FILTRATION ANALYSIS OF FOUR DIFFERENT FILTER FