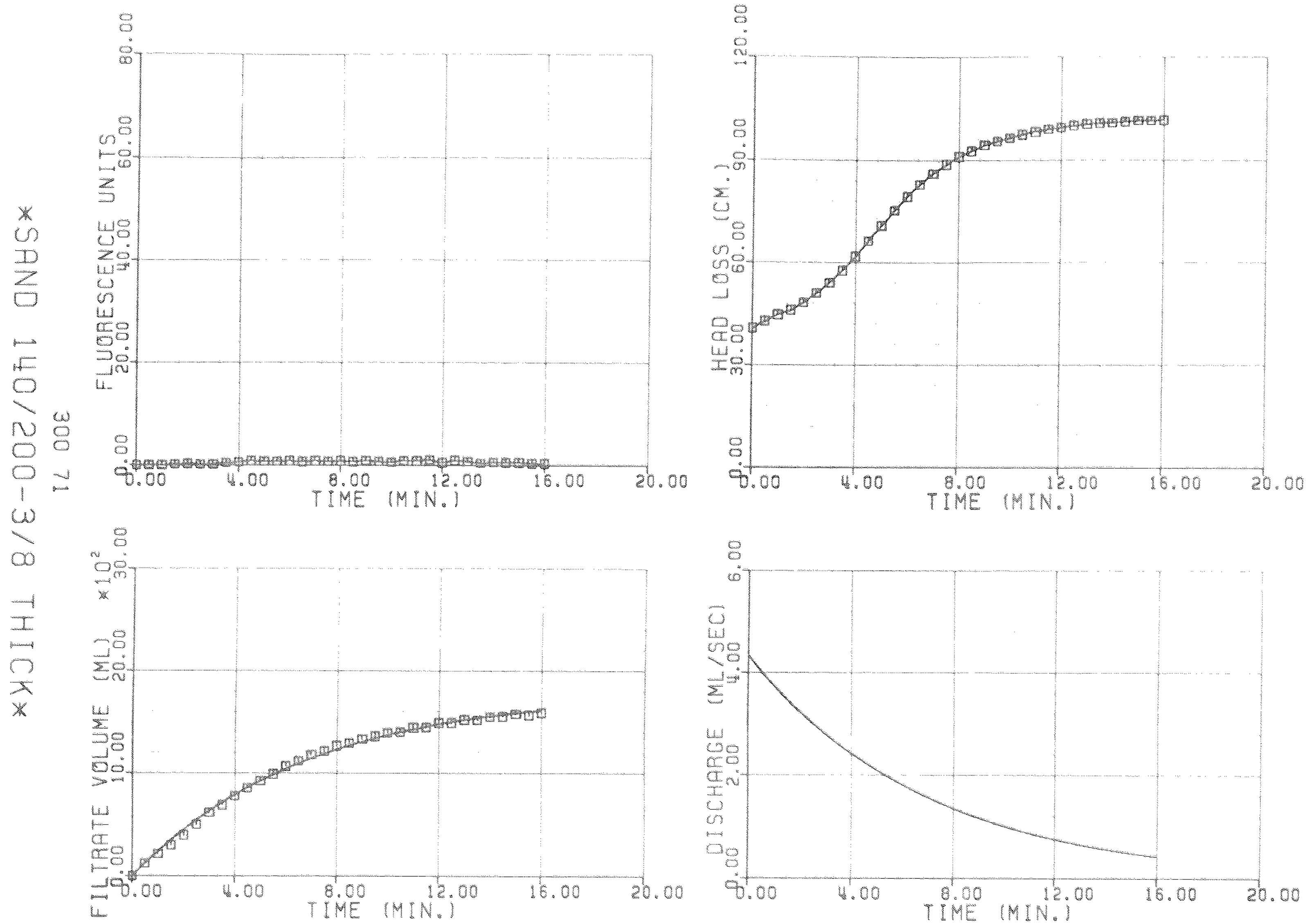


FIGURE 4. GROUP OF PLOTS FOR A TYPICAL RUN

head loss models to predict the head loss. Plot of flow rate versus time is also used to determine operating time based on a desired flow rate. A typical plot of flow rate versus time is also presented in Figure 4.

Five sizes of sand were used as the filter media. The largest grain size diameter used was 0.335 mm. which is normally used for conventional sand filters. It was determined that the effluent quality was deteriorated when sand with grain size diameter of 0.335 mm. was used. This was due to the fact that phytoplanktons were capable of passing through the sand medium with grain diameter of 0.335 mm. This fact is demonstrated on Figure 5 where the effluent quality of 0.335 mm. and 0.200 mm. grain size diameters at two bed depths are compared. Figure 6 illustrates the break point in the effluent quality breakthrough curves. Final algal concentrations (fluorometer readings at the end of 16-minute run time) over the initial (influent) algal concentrations were averaged for identical runs for this plot. Following the determination of breakthrough media, the two runs conducted on this size of sand (median grain size diameter of 0.335 mm.) were eliminated and no further analysis was performed on this media. Results and plots of these two runs are also presented in Appendix B.

The head loss of 88.5 cm. which was the lowest head loss of all the 44 runs (46 total -2 Breakthrough media = 44) at the end of 16 minute period was selected as the upper limit fixed head loss. Average percent removal, average rate of algal mass removed (based on dry weight), run time, and the initial flow rate were determined at this head loss for all the runs. These values and the list of the 46 runs are presented in Table 2.

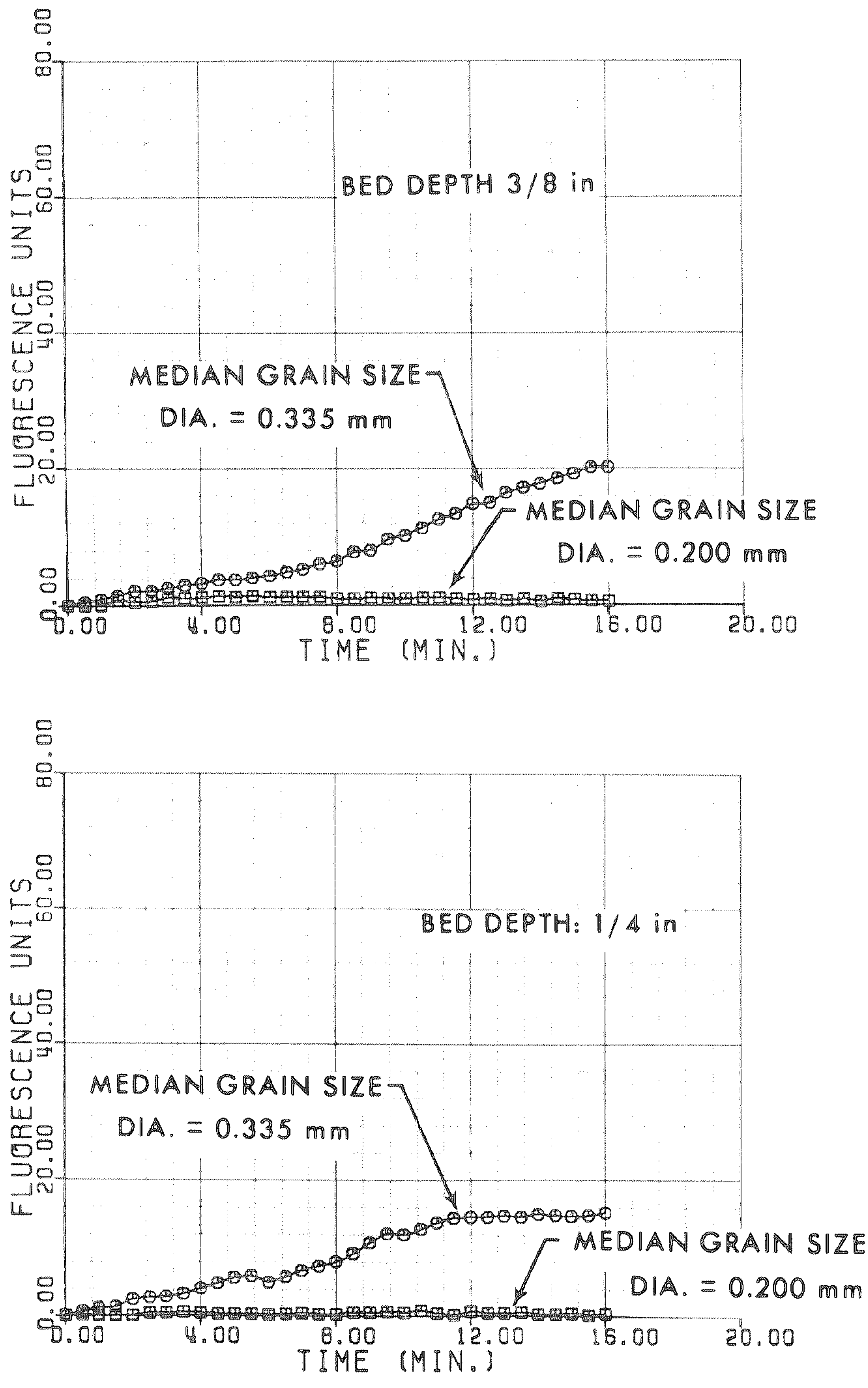
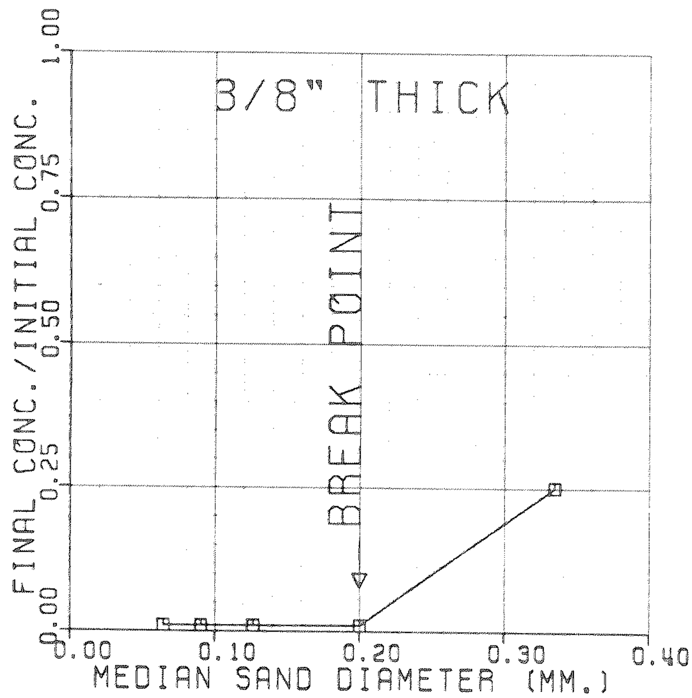


FIGURE 5. COMPARISON OF EFFLUENT QUALITY BETWEEN 0.335 mm AND 0.200 mm GRAIN SIZE DIAMETERS



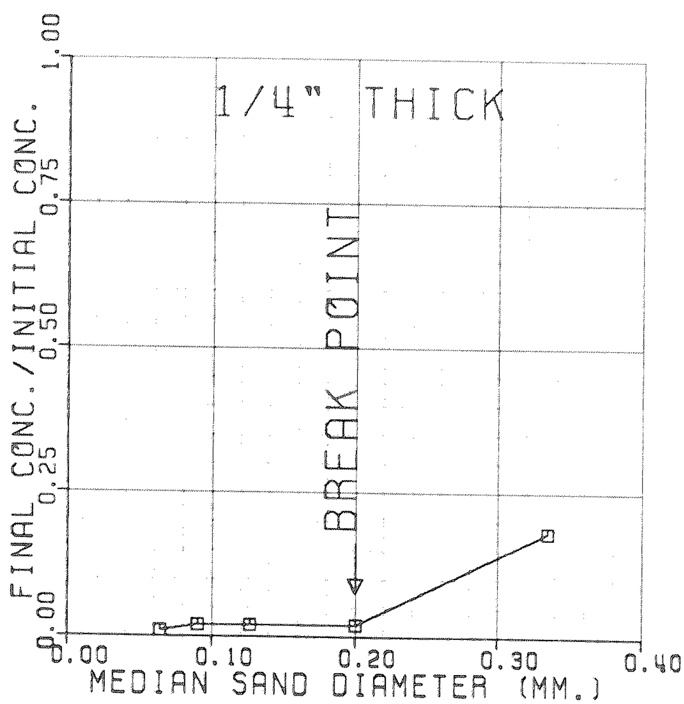


FIGURE 6. EFFLUENT QUALITY BREAKTHROUGH CURVES

TABLE 2. Summary of Results of Average Percent Removal, Initial Flow Rate, Initial Head Loss, Run Time, and Average Rate of Algal Mass Removed (based on dry weight).

Test No.	Test ID. No.	Median Grain Size Diameter (mm.)	Bed Depth (mm.)	Influent Algae Concentration (Fluorescence Units)	Average Percent Removal	Initial Flow Rate (ml/sec.)	Initial Head Loss (cm.)	Run Time (min.)	Average Rate of Algal Mass Removed (mg./min.)
1	10011	0.064	3.175	68.75	99.51	4.46	33.70	6.0	7.09
2	30051	0.064	3.175	79.25	99.52	4.53	30.00	7.0	8.29
3	30052	0.064	6.350	79.25	99.89	3.76	50.30	7.5	7.09
4	40041	0.064	6.350	39.00	98.70	3.25	54.00	13.5	3.40
5	10012	0.064	6.350	68.75	99.79	4.35	43.20	6.5	6.83
6	10031	0.064	9.525	68.75	99.55	3.19	56.50	8.0	5.81
7	40032	0.064	9.525	39.00	98.19	3.08	53.00	14.5	3.44
8	10041	0.064	9.525	86.00	99.87	3.79	53.50	5.5	7.77
9	10022	0.064	12.700	68.75	99.99	3.02	59.00	7.5	5.59
10	30011	0.064	12.700	57.90	99.81	2.73	64.00	12.0	4.48
11	40011	0.090	3.175	39.00	95.71	4.27	24.50	14.0	4.18
12	20012	0.090	3.175	78.25	99.95	5.48	25.00	3.0	10.41
13	20022	0.090	3.175	78.25	99.98	6.00	21.00	3.0	11.07

TABLE 2. Summary of Results of Average Percent Removal, Initial Flow Rate, Initial Head Loss, Run Time, and Average Rate of Algal Mass Removed (based on dry weight).

Test No.	Test ID. No.	Median Grain Size Diameter (mm.)	Bed Depth (mm.)	Influent Algae Concentration (Fluorescence Units)	Average Percent Removal	Initial Flow Rate (ml/sec.)	Initial Head Loss (cm.)	Run Time (min.)	Average Rate of Algal Mass Removed (mg./min.)
14	30022	0.090	6.350	57.90	99.64	4.58	25.00	11.5	6.26
15	20051	0.090	6.350	71.60	99.61	4.27	43.00	6.5	7.05
16	40012	0.090	6.350	39.00	96.29	3.89	35.50	14.0	3.88
17	30071	0.090	9.525	79.25	99.56	4.33	40.70	7.0	7.98
18	10061	0.090	9.525	86.00	99.60	3.64	54.00	6.5	7.35
19	40021	0.090	9.525	39.00	98.15	2.92	55.00	15.5	3.36
20	10062	0.090	12.700	86.00	99.54	4.39	41.00	6.0	8.42
21	40022	0.090	12.700	39.00	97.25	3.16	53.00	15.0	3.50
22	40031	0.090	12.700	39.00	96.77	3.40	46.80	15.0	3.62
23	30031	0.090	12.700	57.90	99.68	3.92	36.00	13.0	5.46
24	20011	0.127	3.175	78.25	99.80	4.78	13.30	2.5	10.28
25	20041	0.127	3.175	71.60	99.57	5.46	14.40	5.5	8.49
26	40042	0.127	3.175	39.00	94.62	4.97	15.50	12.5	4.43

TABLE 2. Summary of Results of Average Percent Removal, Initial Flow Rate, Initial Head Loss, Run Time, and Average Rate of Algal Mass Removed (based on dry weight).

Test No.	Test ID. No.	Median Grain Size Diameter (mm.)	Bed Depth (mm.)	Influent Algae Concentration (Fluorescence Units)	Average Percent Removal	Initial Flow Rate (ml/sec.)	Initial Head Loss (cm.)	Run Time (min.)	Average Rate of Algal Mass Removed (mg./min.)
27	30061	0.127	6.350	79.25	99.54	5.00	25.30	7.0	8.67
28	20042	0.127	6.350	71.60	99.37	4.97	28.00	5.5	7.99
29	40051	0.127	6.350	39.00	96.70	4.40	27.60	12.5	4.16
30	30021	0.127	9.525	57.90	99.44	4.32	29.00	12.0	6.00
31	10042	0.127	9.525	86.00	99.51	4.86	33.00	5.5	9.21
32	30062	0.127	12.700	79.25	99.49	4.67	31.80	7.0	8.25
33	40052	0.127	12.700	39.00	96.45	3.71	41.00	14.5	3.84
34	10052	0.127	12.700	86.00	99.83	4.74	32.70	5.0	9.12
35	20021	0.200	3.175	78.25	99.74	4.91	6.50	2.5	9.86
36	30072	0.200	3.175	79.25	98.65	5.65	8.00	6.5	9.40
37	40061	0.200	3.175	39.00	93.42	5.27	7.50	12.0	4.49
38	30032	0.200	6.350	57.90	98.67	5.21	10.40	11.5	6.73
39	20052	0.200	6.350	71.60	99.74	5.45	14.50	6.0	8.39

TABLE 2. Summary of Results of Average Percent Removal, Initial Flow Rate, Initial Head Loss, Run Time, and Average Rate of Algal Mass Removed (based on dry weight).

Test No.	Test ID. No.	Median Grain Size Diameter (mm.)	Bed Depth (mm.)	Influent Algae Concentration (Fluorescence Units)	Average Percent Removal	Initial Flow Rate (ml/sec.)	Initial Head Loss (cm.)	Run Time (min.)	Average Rate of Algal Mass Removed (mg./min.)
40	30081	0.200	9.525	79.25	99.15	5.61	11.50	6.5	9.44
41	10081	0.200	9.525	86.00	99.06	5.66	12.50	5.0	10.25
42	40062	0.200	12.700	39.00	94.43	4.87	16.00	13.5	4.44
43	20032	0.200	12.700	71.60	99.50	5.84	11.80	7.0	8.59
44	30041	0.200	12.700	57.90	99.45	5.00	15.00	11.5	6.57
45*	10082	0.335	6.350	86.00	---	5.32	3.50	Over 16	---
46*	30082	0.335	9.525	79.25	---	4.92	3.50	Over 16	---

* Breakthrough media.

Values of average precent removal from Table 2 indicate that neither increasing grain size diameter from 0.064 mm. to 0.200 mm. nor increasing the bed depth from 1/8" (3.75 mm.) to 1/2" (12.700 mm.) affects the effluent quality significantly. The results also indicate that increasing the grain size diameter or decreasing bed depth decreases the initial head loss due to clean filter media. This is an important factor because the initial head is then carried as a part of the total head loss through out the run.

These data also showed a direct relationship between influent algal concentration and rate of algal mass removed. Increasing influent algal concentration resulted in an increase in average rate of algal mass removed. The main effect of increasing influent algal concentration on the system, at a fixed head loss, was to shorten run time. This effect is illustrated in Figure 7 where two identical runs were compared at various influent algal concentrations. This was due to the fact that at higher concentrations of algae, head loss in the system increased at a faster rate.

A stepwise regression procedure (SAS, 1979) was used to find the relationship between the initial head loss and average rate of algal mass removed with the variables of importance. The significance of using this stepwise regression is that it ranks the variables based on their significance on contribution to R-square. The following model was developed to evaluate the significance of various parameters on initial head loss through the filter media.

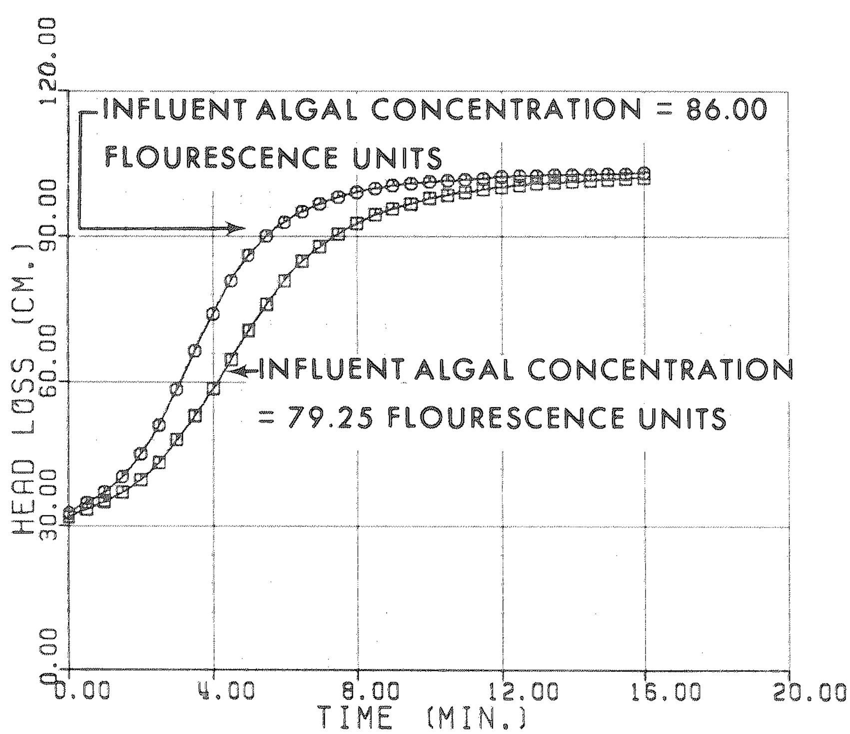


FIGURE 7. COMPARISON OF TWO IDENTICAL RUNS WITH VARIOUS INFLUENT ALGAL CONCENTRATIONS

MODEL 1

Initial Head Loss (IH) =

TABLE 3 - MODEL 1 Parameters.

STEP	VARIABLE COEFFICIENTS	INTERCEPT	R-SQUARE
1	GS = -273.482	64.250	0.675
2	GS = -270.809 BD = 1.932	48.463	0.854
3	GS = -269.789 BD = 1.915 IC = -0.052	51.821	0.857

where

IH = Initial head loss across filter media in centimeters

GS = Grain size diameter in millimeters

IC = Influent algal concentration in fluorescence units

BD = Bed depth in millimeters

This model illustrates that main factors influencing the initial head loss are grain size diameter and bed depth.

Effects of grain size diameter on head loss and flow rate is illustrated on Figure 8. In this figure flow rate versus head loss for various sizes of sand at 1/2" (12.700 mm.) bed depth is plotted. This figure indicates that initial flow rate increases and initial head loss decreases as the grain size diameter is increased. Flow rate in this filtration system could be divided into three (3) zones. The initial flow rate is the upper limit for zone 1 which depends only on the grain size diameter and bed depth. This is the zone of practical utilization of a filtration system. Clogging flow rate (zone 2), which flow rate decreases rapidly because of excessive accumulation of algae on the filter. Clogged flow rate (zone 3), which is zone of no flow because of

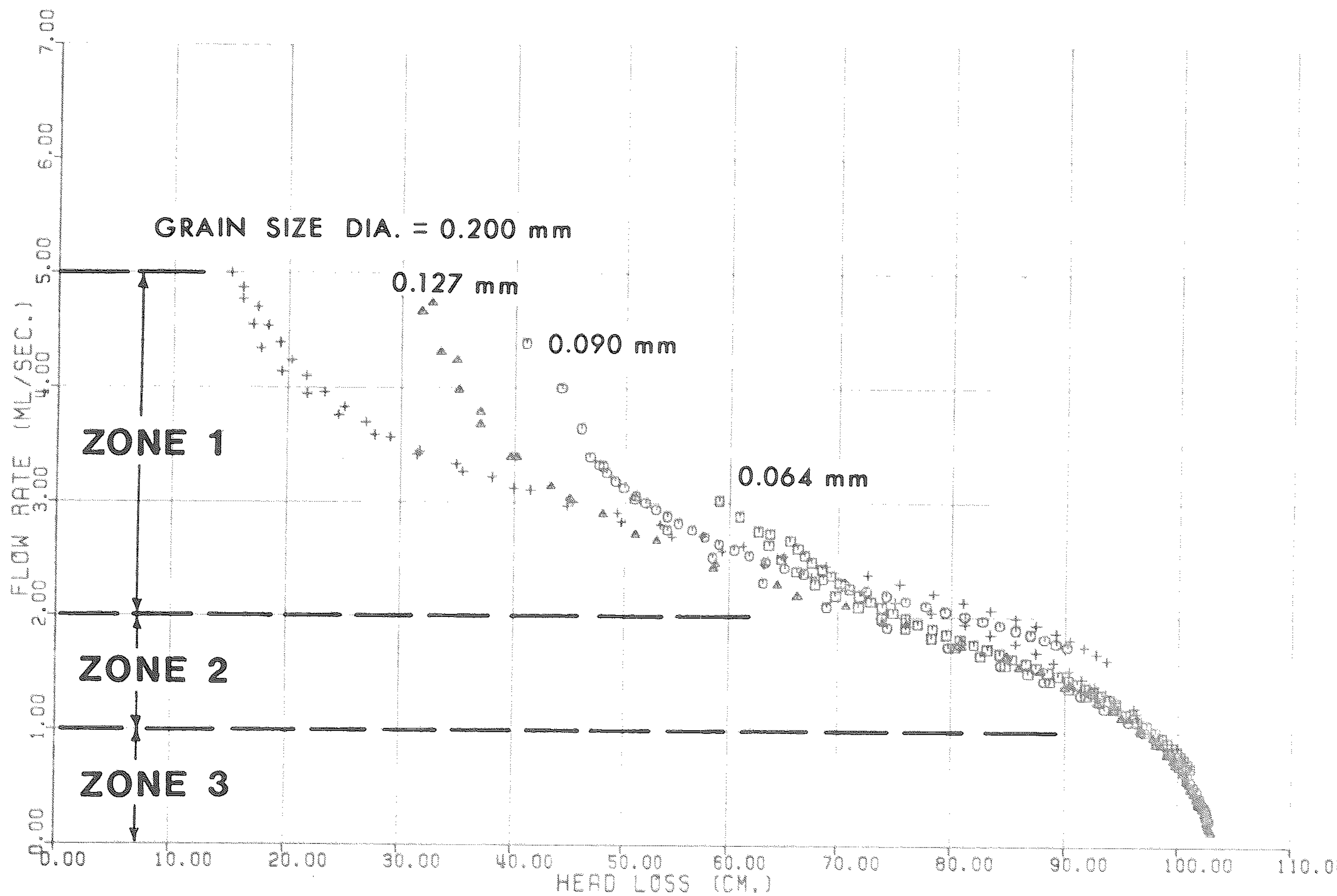


FIGURE 8. FLOW RATE VERSUS HEAD LOSS, 1/2" BED DEPTH, FOR VARIOUS GRAIN SIZE DIAMETERS

the clogged filter and a design head on the filtration system. These zones are illustrated on Figure 8. Figure 8 also illustrates how using sand with larger grain size diameter could increase the zone of practical flow rate. This is due to the fact that flow rate starts at a higher value (and lower initial head loss) and utilizes more time to reach a minimum design flow. At the start of the test, the initial head loss is influenced by initial flow rate, grain size diameter, and depth of sand bed. But as soon as algae starts forming a mat on top of the sand layer, head loss is increased and flow rate is consequently reduced. This phenomena is illustrated on Figure 9. In this figure total algal mass removed is plotted versus head loss (for the same set of runs as in Figure 8). Effects of grain size diameter on the head loss in the system is also illustrated (the larger grain size diameter, the smaller the initial head loss). Formation of an algal mat on top of the sand layer is analogous to the mechanism of mechanical straining in precoat filters (see theory of sand filtration).

Initial head loss as it was discussed in the theory of sand filtration, is affected by depth of the sand bed, grain size diameter of the sand and the flow rate. Measured values of initial flow rate, initial head loss, grain size diameter, and depth of the sand bed were used in the equation 7 (Carman-Kozeny equation, see chapter on theory of sand filtration) to determine the value of R for the various sand media used in this investigation. The water temperature was assumed to be 30°C. Absolute viscosity of 0.798 N. Sec./m^2 and mass density of 995.7 kg/m^3 were used for this temperature. A linear regression procedure (SAS, 1979) was utilized to determine the mean values for R, their corresponding standard deviations, and coefficient of variations. The reason for

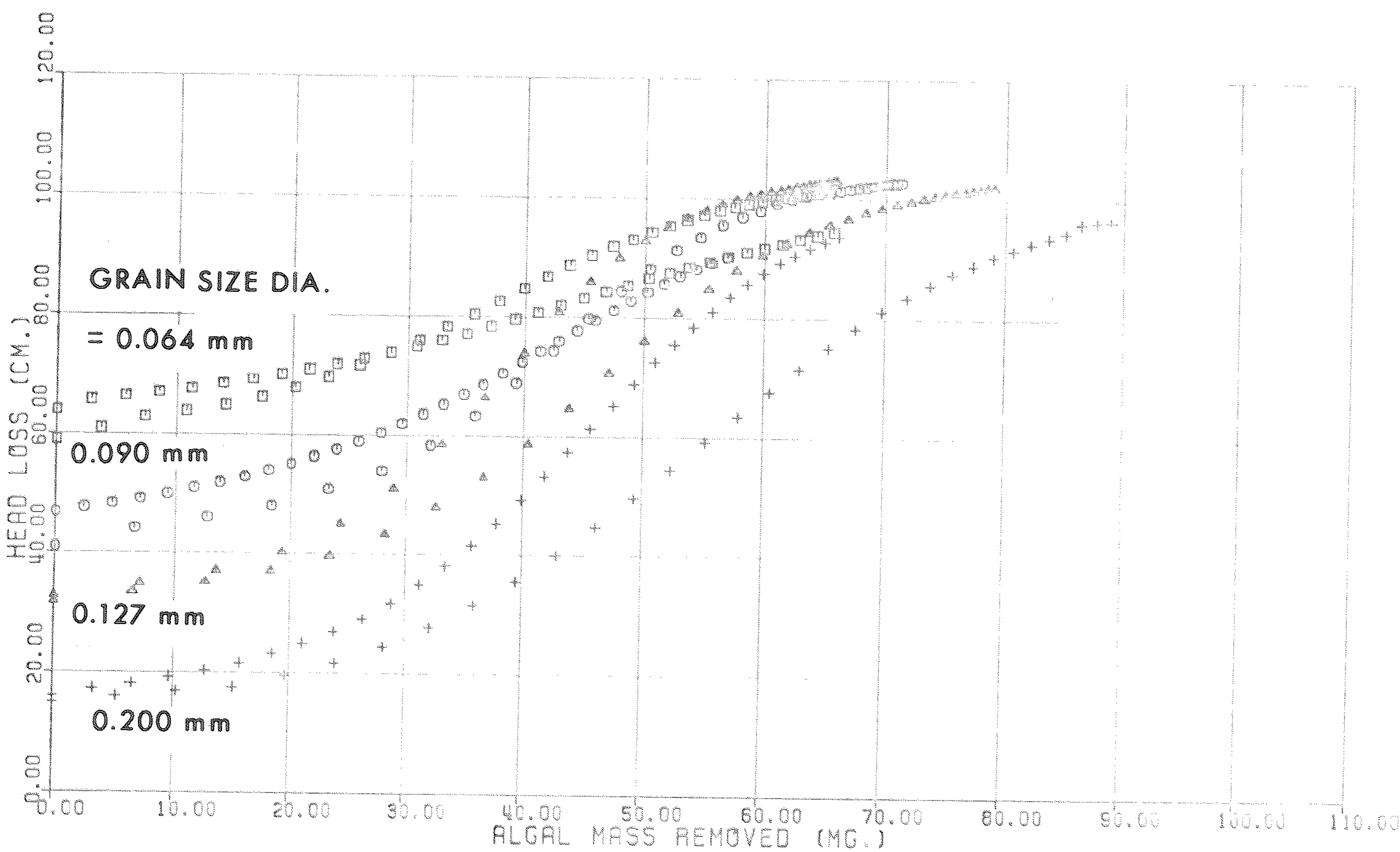


FIGURE 9. HEAD LOSS VERSUS ALGAL MASS REMOVED, 1/2" BED DEPTH, FOR VARIOUS GRAIN SIZE DIAMETERS

this analysis was to illustrate applicability of Carman-Kozeny equation for this filtration technique. Mean values for R, their corresponding standard deviations, and coefficient of variations are presented in Table 4.

TABLE 4 - Values for Filter Media Coefficient R.

Media	Median Grain Size Diameter (mm.)	Mean	Standard Deviation	Coefficient of Variation (%)
1	0.064	1.955×10^{3}	3.756×10^{2}	19
2	0.090	2.567×10^{3}	8.045×10^{2}	31
3	0.127	3.174×10^{3}	6.190×10^{2}	20
4	0.200	3.120×10^{3}	1.080×10^{3}	35

Relatively large coefficient of variation for filter media coefficient (R) in this filtration technique could be due to non-laminar flow through the filter media. Although high degree of variation existed within the same size of sand with different thicknesses, the mean value for R increased with increase in the size of sand. Carman-Kozeny and similar head loss equations are based on laminar flow through the sand media. It is possible that flow pattern through fine sand/silt filters may differ from flow patterns assumed through conventional sand filters because of the type of sand used (fine sand/silt), thickness of the sand media (less than 13 mm) and presence of algal suspensions.

One of the major parameters influencing the operation of this filtration system was the amount of algae removed from the water. Removed algae formed a mat on top of the sand layer. Therefore, a stepwise regression model was employed to determine factors influencing average rate of algal mass removed.

MODEL 2

Average Rate of Algal Mass removed (ARAMR) =

TABLE 5 - MODEL 2 Parameters.

STEP	VARIABLE COEFFICIENTS	INTERCEPT	R-SQUARE
1	IC = 0.117	-0.698	0.813
2	IC = 0.096 IF = 1.064	-4.060	0.949
3	IC = 0.097 IF = 0.982 BD = -0.042	-3.424	0.953
4	IC = 0.100 IF = 0.728 BD = -0.040 IH = -0.013	-2.116	0.954
5	IC = 0.101 IF = 0.670 BD = -0.015 IH = -0.029 GS = -4.294	-1.066	0.956

where

ARAMR = Average rate of algal mass removed (based on dry weight) in mg/min

IF = Initial flow rate in milliliters/second

IH = Initial head loss in centimeters

IC = Influent algal concentration in fluorescence units

BD = Bed depth in millimeter

GS = Grain size diameter in millimeter

As we see the most two important parameters influencing rate of algal mass removed are first, the influent concentration and second, the flow rate. The significance of this model is that it illustrates that the operation of this filtration technique depends greatly on the mass loading which is a function of initial algal concentration and flow rate. The major effect of mass loading on this filtration technique is shortening of the run time. This model also illustrates that the average rate of algal mass removed does not depend significantly on grain size diameter, bed depth, and initial head loss even though these variables have significant influence on the flow rate.

From the results produced with the fine sand/silt filter bed it is apparent that the median grain sizes lie outside the range compatible with conventional filter units. The results also suggest that the principal filtration mechanism with the fine sand/silt filter is direct straining on the surface of the filter media. Sand with the median grain size diameter of 0.200 mm. with the bed depth of 1/8" (3.175 mm.) produced an effluent quality with the average removal of 96 percent. This combination of grain size diameter and bed depth also results in the highest average initial flow rate of 246 m^3/m^2-d. (4.2 gpm/$ft.^2$). Initial flow rate was used for this comparison because at the start of the test, this parameter is influenced only by the selected combination of grain size diameter and bed depth. Thereafter, flow rate is greatly influenced by the amount of algal mass removed.

Utilizing 0.200 mm. size of sand with the smallest bed depth (3.175 mm.) has the advantage of the lowest average initial head loss (7.75 cm.). The major factor affecting run time of this filter at a fixed head loss seems to be the influent algal concentration. Higher influent algal concentrations resulted in shorter runs at a fixed head loss. This was due to the fact that at higher concentrations of algae, head loss in the system was increased at a faster rate.

This filtration technique is capable of producing a high quality effluent with the initial flow rate of 4.2 gpm/$ft.^2$ (246 m^3/m^2-d).

This initial flow rate falls in the range of flow rate for rapid sand filters, 2-5 gpm/ ft.^{2} (117-293 m^3/m^2-d) (Middlebrooks, et al., 1974). It has the advantage of the effluent quality and lower initial head loss due to a much smaller bed depth (compared to 45-75 cm. of sand used in rapid sand filters). Run time of this filtration technique is relatively shorter than run time of rapid sand filters and depends greatly on the influent algal concentration.

CONCLUSIONS

1. Principal filtration mechanism with the fine sand/silt filter appears to be direct straining on the surface of the filter media. This filtration mechanism is similar to the filtration mechanism in precoat filters.
2. Increasing bed depth did not have significant affects on effluent quality.
3. Increasing grain size diameter from 0.064 to 0.200 mm. did not have significant effects on the effluent quality.
4. Effluent quality for all the runs was fairly consistant and stayed the same thoughout the runs.
5. High values of average percent removal were obtained without addition of chemical coagulants. Average removal of 98.7 percent (based on chlorophyll a) was obtained for all the 44 runs.
6. Effluent quality deteriorated when sand with a grain size diameter of 0.335 mm. was used. This was due to the fact that phytoplanktons were capable of passing through the sand medium.
7. Sand with median grain size diameter of 0.200 mm. with the bed depth of 3.175 mm. produced an effluent quality with average removal of 96 percent (based on chlorophyll a). This combination of grain size and bed depth also resulted in highest initial flow rate (246 m^3/m^2-d) and lowest initial head loss (7.75 cm.).

8. Run time was found to be greatly affected by influent algal concentration. Higher influent algal concentrations resulted in shorter runs at a fixed head loss.
9. Average rate of algal mass removed was increased with increase in influent algal concentration. Major factors influencing average rates of algal mass removed were influent algal concentration and flow rate.

RECOMMENDATIONS

Results of this investigation suggests that fine sand/silt filtration is an effective means for removing *Scenedesmus quadricauda*. Further investigation to provide a better understanding of this filtration technique for other species of phytoplanktons is required. Consideration should also be given to their different physiological states. Mathematical relationships between design parameters of this filtration technique should be developed. Development of a cleaning mechanism for the clogged filter bed to allow continuous operation of such filter is also required.

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APPENDIX A

Listing of Programs

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C       ALGAE REMOVAL BY FINE SAND/SILT FILBRATION
C       BABAK NAGHAVI,JUNE 20,1981
        DIMENSION NFILE(8),IV1(1050),IV2(1050),IF1(1050),IF2(1050),
       1IVAL(5000),CV1(1050),CV2(1050),XT1(1050),CF1(1050),CF2(1050),
       2XT2(1050),CFL1(1000),CFL2(1000),CVL1(1000),CVL2(1000),NID1(6),
       3NID2(6),CY1(40),CY2(40)
C       JJ=FILE NO.
C       NTRCK=NO. OF TRACKS TO BE SKIPPED
        READ(5,70) JJ,NTRCK
   70   FORMAT(2I5)
        IF(NTRCK.EQ.0) GO TO 100
        DO 110 N=1,NTRCK
        READ(JJ,20) NFILE(N)
        DO 130 J=1,256
        READ(JJ,140) (IVAL(L),L=1,20)
  140   FORMAT(20A4)
  130   CONTINUE
  110   CONTINUE
  100   CONTINUE
C       NFILE=FILE ID. NO.
        DO 10 N=1,1
        READ(JJ,20) NFILE(N)
   20   FORMAT(75X,I5)
        WRITE(6,501) NFILE(N)
  501   FORMAT(I5)
        DO 30 J=1,256
        M=4*J-3
        READ(JJ,40) (IV1(M+I-1),IV2(M+I-1),IF1(M+I-1),IF2(M+I-1),I=1,4)
   40   FORMAT(16I5)
   30   CONTINUE
```

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      C      NID1=SAND IDENTIFICATION
      C      NDD1=TEST ID. NO.
      C      IJJ1=NO. OF DATA CARDS
      C      IT1=TIME BETWEEN DATA POINTS(FILTRATE VOLUME AND QUALITY DATA)
      C      ISTEP1=TIME BETWEEN DATA POINTS(HEAD LOSS DATA)
      C      RANG1 AND RANG2=RECORDER PARAMETERS
      C      TCONC=INITIAL CONCENTRATION
      C      VLAG=LAG VOLUME
0023         READ(5,90)NID1,NDD1,IJJ1,IT1,ISTEP1,RANG1,RANG2,TCONC,VLAG
0024      90 FORMAT(6A4,I5,2I3,I5,4F10.2)
0025         WRITE(6,95)NID1,NDD1,IJJ1,IT1,ISTEP1,RANG1,RANG2,TCONC,VLAG
0026      95 FORMAT(1H1,6A4,I5,2I3,I5,4F10.2)
0027         WRITE(7,98)NID1,NDD1,IJJ1,IT1,ISTEP1,RANG1,RANG2,TCONC,VLAG
0028      98 FORMAT(6A4,I5,2I3,I5,4F10.2)
0029         IF (IJJ1.EQ.0) GO TO 101
0030         DO 165 I=1,33
      C      CY1=HEAD LOSS DATA
0031         READ(5,65)CY1(I)
0032      65 FORMAT(F5.1)
0033     165 CONTINUE
0034         DO 50 I=1,1024
      C      CV1=FILTRATE VOLUME
0035         CV1(I)=(FLOAT(IV1(I))*((  40.00 )/4000.)+RANG1)*453.5924
      C      CF1=FILTRATE QUALITY IN FLUORESCENCE UNITS
0036         CF1(I)=(FLOAT(IF1(I))*(( 2000.00)/4000.)+RANG2)
0037      50 CONTINUE
0038         DO 71 I=1,1024
0039         IF (CV1(I).GE.VLAG) GO TO 52
```

```
   71 CONTINUE
   52 CONTINUE
      IL1=I*(IT1)
      IJ=1024-(IL1/IT1)
      DO 35 I=1,IJ
C     CFL1=FILTRATE QUALITY
      CFL1(I)=CF1(((IL1)/(IT1))+I)
      IF (CFL1(I).LT.0) CFL1(I)=0.00
C     CVL1=FILTRATE VOLUME
      CVL1(I)=CV1(I)
C     XT1=TIME
      XT1(I)=((FLOAT(I)-1)*(IT1))*(1.0)
   35 CONTINUE
      DO 981 I=1,33
      WRITE(6,663) XT1(1+(I-1)*30),CVL1(1+(I-1)*30),CFL1(1+(I-1)*30),
     *CY1(I)
  663 FORMAT(4F10.2)
      WRITE(7,963) XT1(1+(I-1)*30),CVL1(1+(I-1)*30),CFL1(1+(I-1)*30),
     *CY1(I)
  963 FORMAT(4F10.2)
  981 CONTINUE
  101 CONTINUE
C     NID2=SAND IDENTIFICATION
C     NDD2=TEST ID. NO.
C     IJJ2=NO. OF DATA CARDS
C     IT2=TIME BETWEEN DATA POINTS(FILTRATE VOLUME AND QUALITY DATA)
C     ISTEP2=TIME BETWEEN DATA POINTS(HEAD LOSS DATA)
C     RANG3 AND RANG4=RECORDER PARAMETERS
C     TCONC=INITIAL CONCENTRATION
C     VLAG=LAG VOLUME
```

```
      READ(5,91)NID2,NDD2,IJJ2,IT2,ISTEP2,RANG3,RANG4,TCONC,VLAG
   91 FORMAT(6A4,I5,2I3,I5,4F10.2)
      WRITE(6,96)NID2,NDD2,IJJ2,IT2,ISTEP2,RANG3,RANG4,TCONC,VLAG
   96 FORMAT(1H1,6A4,I5,2I3,I5,4F10.2)
      WRITE(7,99)NID2,NDD2,IJJ2,IT2,ISTEP2,RANG3,RANG4,TCONC,VLAG
   99 FORMAT(6A4,I5,2I3,I5,4F10.2)
      IF (IJJ2.EQ.0) GO TO 102
      DO 166 I=1,33
C     CY2=HEAD LOSS DATA
      READ(5,66)CY2(I)
   66 FORMAT(F5.1)
  166 CONTINUE
      DO 60 L=1,1024
C     CV2=FILTRATE VOLUME
      CV2(L)=(FLOAT(IV2(L))*((    40.00)/4000.)+RANG3)*453.5924
C     CF2=FILTRATE QUALITY IN FLUORESCENCE UNITS
      CF2(L)=(FLOAT(IF2(L))*(( 2000.00)/4000.)+RANG4)
   60 CONTINUE
      DO 53 I=1,1024
      IF (CV2(I).GE.VLAG) GO TO 54
   53 CONTINUE
   54 CONTINUE
      IL2=I*(IT2)
      IJ1=1024-(IL2/IT2)
      DO 333 I=1,IJ1
C     CFL2=FILTRATE QUALITY
      CFL2(I)=CF2(((IL2)/(IT2))+I)
      IF (CFL2(I).LT.0) CFL2(I)=0.00
```

```
C       CVL2=FILTRATE VOLUME
        CVL2(I)=CV2(I)
C       XT2=TIME
        XT2(I)=(FLOAT(I)-1)*(IT2)
  333   CONTINUE
        DO 982 L=1,33
        WRITE(6,664)XT2(1+(L-1)*30),CVL2(1+(L-1)*30),CFL2(1+(L-1)*30),
       *CY2(L)
  664   FORMAT(4F10.2)
        WRITE(7,964)XT2(1+(L-1)*30),CVL2(1+(L-1)*30),CFL2(1+(L-1)*30),
       *CY2(L)
  964   FORMAT(4F10.2)
  982   CONTINUE
  102   CONTINUE
  10    CONTINUE
        STOP
        END
```

```
            C      ALGAE REMOVAL BY FINE SAND/SILT FILTRATION
            C      BABAK NAGHAVI,JUNE 20,1981
0001               DIMENSION XT(1000),CVL(35),CFL(35),NID1(6),CY(35),XP(35),
                  1CEX(1000),CDR(1000),CR(35),CPL(35),CM(35),CFT(35),NDD1(2)
0002               CALL IDENT('1304 5  ALGAE  B. NAGHAVI')
0003               CALL PLOT(2.5,3.5,-3)
0004               CALL VTHICK(2)
0005               CALL FACTOR(.75)
0006               CALL PLOT(0.,0.,3)
0007               DO 10 N=1,16
0008               IM=N-1
            C      NDD1=TEST ID. NO.
            C      NID1=SAND IDENTIFICATION
            C      IJJ1=NO. OF DATA CARDS
            C      IT1=TIME BETWEEN DATA POINTS(FILTRATE VOLUME AND QUALITY DATA)
            C      ISTEP1=TIME BETWEEN DATA POINTS(HEAD LOSS DATA)
            C      RANG1 AND RANG2=RECORDER PARAMETERS
            C      TCONC=INITIAL CONCENTRATION
            C      VLAG=LAG VOLUME
0009               READ(5,90)NID1,NDD1,IJJ1,IT1,ISTEP1,RANG1,RANG2,TCONC,VLAG
0010          90   FORMAT(6A4,A3,A2,2I3,I5,4F10.2)
0011               CALL SYMBOL(-1.2,6.5,.21,NID1,270.,24)
0012               CALL SYMBOL(-0.8,4.5,.14,NDD1,270.,6)
            C      B0 AND B1=FILTRATE EQ. COEFFICIENTS
0013               READ(5,99)B0,B1
0014          99   FORMAT(2F15.8)
0015               DO 165 I=1,IJJ1
            C      XP=TIME
            C      CVL=FILTRATE VOLUME
```

```
C       CFL=EFFLUENT QUALITY
C       CY=HEAD LOSS
        READ(5,663)XP(I),CVL(I),CFL(I),CY(I)
   663  FORMAT(4F10.2)
        CFT(I)=CFL(I)/10.
   165  CONTINUE
C       XT=TIME
C       CEX=FILTRATE EQ.
C       CDR=DISCHARGE EQ.
        DO 31 I=1,965
        XP(I)=(FLOAT(I)-1)*(1.0)
        CEX(I)=B0*(1-EXP(-B1*(XT(I))))
        CDR(I)=B0*B1*(EXP(-B1*(XT(I))))
    31  CONTINUE
        DO 61 I=1,IJJ1
        IF (CY(I).GT.88.5) GO TO 23
        CR(I)=((TCONC-CFL(I))/TCONC)*100
    61  CONTINUE
    23  CONTINUE
        IP=I-1
C       VT=TOTAL FILTRATE VOLUME
        VT=CEX(1+(I-1)*30)
C       CRL=AVERAGE PERCENT REMOVAL
        DO 62 I=1,IP
        IF (I.NE.1) GO TO 656
        CRL(I)=((CEX(1+I*30)-CEX(1+(I-1)*30))/VT)*CR(I)
        GO TO 657
   656  CONTINUE
        CRL(I)=((CEX(1+I*30)-CEX(1+(I-1)*30))/VT)*CR(I)+CRL(I-1)
```

```
  657 CONTINUE
  62  CONTINUE
C      REM=REMOVAL IN FLUORESCENCE UNITS
       REM=((CRL(IP))/(100))*(TCONC)
C      RET=REMOVAL AS SUSPENDED SOLIDS IN MG./L
       RET=0.9897392+0.0671717*REM
       DO 68 I=1,IP
       IF (I.NE.1) GO TO 456
C      CM=ALGAL MASS REMOVED
       CM(I)=(RET*(CEX(1+I*30)-CEX(1+(I-1)*30)))/1000.00
       GO TO 457
  456  CONTINUE
       CM(I)=(RET*(CEX(1+I*30)-CEX(1+(I-1)*30)))/1000.00+CM(I-1)
  457  CONTINUE
  68   CONTINUE
       ECONC=TCONC/10.
       WRITE(6,95)NID1,NID1
  95   FORMAT(1H1,9X,6A4,5X,'TEST ID. NO. = ',A3,A2/)
       WRITE(6,81)CRL(IP)
  81   FORMAT(10X,'AVERAGE PERCENT REMOVAL -',F6.2/)
       WRITE(6,36)CM(IP)
  36   FORMAT(10X,'TOTAL ALGAL MASS REMOVED=',F6.2,' MG.'/)
       WRITE(6,82)ECONC
  82   FORMAT(10X,'INITIAL CONCENTRATION=',F5.2,' FLUORESCENCE UNITS'/)
       WRITE(6,83)B0,B1
  83   FORMAT(8X,'FILTRATE EQ.',7X,'Y=',F10.5,'*(1-EXP(-',F10.8,'*X))'//)
       WRITE(6,85)
  85   FORMAT(10X,'TIME',9X,'FILTRATE',8X,'EFFLUENT',9X,'HEAD'/23X,'VOLUM
      *E',10X,'QUALITY',9X,'LOSS'/9X,'(SEC.)',9X,'(ML.)    (FLUORESCENCE U
      *NITS)    (CM.)'//)
```

```
      DO 86 I=1,IJJ1
      WRITE(6,65) XP(I),CVL(I),CFT(I),CY(I)
65    FORMAT(4F15.2)
86    CONTINUE
      XLEN=5.
      YLEN=3.
      XP(34)=0.0
      XP(35)=240.0
      CVL(34)=0.0
      CVL(35)=1000.0
      CALL GRID(0.,0.,1,5.,1.,1,3.,1.)
      CALL AXIS(0.,0.,'FILTRATE VOLUME (ML)',20,3.,90.,0.,CVL(35))
      CALL AXIS(0.,0.,'TIME (MIN.)',-11,5.,0.,0.,4.0)
      CALL LINE(XP,CVL,33,1,-1,IM)
      CALL PLOT(0.,0.,3)
      XT(961)=0.0
      XT(962)=240.0
      CFX(961)=0.0
      CFX(962)=1000.0
      CALL FLINE(XT,CFX,-960,1,0,0)
      CALL PLOT(0.,0.,3)
      CALL PLOT(0.,4.,-3)
      XLEN=5.
      YLEN=4.
      XP(34)=0.0
      XP(35)=240.0
      CFL(34)=0.0
      CFL(35)=200.
```

```
CALL GRID(0.,0.,1,5.,1.,1,4.,1.)
CALL AXIS(0.,0.,'FLUORESCENCE UNITS',18,4.,90.,0.,20.0)
CALL AXIS(0.,0.,'TIME (MIN.)',-11,5.,0.,0.,4.0)
CALL FLINE(XP,CFL,-33,1,1,IM)
CALL PLOT(0.,0.,3)
CALL PLOT(0.,-4.,-3)
CALL PLOT(6.,0.,-3)
XLEN=5.
YLEN=3.
CDR(961)=0.0
CDR(962)=2.0
XT(961)=0.0
XT(962)=240.0
CALL GRID(0.,0.,1,5.,1.,1,3.,1.)
CALL AXIS(0.,0.,'DISCHARGE (ML/SEC)',18,3.,90.,0.,CDR(962))
CALL AXIS(0.,0.,'TIME (MIN.)',-11,5.,0.,0.,4.0)
CALL FLINE(XT,CDR,-960,1,0,0)
CALL PLOT(0.,0.,3)
CALL PLOT(0.,4.,-3)
XLEN=5.
YLEN=4.
CY(34)=0.0
CY(35)=30.0
XP(34)=0.0
XP(35)=240.0
CALL GRID(0.,0.,1,5.,1.,1,4.,1.)
CALL AXIS(0.,0.,'HEAD LOSS (CM.)',15,4.,90.,0.,CY(35))
CALL AXIS(0.,0.,'TIME (MIN.)',-11,5.,0.,0.,4.0)
CALL FLINE(XP,CY,-33,1,1,IM)
```

```
      CALL PLOT(0.,0.,3)
      CALL PLOT(0.,-4.,-3)
      CALL PLOT(6.,0.,-3)
      XLEN=10.
      YLEN=4.
      CALL GRID(0.,0.,1,10.,1.,1,4.,1.)
      CY(IP+1)=0.0
      CY(IP+2)=25.0
      CM(IP+1)=0.0
      CM(IP+2)=10.0
      CALL AXIS(0.,0.,'HEAD LOSS (CM.)',15,4.,90.,0.,CY(IP+2))
      CALL AXIS(0.,0.,'ALGAL MASS REMOVED (MG.)',-24,10.,0.,0.,10.)
      CALL FLINE(CM,CY,-IP,1,1,IM)
      CALL PLOT(0.,0.,3)
      CALL PLOT(-12.,0.,-3)
   10 CONTINUE
      CALL EOJOB
      STOP
      END
```

APPENDIX B

Tables and Plots of Typical Runs

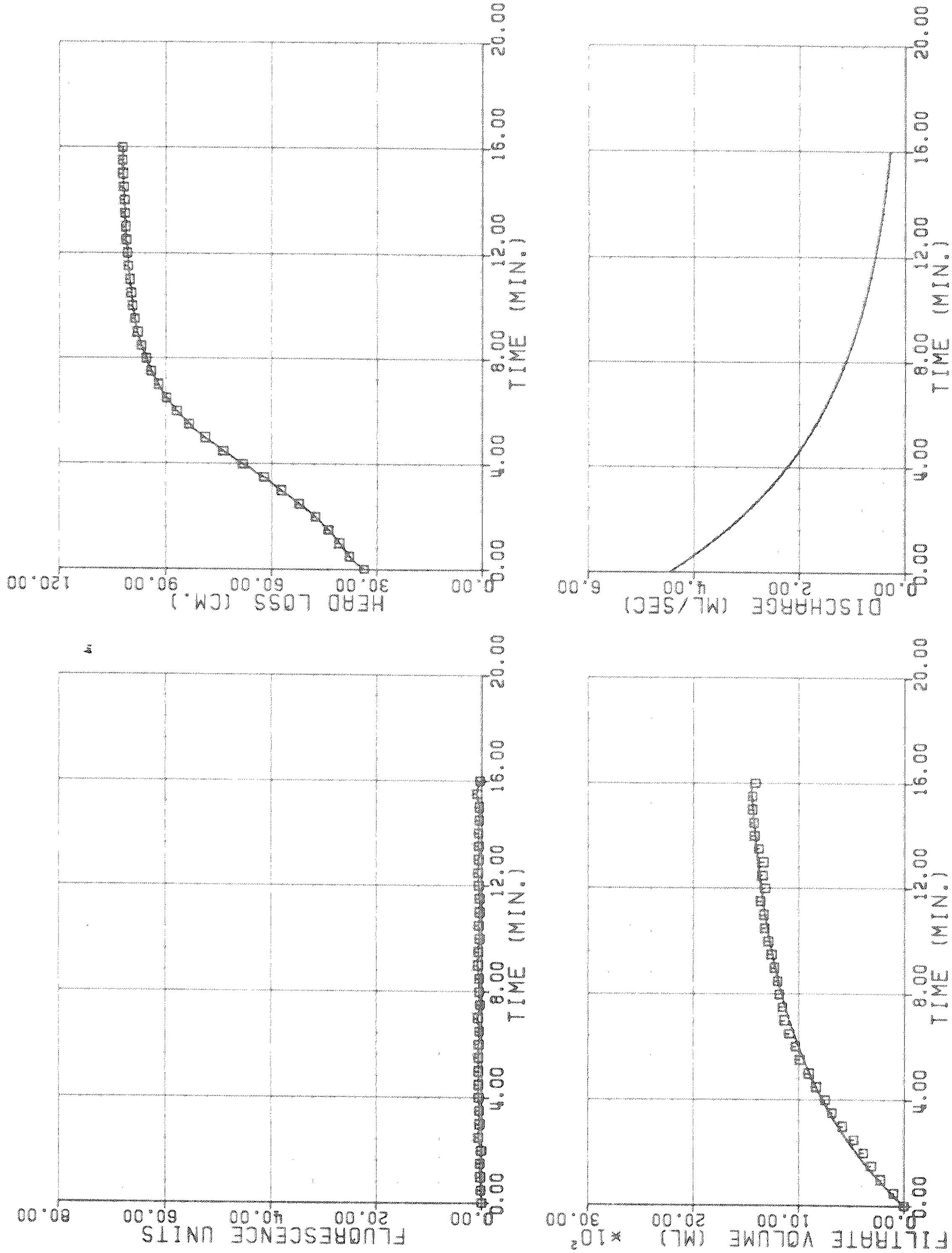
SAND 200/270-1/8 THICK   TEST ID. NO. = 10011

AVERAGE PERCENT REMOVAL = 99.51

INITIAL CONCENTRATION=68.75 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1550.62817*(1-EXP(-0.00287694*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	33.70
30.00	99.79	0.15	37.90
60.00	222.26	0.25	40.70
90.00	312.98	0.30	43.90
120.00	385.55	0.05	47.50
150.00	476.27	0.60	52.20
180.00	585.13	0.40	57.30
210.00	684.92	0.50	62.20
240.00	748.43	0.55	68.20
270.00	834.61	0.60	73.70
300.00	902.65	0.60	78.80
330.00	988.83	0.60	83.40
360.00	1029.65	0.55	86.90
390.00	1088.62	0.45	89.80
420.00	1133.98	0.70	92.10
450.00	1152.12	0.30	94.10
480.00	1183.88	0.45	95.50
510.00	1202.02	0.50	96.90
540.00	1229.24	0.70	98.00
570.00	1256.45	0.65	98.80
600.00	1288.20	0.40	99.40
630.00	1324.49	0.55	99.80
660.00	1329.02	0.40	100.20
690.00	1360.78	0.40	100.60
720.00	1319.95	0.55	100.80
750.00	1342.63	0.70	101.20
780.00	1333.56	0.55	101.30
810.00	1378.92	0.55	101.60
840.00	1419.74	0.65	101.70
870.00	1424.28	0.50	101.90
900.00	1437.89	0.50	102.10
930.00	1437.89	0.85	102.20
960.00	1410.67	0.30	102.30



100 11

SAND 200/270-1/8 THICK

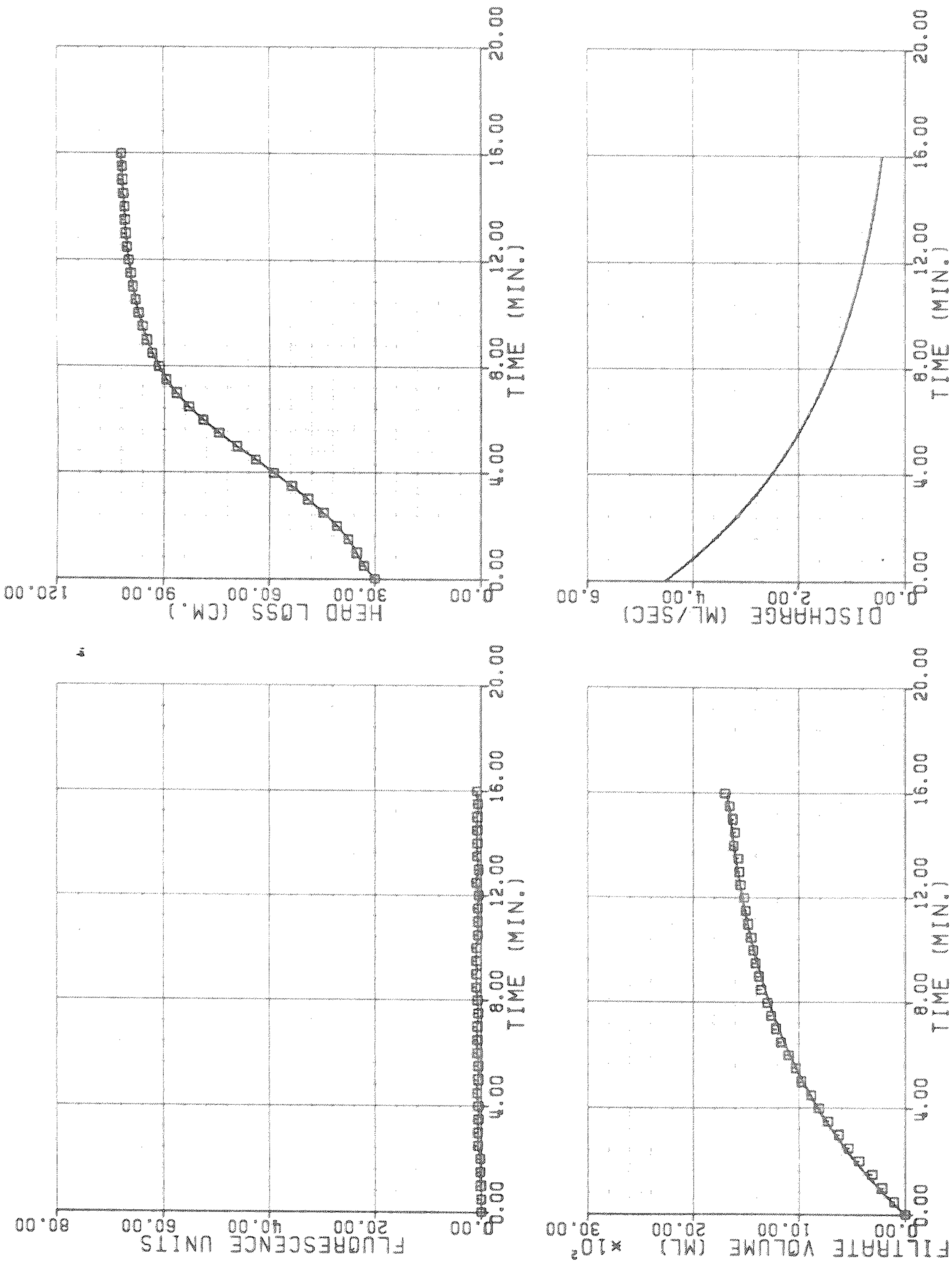
SAND 200/270-1/8 THICK TEST ID. NO. = 30051

AVERAGE PERCENT REMOVAL = 99.52

INITIAL CONCENTRATION=79.25 FLUORESCENCE UNITS

FILTRATE EQ. Y=1848.62109*(1-EXP(-0.00244923*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	30.00
30.00	108.86	0.0	33.10
60.00	217.72	0.10	35.20
90.00	312.98	0.20	37.60
120.00	435.45	0.15	40.80
150.00	530.70	0.65	44.70
180.00	621.42	0.65	49.00
210.00	725.75	0.55	53.70
240.00	811.93	0.55	58.80
270.00	884.51	0.75	63.90
300.00	975.22	0.55	69.20
330.00	1029.66	0.55	74.40
360.00	1097.69	0.70	78.90
390.00	1170.27	0.70	83.00
420.00	1215.63	0.70	86.40
450.00	1260.99	0.55	89.30
480.00	1297.27	0.70	91.30
510.00	1356.24	0.95	93.20
540.00	1378.92	0.85	94.70
570.00	1406.14	0.85	95.90
600.00	1428.82	0.85	97.00
630.00	1451.50	0.60	97.80
660.00	1478.71	0.65	98.50
690.00	1501.39	0.65	99.10
720.00	1515.00	0.50	99.70
750.00	1551.29	0.95	100.10
780.00	1560.36	0.50	100.50
810.00	1569.43	0.75	100.70
840.00	1614.79	0.70	100.90
870.00	1601.18	0.70	101.20
900.00	1623.86	0.70	101.40
930.00	1655.61	0.65	101.60
960.00	1696.44	0.80	101.80



300 51

SAND 200/270-1/8 THICK

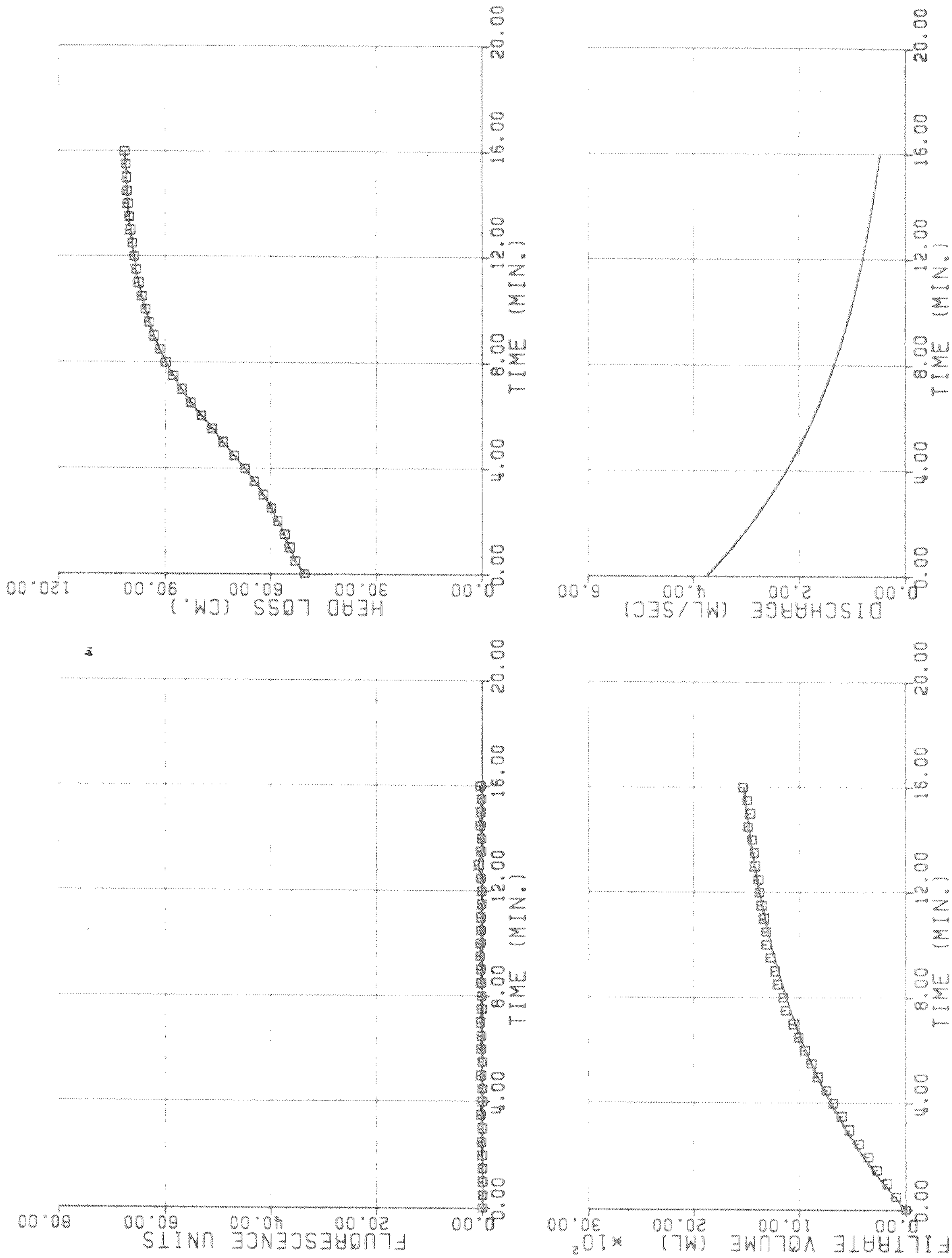
SAND 200/270-1/4 THICK   TEST ID. NO. = 30052

AVERAGE PERCENT REMOVAL = 99.89

INITIAL CONCENTRATION=79.25 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1748.11694*(1-EXP(-0.00214909*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	50.30
30.00	95.25	0.0	53.00
60.00	176.90	0.0	54.60
90.00	272.16	0.0	56.00
120.00	344.73	0.10	57.90
150.00	439.98	0.15	59.80
180.00	530.70	0.0	62.10
210.00	603.28	0.30	64.60
240.00	684.92	0.05	67.40
270.00	748.43	0.0	70.40
300.00	825.54	0.25	73.60
330.00	889.04	0.0	76.70
360.00	948.01	0.25	79.90
390.00	1006.97	0.15	82.80
420.00	1056.87	0.30	85.40
450.00	1129.45	0.10	87.80
480.00	1152.12	0.15	89.90
510.00	1206.56	0.25	91.60
540.00	1229.24	0.35	93.20
570.00	1274.59	0.50	94.50
600.00	1310.88	0.40	95.60
630.00	1315.42	0.30	96.60
660.00	1333.56	0.35	97.50
690.00	1356.24	0.20	98.20
720.00	1378.92	0.15	98.80
750.00	1387.99	0.35	99.30
780.00	1419.74	0.70	99.80
810.00	1424.28	0.25	100.20
840.00	1446.96	0.20	100.50
870.00	1483.25	0.40	100.70
900.00	1465.10	0.30	100.80
930.00	1492.32	0.15	101.10
960.00	1528.61	0.40	101.40



300 52

SAND 200/270-1/4 THICK

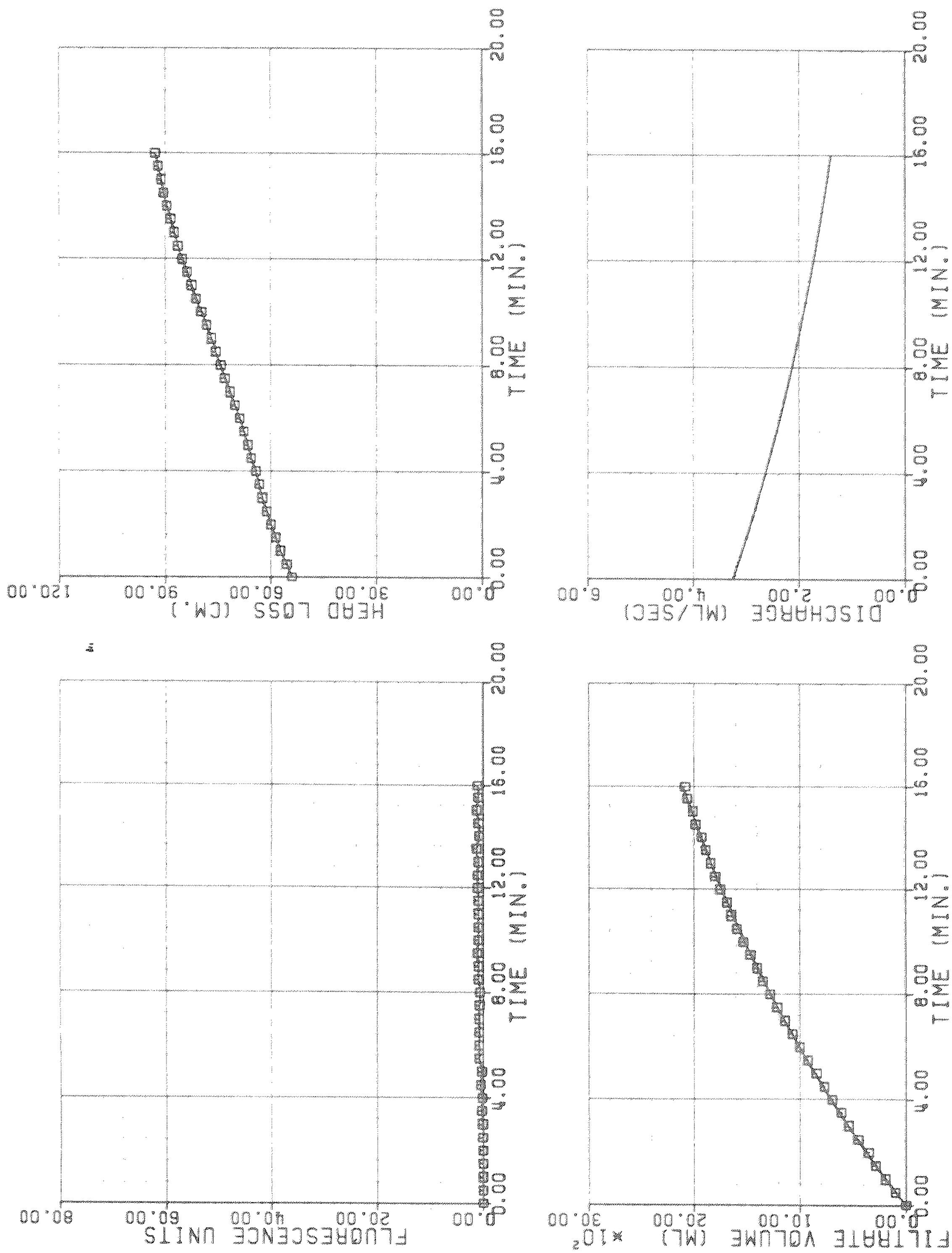
SAND 200/270-1/4 THICK   TEST ID. NO. = 40041

AVERAGE PERCENT REMOVAL = 98.70

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=3633.40527*(1-EXP(-0.00088345*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	54.00
30.00	99.79	0.0	55.50
60.00	190.51	0.0	57.30
90.00	285.76	0.0	58.60
120.00	349.27	0.0	60.00
150.00	449.06	0.05	61.20
180.00	539.78	0.10	62.40
210.00	607.81	0.25	63.30
240.00	694.00	0.20	64.20
270.00	771.11	0.50	65.50
300.00	843.68	0.25	66.50
330.00	920.79	0.75	67.60
360.00	997.90	0.75	68.80
390.00	1070.48	0.75	70.10
420.00	1138.52	0.75	71.50
450.00	1211.09	0.70	73.00
480.00	1279.13	0.60	74.20
510.00	1347.17	0.90	75.60
540.00	1401.60	0.90	76.90
570.00	1465.10	1.05	78.30
600.00	1528.61	0.95	79.70
630.00	1592.11	0.90	81.30
660.00	1646.54	0.90	82.50
690.00	1682.83	0.95	83.80
720.00	1746.33	1.05	85.10
750.00	1796.23	1.05	86.40
780.00	1837.05	0.95	87.40
810.00	1882.41	1.25	88.50
840.00	1923.23	0.80	89.50
870.00	1982.20	0.85	90.50
900.00	2009.41	1.25	91.20
930.00	2059.31	0.95	92.10
960.00	2081.99	1.05	92.90



400 41

SAND 200/270-1/4 THICK

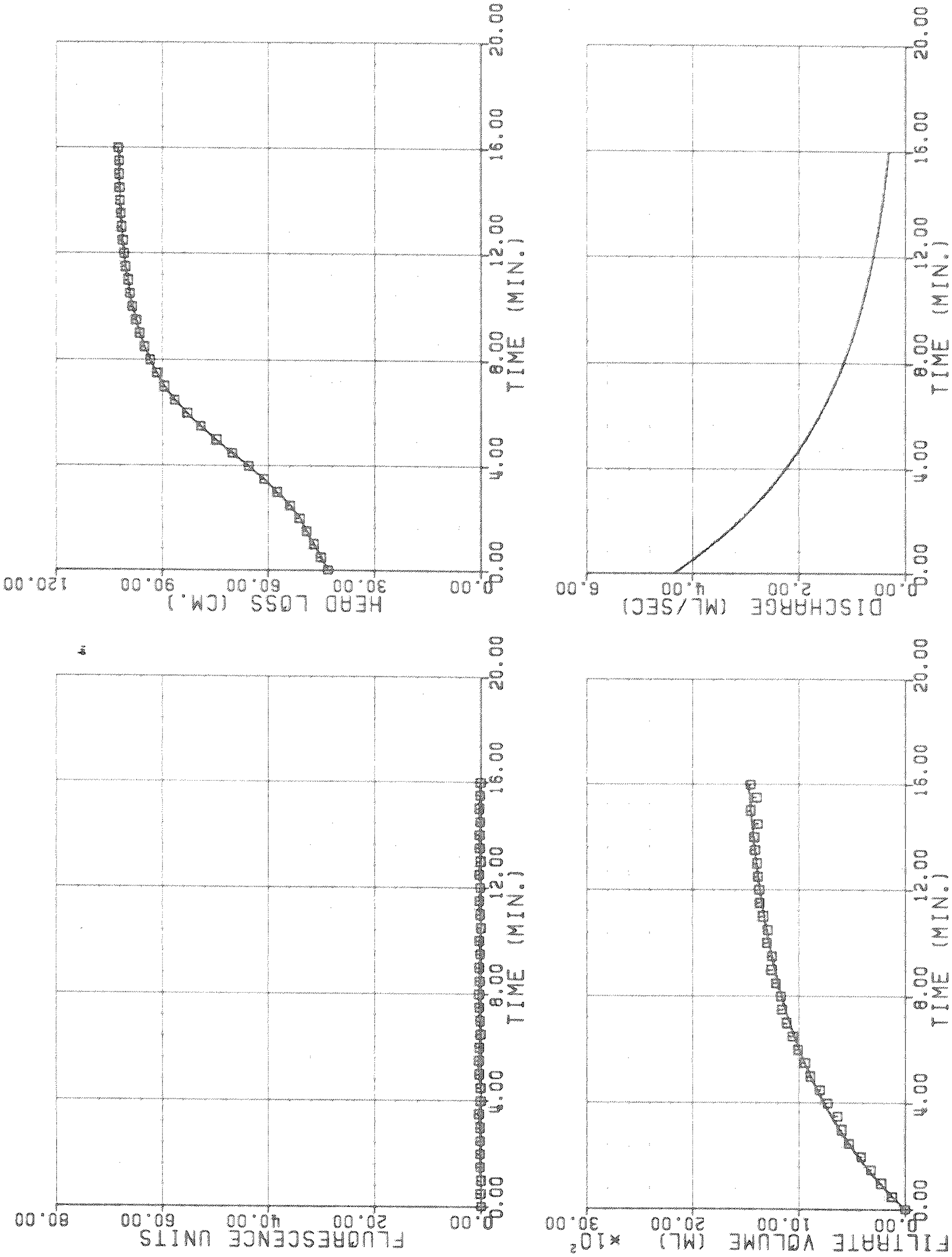
SAND 200/270-1/4 THICK   TEST ID. NO. = 10012

AVERAGE PERCENT REMOVAL = 99.79

INITIAL CONCENTRATION=68.75 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1585.71265*(1-EXP(-0.00274088*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	43.20
30.00	127.01	0.05	45.10
60.00	226.80	0.0	47.10
90.00	322.05	0.20	49.10
120.00	417.31	0.15	51.10
150.00	530.70	0.15	53.80
180.00	598.74	0.15	57.40
210.00	639.56	0.40	61.20
240.00	730.28	0.10	65.60
270.00	802.86	0.05	70.20
300.00	893.58	0.35	74.70
330.00	943.47	0.40	79.20
360.00	1006.97	0.30	83.00
390.00	1056.87	0.10	86.50
420.00	1115.84	0.20	89.40
450.00	1156.66	0.30	91.60
480.00	1170.27	0.40	93.40
510.00	1215.63	0.25	95.10
540.00	1256.45	0.30	96.40
570.00	1251.91	0.15	97.50
600.00	1301.81	0.30	98.50
630.00	1292.74	0.0	99.30
660.00	1333.56	0.20	99.70
690.00	1369.85	0.30	100.40
720.00	1374.38	0.20	100.80
750.00	1383.46	0.30	101.20
780.00	1392.53	0.10	101.50
810.00	1410.67	0.25	101.80
840.00	1419.74	0.25	102.00
870.00	1383.46	0.20	102.10
900.00	1456.03	0.35	102.20
930.00	1397.06	0.15	102.30
960.00	1456.03	0.10	102.40



100 12

SAND 200/270-1/4 THICK

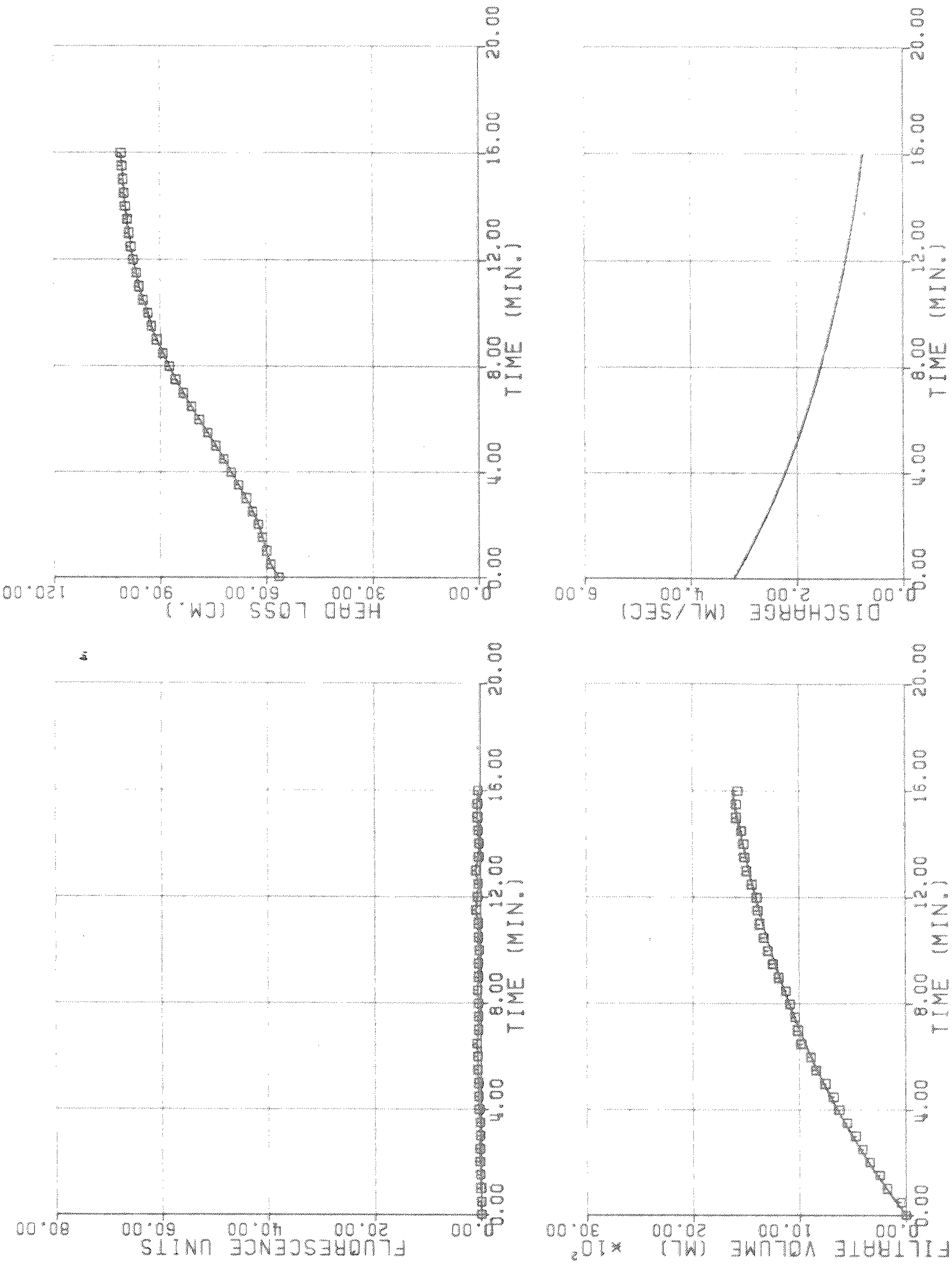
SAND 200/270-3/8 THICK   TEST ID. NO. = 10031

AVERAGE PERCENT REMOVAL = 99.55

INITIAL CONCENTRATION=68.75 FLUORESCENCE UNITS

FILTRATE EQ.   Y=2130.39844*(1-EXP(-0.00149822*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	56.50
30.00	45.36	0.0	58.90
60.00	176.90	0.10	60.00
90.00	244.94	0.15	61.20
120.00	340.19	0.25	62.30
150.00	408.23	0.25	63.90
180.00	471.74	0.20	65.70
210.00	553.38	0.20	67.80
240.00	625.96	0.40	69.90
270.00	680.39	0.45	72.00
300.00	757.50	0.45	74.30
330.00	848.22	0.65	76.60
360.00	893.58	0.65	79.00
390.00	979.76	0.75	81.30
420.00	1011.51	0.50	83.50
450.00	1038.73	0.50	85.70
480.00	1084.09	0.45	87.50
510.00	1124.91	0.65	89.30
540.00	1192.95	0.45	91.00
570.00	1247.38	0.45	92.50
600.00	1292.74	0.35	93.50
630.00	1329.02	0.50	94.80
660.00	1369.85	0.45	96.00
690.00	1387.99	0.85	96.70
720.00	1397.06	0.65	97.60
750.00	1442.42	0.45	98.20
780.00	1492.32	0.90	98.80
810.00	1510.46	0.40	99.30
840.00	1519.53	0.35	99.80
870.00	1537.68	0.45	100.10
900.00	1587.57	0.55	100.40
930.00	1587.57	0.55	100.70
960.00	1573.96	0.45	101.00



100 31

SAND 200/270-3/8 THICK

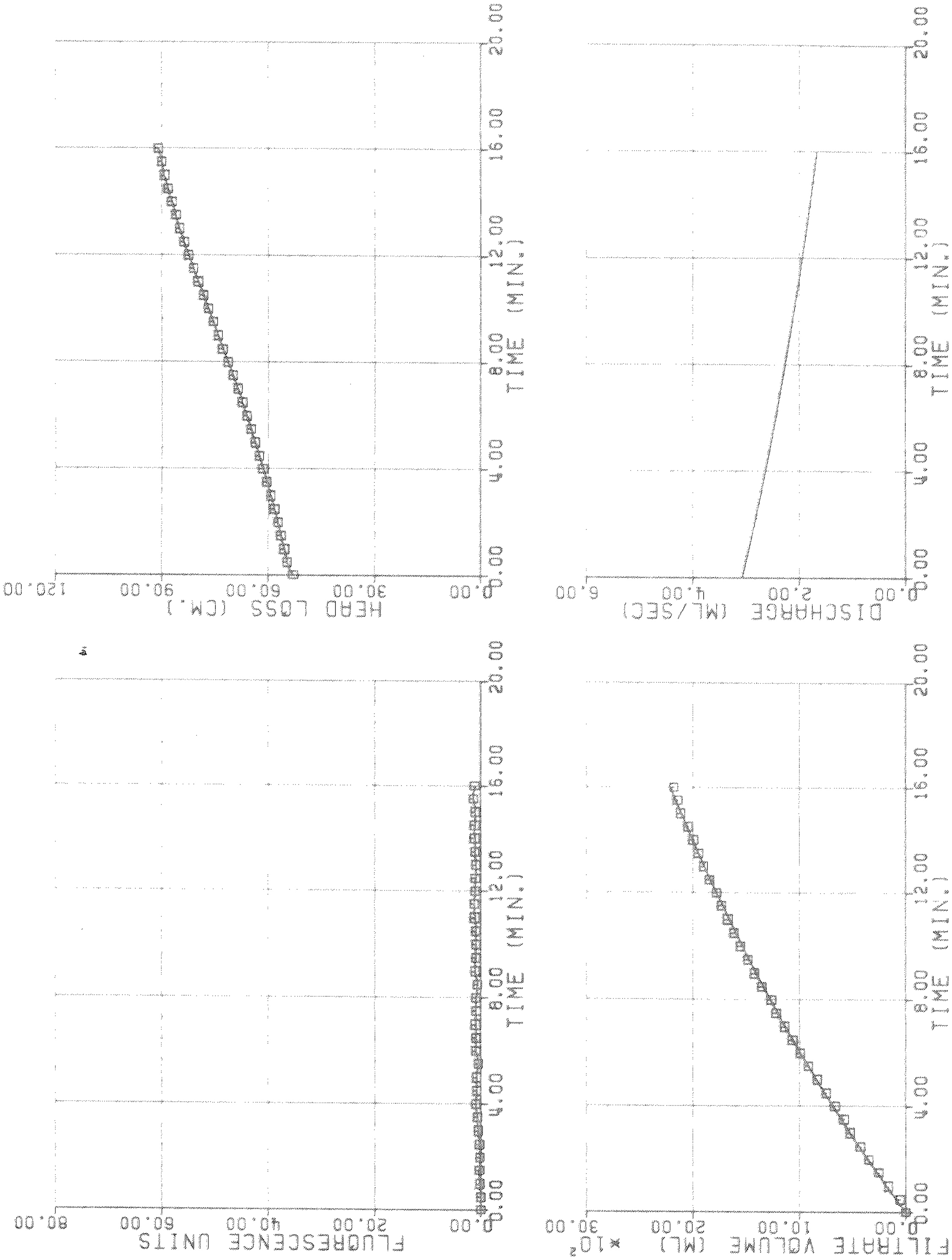
SAND 200/270-3/8 THICK   TEST ID. NO. = 40032

AVERAGE PERCENT REMOVAL = 98.19

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=4842.15234*(1-EXP(-0.00063520*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	53.00
30.00	54.43	0.0	54.70
60.00	163.29	0.15	55.50
90.00	254.01	0.25	56.40
120.00	344.73	0.15	57.30
150.00	426.38	0.25	58.30
180.00	521.63	0.50	59.30
210.00	580.60	0.65	60.40
240.00	666.78	0.95	61.50
270.00	743.89	0.75	62.50
300.00	830.07	0.80	63.70
330.00	916.26	0.50	64.90
360.00	993.37	0.95	66.00
390.00	1065.94	0.95	67.30
420.00	1138.52	1.00	68.50
450.00	1220.16	0.85	69.90
480.00	1265.52	0.90	71.30
510.00	1351.71	0.60	72.80
540.00	1424.28	1.10	74.10
570.00	1483.25	0.95	75.40
600.00	1555.82	0.90	76.80
630.00	1614.79	0.90	78.30
660.00	1673.76	1.15	79.70
690.00	1732.72	1.20	81.00
720.00	1778.08	1.10	82.40
750.00	1846.12	1.00	83.70
780.00	1900.55	0.95	84.90
810.00	1950.45	1.05	86.00
840.00	1995.81	1.15	87.10
870.00	2045.70	1.15	88.20
900.00	2113.74	1.05	89.20
930.00	2140.96	1.35	90.00
960.00	2177.24	1.15	90.90



400 32

SAND 200/270-3/8 THICK

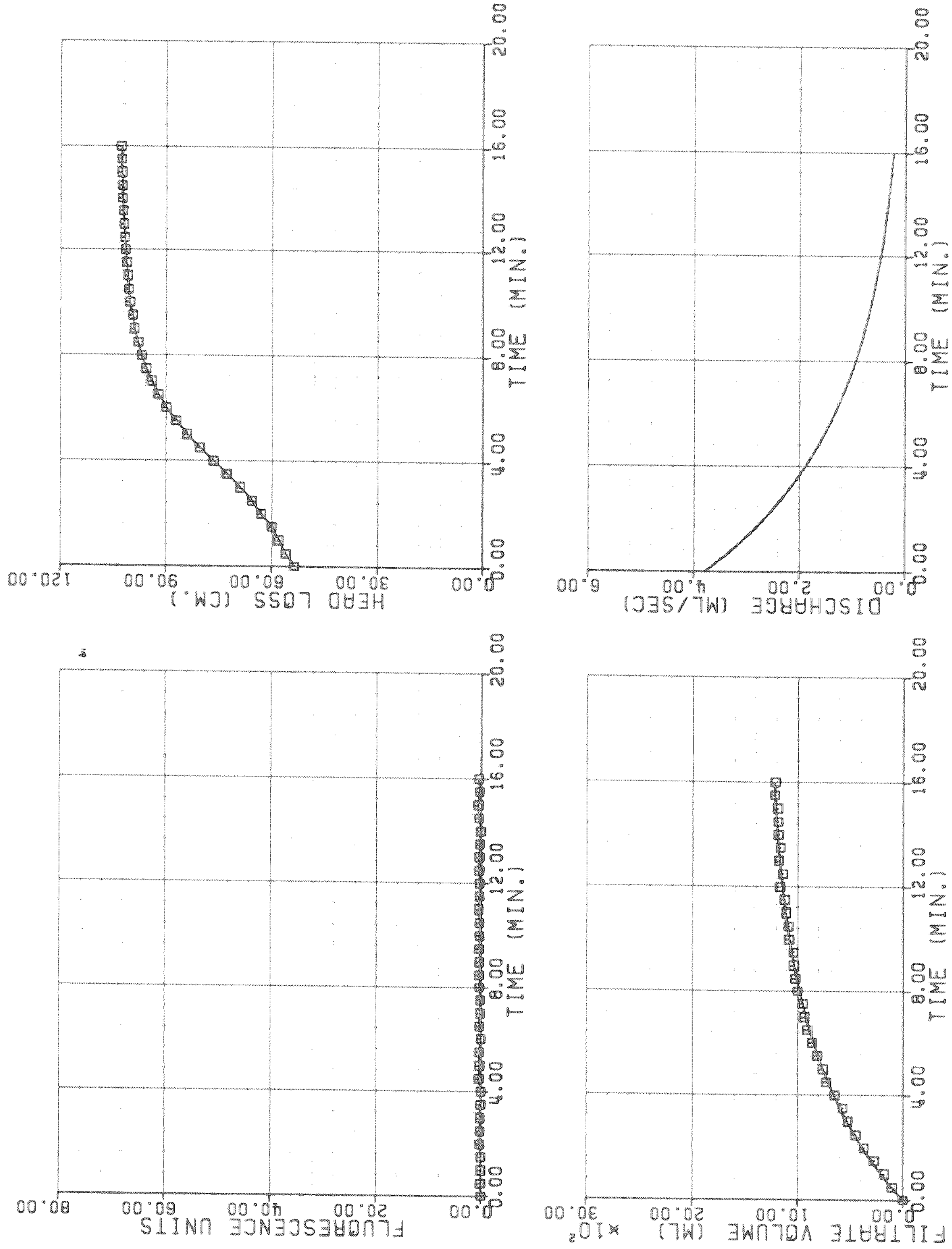
SAND 200/270-3/8 THICK   TEST ID. NO. = 10041

AVERAGE PERCENT REMOVAL = 99.87

INITIAL CONCENTRATION=86.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1301.86694*(1-EXP(-0.00291293*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	53.50
30.00	104.33	0.05	56.00
60.00	176.90	0.0	58.00
90.00	272.16	0.0	60.00
120.00	367.41	0.25	63.00
150.00	449.06	0.20	65.60
180.00	521.63	0.15	69.00
210.00	571.53	0.05	72.80
240.00	644.10	0.0	76.50
270.00	725.75	0.40	80.40
300.00	757.50	0.25	84.00
330.00	811.93	0.30	87.10
360.00	861.83	0.0	89.90
390.00	902.65	0.30	92.20
420.00	934.40	0.20	94.00
450.00	948.01	0.15	95.70
480.00	997.90	0.30	96.90
510.00	1020.58	0.40	98.00
540.00	1034.19	0.30	99.00
570.00	1038.73	0.40	99.50
600.00	1079.55	0.30	100.30
630.00	1084.09	0.30	100.60
660.00	1106.77	0.45	100.90
690.00	1120.37	0.35	101.20
720.00	1165.73	0.30	101.50
750.00	1138.52	0.40	101.80
780.00	1174.80	0.40	102.00
810.00	1161.20	0.30	102.20
840.00	1179.34	0.05	102.40
870.00	1183.88	0.50	102.50
900.00	1188.41	0.55	102.60
930.00	1215.63	0.35	102.70
960.00	1211.09	0.50	102.80



100 41

SAND 200/270-3/8 THICK

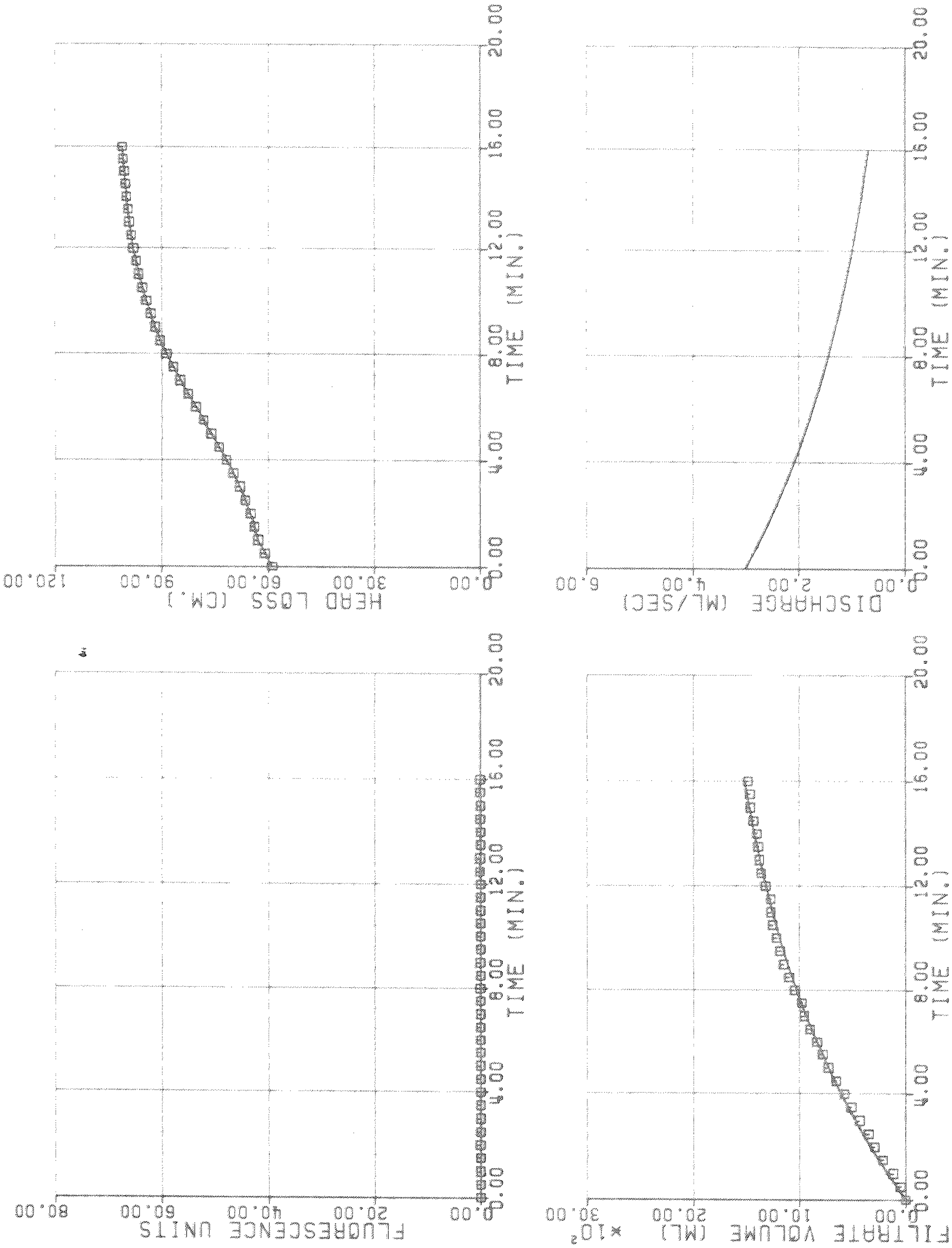
SAND 200/270-1/2 THICK   TEST ID. NO. = 10022

AVERAGE PERCENT REMOVAL = 99.99

INITIAL CONCENTRATION=68.75 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1964.12500*(1-EXP(-0.00153789*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	59.00
30.00	49.90	0.0	61.00
60.00	117.93	0.0	62.90
90.00	213.19	0.0	63.90
120.00	290.30	0.05	65.00
150.00	349.27	0.0	66.40
180.00	435.45	0.0	68.00
210.00	512.56	0.0	69.80
240.00	576.06	0.0	71.80
270.00	653.17	0.0	73.90
300.00	725.75	0.0	76.00
330.00	780.18	0.0	78.30
360.00	834.61	0.0	80.40
390.00	898.11	0.0	82.60
420.00	952.54	0.0	84.80
450.00	975.22	0.0	86.80
480.00	1043.26	0.05	88.70
510.00	1097.69	0.0	90.40
540.00	1147.59	0.05	91.90
570.00	1179.34	0.0	93.10
600.00	1215.63	0.0	94.30
630.00	1251.91	0.0	95.40
660.00	1270.06	0.0	96.40
690.00	1270.06	0.0	97.20
720.00	1319.95	0.0	98.00
750.00	1360.78	0.20	98.60
780.00	1378.92	0.10	99.10
810.00	1387.99	0.0	99.50
840.00	1401.60	0.0	99.90
870.00	1433.35	0.10	100.20
900.00	1460.57	0.0	100.50
930.00	1465.10	0.10	100.80
960.00	1483.25	0.05	101.10



100 22

SAND 200/270-1/2 THICK

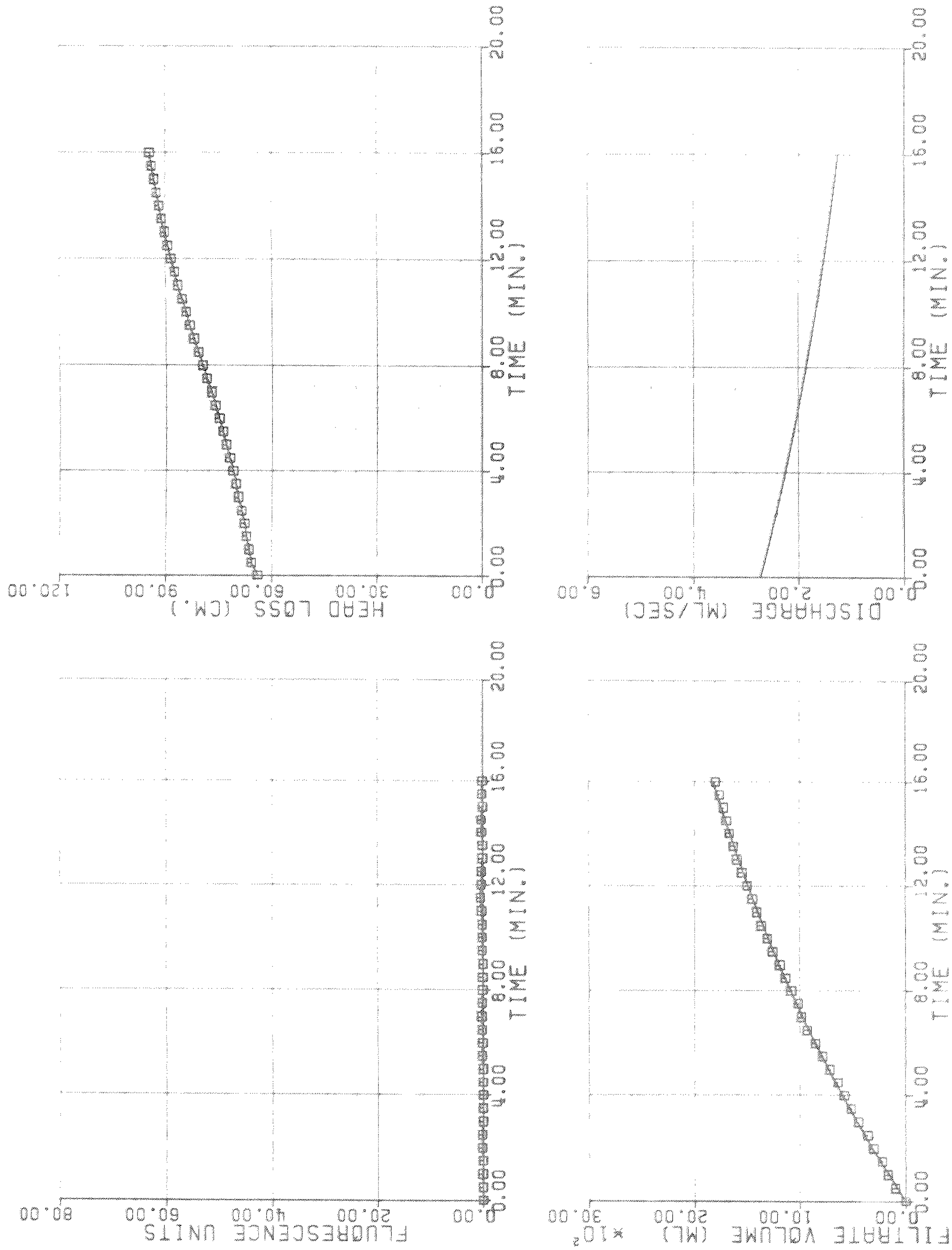
SAND 200/270-1/2 THICK   TEST ID. NO. = 30011

AVERAGE PERCENT REMOVAL = 99.81

INITIAL CONCENTRATION=57.90 FLUORESCENCE UNITS

FILTRATE EQ.   Y=3365.59058*(1-EXP(-0.00081190*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	64.00
30.00	99.79	0.0	65.80
60.00	167.83	0.10	66.50
90.00	222.26	0.0	67.10
120.00	303.91	0.20	67.70
150.00	358.34	0.20	68.60
180.00	444.52	0.0	69.40
210.00	517.10	0.0	70.20
240.00	580.60	0.0	71.00
270.00	639.57	0.0	71.90
300.00	716.08	0.0	72.90
330.00	784.71	0.20	73.90
360.00	852.75	0.05	74.90
390.00	929.86	0.15	76.00
420.00	984.30	0.25	77.10
450.00	1016.05	0.15	78.40
480.00	1079.55	0.05	79.60
510.00	1133.98	0.05	80.80
540.00	1188.41	0.0	82.00
570.00	1256.45	0.15	83.20
600.00	1306.35	0.15	84.30
630.00	1365.31	0.20	85.40
660.00	1406.14	0.25	86.60
690.00	1451.50	0.50	87.50
720.00	1501.39	0.35	88.50
750.00	1551.29	0.30	89.40
780.00	1596.65	0.05	90.30
810.00	1632.93	0.05	91.10
840.00	1669.22	0.25	91.80
870.00	1696.44	0.35	92.50
900.00	1723.65	0.0	93.20
930.00	1759.94	0.20	93.90
960.00	1800.76	0.10	94.50



300 11

SAND 200/270-1/2 THICK

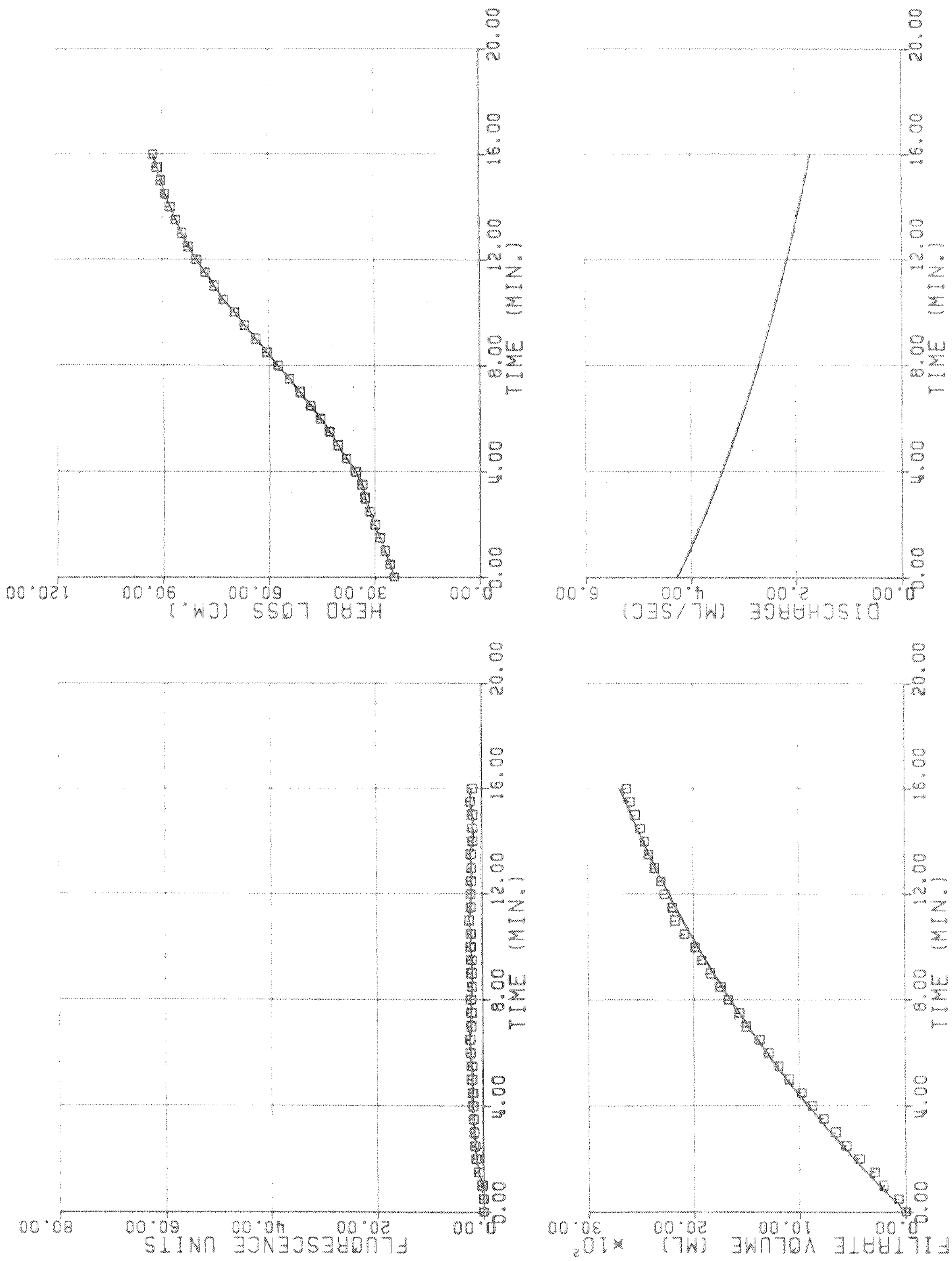
SAND 140/200-1/8 THICK   TEST ID. NO. = 40011

AVERAGE PERCENT REMOVAL = 95.71

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=4511.39453*(1-EXP(-0.00094746*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	24.50
30.00	68.04	0.0	25.60
60.00	208.65	0.25	27.00
90.00	290.30	0.85	28.50
120.00	435.45	1.30	29.90
150.00	557.92	1.50	31.30
180.00	657.71	1.70	32.80
210.00	771.11	1.85	33.60
240.00	875.43	1.95	35.40
270.00	975.22	1.95	38.10
300.00	1093.16	2.05	40.50
330.00	1192.95	2.10	42.90
360.00	1288.20	2.30	45.50
390.00	1374.38	2.40	48.30
420.00	1501.39	2.15	51.30
450.00	1564.89	2.10	54.30
480.00	1669.22	2.25	57.50
510.00	1741.79	2.00	60.60
540.00	1837.05	2.05	63.70
570.00	1923.23	2.05	66.90
600.00	1986.73	2.25	69.70
630.00	2086.52	2.15	72.90
660.00	2172.71	2.45	75.40
690.00	2199.92	2.20	78.00
720.00	2272.50	2.15	80.40
750.00	2308.78	2.05	82.70
780.00	2367.75	2.00	84.50
810.00	2422.18	2.10	86.30
840.00	2463.01	1.75	87.80
870.00	2503.83	1.75	89.30
900.00	2549.19	1.80	90.50
930.00	2590.01	2.20	91.50
960.00	2630.83	1.80	92.60



400 11

SAND 140/200-1/8 THICK

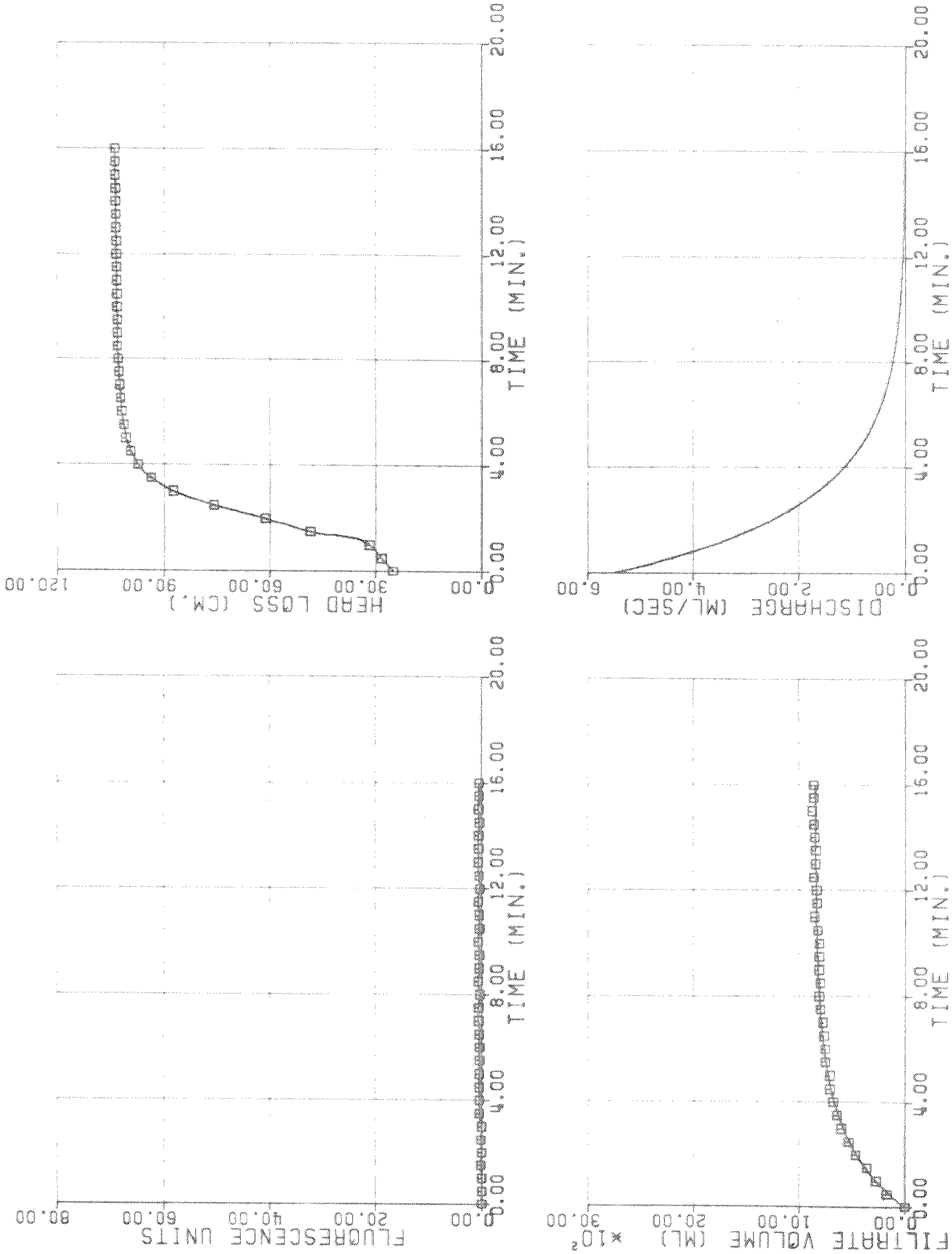
SAND 140/200-1/8 THICK   TEST ID. NO. = 20012

AVERAGE PERCENT REMOVAL = 99.95

INITIAL CONCENTRATION=78.25 FLUORESCENCE UNITS

FILTRATE EQ.   Y= 848.16528*(1-EXP(-0.00649928*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	25.00
30.00	172.37	0.0	28.30
60.00	272.16	0.0	31.70
90.00	362.87	0.15	48.60
120.00	467.20	0.0	61.40
150.00	535.24	0.20	75.90
180.00	603.28	0.0	87.50
210.00	644.10	0.45	93.70
240.00	680.39	0.50	97.40
270.00	712.14	0.45	99.40
300.00	712.14	0.50	100.70
330.00	752.96	0.40	101.30
360.00	752.96	0.40	101.90
390.00	766.57	0.45	102.20
420.00	775.64	0.55	102.50
450.00	798.32	0.55	102.70
480.00	811.93	0.35	102.90
510.00	798.32	0.65	103.10
540.00	811.93	0.45	103.20
570.00	811.93	0.40	103.20
600.00	807.39	0.60	103.30
630.00	821.00	0.40	103.30
660.00	852.75	0.45	103.40
690.00	830.07	0.65	103.40
720.00	834.61	0.30	103.50
750.00	861.83	0.50	103.50
780.00	848.22	0.60	103.60
810.00	843.68	0.55	103.60
840.00	852.75	0.55	103.70
870.00	861.83	0.40	103.70
900.00	875.43	0.55	103.80
930.00	861.83	0.50	103.80
960.00	861.83	0.50	103.90



200 12

SAND 140/200-1/8 THICK

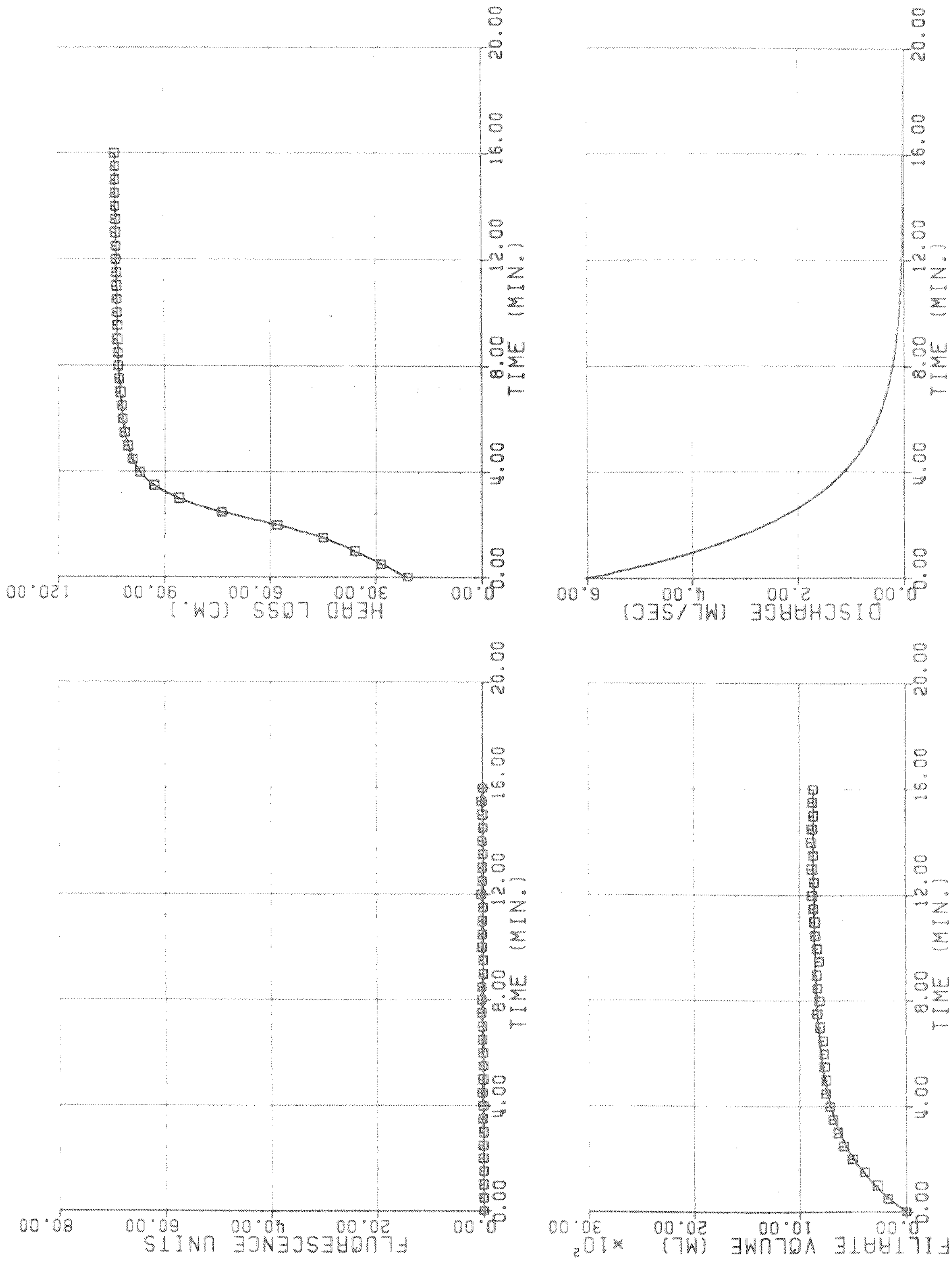
SAND 140/200-1/8 THICK   TEST ID. NO. = 20022

AVERAGE PERCENT REMOVAL = 99.98

INITIAL CONCENTRATION=78.25 FLUORESCENCE UNITS

FILTRATE EQ.   Y= 870.67114*(1-EXP(-0.00693880*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	21.00
30.00	176.90	0.0	28.60
60.00	272.16	0.0	35.90
90.00	390.09	0.0	45.00
120.00	503.49	0.10	58.00
150.00	589.67	0.05	73.80
180.00	639.57	0.0	86.00
210.00	684.92	0.15	93.10
240.00	716.68	0.05	97.20
270.00	752.96	0.25	99.30
300.00	748.43	0.10	100.50
330.00	766.57	0.0	101.40
360.00	771.11	0.10	102.00
390.00	775.64	0.15	102.30
420.00	807.39	0.15	102.60
450.00	834.61	0.35	102.90
480.00	811.93	0.30	103.20
510.00	830.07	0.30	103.20
540.00	839.15	0.0	103.30
570.00	816.47	0.0	103.30
600.00	834.61	0.25	103.40
630.00	852.75	0.20	103.40
660.00	857.29	0.20	103.50
690.00	870.90	0.0	103.50
720.00	879.97	0.40	103.60
750.00	861.83	0.15	103.60
780.00	879.97	0.15	103.70
810.00	870.90	0.0	103.70
840.00	889.04	0.20	103.80
870.00	879.97	0.0	103.80
900.00	870.90	0.05	103.90
930.00	875.43	0.25	103.90
960.00	870.90	0.0	104.00



200 22

SAND 140/200-1/8 THICK

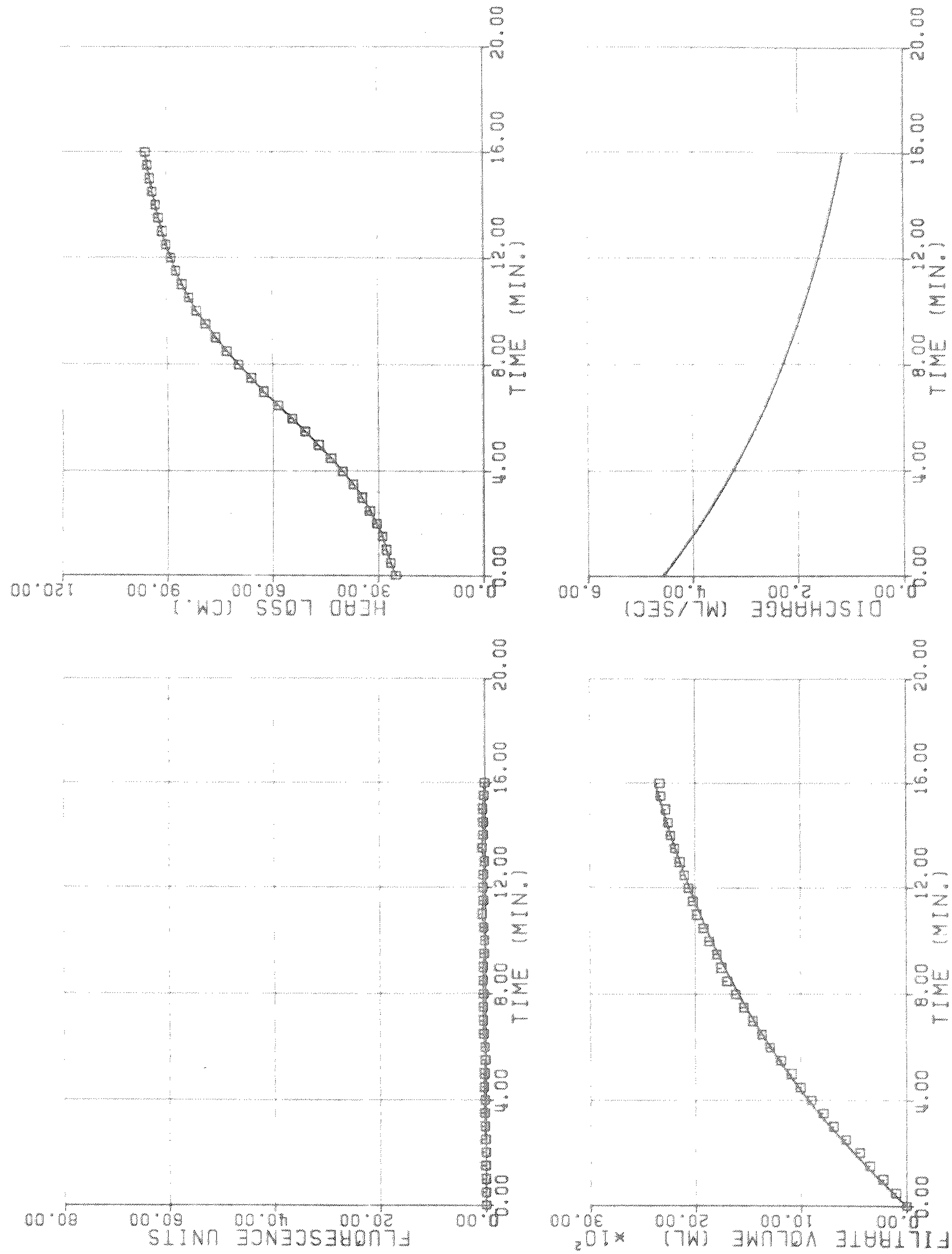
SAND 140/200-1/4 THICK   TEST ID. NO. = 30022

AVERAGE PERCENT REMOVAL = 99.64

INITIAL CONCENTRATION=57.90 FLUORESCENCE UNITS

FILTRATE EQ.   Y=3168.53589*(1-EXP(-0.00144568*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	25.00
30.00	104.33	0.0	26.50
60.00	226.80	0.0	27.70
90.00	349.27	0.05	28.90
120.00	444.52	0.0	30.50
150.00	576.06	0.05	32.40
180.00	694.00	0.15	34.60
210.00	789.25	0.25	37.20
240.00	898.11	0.20	40.20
270.00	1002.44	0.35	43.50
300.00	1068.62	0.25	47.00
330.00	1188.41	0.05	50.80
360.00	1292.74	0.20	54.50
390.00	1369.85	0.40	58.50
420.00	1456.03	0.50	62.50
450.00	1537.68	0.45	66.10
480.00	1614.79	0.40	69.70
510.00	1696.44	0.45	73.00
540.00	1750.87	0.50	76.20
570.00	1791.69	0.25	79.00
600.00	1864.26	0.20	81.60
630.00	1918.70	0.30	83.30
660.00	1986.73	0.65	85.70
690.00	2018.49	0.40	87.50
720.00	2063.84	0.45	88.90
750.00	2100.13	0.40	90.30
780.00	2140.96	0.20	91.30
810.00	2190.85	0.60	92.40
840.00	2231.67	0.40	93.30
870.00	2254.35	0.40	94.10
900.00	2277.03	0.50	94.90
930.00	2322.39	0.25	95.50
960.00	2336.00	0.10	96.10



300 22

SAND 140/200-1/4 THICK

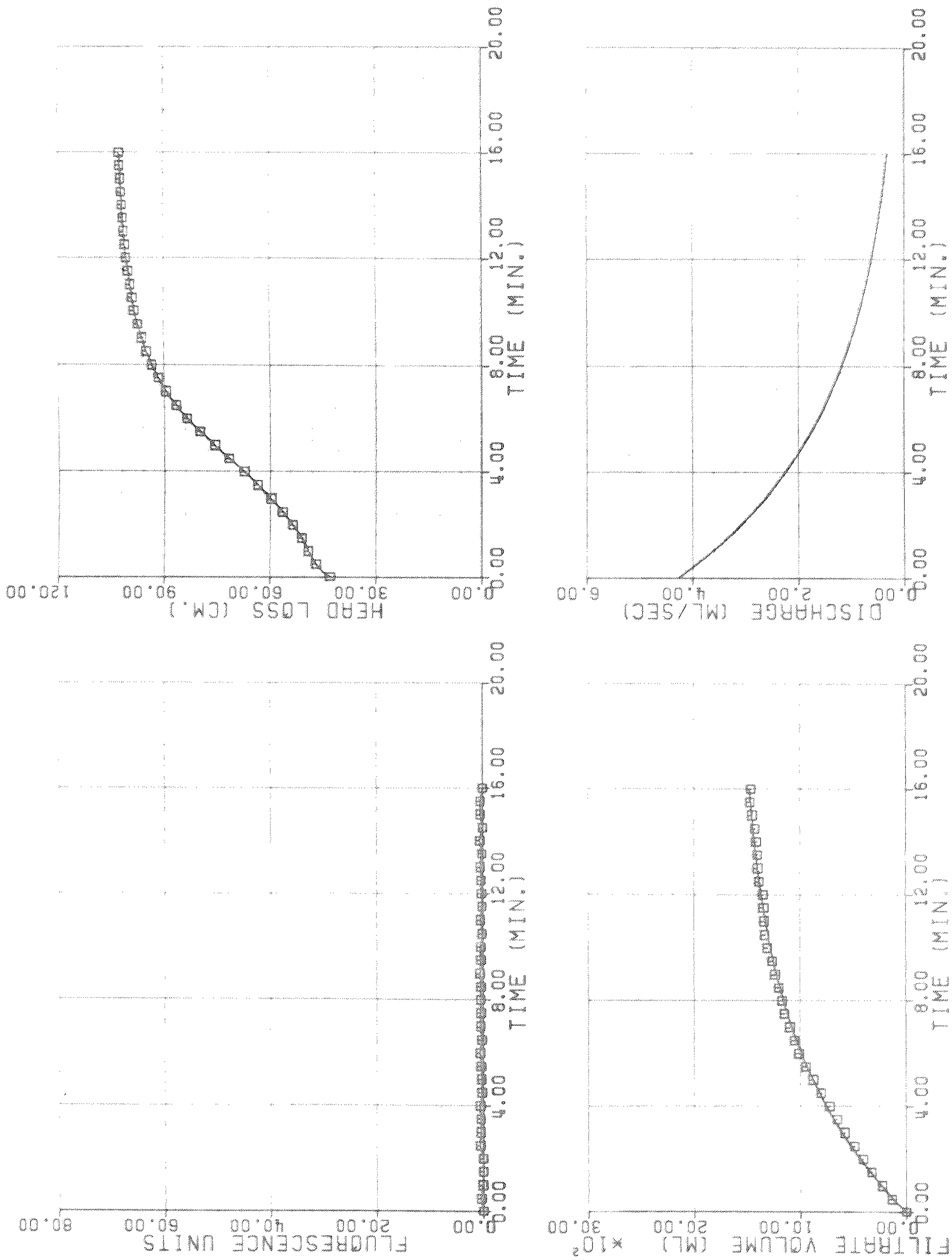
SAND 140/200-1/4 THICK   TEST ID. NO. = 20051

AVERAGE PERCENT REMOVAL = 99.61

INITIAL CONCENTRATION=71.60 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1598.13916*(1-EXP(-0.00267386*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	43.00
30.00	140.61	0.40	47.00
60.00	231.33	0.10	49.10
90.00	331.12	0.0	51.00
120.00	412.77	0.0	53.50
150.00	494.42	0.55	56.40
180.00	585.13	0.45	59.70
210.00	653.17	0.50	63.50
240.00	725.75	0.55	67.30
270.00	807.39	0.25	71.50
300.00	879.97	0.35	75.60
330.00	948.01	0.40	79.80
360.00	1011.51	0.55	83.50
390.00	1052.33	0.25	86.60
420.00	1097.69	0.50	89.40
450.00	1147.59	0.40	91.60
480.00	1170.27	0.45	93.40
510.00	1202.02	0.40	95.00
540.00	1233.77	0.55	96.20
570.00	1260.99	0.40	97.40
600.00	1306.35	0.40	98.40
630.00	1329.02	0.15	98.90
660.00	1338.10	0.45	99.40
690.00	1342.63	0.15	100.00
720.00	1347.17	0.25	100.60
750.00	1383.46	0.30	101.00
780.00	1397.06	0.50	101.30
810.00	1401.60	0.15	101.60
840.00	1410.67	0.55	101.80
870.00	1424.28	0.0	102.00
900.00	1451.49	0.50	102.20
930.00	1469.64	0.45	102.40
960.00	1460.57	0.0	102.60



200 51

SAND 140/200-1/4 THICK

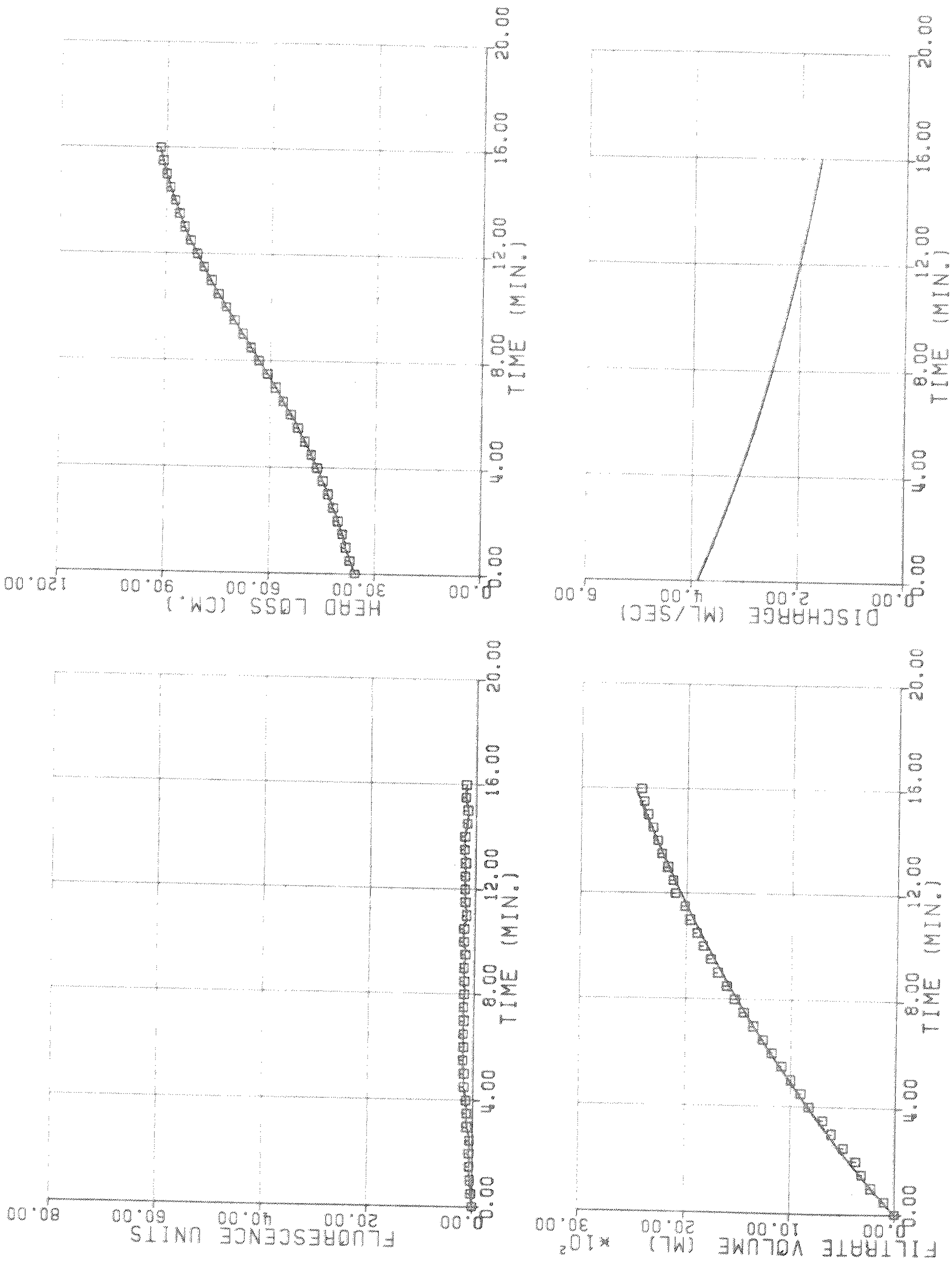
SAND 140/200-1/4 THICK   TEST ID. NO. = 40012

AVERAGE PERCENT REMOVAL = 96.29

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=4272.19922*(1-EXP(-0.00090976*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	35.50
30.00	99.79	0.25	37.00
60.00	226.80	0.50	38.20
90.00	317.51	0.60	39.20
120.00	371.95	0.70	40.50
150.00	494.42	0.60	41.90
180.00	607.81	1.15	43.40
210.00	694.00	1.25	44.90
240.00	825.54	1.40	46.50
270.00	902.65	1.80	48.30
300.00	997.90	1.80	50.10
330.00	1088.62	2.00	52.00
360.00	1179.34	1.90	54.10
390.00	1265.52	2.00	56.30
420.00	1356.24	1.90	58.50
450.00	1451.50	2.00	60.80
480.00	1533.14	1.90	63.20
510.00	1610.25	1.95	65.50
540.00	1696.44	2.00	67.90
570.00	1764.47	1.80	70.30
600.00	1837.05	2.10	72.70
630.00	1900.55	2.10	74.90
660.00	1964.05	1.65	77.00
690.00	2013.95	1.95	79.10
720.00	2109.20	2.00	81.00
750.00	2131.88	2.00	83.00
780.00	2181.78	1.95	84.70
810.00	2236.21	2.20	86.20
840.00	2277.03	2.10	87.50
870.00	2322.39	1.65	88.80
900.00	2367.75	1.60	90.00
930.00	2408.57	2.00	91.00
960.00	2435.79	1.90	91.90



400 12

SAND 140/200-1/4 THICK

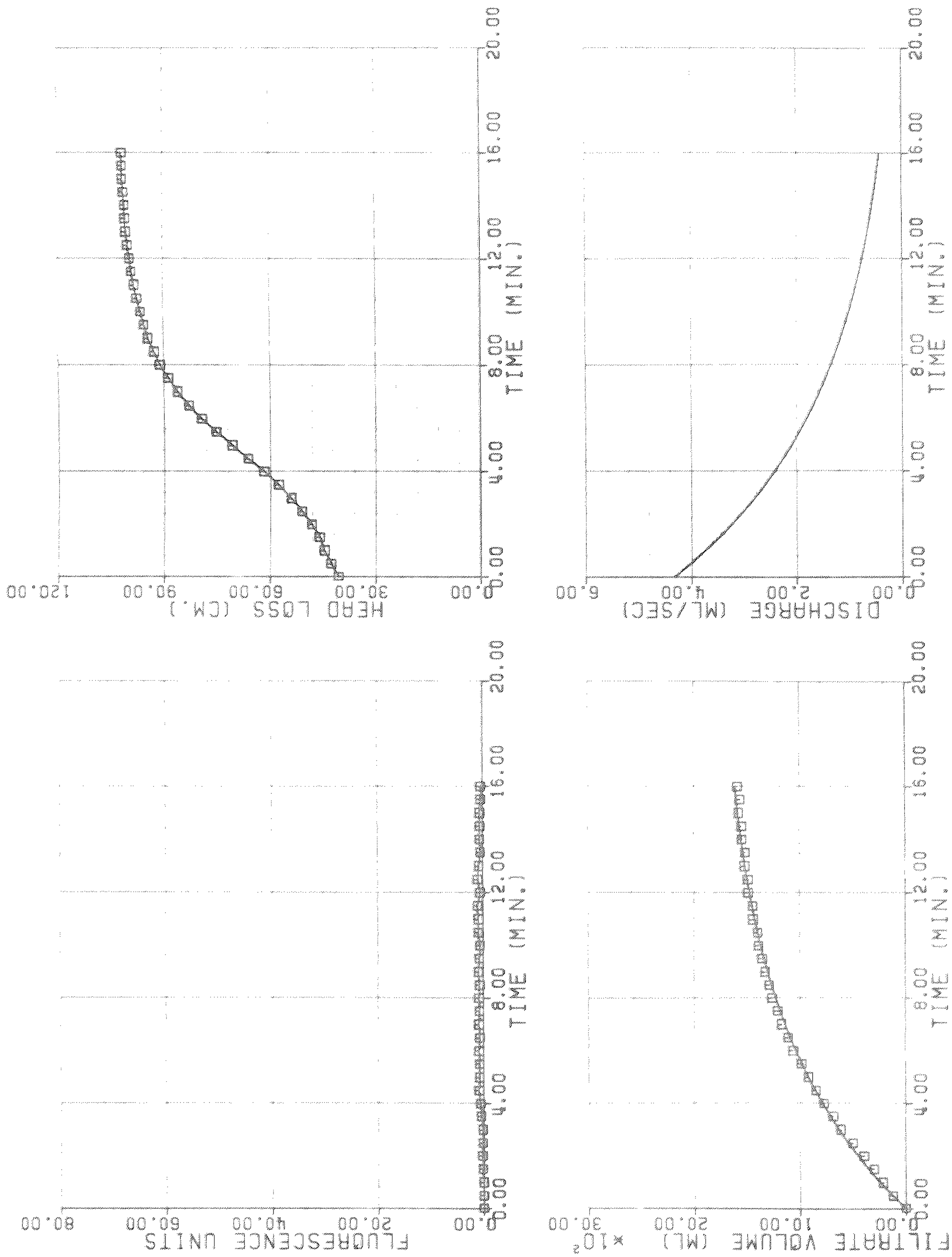
SAND 140/200-3/8 THICK   TEST ID. NO. = 30071

AVERAGE PERCENT REMOVAL = 99.56

INITIAL CONCENTRATION=79.25 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1788.43213*(1-EXP(-0.00242275*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	40.70
30.00	122.47	0.0	42.80
60.00	213.19	0.0	44.70
90.00	299.37	0.15	46.00
120.00	394.63	0.25	48.30
150.00	498.95	0.20	51.00
180.00	616.89	0.20	54.00
210.00	689.46	0.45	57.60
240.00	775.64	0.65	61.70
270.00	852.75	0.85	66.20
300.00	925.33	0.75	70.70
330.00	988.83	0.75	75.20
360.00	1065.94	0.85	79.30
390.00	1115.84	0.70	82.90
420.00	1174.80	0.85	86.10
450.00	1211.09	0.80	88.70
480.00	1265.52	0.85	91.00
510.00	1292.74	0.70	92.70
540.00	1329.03	0.95	94.40
570.00	1356.24	0.75	95.50
600.00	1392.53	0.60	96.50
630.00	1401.60	0.95	97.50
660.00	1442.42	0.85	98.20
690.00	1446.96	1.05	99.00
720.00	1487.78	0.55	99.50
750.00	1487.78	1.00	100.00
780.00	1519.53	0.80	100.50
810.00	1515.00	0.50	100.70
840.00	1546.75	0.65	100.90
870.00	1551.29	0.55	101.20
900.00	1578.50	0.55	101.50
930.00	1564.89	0.40	101.60
960.00	1587.57	0.40	101.70



300 71

SAND 140/200-3/8 THICK

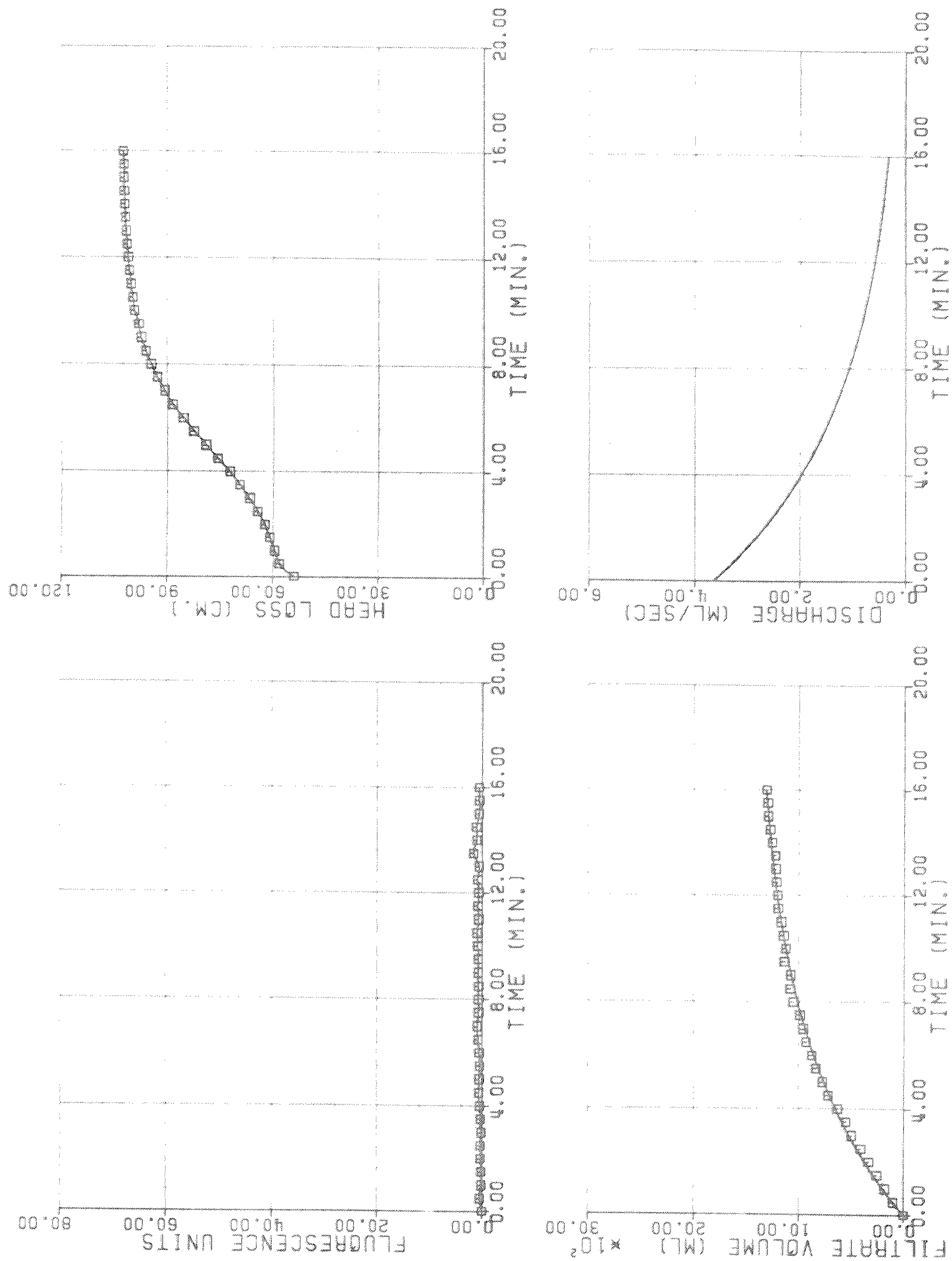
SAND 140/200-3/8 THICK   TEST ID. NO. = 10061

AVERAGE PERCENT REMOVAL = 99.60

INITIAL CONCENTRATION=86.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1436.25244*(1-EXP(-0.00253403*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	58.00
30.00	99.79	0.45	58.10
60.00	181.44	0.20	59.60
90.00	258.55	0.15	60.90
120.00	335.66	0.35	62.30
150.00	412.77	0.25	64.40
180.00	498.95	0.20	66.60
210.00	553.38	0.30	69.50
240.00	635.03	0.50	72.30
270.00	721.21	0.60	75.70
300.00	775.64	0.55	79.00
330.00	839.15	0.45	82.50
360.00	875.43	0.55	85.50
390.00	929.86	0.80	88.40
420.00	957.08	0.90	90.70
450.00	988.83	0.70	92.80
480.00	1052.33	0.70	94.50
510.00	1079.55	0.70	96.00
540.00	1075.01	0.80	97.30
570.00	1133.98	0.75	98.00
600.00	1124.91	0.85	99.20
630.00	1143.05	1.00	99.70
660.00	1165.73	0.70	100.20
690.00	1197.48	0.85	100.60
720.00	1202.02	0.70	101.00
750.00	1211.09	0.85	101.30
780.00	1220.16	0.65	101.60
810.00	1224.70	1.70	101.80
840.00	1251.92	1.10	102.00
870.00	1274.59	1.15	102.10
900.00	1292.74	0.60	102.20
930.00	1297.27	0.55	102.30
960.00	1306.35	0.65	102.50



100 61

SAND 140/200-3/8 THICK

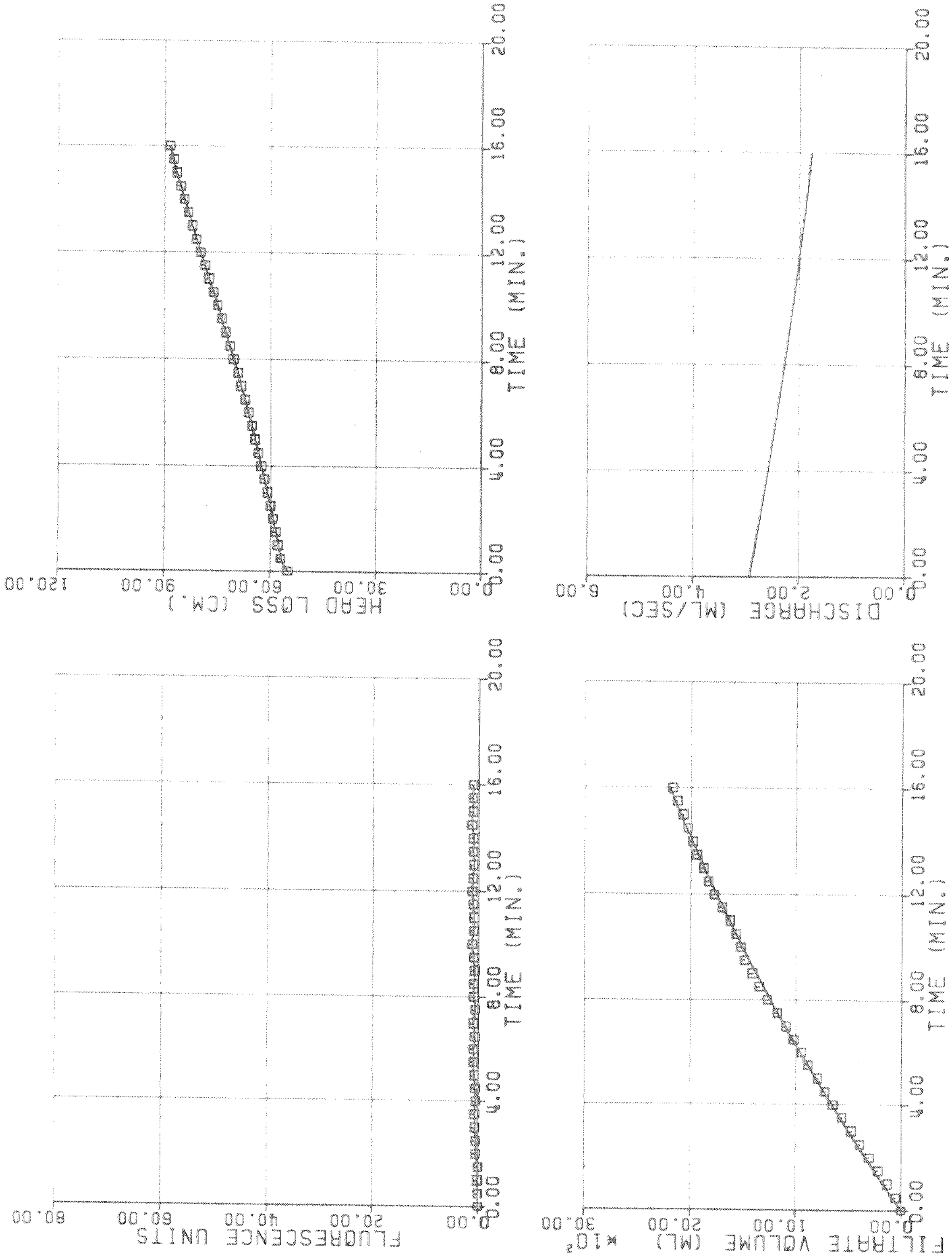
SAND 140/200-3/8 THICK   TEST ID. NO. = 40021

AVERAGE PERCENT REMOVAL = 98.15

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=5582.47656*(1-EXP(-0.00052324*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	55.00
30.00	54.43	0.0	57.00
60.00	131.54	0.10	57.80
90.00	217.72	0.0	58.50
120.00	303.91	0.45	59.30
150.00	390.09	0.50	60.00
180.00	471.74	0.60	60.90
210.00	562.46	0.70	61.80
240.00	648.64	0.50	62.70
270.00	721.21	0.55	63.50
300.00	793.79	0.80	64.40
330.00	884.51	0.90	65.30
360.00	948.01	0.90	66.30
390.00	1020.58	0.70	67.30
420.00	1093.16	0.95	68.40
450.00	1174.80	0.60	69.30
480.00	1270.06	0.85	70.50
510.00	1347.17	0.90	71.50
540.00	1410.67	0.70	72.70
570.00	1483.25	0.95	73.90
600.00	1519.53	1.25	75.00
630.00	1564.89	0.95	76.20
660.00	1623.86	0.85	77.40
690.00	1700.97	1.10	78.60
720.00	1778.08	1.20	79.80
750.00	1832.51	1.10	81.00
780.00	1877.87	0.90	82.20
810.00	1941.37	1.05	83.30
840.00	1982.20	1.00	84.50
870.00	2032.09	1.30	85.50
900.00	2072.92	1.10	86.60
930.00	2127.35	1.10	87.50
960.00	2172.71	1.05	88.50



400 21

SAND 140/200-3/8 THICK

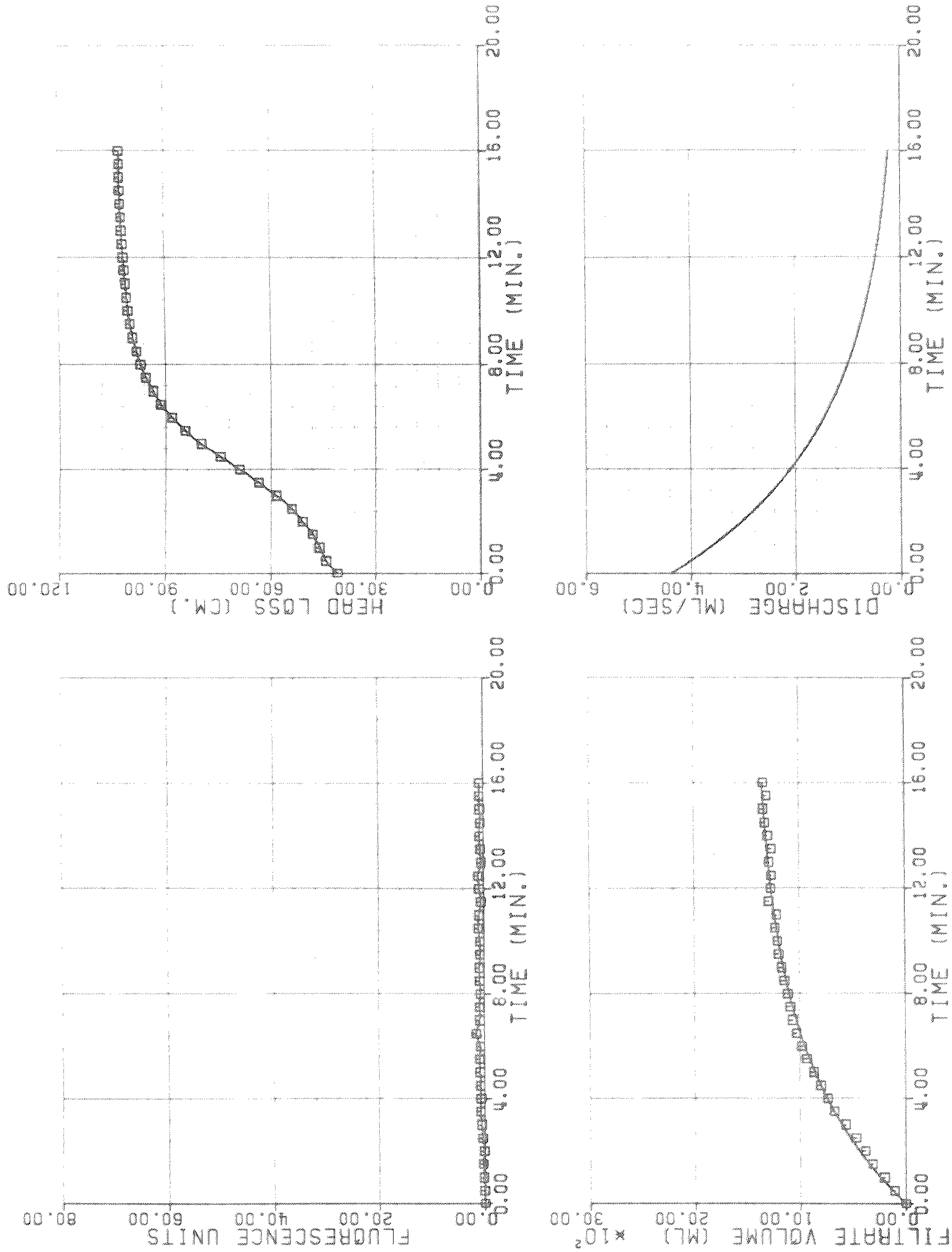
SAND 140/200-1/2 THICK   TEST ID. NO. = 100F2

AVERAGE PERCENT REMOVAL = 99.54

INITIAL CONCENTRATION=86.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1421.47876*(1-EXP(-0.00308842*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	41.00
30.00	108.86	0.05	44.20
60.00	204.12	0.15	46.00
90.00	317.51	0.35	48.00
120.00	385.55	0.10	50.90
150.00	471.74	0.40	54.00
180.00	571.53	0.55	58.40
210.00	675.85	0.80	63.40
240.00	739.36	0.70	69.00
270.00	802.86	0.80	74.40
300.00	870.90	0.85	79.80
330.00	934.40	0.90	84.40
360.00	979.76	0.80	88.20
390.00	1029.65	1.50	91.40
420.00	1065.94	0.85	93.50
450.00	1088.62	0.95	95.60
480.00	1111.30	0.80	97.00
510.00	1143.05	0.85	98.10
540.00	1170.27	0.90	99.20
570.00	1197.48	0.80	99.90
600.00	1206.56	0.80	100.50
630.00	1229.24	1.05	100.80
660.00	1215.63	0.95	101.10
690.00	1283.20	0.55	101.40
720.00	1270.06	0.85	101.70
750.00	1260.99	1.05	101.90
780.00	1283.67	0.45	102.10
810.00	1260.99	0.65	102.30
840.00	1297.27	0.80	102.50
870.00	1324.49	0.65	102.60
900.00	1338.10	0.70	102.70
930.00	1306.35	0.80	102.70
960.00	1338.10	0.80	102.80



100 62

SAND 140/200-1/2 THICK

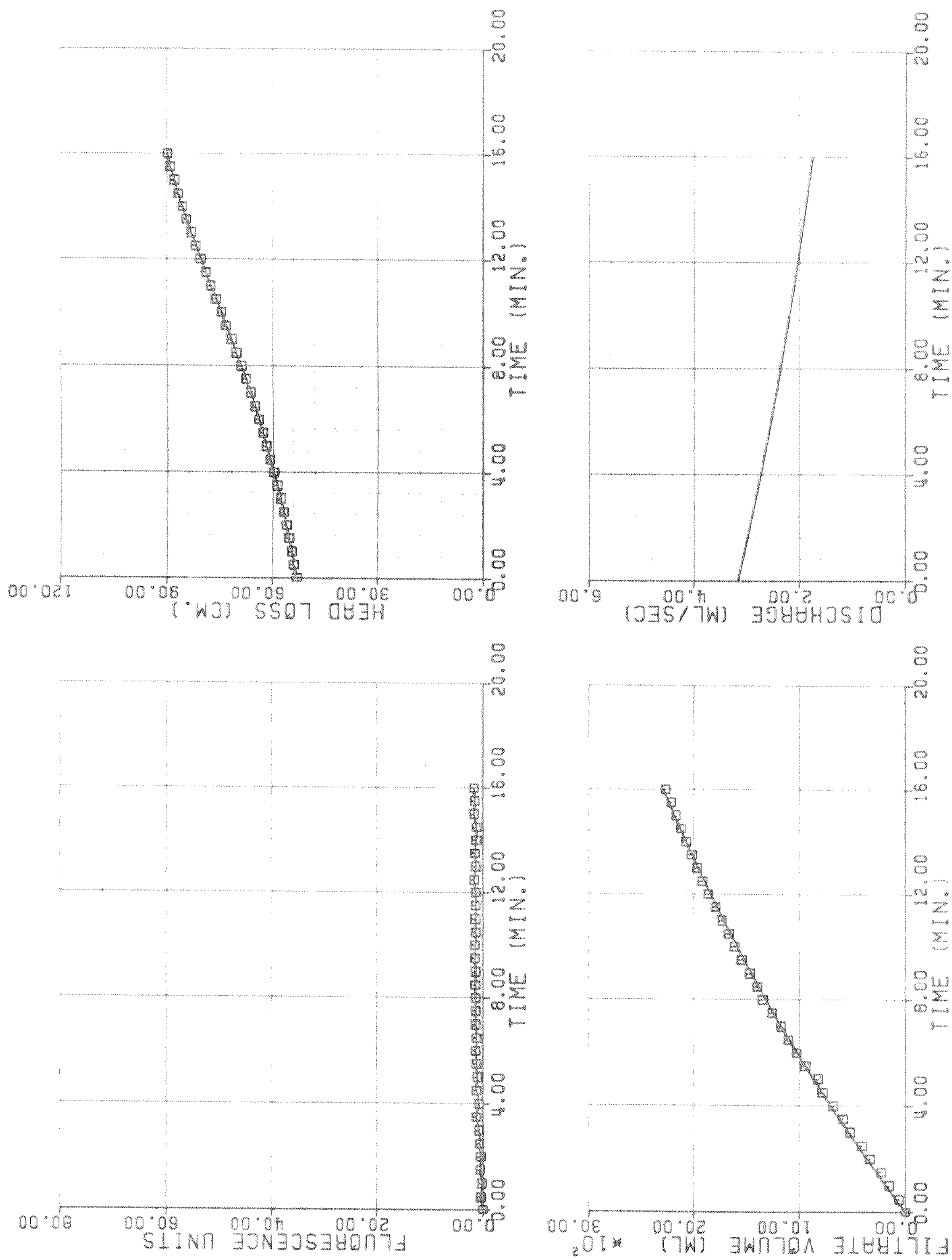
SAND 140/200-1/2 THICK TEST ID. NO. = 40022

AVERAGE PERCENT REMOVAL = 97.25

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ. Y=5163.00000*(1-EXP(-0.00061156*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	53.00
30.00	63.50	0.40	53.90
60.00	154.22	0.15	54.50
90.00	226.80	0.50	55.30
120.00	335.66	0.40	56.00
150.00	412.77	0.65	56.80
180.00	521.63	0.70	57.70
210.00	589.67	1.20	58.70
240.00	680.39	0.80	59.70
270.00	780.18	1.25	60.70
300.00	821.00	1.10	61.80
330.00	943.47	1.25	62.80
360.00	1025.12	1.35	63.90
390.00	1102.23	1.20	65.10
420.00	1170.27	1.35	66.20
450.00	1251.91	1.40	67.60
480.00	1342.63	1.35	68.90
510.00	1397.06	1.45	70.30
540.00	1465.10	1.40	71.70
570.00	1542.21	1.50	73.30
600.00	1610.25	1.50	74.60
630.00	1664.68	1.35	76.00
660.00	1732.72	1.45	77.50
690.00	1791.69	1.35	78.90
720.00	1859.73	1.40	80.40
750.00	1918.70	1.70	81.80
780.00	1968.59	1.35	83.10
810.00	2018.49	1.55	84.40
840.00	2072.92	1.30	85.60
870.00	2122.81	1.20	86.80
900.00	2168.17	1.65	87.80
930.00	2213.53	1.55	89.00
960.00	2267.96	1.70	89.80



400 22

SAND 140/200-1/2 THICK

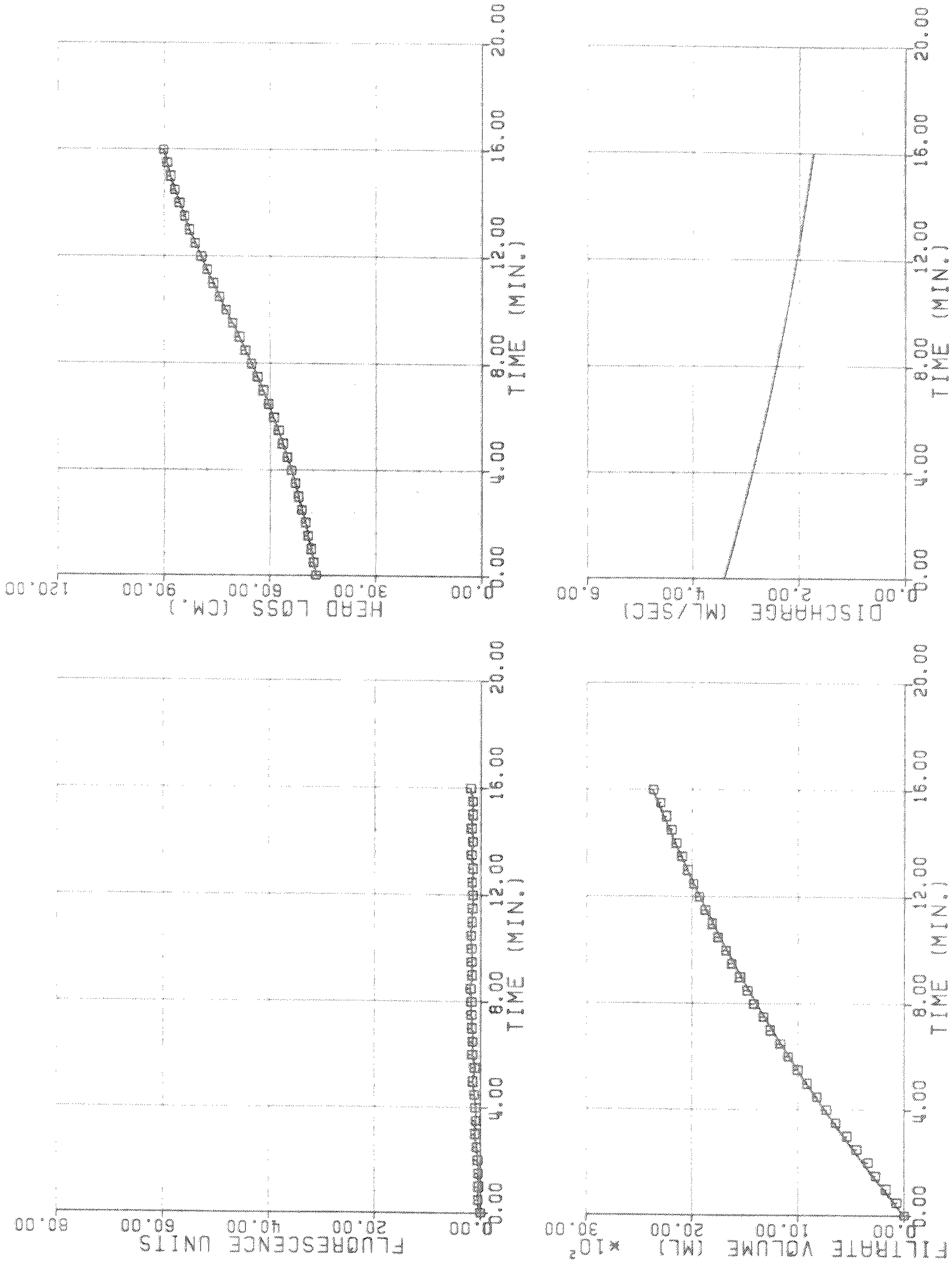
SAND 140/200-1/2 THICK   TEST ID. NO. = 40031

AVERAGE PERCENT REMOVAL = 96.77

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=4858.13281*(1-EXP(-0.00070025*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	46.80
30.00	72.58	0.50	47.60
60.00	172.37	0.40	48.30
90.00	267.62	0.45	49.10
120.00	340.19	0.55	49.90
150.00	449.06	0.80	51.00
180.00	539.78	1.10	51.90
210.00	644.10	0.95	52.90
240.00	734.82	1.00	54.00
270.00	821.00	1.20	55.10
300.00	916.26	1.50	56.40
330.00	1002.44	1.15	57.60
360.00	1093.16	1.60	59.00
390.00	1165.73	1.55	60.50
420.00	1260.99	1.65	62.00
450.00	1324.49	1.80	63.60
480.00	1415.21	1.80	65.30
510.00	1474.18	1.95	67.00
540.00	1542.21	1.65	68.70
570.00	1623.86	1.75	70.60
600.00	1678.29	1.75	72.50
630.00	1755.40	1.85	74.30
660.00	1809.83	1.70	76.00
690.00	1873.34	1.60	77.80
720.00	1932.30	1.55	79.50
750.00	1986.73	1.65	81.20
780.00	2041.17	1.50	82.80
810.00	2095.60	1.75	84.30
840.00	2150.03	1.50	85.70
870.00	2195.39	1.75	87.00
900.00	2245.28	1.55	88.20
930.00	2299.71	1.55	89.20
960.00	2367.75	1.95	90.20



400 31

SAND 140/200-1/2 THICK

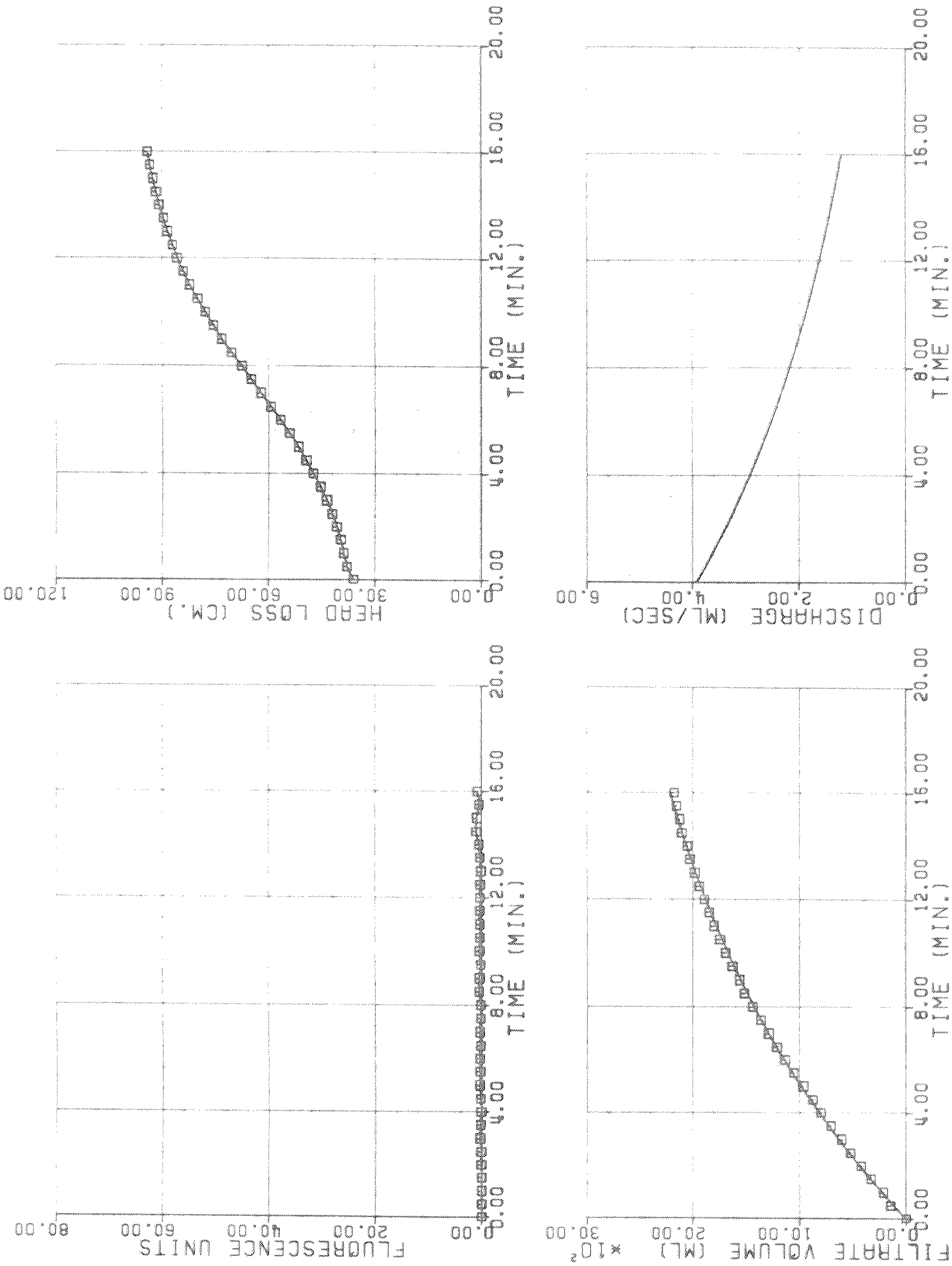
SAND 140/200-1/2 THICK TEST ID. NO. = 30031

AVERAGE PERCENT REMOVAL = 99.68

INITIAL CONCENTRATION=57.90 FLUORESCENCE UNITS

FILTRATE EQ. Y=3208.44556*(1-EXP(-0.00122208*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	36.00
30.00	145.15	0.0	37.80
60.00	213.19	0.0	38.80
90.00	331.12	0.0	39.60
120.00	421.84	0.10	40.70
150.00	521.63	0.05	42.00
180.00	607.81	0.25	43.50
210.00	707.60	0.20	45.30
240.00	798.32	0.05	47.30
270.00	875.43	0.15	49.30
300.00	966.15	0.35	51.50
330.00	1052.33	0.25	54.00
360.00	1133.98	0.35	56.60
390.00	1211.09	0.20	59.30
420.00	1288.20	0.35	62.10
450.00	1360.78	0.20	64.90
480.00	1437.89	0.20	67.50
510.00	1515.00	0.45	70.40
540.00	1560.36	0.40	73.10
570.00	1628.40	0.20	75.50
600.00	1691.90	0.40	77.80
630.00	1741.79	0.35	80.00
660.00	1800.76	0.30	82.10
690.00	1846.12	0.35	84.00
720.00	1891.48	0.35	85.70
750.00	1936.84	0.25	87.00
780.00	1982.20	0.05	88.50
810.00	2027.56	0.30	89.60
840.00	2054.77	0.50	90.80
870.00	2104.67	1.00	91.70
900.00	2122.81	0.85	92.60
930.00	2154.56	0.45	93.50
960.00	2177.24	0.75	94.20



300 31

SAND 140/200-1/2 THICK

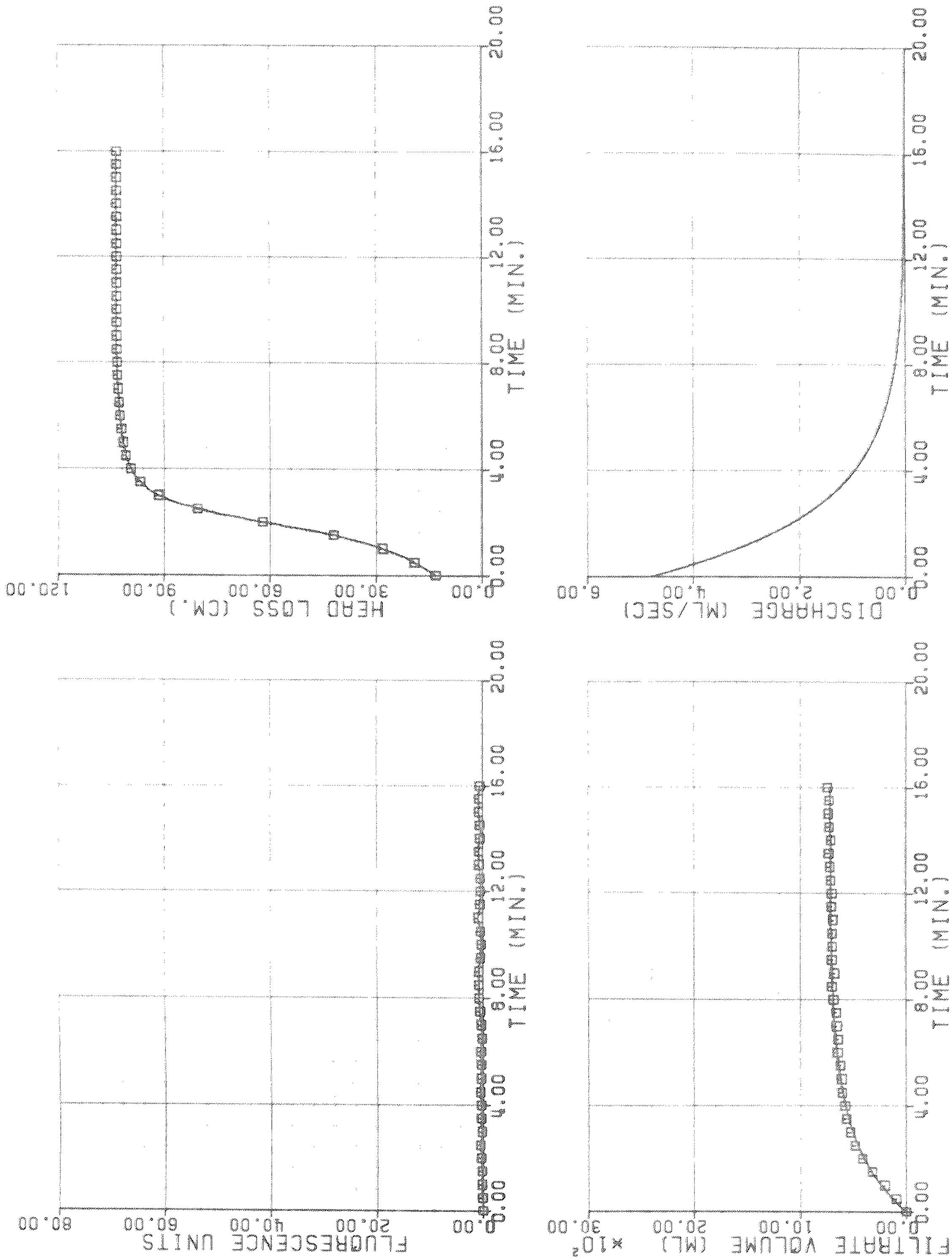
SAND 100/140-1/8 THICK TEST ID. NO. = 20011

AVERAGE PERCENT REMOVAL = 99.80

INITIAL CONCENTRATION=78.25 FLUORESCENCE UNITS

FILTRATE EQ. Y= 721.69360*(1-EXP(-0.00566266*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	13.30
30.00	95.25	0.10	19.30
60.00	204.12	0.20	28.20
90.00	322.05	0.15	42.00
120.00	417.31	0.30	62.10
150.00	485.34	0.45	80.60
180.00	530.70	0.15	91.60
210.00	571.53	0.35	96.80
240.00	580.60	0.30	99.40
270.00	607.81	0.50	100.80
300.00	612.35	0.30	101.50
330.00	621.42	0.35	102.10
360.00	648.64	0.40	102.50
390.00	644.10	0.15	102.70
420.00	657.71	0.30	102.90
450.00	662.25	0.55	103.10
480.00	689.46	0.75	103.20
510.00	703.07	0.75	103.30
540.00	680.39	0.80	103.30
570.00	703.07	0.50	103.30
600.00	698.53	0.35	103.30
630.00	698.53	0.50	103.30
660.00	694.00	0.85	103.30
690.00	707.60	0.55	103.30
720.00	703.07	0.50	103.30
750.00	716.68	0.50	103.30
780.00	721.21	0.70	103.30
810.00	734.82	0.75	103.30
840.00	716.68	0.55	103.30
870.00	730.28	0.55	103.30
900.00	739.36	0.80	103.30
930.00	730.28	0.75	103.30
960.00	743.89	0.55	103.30



200 11

SAND 100/140-1/8 THICK

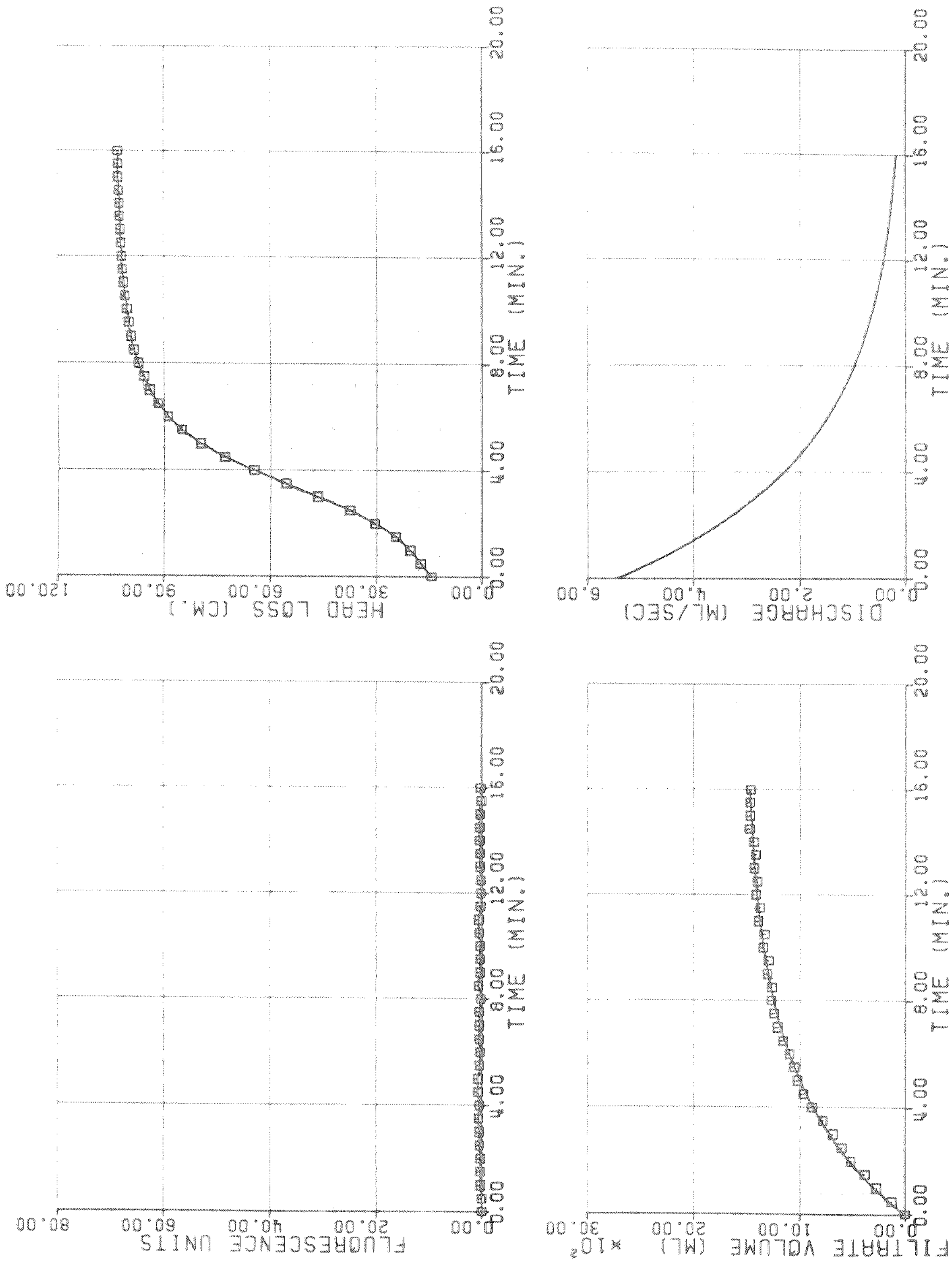
SAND 100/140-1/8 THICK   TEST ID. NO. = 20041

AVERAGE PERCENT REMOVAL = 99.57

INITIAL CONCENTRATION=71.60 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1519.17139*(1-EXP(-0.00359200*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	14.40
30.00	127.01	0.0	17.40
60.00	272.16	0.25	20.40
90.00	381.02	0.25	24.50
120.00	517.10	0.25	30.40
150.00	603.28	0.45	37.50
180.00	689.46	0.45	46.50
210.00	784.72	0.65	55.50
240.00	889.04	0.45	64.50
270.00	970.69	0.70	72.80
300.00	1025.12	0.70	79.60
330.00	1056.87	0.45	84.90
360.00	1102.23	0.30	88.80
390.00	1161.20	0.45	91.60
420.00	1211.09	0.45	94.00
450.00	1247.38	0.45	95.70
480.00	1270.06	0.15	97.20
510.00	1265.52	0.60	98.40
540.00	1306.35	0.35	99.30
570.00	1297.27	0.30	99.80
600.00	1347.17	0.30	100.30
630.00	1333.56	0.50	100.80
660.00	1392.53	0.55	101.30
690.00	1378.92	0.25	101.60
720.00	1415.21	0.20	101.80
750.00	1401.60	0.15	102.00
780.00	1428.82	0.35	102.20
810.00	1415.21	0.30	102.40
840.00	1433.35	0.40	102.50
870.00	1474.18	0.40	102.70
900.00	1469.64	0.35	102.90
930.00	1469.64	0.35	102.90
960.00	1460.57	0.25	103.00



200 41

SAND 100/140-1/8 THICK

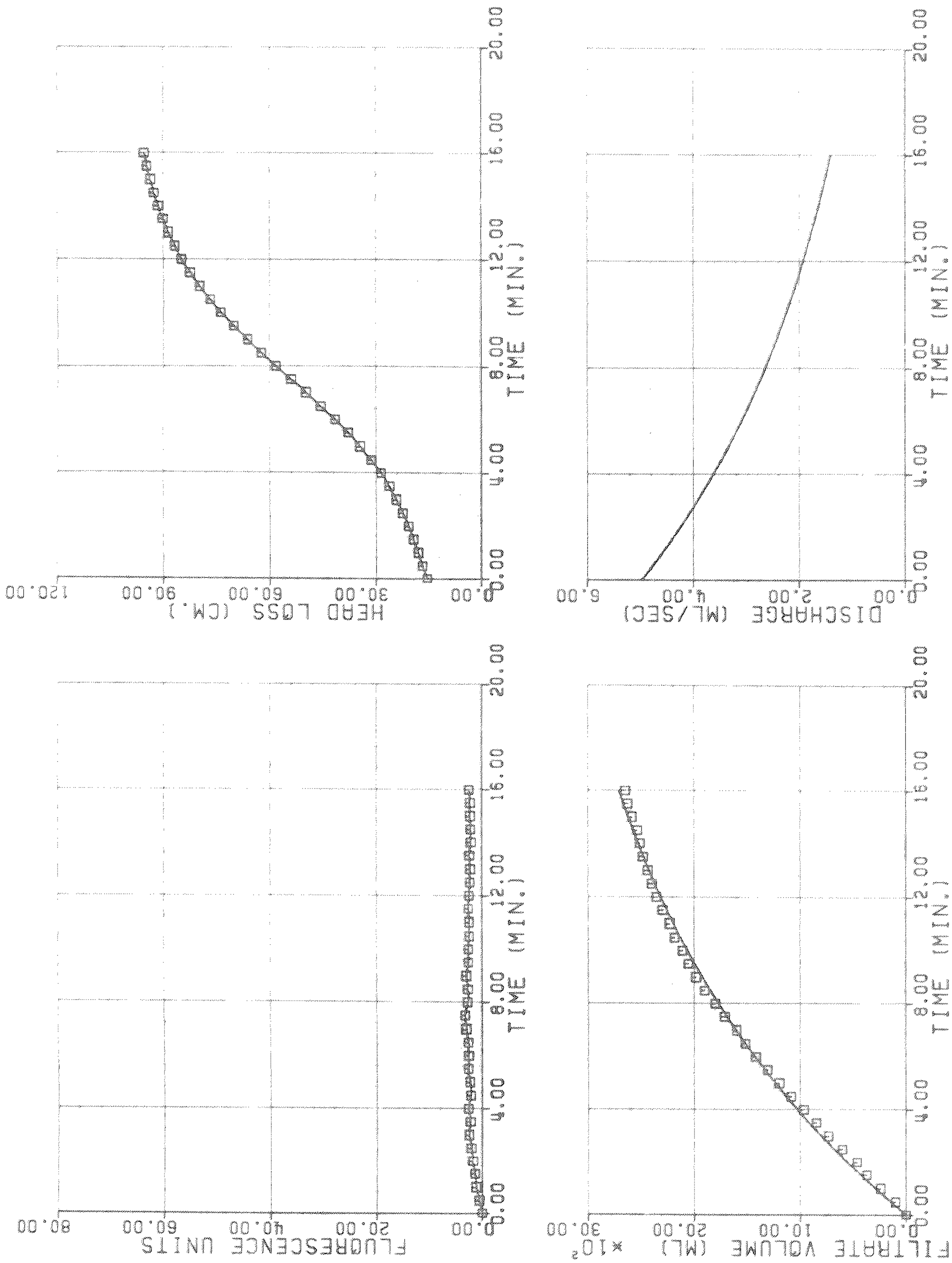
SAND 100/140-1/8 THICK   TEST ID. NO. = 40042

AVERAGE PERCENT REMOVAL = 94.62

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=3774.76562*(1-EXP(-0.00131718*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	15.50
30.00	99.79	0.55	16.80
60.00	240.40	1.15	18.00
90.00	367.41	1.35	19.40
120.00	462.66	1.80	20.80
150.00	598.74	2.05	22.40
180.00	730.28	2.45	24.20
210.00	848.22	2.25	26.20
240.00	966.15	2.60	28.60
270.00	1084.09	2.20	31.40
300.00	1197.48	2.30	34.50
330.00	1306.35	2.65	37.90
360.00	1419.74	2.55	41.50
390.00	1515.00	2.60	45.60
420.00	1601.18	3.00	49.70
450.00	1710.04	3.25	53.90
480.00	1800.76	2.75	58.20
510.00	1900.55	2.70	62.30
540.00	1982.20	3.00	66.30
570.00	2054.77	2.60	70.10
600.00	2109.20	2.65	73.80
630.00	2186.31	2.45	76.90
660.00	2227.14	2.45	79.90
690.00	2295.18	2.65	82.50
720.00	2354.14	2.45	84.90
750.00	2394.97	2.35	86.80
780.00	2435.79	2.25	88.60
810.00	2461.15	2.40	90.10
840.00	2512.90	2.10	91.50
870.00	2535.58	2.20	92.70
900.00	2585.48	2.25	93.60
930.00	2626.30	2.25	94.60
960.00	2648.98	2.45	95.40



400 42

SAND 100/140-1/8 THICK

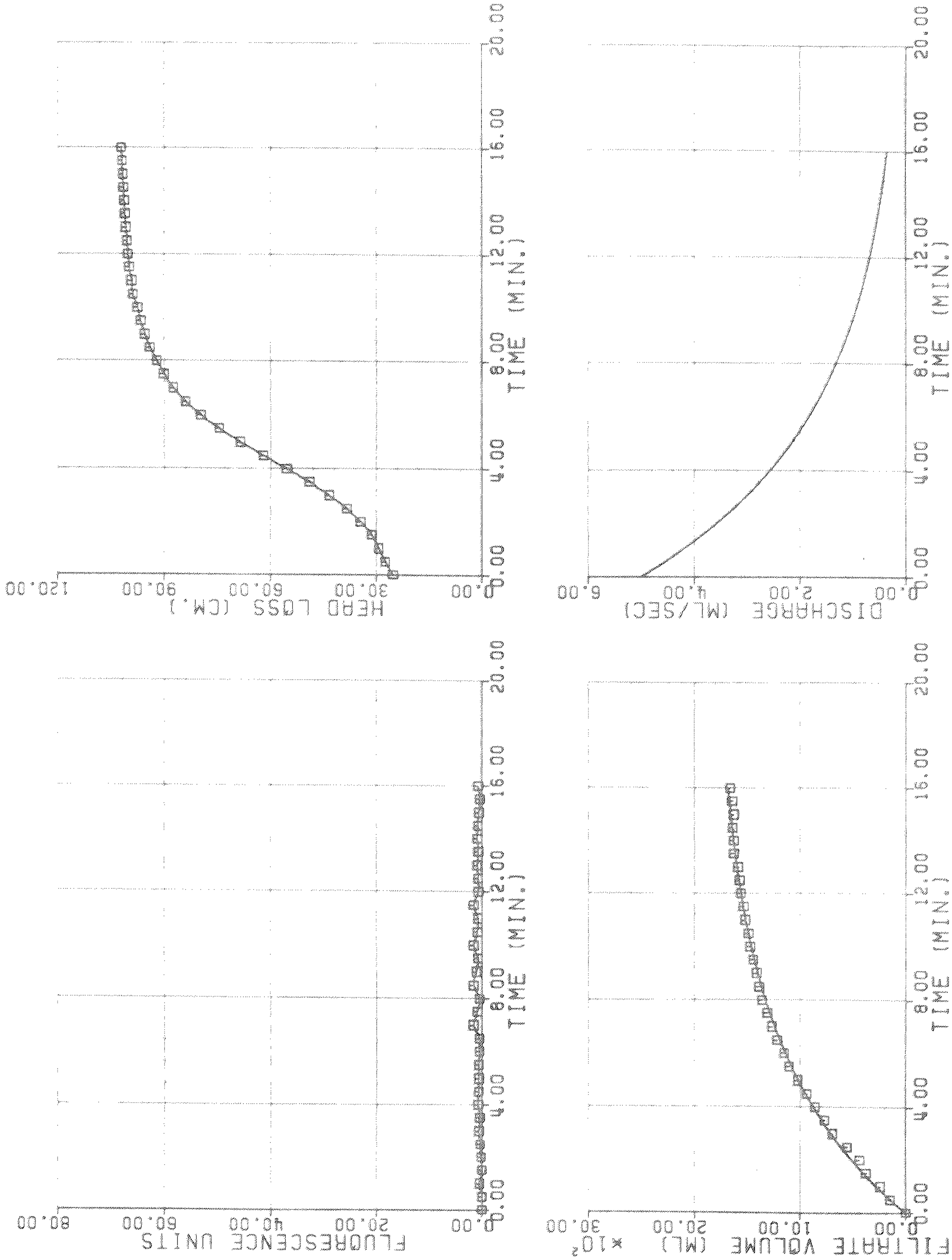
SAND 100/140-1/4 THICK   TEST ID. NO. = 30061

AVERAGE PERCENT REMOVAL = 99.54

INITIAL CONCENTRATION=79.25 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1806.50952*(1-EXP(-0.00276794*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	25.30
30.00	145.15	0.0	27.40
60.00	240.40	0.50	29.30
90.00	371.95	0.0	31.40
120.00	435.45	0.20	34.50
150.00	553.38	0.30	38.40
180.00	694.00	0.55	43.40
210.00	771.11	0.40	49.00
240.00	861.83	0.70	55.50
270.00	938.94	0.60	62.10
300.00	1025.12	0.55	68.50
330.00	1106.77	0.65	74.50
360.00	1152.12	0.45	79.70
390.00	1220.16	0.45	84.00
420.00	1270.06	1.60	87.40
450.00	1310.88	0.85	90.10
480.00	1360.78	0.50	92.10
510.00	1387.99	1.60	94.00
540.00	1410.67	1.10	95.40
570.00	1446.96	0.75	96.60
600.00	1474.18	1.60	97.50
630.00	1487.78	0.85	98.80
660.00	1519.53	0.75	99.10
690.00	1533.14	1.60	99.80
720.00	1560.36	0.70	100.10
750.00	1573.97	0.80	100.40
780.00	1587.57	0.90	100.70
810.00	1628.40	0.70	101.00
840.00	1628.40	0.85	101.20
870.00	1637.47	0.80	101.40
900.00	1628.40	0.55	101.60
930.00	1642.00	0.40	101.80
960.00	1660.15	0.70	102.00



300 61

SAND 100/140-1/4 THICK

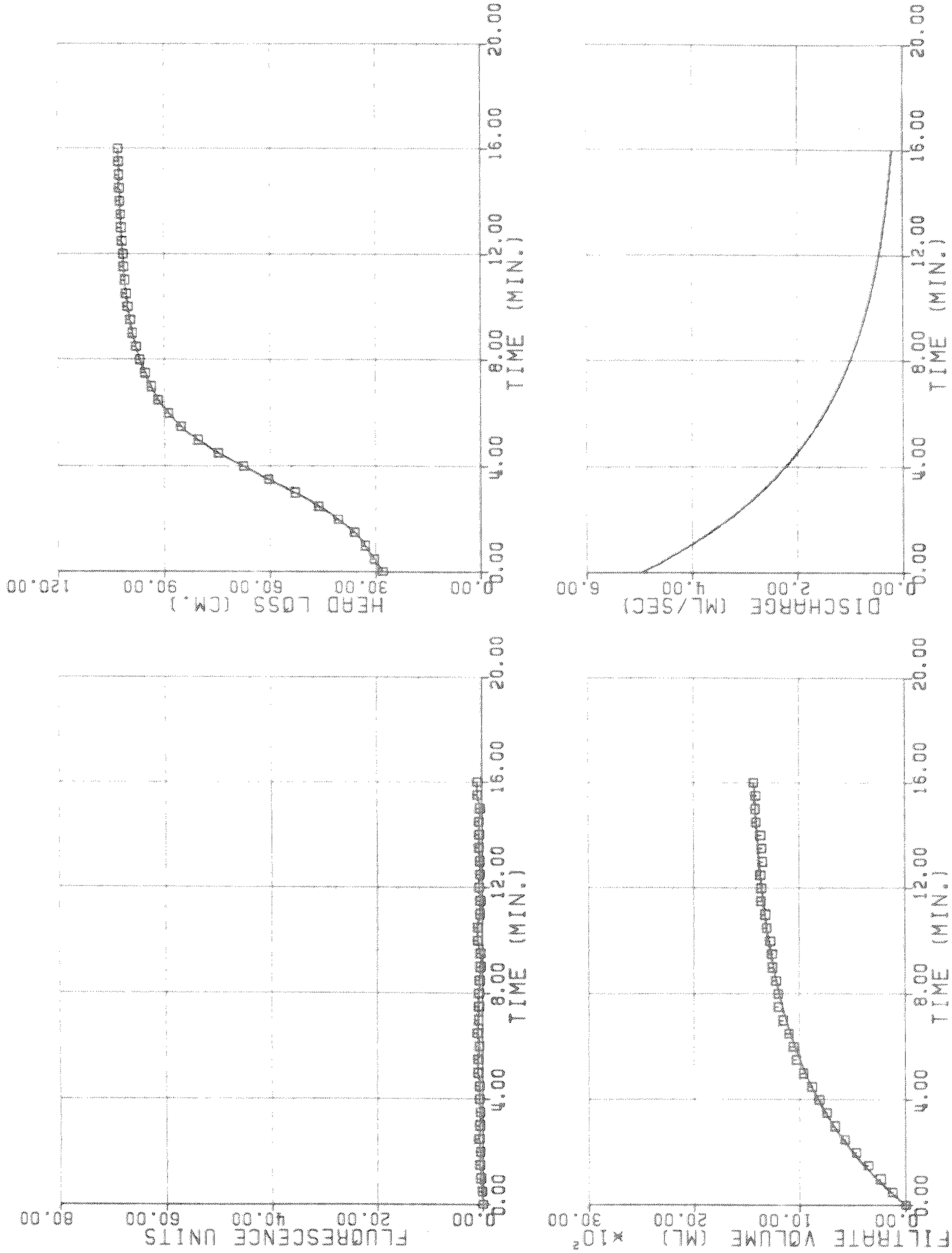
SAND 100/140-1/4 THICK   TEST ID. NO. = 20042

AVERAGE PERCENT REMOVAL = 99.37

INITIAL CONCENTRATION=71.60 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1489.83252*(1-EXP(-0.00333802*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	28.00
30.00	122.47	0.15	30.50
60.00	235.87	0.40	33.00
90.00	344.73	0.55	36.00
120.00	462.66	0.50	40.60
150.00	571.53	0.70	46.10
180.00	662.25	0.55	52.90
210.00	739.36	0.50	60.40
240.00	811.93	0.60	67.60
270.00	879.97	0.60	74.80
300.00	961.62	0.90	80.50
330.00	1029.66	0.90	85.40
360.00	1056.37	0.65	88.80
390.00	1102.23	1.00	91.80
420.00	1152.12	0.80	93.70
450.00	1202.02	0.70	95.40
480.00	1202.02	0.70	96.90
510.00	1220.16	0.55	98.00
540.00	1251.92	0.40	99.00
570.00	1256.45	0.40	99.60
600.00	1274.59	0.95	100.30
630.00	1306.35	0.90	100.70
660.00	1319.95	0.50	101.10
690.00	1360.78	0.40	101.40
720.00	1356.24	0.60	101.60
750.00	1365.31	0.45	101.90
780.00	1347.17	0.50	102.10
810.00	1351.71	0.60	102.30
840.00	1365.31	0.55	102.50
870.00	1406.14	0.60	102.60
900.00	1415.21	0.40	102.70
930.00	1410.67	0.90	102.80
960.00	1428.82	0.95	102.90



200 42

SAND 100/140-1/4 THICK

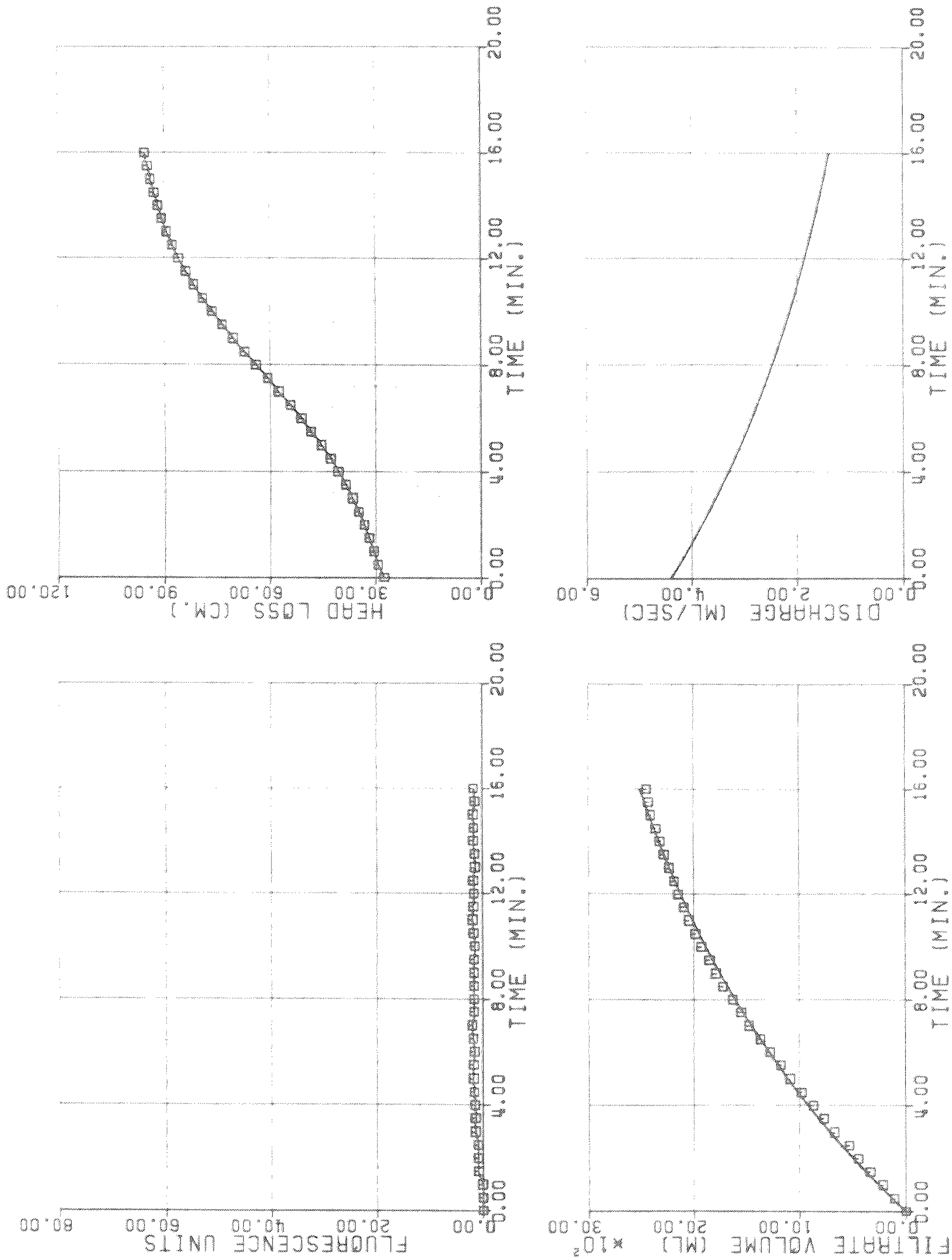
SAND 100/140-1/4 THICK   TEST ID. NO. = 40051

AVERAGE PERCENT REMOVAL = 96.70

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=3665.11060*(1-EXP(-0.00120099*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	27.60
30.00	108.86	0.0	29.30
60.00	213.19	0.05	30.50
90.00	335.66	0.85	31.90
120.00	444.52	0.90	33.20
150.00	530.70	0.95	34.90
180.00	671.32	1.45	36.60
210.00	771.11	1.45	38.50
240.00	870.90	1.50	40.70
270.00	979.76	1.70	42.80
300.00	1088.62	1.80	45.50
330.00	1174.80	1.80	48.40
360.00	1279.13	1.60	51.10
390.00	1369.85	1.85	54.30
420.00	1478.71	2.00	57.60
450.00	1551.29	1.65	60.70
480.00	1632.93	1.70	64.00
510.00	1723.65	1.70	67.30
540.00	1787.15	1.70	70.50
570.00	1850.66	1.65	73.60
600.00	1927.77	1.50	76.50
630.00	1982.20	1.75	79.20
660.00	2045.70	1.95	81.70
690.00	2091.06	1.80	83.90
720.00	2145.49	1.65	86.00
750.00	2186.31	1.75	87.70
780.00	2231.67	1.45	89.30
810.00	2281.57	1.55	90.70
840.00	2317.86	1.75	91.80
870.00	2358.68	1.65	92.90
900.00	2408.57	1.80	93.90
930.00	2426.72	1.45	94.70
960.00	2444.86	1.70	95.50



400 51

SAND 100/140-1/4 THICK

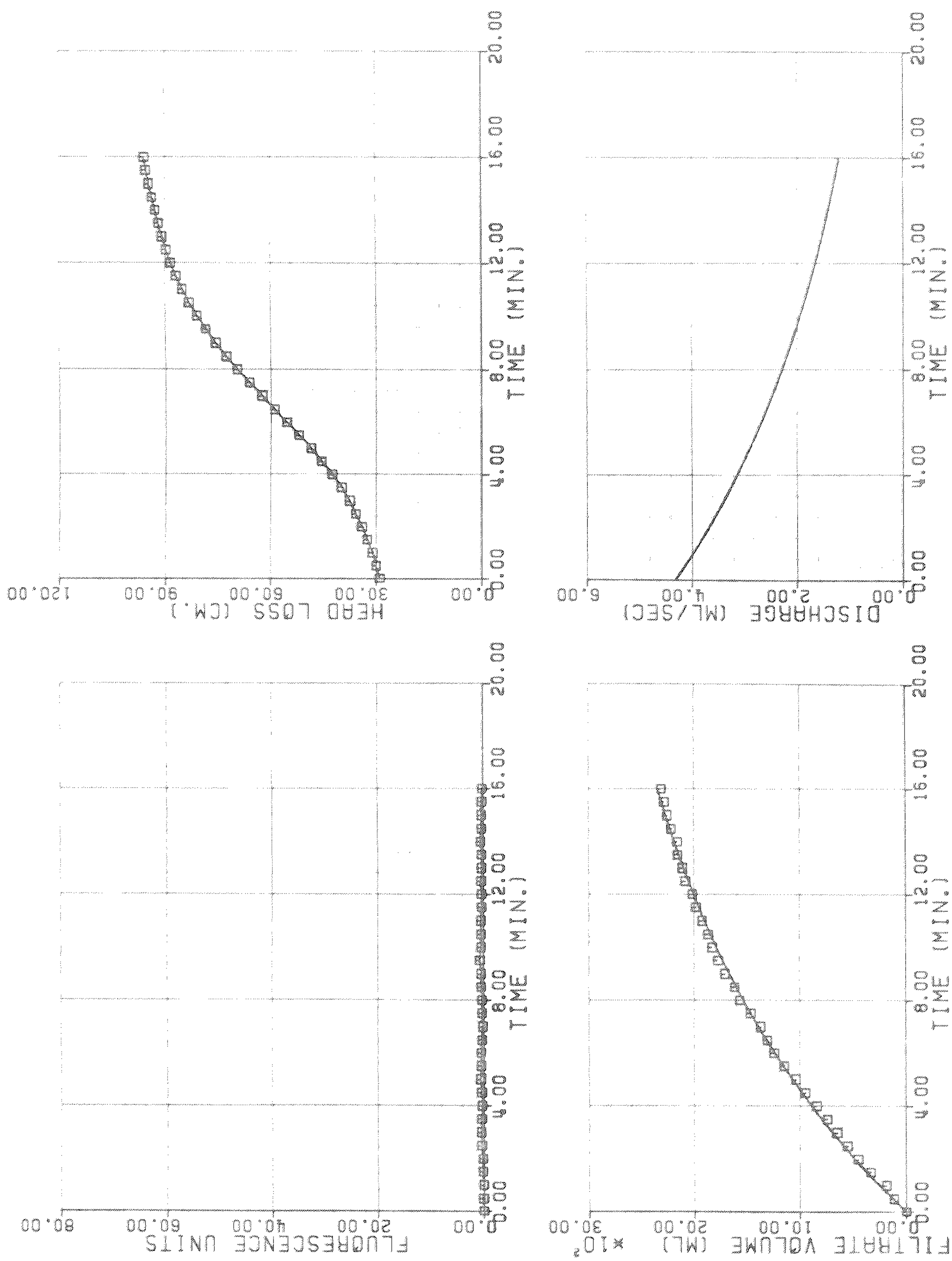
SAND 100/140-3/8 THICK   TEST ID. NO. = 30021

AVERAGE PERCENT REMOVAL = 99.44

INITIAL CONCENTRATION=57.90 FLUORESCENCE UNITS

FILTRATE EQ.   Y=3251.10620*(1-EXP(-0.00132887*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	29.00
30.00	113.40	0.10	30.00
60.00	185.97	0.0	31.00
90.00	331.12	0.20	32.50
120.00	449.06	0.20	34.00
150.00	548.85	0.40	35.80
180.00	648.64	0.45	37.50
210.00	739.36	0.40	39.80
240.00	843.68	0.30	42.50
270.00	948.01	0.40	45.40
300.00	1038.73	0.55	48.40
330.00	1147.59	0.45	51.90
360.00	1242.84	0.50	55.40
390.00	1306.35	0.35	58.90
420.00	1369.85	0.20	62.40
450.00	1465.10	0.30	66.00
480.00	1569.43	0.35	69.40
510.00	1614.79	0.45	72.60
540.00	1705.51	0.45	75.60
570.00	1773.55	0.70	78.40
600.00	1827.98	0.50	81.00
630.00	1864.26	0.45	83.20
660.00	1923.23	0.50	85.10
690.00	1982.20	0.35	86.90
720.00	2013.95	0.35	88.40
750.00	2081.99	0.40	89.70
780.00	2109.20	0.30	90.80
810.00	2154.56	0.30	91.90
840.00	2159.10	0.45	92.80
870.00	2213.53	0.35	93.70
900.00	2254.35	0.35	94.60
930.00	2281.57	0.25	95.40
960.00	2308.78	0.15	95.90



300 21

SAND 100/140-3/8 THICK

SAND 100/140-3/8 THICK   TEST ID. NO. = 10042

AVERAGE PERCENT REMOVAL = 99.51

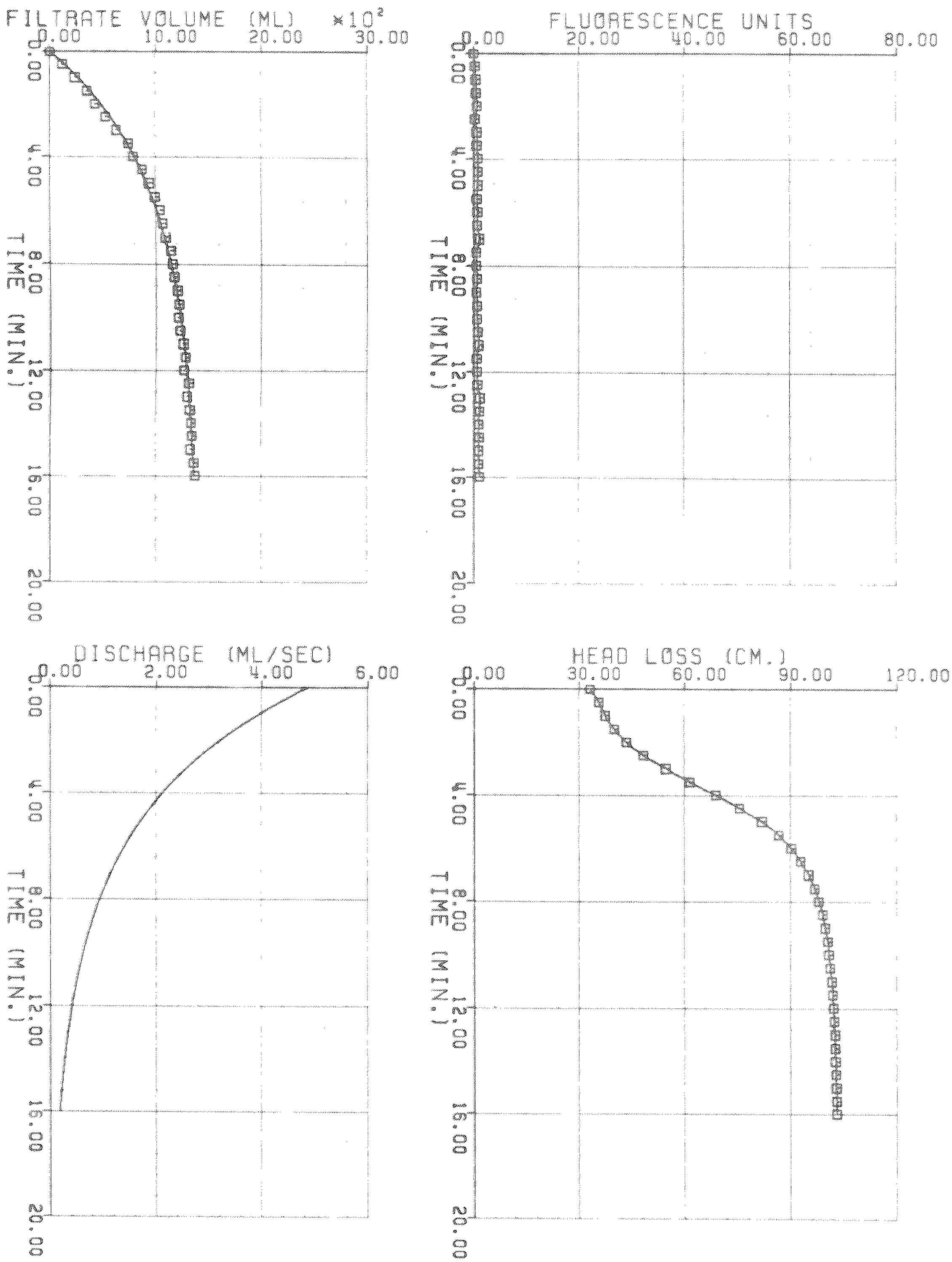
INITIAL CONCENTRATION=86.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1408.11792*(1-EXP(-0.00344846*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	33.00
30.00	117.93	0.25	35.60
60.00	235.87	0.40	37.40
90.00	344.73	0.40	39.90
120.00	421.84	0.60	43.40
150.00	521.63	0.25	48.30
180.00	621.42	0.55	54.60
210.00	739.36	0.55	61.40
240.00	784.71	0.80	68.80
270.00	870.90	0.75	75.50
300.00	934.40	0.75	81.80
330.00	988.33	0.55	86.60
360.00	1038.73	0.70	90.10
390.00	1061.41	0.60	92.80
420.00	1088.62	1.05	95.00
450.00	1138.52	0.45	96.70
480.00	1152.12	0.45	97.90
510.00	1170.27	0.60	99.00
540.00	1202.02	0.45	99.70
570.00	1215.63	0.60	100.40
600.00	1206.56	0.65	100.70
630.00	1224.70	0.80	101.10
660.00	1256.45	0.90	101.50
690.00	1279.13	0.55	101.80
720.00	1260.99	0.65	102.00
750.00	1310.88	0.70	102.20
780.00	1292.74	1.15	102.40
810.00	1319.95	1.05	102.50
840.00	1329.03	0.90	102.60
870.00	1338.10	1.00	102.70
900.00	1324.49	0.95	102.80
930.00	1356.24	0.80	102.90
960.00	1369.85	1.10	102.90

SAND 100/140-3/8 THICK

100 42



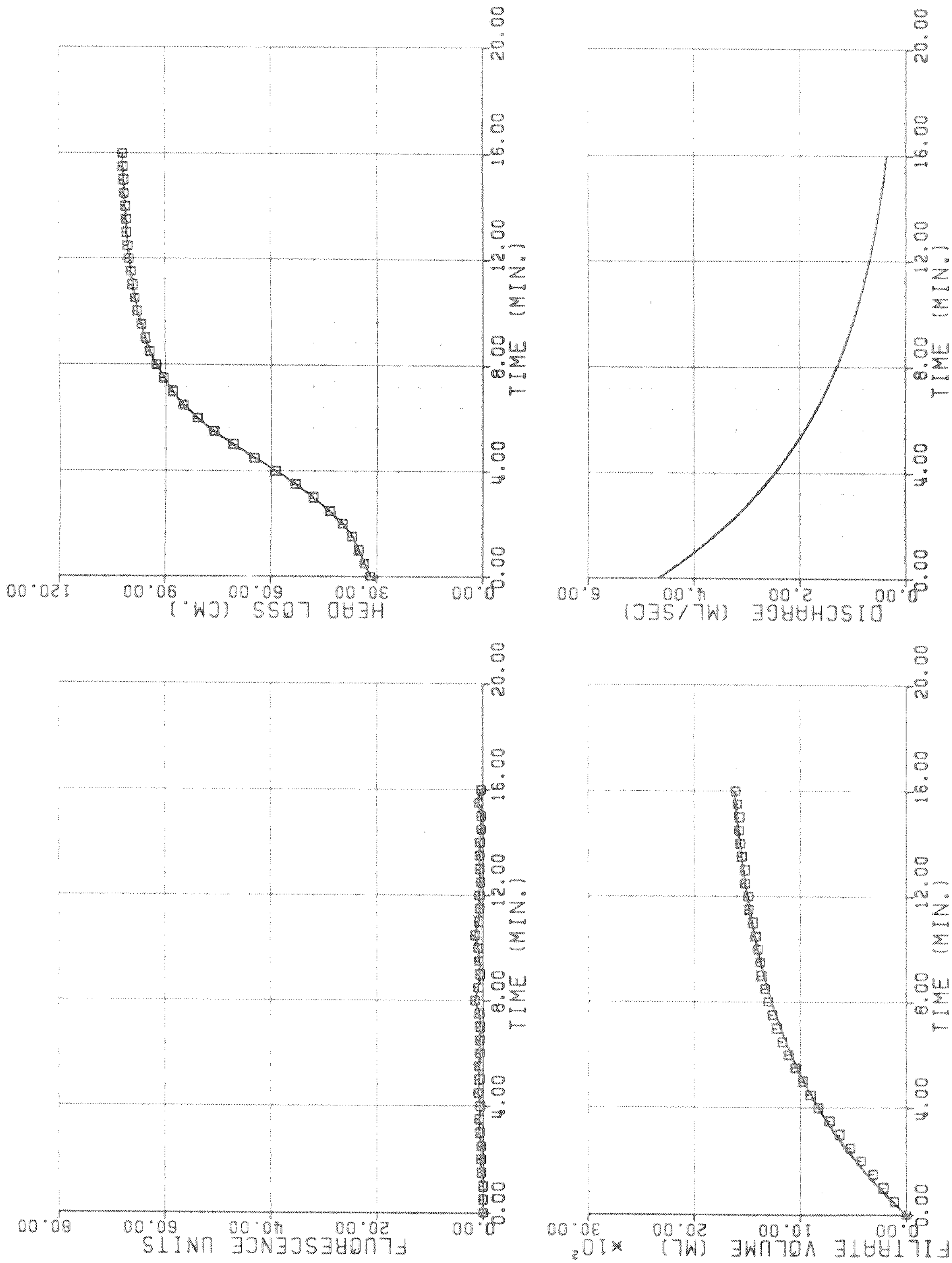
SAND 100/140-1/2 THICK   TEST ID. NO. = 30062

AVERAGE PERCENT REMOVAL = 99.49

INITIAL CONCENTRATION=79.25 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1757.53662*(1-EXP(-0.00265384*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	31.80
30.00	113.40	0.0	33.50
60.00	217.72	0.0	35.10
90.00	317.52	0.35	37.00
120.00	430.91	0.40	39.70
150.00	530.70	0.35	43.30
180.00	630.49	0.65	48.00
210.00	725.75	0.75	53.00
240.00	830.07	0.55	58.70
270.00	902.65	0.95	64.70
300.00	975.22	0.70	70.70
330.00	1047.80	0.75	76.10
360.00	1106.77	0.60	80.90
390.00	1170.27	0.65	84.90
420.00	1220.16	0.55	87.90
450.00	1260.99	0.70	90.50
480.00	1301.81	1.55	92.60
510.00	1329.03	0.35	94.40
540.00	1365.31	0.55	95.60
570.00	1378.92	0.75	96.70
600.00	1401.60	0.90	97.80
630.00	1419.74	1.55	98.50
660.00	1446.96	0.80	99.10
690.00	1483.25	0.65	99.60
720.00	1487.78	0.70	100.10
750.00	1519.53	0.50	100.50
780.00	1519.53	0.65	100.80
810.00	1551.29	0.60	101.00
840.00	1564.89	0.55	101.20
870.00	1578.50	0.35	101.50
900.00	1573.97	0.35	101.70
930.00	1592.11	0.75	101.90
960.00	1605.72	0.30	102.00



300 62

SAND 100/140-1/2 THICK

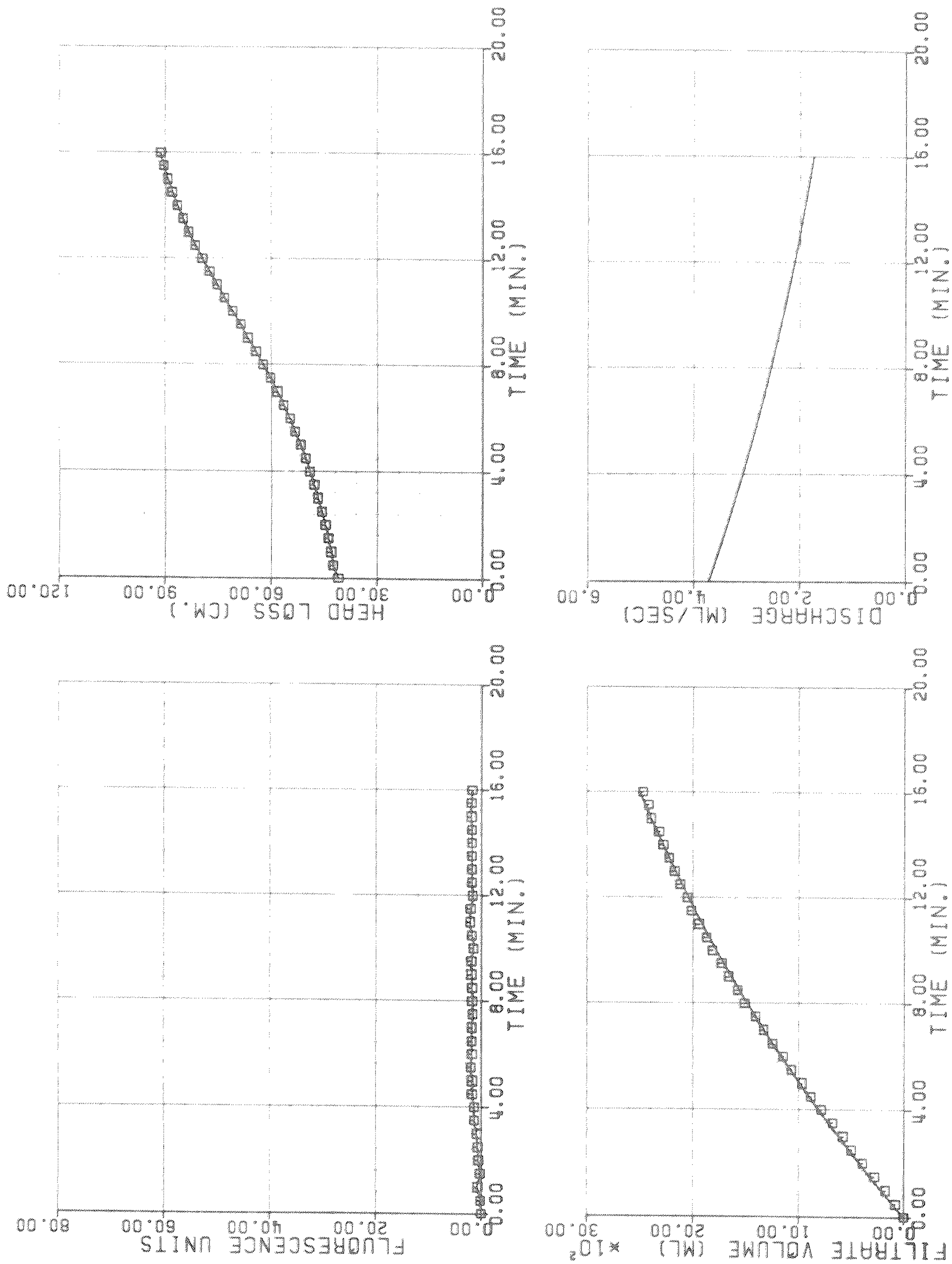
SAND 100/140-1/2 THICK TEST ID. NO. = 40052

AVERAGE PERCENT REMOVAL = 96.45

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ. Y=4712.31250*(1-EXP(-0.00078836*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	41.00
30.00	81.65	0.20	42.40
60.00	176.90	0.70	43.00
90.00	281.23	0.25	43.90
120.00	390.09	0.55	44.70
150.00	498.95	0.70	45.70
180.00	580.60	0.85	46.80
210.00	675.85	1.40	47.90
240.00	784.72	1.35	49.10
270.00	884.51	1.75	50.30
300.00	970.69	1.75	51.70
330.00	1070.48	2.00	53.30
360.00	1147.59	1.80	54.70
390.00	1247.38	1.85	56.50
420.00	1329.03	1.85	58.30
450.00	1406.14	1.65	60.30
480.00	1510.46	1.75	62.30
510.00	1578.50	1.80	64.30
540.00	1660.15	1.90	66.60
570.00	1728.19	1.90	68.60
600.00	1814.37	1.55	70.90
630.00	1868.80	1.85	73.20
660.00	1941.37	2.20	75.30
690.00	2013.95	2.05	77.40
720.00	2054.77	1.65	79.50
750.00	2118.28	1.85	81.40
780.00	2172.71	1.85	83.30
810.00	2222.60	1.85	84.90
840.00	2281.57	1.85	86.50
870.00	2317.86	1.85	88.00
900.00	2390.43	1.95	89.30
930.00	2413.11	1.90	90.40
960.00	2467.54	1.75	91.40



400 52

SAND 100/140-1/2 THICK

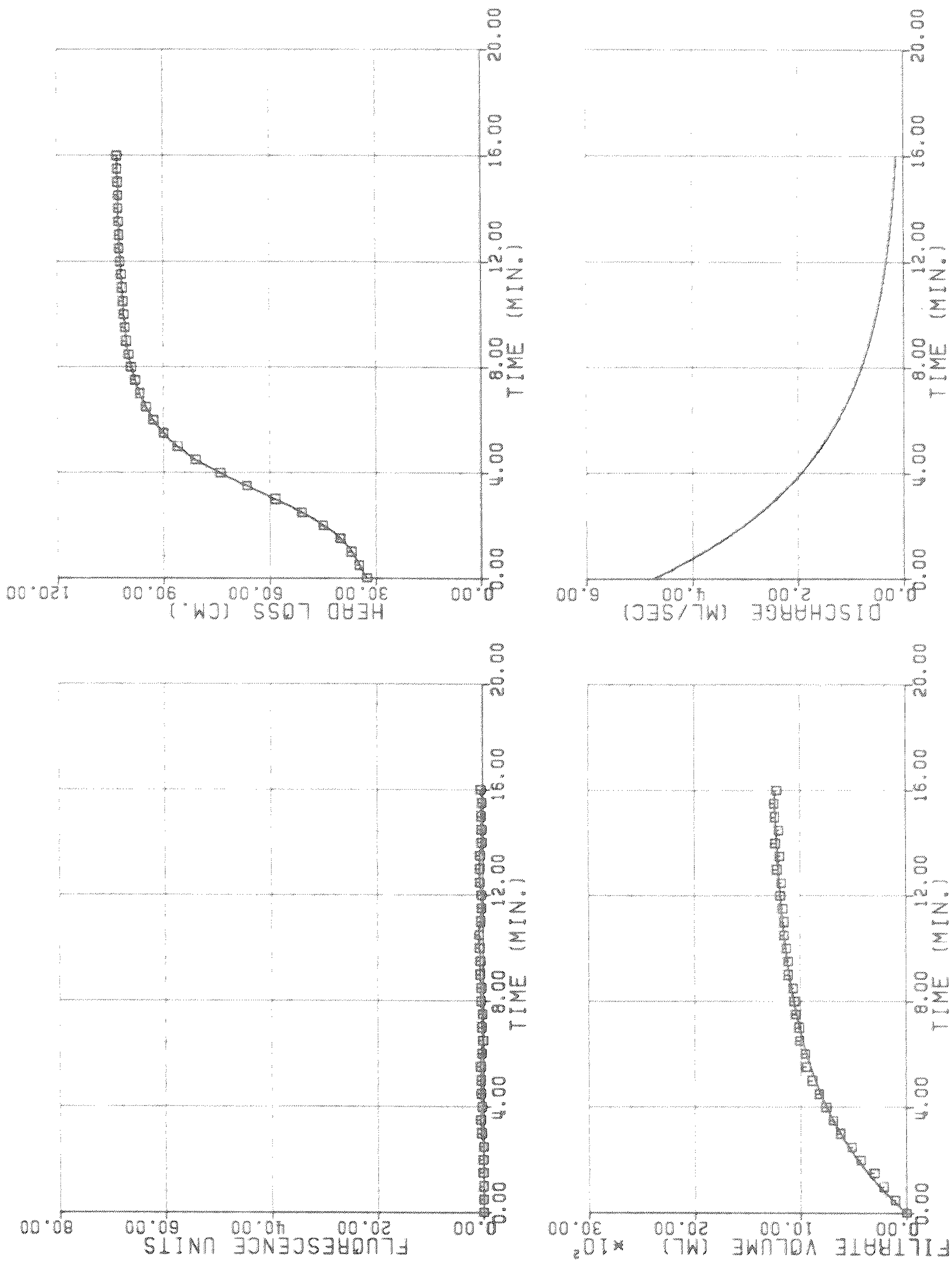
SAND 100/140-1/2 THICK   TEST ID. NO. = 10052

AVERAGE PERCENT REMOVAL = 99.83

INITIAL CONCENTRATION=86.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=1277.87451*(1-EXP(-0.0037102 0*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	32.70
30.00	108.86	0.0	34.90
60.00	213.19	0.0	37.00
90.00	303.91	0.05	40.20
120.00	430.91	0.05	45.00
150.00	517.10	0.0	51.00
180.00	621.42	0.40	58.50
210.00	694.00	0.55	66.50
240.00	757.50	0.35	74.00
270.00	821.00	0.45	80.90
300.00	889.04	0.45	86.00
330.00	948.01	0.55	90.00
360.00	952.54	0.35	92.90
390.00	1006.98	0.10	95.00
420.00	1011.51	0.30	96.70
450.00	1047.80	0.15	98.00
480.00	1056.87	0.50	99.10
510.00	1070.48	0.40	99.80
540.00	1115.84	0.60	100.50
570.00	1115.84	0.55	100.80
600.00	1129.45	0.70	101.20
630.00	1152.12	0.80	101.40
660.00	1152.12	0.50	101.70
690.00	1165.73	0.35	101.90
720.00	1188.41	0.35	102.20
750.00	1174.80	0.60	102.40
780.00	1220.16	0.60	102.50
810.00	1192.95	0.55	102.60
840.00	1233.77	0.25	102.70
870.00	1202.02	0.25	102.70
900.00	1238.31	0.35	102.80
930.00	1247.38	0.20	102.90
960.00	1220.16	0.40	103.00



100 52

SAND 100/140-1/2 THICK

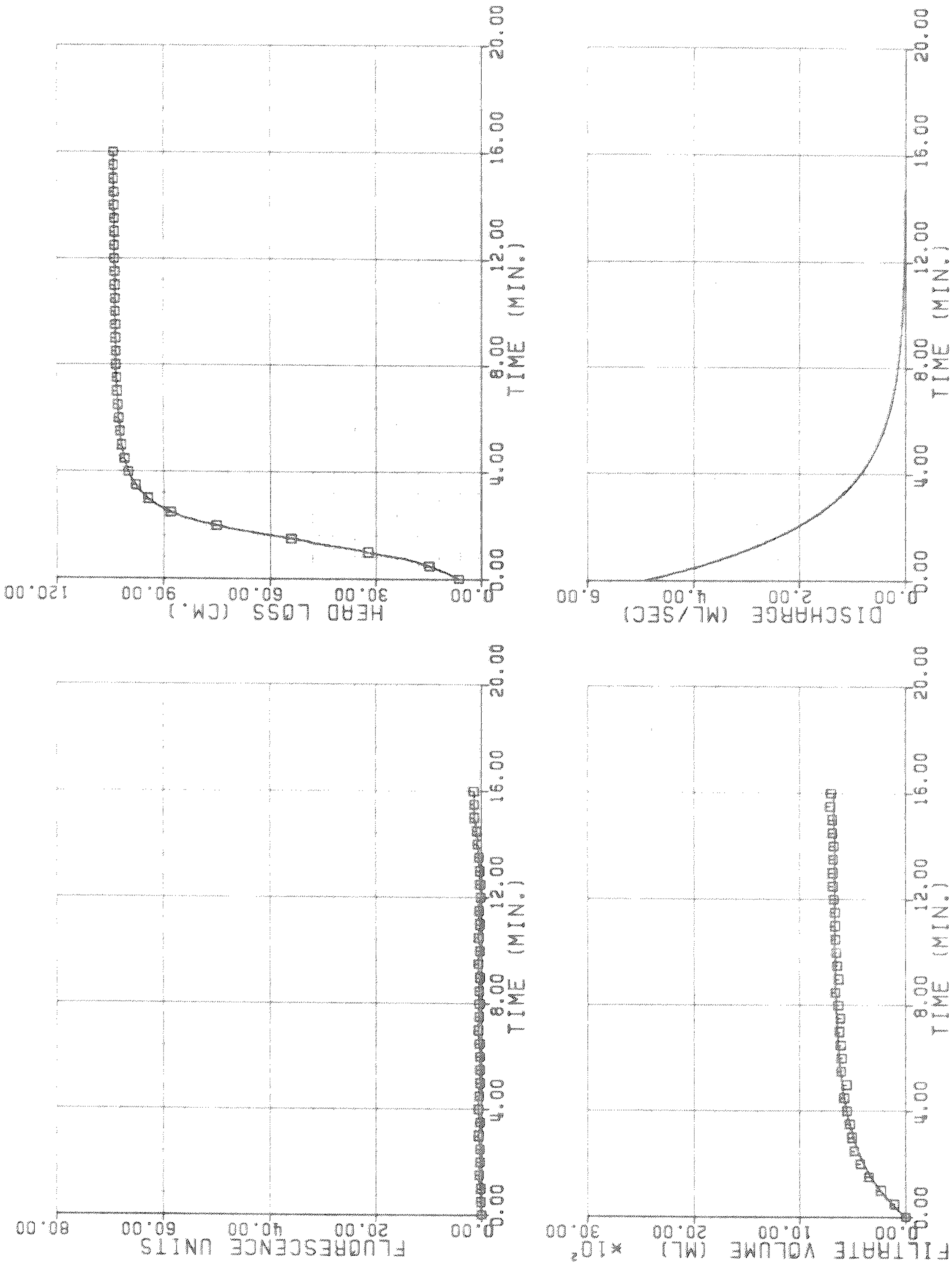
SAND 60/100-1/8 THICK   TEST ID. NO. = 20021

AVERAGE PERCENT REMOVAL = 99.74

INITIAL CONCENTRATION=78.25 FLUORESCENCE UNITS

FILTRATE EQ.   Y= 674.13232*(1-EXP(-0.00733324*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	6.50
30.00	108.86	0.20	14.90
60.00	235.87	0.20	32.20
90.00	344.73	0.45	54.10
120.00	430.91	0.30	75.10
150.00	485.34	0.35	88.00
180.00	508.02	0.55	94.40
210.00	526.17	0.30	97.90
240.00	553.38	0.65	99.90
270.00	580.60	0.50	101.00
300.00	557.92	0.30	101.80
330.00	607.81	0.35	102.20
360.00	603.28	0.30	102.60
390.00	612.35	0.40	102.80
420.00	621.42	0.60	103.00
450.00	616.89	0.45	103.20
480.00	635.03	0.40	103.40
510.00	662.25	0.50	103.40
540.00	630.49	0.30	103.50
570.00	644.10	0.65	103.50
600.00	653.17	0.30	103.60
630.00	662.25	0.55	103.60
660.00	666.78	0.30	103.70
690.00	666.78	0.50	103.70
720.00	675.85	0.15	103.80
750.00	689.46	0.25	103.80
780.00	689.46	0.30	103.90
810.00	684.92	0.45	103.90
840.00	680.39	0.75	104.00
870.00	694.00	0.95	104.00
900.00	694.00	1.35	104.10
930.00	712.14	1.40	104.10
960.00	703.07	1.45	104.10



200 21

SAND 60/100-1/8 THICK

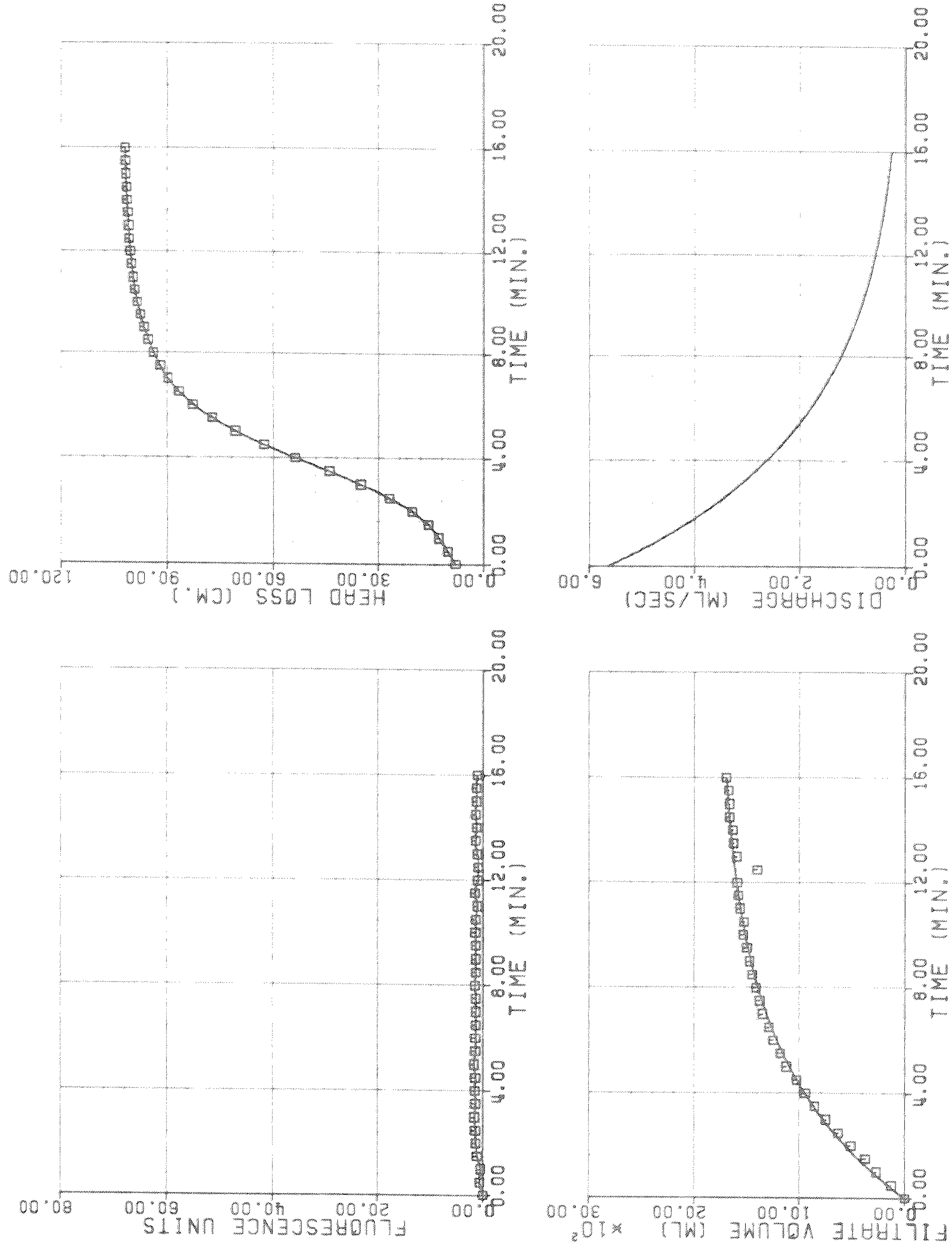
SAND 60/100-1/8 THICK TEST ID. NO. = 30072

AVERAGE PERCENT REMOVAL = 98.65

INITIAL CONCENTRATION=79.25 FLUORESCENCE UNITS

FILTRATE EQ. Y=1773.79834*(1-EXP(-0.00318375*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	8.00
30.00	127.01	0.65	10.20
60.00	267.62	0.50	12.70
90.00	371.95	1.15	15.70
120.00	512.56	1.35	20.30
150.00	630.49	1.45	26.80
180.00	748.43	1.60	35.00
210.00	852.75	1.45	44.00
240.00	943.47	1.50	53.80
270.00	1025.12	1.45	62.70
300.00	1120.37	1.70	70.70
330.00	1174.80	1.45	77.30
360.00	1247.38	1.45	82.70
390.00	1283.67	1.35	86.70
420.00	1347.17	1.35	89.80
450.00	1374.38	1.40	92.00
480.00	1406.14	1.50	93.90
510.00	1446.96	1.35	95.40
540.00	1469.64	1.35	96.60
570.00	1496.85	1.35	97.60
600.00	1528.61	1.45	98.50
630.00	1524.07	1.40	99.20
660.00	1560.36	1.10	99.70
690.00	1578.50	1.50	100.10
720.00	1587.57	1.00	100.50
750.00	1397.06	0.90	100.80
780.00	1592.11	1.05	101.00
810.00	1623.86	1.40	101.20
840.00	1632.93	1.20	101.40
870.00	1660.15	1.40	101.60
900.00	1660.15	1.25	101.80
930.00	1669.22	1.25	101.90
960.00	1691.90	1.05	102.00



300 72

SAND 60/100-1/8 THICK

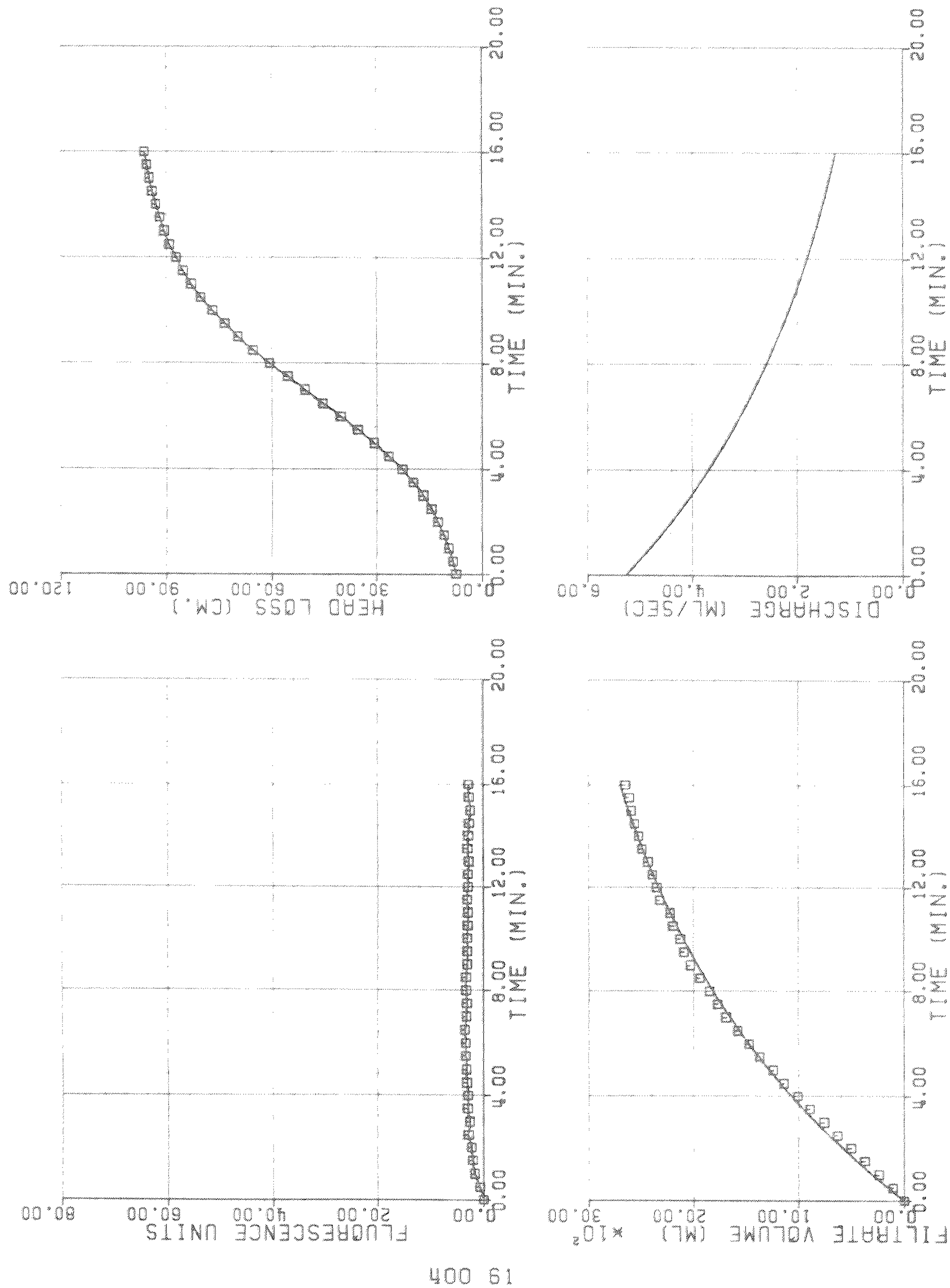
SAND 60/100-1/8 THICK TEST ID. NO. = 40061

AVERAGE PERCENT REMOVAL = 93.42

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ. Y=3553.00781*(1-EXP(-0.00148442*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	7.50
30.00	108.86	0.70	8.30
60.00	240.40	1.70	9.50
90.00	371.95	2.05	10.90
120.00	503.49	2.35	12.60
150.00	630.49	2.85	14.40
180.00	757.50	2.60	16.70
210.00	893.58	3.00	19.60
240.00	1006.97	2.90	22.70
270.00	1138.52	3.15	26.50
300.00	1238.31	3.20	30.70
330.00	1369.85	3.35	35.40
360.00	1469.64	3.40	40.30
390.00	1578.50	3.50	45.40
420.00	1687.36	3.25	50.50
450.00	1769.01	3.15	55.50
480.00	1846.12	3.30	60.70
510.00	1936.84	3.30	65.40
540.00	2032.09	3.10	69.70
570.00	2091.06	3.10	73.50
600.00	2127.35	3.10	77.00
630.00	2195.39	3.00	80.30
660.00	2222.60	2.90	83.00
690.00	2322.39	3.10	85.30
720.00	2349.61	2.95	87.30
750.00	2390.43	2.90	89.20
780.00	2435.79	2.80	90.60
810.00	2490.22	3.00	91.90
840.00	2521.97	2.85	93.00
870.00	2562.80	2.70	94.00
900.00	2594.55	2.45	94.90
930.00	2612.69	2.70	95.50
960.00	2648.98	2.75	96.30



SAND 60/100-1/8 THICK

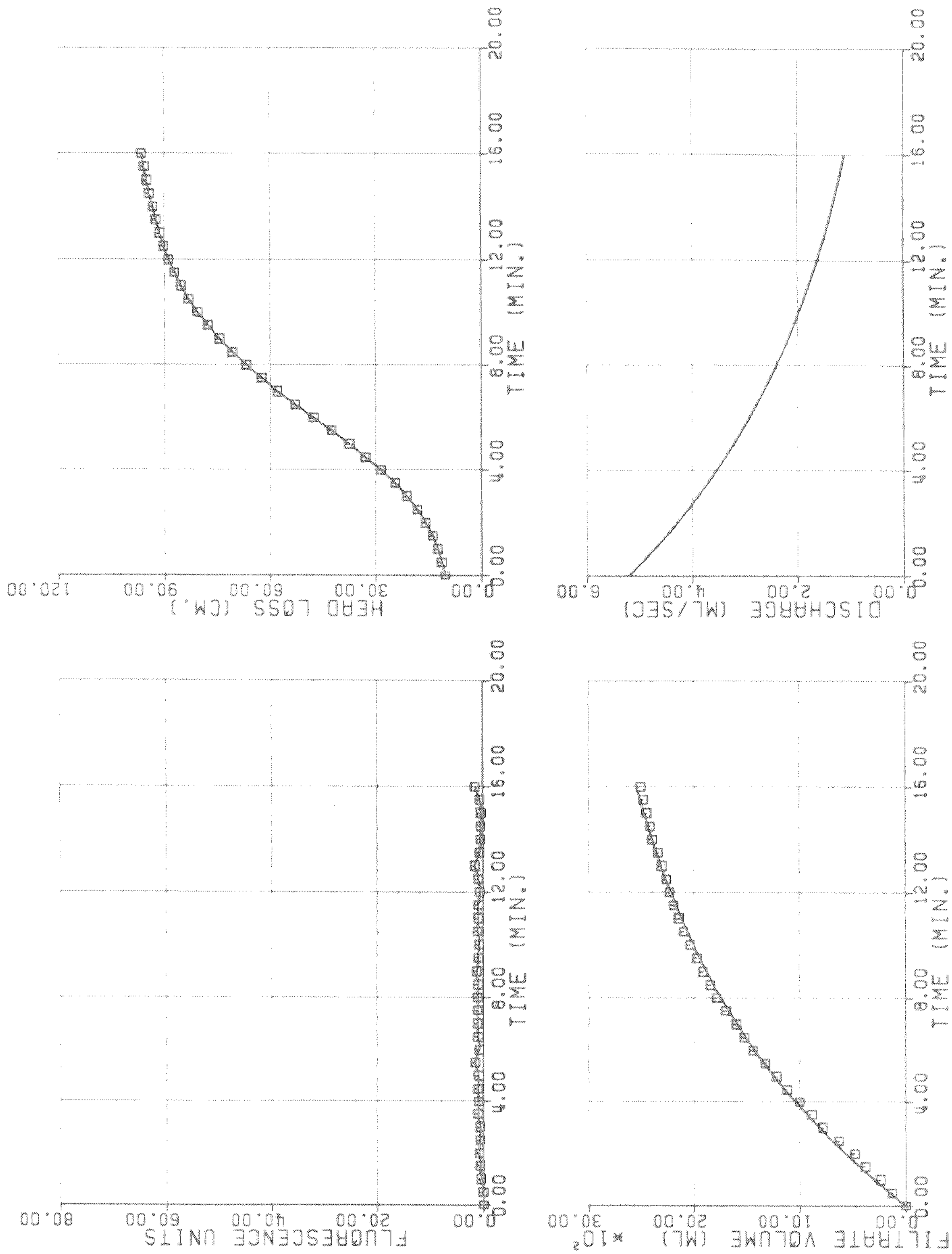
SAND 60/100-1/4 THICK   TEST ID. NO. = 30032

AVERAGE PERCENT REMOVAL = 98.67

INITIAL CONCENTRATION=57.90 FLUORESCENCE UNITS

FILTRATE EQ.   Y=3226.69922*(1-EXP(-0.00161616*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	10.40
30.00	131.54	0.10	11.40
60.00	240.40	0.45	12.50
90.00	381.02	0.60	13.90
120.00	480.81	0.80	15.90
150.00	630.49	0.65	18.30
180.00	784.72	0.60	21.20
210.00	889.04	1.00	24.50
240.00	997.90	0.90	28.50
270.00	1120.37	1.05	32.90
300.00	1215.63	0.85	37.50
330.00	1324.49	1.55	42.50
360.00	1437.89	0.80	47.70
390.00	1519.53	1.00	52.90
420.00	1596.65	1.05	57.90
450.00	1696.44	1.10	62.40
480.00	1782.62	1.05	66.80
510.00	1846.12	1.00	70.70
540.00	1914.16	1.20	74.40
570.00	1973.13	0.95	77.70
600.00	2036.63	0.75	80.70
630.00	2100.13	1.05	83.20
660.00	2140.96	0.95	85.40
690.00	2190.35	0.85	87.20
720.00	2231.67	0.65	88.80
750.00	2263.43	0.90	90.20
780.00	2304.25	1.55	91.30
810.00	2340.54	0.65	92.40
840.00	2394.97	0.50	93.30
870.00	2417.65	0.50	94.30
900.00	2449.40	0.40	95.00
930.00	2476.61	0.65	95.70
960.00	2503.83	1.55	96.40



300 32

SAND 60/100-1/4 THICK

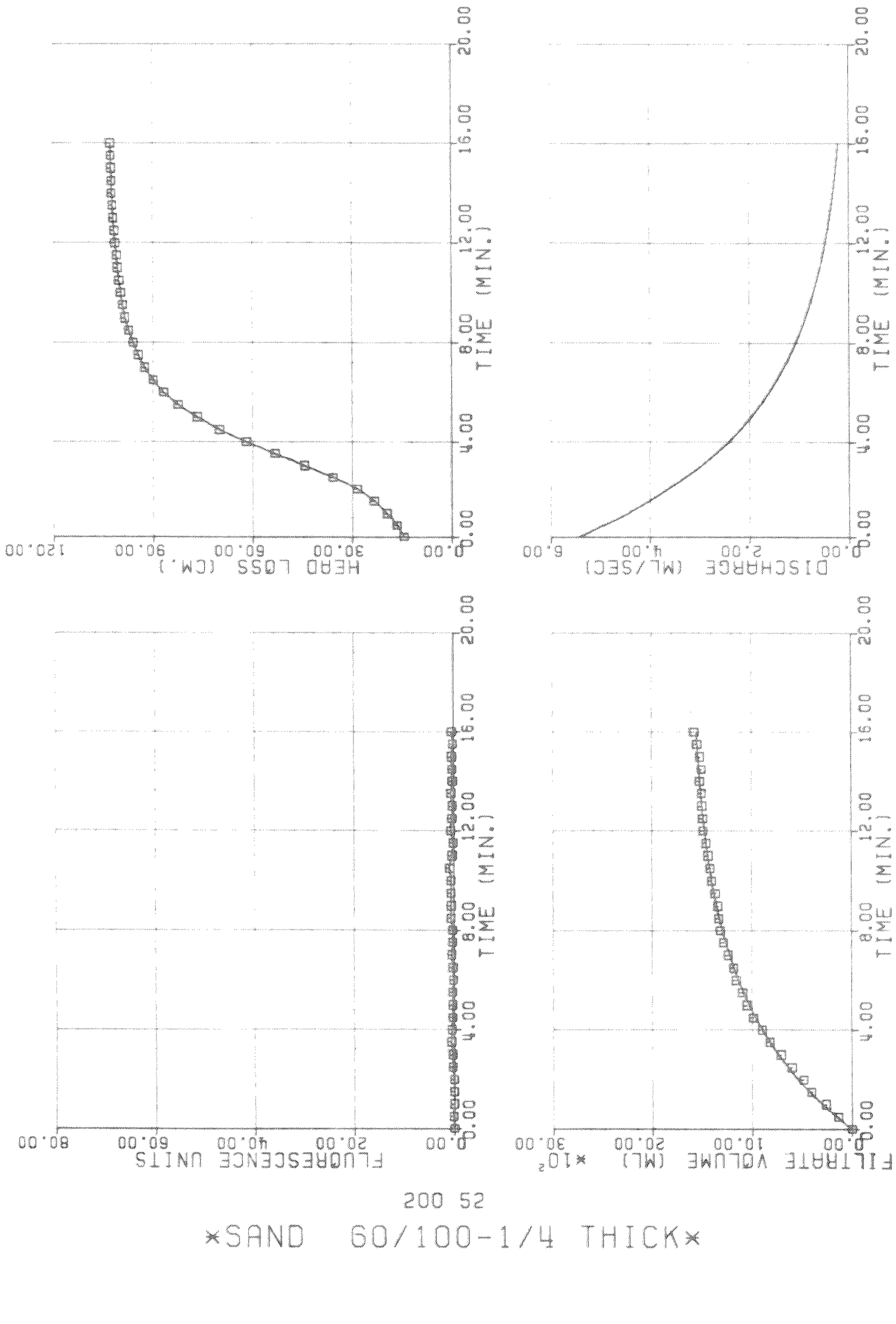
SAND 60/100-1/4 THICK TEST ID. NO. = 20052

AVERAGE PERCENT REMOVAL = 99.74

INITIAL CONCENTRATION=71.60 FLUORESCENCE UNITS

FILTRATE EQ. Y=1611.50049*(1-EXP(-0.00338493*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	14.50
30.00	140.61	0.20	16.60
60.00	263.08	0.0	19.60
90.00	408.23	0.0	23.40
120.00	485.34	0.0	28.50
150.00	603.28	0.35	35.80
180.00	712.14	0.35	44.30
210.00	821.00	0.55	53.20
240.00	898.11	0.45	62.00
270.00	988.83	0.30	70.00
300.00	1052.33	0.30	76.70
330.00	1097.69	0.30	82.50
360.00	1156.66	0.20	86.90
390.00	1183.88	0.25	90.00
420.00	1238.31	0.45	92.50
450.00	1283.67	0.30	94.50
480.00	1315.42	0.30	96.00
510.00	1329.03	0.60	97.40
540.00	1338.10	0.55	98.50
570.00	1365.31	0.65	99.20
600.00	1401.60	0.60	99.80
630.00	1415.21	0.85	100.30
660.00	1433.35	0.40	100.70
690.00	1456.03	0.20	101.00
720.00	1483.25	0.65	101.40
750.00	1487.78	0.40	101.70
780.00	1496.85	0.35	102.00
810.00	1501.39	0.55	102.20
840.00	1519.53	0.25	102.40
870.00	1501.39	0.30	102.50
900.00	1515.00	0.40	102.60
930.00	1542.21	0.20	102.70
960.00	1573.97	0.40	102.80



200 52

SAND 60/100-1/4 THICK

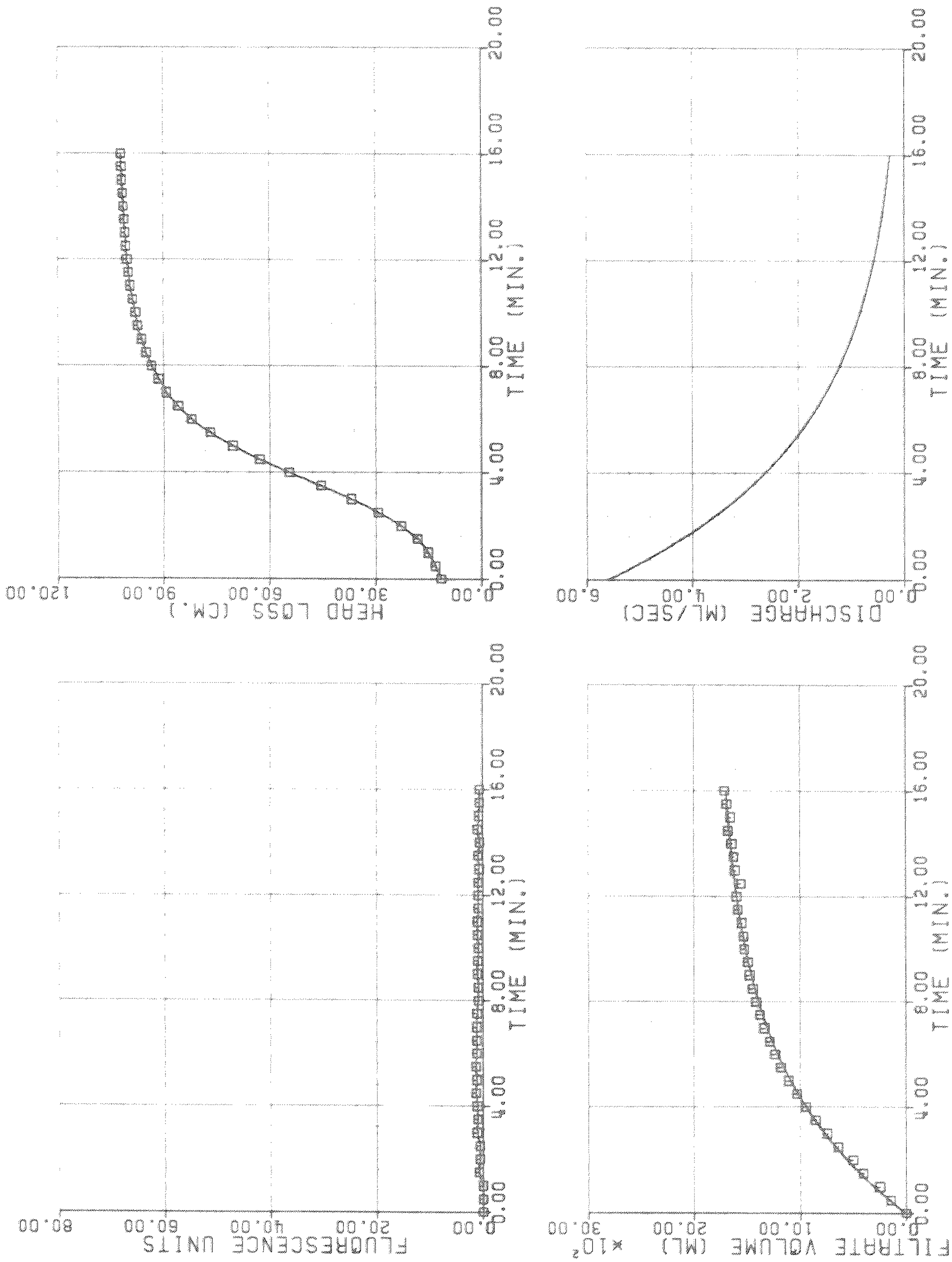
SAND 60/100-3/8 THICK TEST ID. NO. = 30081

AVERAGE PERCENT REMOVAL = 99.15

INITIAL CONCENTRATION=79.25 FLUORESCENCE UNITS

FILTRATE EQ. Y=1780.69800*(1-EXP(-0.00315062*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	11.50
30.00	145.15	0.0	13.20
60.00	249.48	0.0	15.30
90.00	408.23	0.80	18.30
120.00	503.49	0.60	22.80
150.00	644.10	0.65	29.30
180.00	748.43	1.15	36.90
210.00	857.29	1.10	45.50
240.00	948.01	1.15	54.50
270.00	1029.65	1.35	62.90
300.00	1106.77	1.25	70.50
330.00	1179.34	1.40	76.90
360.00	1233.77	1.20	82.20
390.00	1283.67	1.25	86.00
420.00	1333.56	1.20	89.30
450.00	1378.92	1.15	91.50
480.00	1410.67	0.95	93.40
510.00	1442.42	0.90	95.00
540.00	1474.18	1.05	96.20
570.00	1487.78	1.00	97.40
600.00	1524.07	0.90	98.00
630.00	1528.61	1.10	98.80
660.00	1546.75	1.05	99.50
690.00	1583.04	0.90	99.90
720.00	1596.65	0.85	100.30
750.00	1555.82	0.90	100.60
780.00	1610.25	0.70	100.80
810.00	1623.86	0.90	101.10
840.00	1642.00	0.60	101.30
870.00	1678.29	1.00	101.50
900.00	1655.61	0.75	101.80
930.00	1687.36	0.65	101.90
960.00	1705.51	0.60	102.00



300 81

SAND 60/100-3/8 THICK

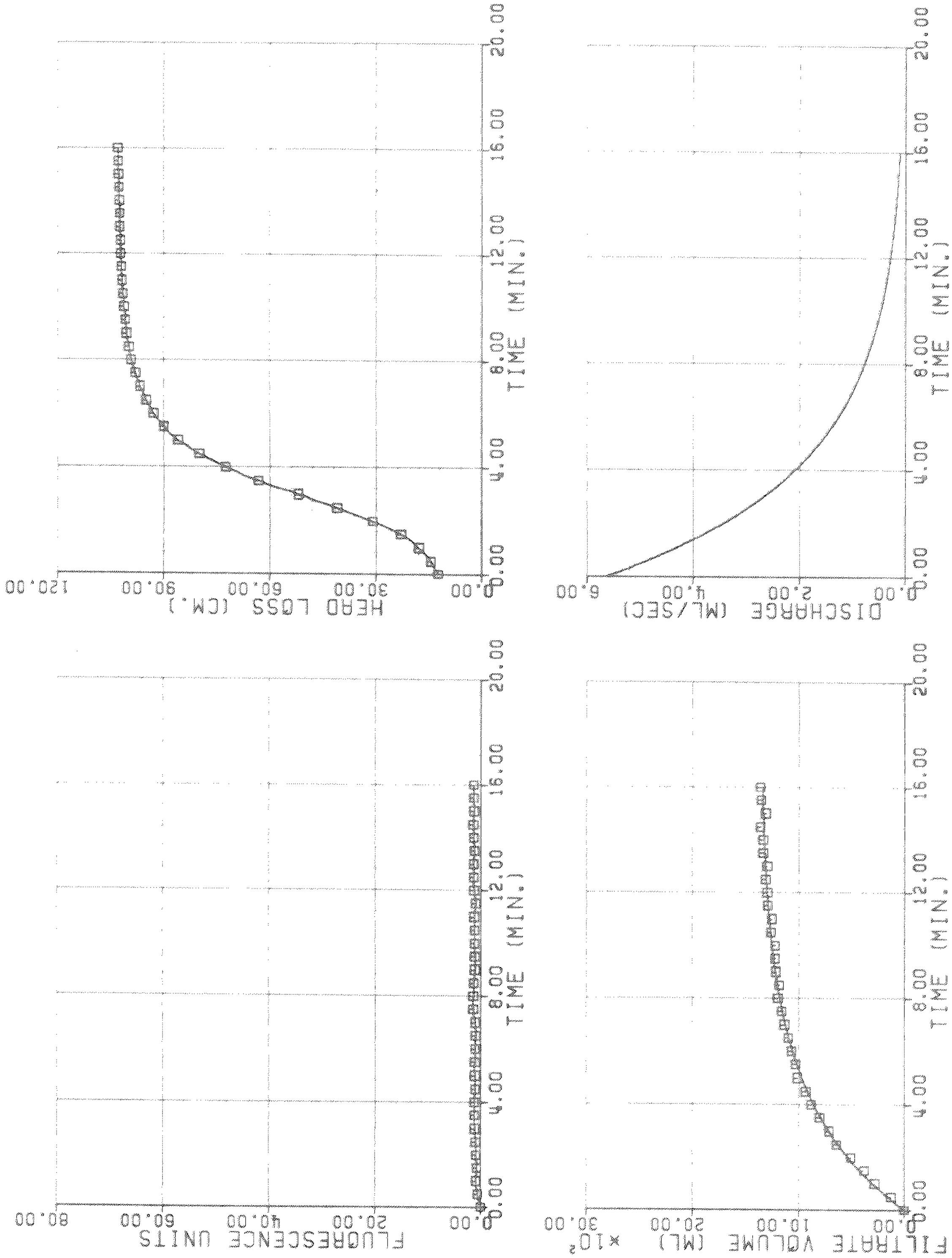
SAND 60/100-3/8 THICK TEST ID. NO. = 10081

AVERAGE PERCENT REMOVAL = 99.06

INITIAL CONCENTRATION=86.00 FLUORESCENCE UNITS

FILTRATE EQ. Y=1367.56860*(1-EXP(-0.00413580*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	12.50
30.00	127.01	0.65	14.60
60.00	281.23	0.90	17.90
90.00	381.02	0.80	23.00
120.00	508.02	0.95	30.90
150.00	644.10	1.00	41.00
180.00	716.68	1.15	51.90
210.00	802.86	1.25	63.20
240.00	884.51	1.20	72.40
270.00	934.40	1.10	80.00
300.00	1016.05	1.15	86.00
330.00	1029.66	1.15	90.00
360.00	1070.48	1.10	92.90
390.00	1102.23	1.00	95.00
420.00	1133.98	1.05	96.70
450.00	1161.20	1.45	98.00
480.00	1197.48	1.45	99.20
510.00	1183.88	1.35	99.80
540.00	1215.63	1.15	100.50
570.00	1224.70	1.15	100.80
600.00	1224.70	1.25	101.20
630.00	1260.99	1.25	101.50
660.00	1251.92	1.30	101.80
690.00	1292.74	1.00	102.00
720.00	1297.27	1.30	102.20
750.00	1310.88	1.40	102.30
780.00	1297.27	1.40	102.40
810.00	1333.56	1.25	102.50
840.00	1333.56	1.40	102.60
870.00	1360.78	1.45	102.70
900.00	1310.88	1.30	102.80
930.00	1351.71	1.35	102.90
960.00	1360.78	1.35	103.00



100 81

SAND 60/100-3/8 THICK

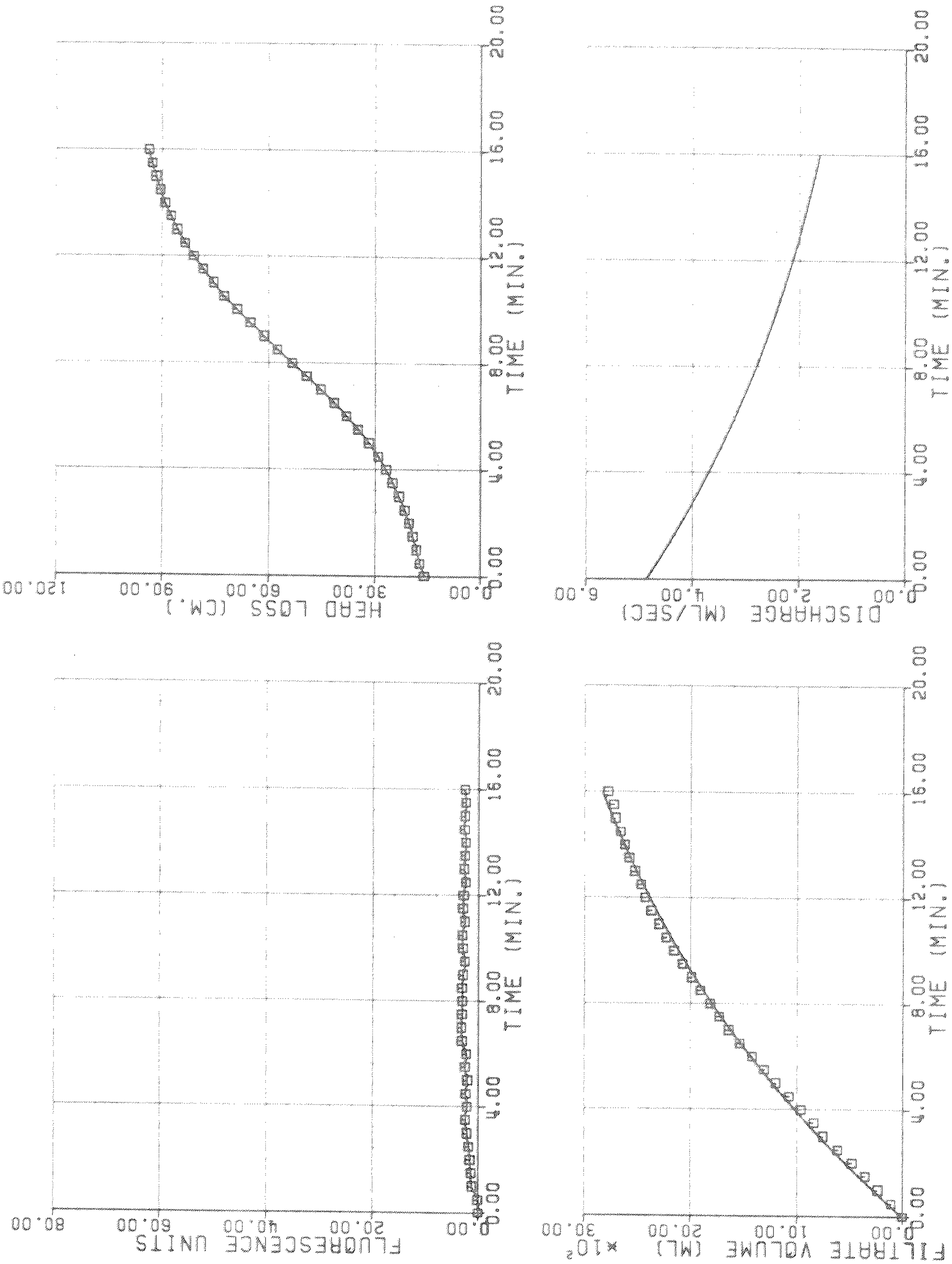
SAND 60/100-1/2 THICK TEST ID. NO. = 40062

AVERAGE PERCENT REMOVAL = 94.43

INITIAL CONCENTRATION=39.00 FLUORESCENCE UNITS

FILTRATE EQ. Y=4251.49219*(1-EXP(-0.00114455*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	16.00
30.00	108.86	0.05	17.30
60.00	235.87	1.20	18.20
90.00	353.80	1.40	19.30
120.00	480.81	1.60	20.30
150.00	616.89	1.85	21.60
180.00	752.96	2.20	23.20
210.00	843.68	2.50	25.00
240.00	966.15	2.15	26.90
270.00	1075.01	2.40	29.10
300.00	1202.02	2.10	31.70
330.00	1310.88	2.55	34.90
360.00	1424.28	2.35	38.10
390.00	1537.68	3.15	41.50
420.00	1642.00	3.20	45.30
450.00	1732.72	3.15	49.30
480.00	1814.37	3.05	53.30
510.00	1909.62	3.15	57.40
540.00	1991.27	2.90	61.40
570.00	2077.45	2.65	65.20
600.00	2159.10	3.00	68.90
630.00	2231.67	3.05	72.60
660.00	2299.71	2.65	75.50
690.00	2372.29	3.00	78.50
720.00	2431.25	2.85	81.10
750.00	2467.54	2.50	83.50
780.00	2526.51	2.75	85.70
810.00	2580.94	2.60	87.50
840.00	2621.76	2.45	89.20
870.00	2662.59	2.70	90.50
900.00	2712.48	2.60	91.70
930.00	2726.09	2.50	92.80
960.00	2780.52	2.65	93.70



400 62

SAND 60/100-1/2 THICK

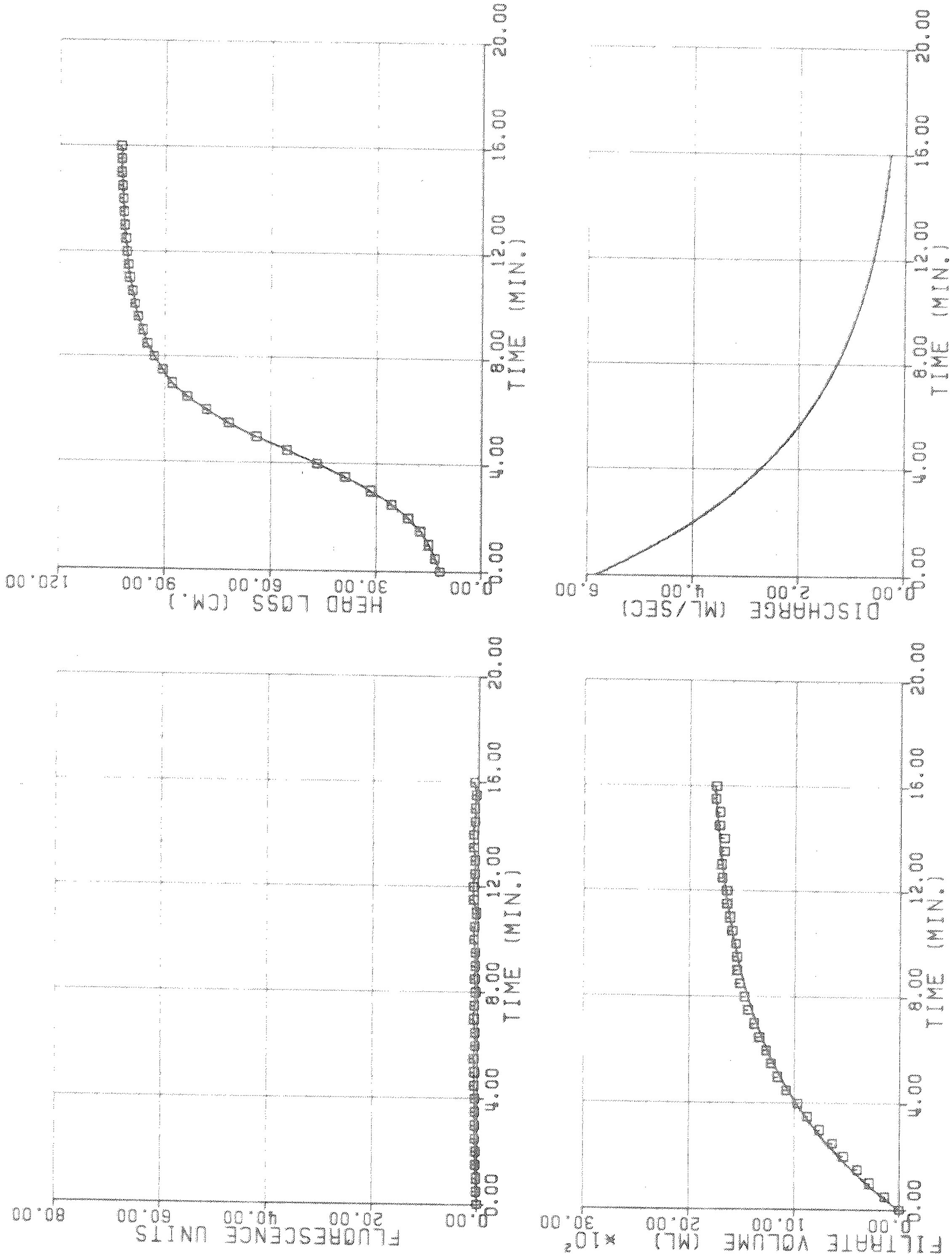
SAND 60/100-1/2 THICK TEST ID. NO. = 20032

AVERAGE PERCENT REMOVAL = 99.50

INITIAL CONCENTRATION=71.60 FLUORESCENCE UNITS

FILTRATE EQ. Y=1851.78076*(1-EXP(-0.00315366*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	11.80
30.00	140.61	0.15	13.20
60.00	285.76	0.15	15.00
90.00	399.16	0.35	17.40
120.00	535.24	0.30	20.90
150.00	639.57	0.45	25.60
180.00	762.04	0.50	31.60
210.00	875.43	0.50	38.90
240.00	970.69	0.50	46.90
270.00	1075.01	0.65	55.40
300.00	1161.20	0.55	64.00
330.00	1224.70	0.70	71.90
360.00	1270.06	0.50	78.30
390.00	1333.56	0.50	83.70
420.00	1383.46	0.70	87.90
450.00	1442.42	0.60	90.60
480.00	1478.71	0.40	93.00
510.00	1524.07	0.55	95.00
540.00	1546.75	0.50	96.20
570.00	1551.29	0.45	97.60
600.00	1560.36	0.75	98.60
630.00	1596.65	0.65	99.30
660.00	1619.32	0.35	100.00
690.00	1651.08	0.85	100.40
720.00	1651.08	0.95	100.80
750.00	1691.90	0.60	101.20
780.00	1700.97	0.60	101.60
810.00	1673.76	0.85	101.80
840.00	1673.76	0.95	102.00
870.00	1719.11	0.60	102.20
900.00	1714.58	0.65	102.40
930.00	1755.40	0.40	102.50
960.00	1750.87	0.80	102.60



200 32

SAND 60/100-1/2 THICK

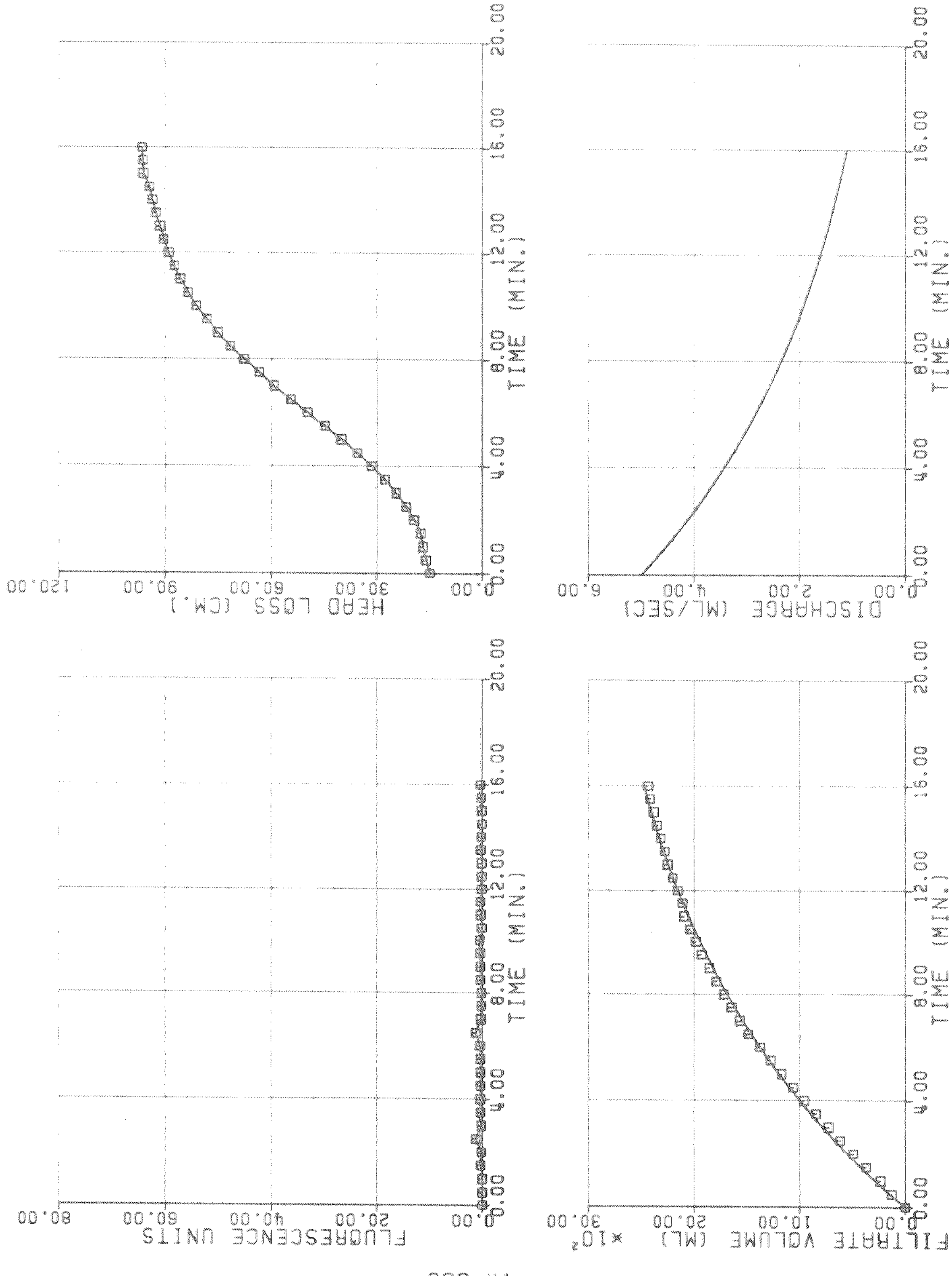
SAND 60/100-1/2 THICK   TEST ID. NO. = 30041

AVERAGE PERCENT REMOVAL = 99.45

INITIAL CONCENTRATION=57.90 FLUORESCENCE UNITS

FILTRATE EQ.   Y=3173.01636*(1-EXP(-0.00157485*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	15.00
30.00	127.01	0.0	16.00
60.00	235.87	0.0	16.90
90.00	367.41	0.30	17.60
120.00	494.42	0.15	19.50
150.00	616.89	1.20	21.70
180.00	725.75	0.20	24.50
210.00	848.22	0.35	27.70
240.00	957.08	0.40	31.50
270.00	1061.41	0.30	35.50
300.00	1170.27	0.35	40.00
330.00	1274.59	0.30	44.80
360.00	1374.38	0.40	49.70
390.00	1483.25	1.20	54.50
420.00	1564.89	0.25	59.30
450.00	1642.00	0.15	63.50
480.00	1714.58	0.15	67.70
510.00	1787.15	0.35	71.50
540.00	1855.19	0.35	75.10
570.00	1927.77	0.40	78.30
600.00	1982.20	0.50	81.20
630.00	2036.63	0.05	83.50
660.00	2091.06	0.25	85.70
690.00	2109.20	0.35	87.50
720.00	2150.03	0.10	89.00
750.00	2199.92	0.10	90.40
780.00	2249.82	0.05	91.50
810.00	2277.03	0.25	92.60
840.00	2313.32	0.15	93.60
870.00	2349.61	0.0	94.40
900.00	2381.36	0.10	96.10
930.00	2413.11	0.20	96.30
960.00	2435.79	0.35	96.50



300 41

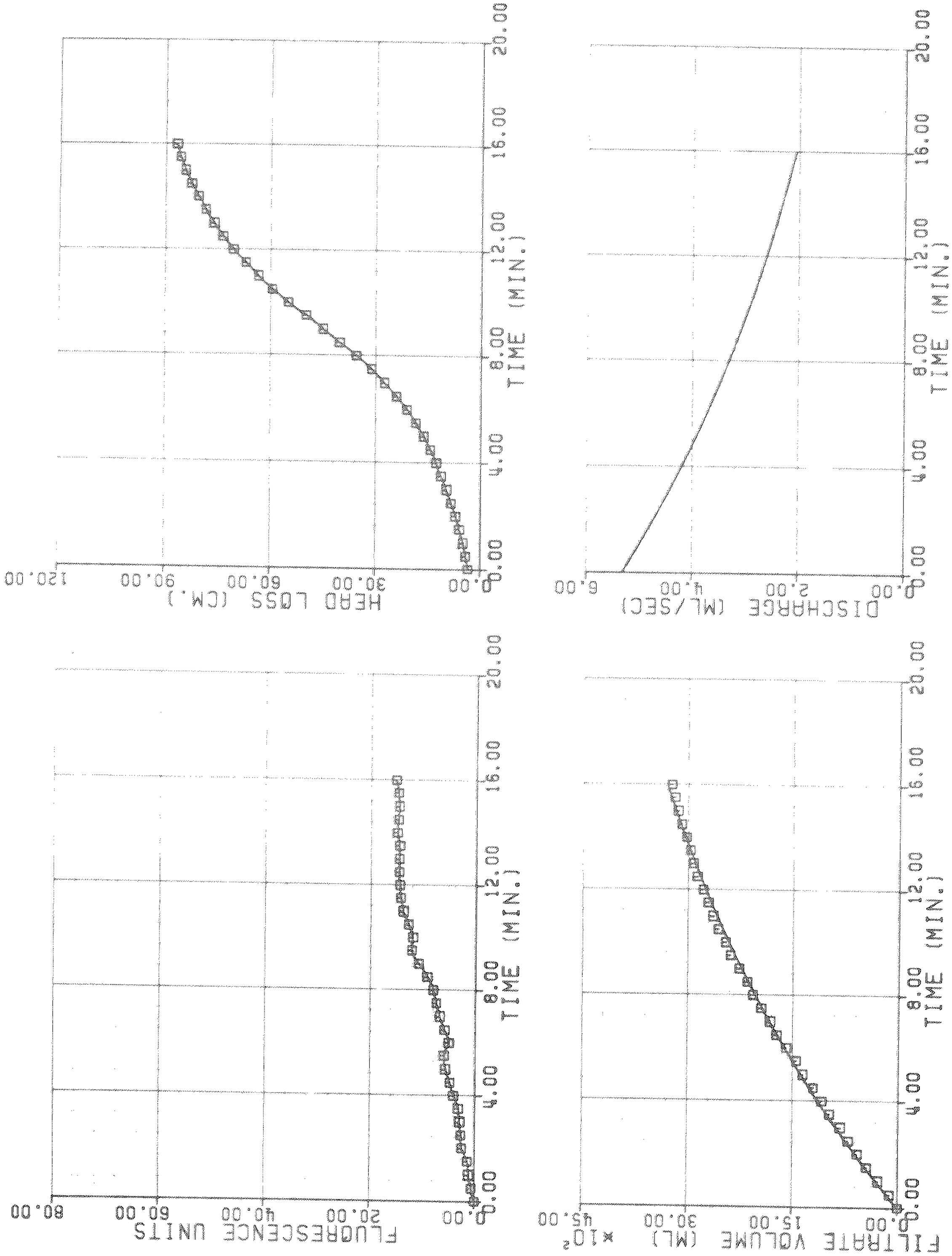
SAND 60/100-1/2 THICK

SAND 40/60 -1/4 THICK   TEST ID. NO. = 10082

INITIAL CONCENTRATION=86.00 FLUORESCENCE UNITS

FILTRATE EQ.   Y=5382.68359*(1-EXP(-0.00093905*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	3.50
30.00	117.93	0.65	4.10
60.00	276.69	1.15	4.90
90.00	439.98	1.35	5.90
120.00	571.53	2.45	7.00
150.00	698.53	2.65	8.30
180.00	811.93	2.85	9.60
210.00	966.15	3.15	11.20
240.00	1079.55	4.05	12.60
270.00	1202.02	4.80	14.30
300.00	1347.17	5.60	16.20
330.00	1442.42	5.90	18.50
360.00	1587.57	5.00	21.00
390.00	1723.65	5.80	24.00
420.00	1818.90	6.70	27.40
450.00	1945.91	7.40	31.20
480.00	2063.84	8.00	35.50
510.00	2145.49	9.15	40.30
540.00	2263.42	10.75	45.00
570.00	2385.90	12.20	49.80
600.00	2458.47	11.95	54.90
630.00	2562.80	12.75	59.50
660.00	2635.37	13.80	63.50
690.00	2707.95	14.35	67.20
720.00	2780.52	14.50	70.70
750.00	2866.70	14.60	73.70
780.00	2921.13	14.65	76.30
810.00	2966.49	14.55	78.70
840.00	3020.92	15.00	80.80
870.00	3088.96	14.75	82.70
900.00	3143.39	14.65	84.40
930.00	3188.75	14.80	85.80
960.00	3229.58	15.20	86.90



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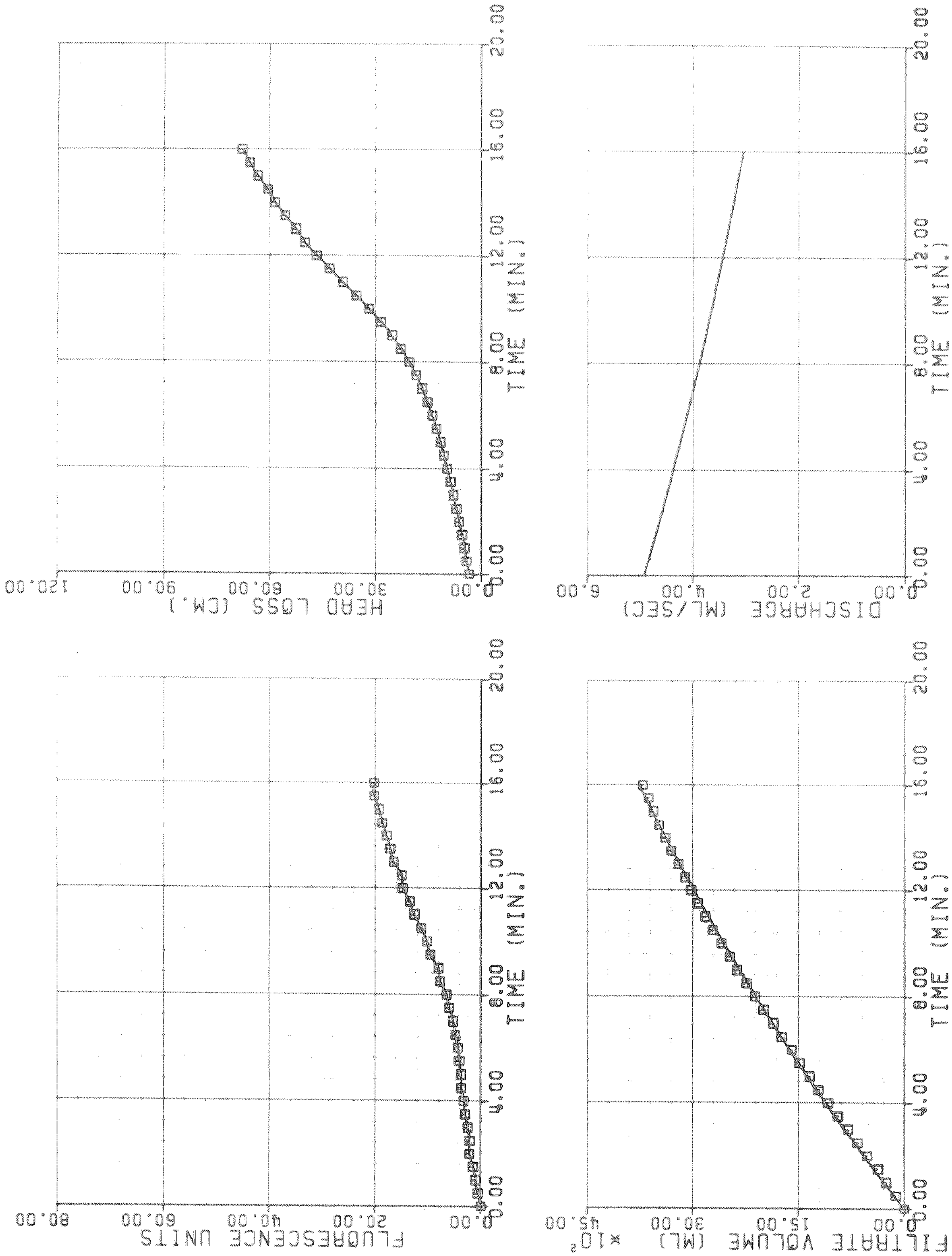
SAND 40/60 -1/4 THICK

SAND 40/60 -3/8 THICK TEST ID. NO. = 30082

INITIAL CONCENTRATION=79.25 FLUORESCENCE UNITS

FILTRATE EQ. Y=9874.25781*(1-EXP(-0.00049852*X))

TIME (SEC.)	FILTRATE VOLUME (ML.)	EFFLUENT QUALITY (FLUORESCENCE UNITS)	HEAD LOSS (CM.)
0.0	0.0	0.0	3.50
30.00	122.47	0.55	4.10
60.00	258.55	1.00	4.70
90.00	376.48	1.45	5.40
120.00	526.17	2.15	6.20
150.00	662.25	2.10	7.00
180.00	798.32	2.50	7.90
210.00	938.94	2.90	8.70
240.00	1079.55	3.20	9.70
270.00	1215.63	3.70	10.60
300.00	1338.10	3.70	11.60
330.00	1483.25	4.05	12.70
360.00	1592.11	4.30	13.90
390.00	1737.26	4.75	15.20
420.00	1850.66	5.20	16.70
450.00	1991.27	6.00	18.50
480.00	2109.20	6.45	20.40
510.00	2231.67	7.70	22.70
540.00	2363.22	8.00	25.30
570.00	2467.54	9.55	28.50
600.00	2585.48	10.20	31.80
630.00	2712.48	11.25	35.40
660.00	2816.81	12.55	39.30
690.00	2916.60	13.40	43.00
720.00	3016.39	14.75	46.70
750.00	3107.11	14.95	50.00
780.00	3197.83	16.45	52.50
810.00	3297.62	17.15	55.60
840.00	3388.33	17.80	58.50
870.00	3474.52	18.60	60.40
900.00	3556.16	19.25	63.30
930.00	3619.67	20.15	65.50
960.00	3705.85	20.20	67.70



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SAND 40/60 -3/8 THICK

VITA

Babak Naghavi was born in Tehran, Iran, on January 2, 1955, the son of Gholamreza and Ghodsi A. Naghavi. He graduated from Alborz High School, Tehran, Iran, in May, 1973 and enrolled at Louisiana State University, Baton Rouge, Louisiana, in June of 1974. In May of 1979, he received the Bachelor of Science degree in Civil Engineering. In August, 1979, he enrolled in Graduate School of Louisiana State University, Baton Rouge, Louisiana, to begin work towards the degree of Master of Science in Civil Engineering. He is married to Lisette L. Naghavi and has a daughter, Cydney Marie Naghavi.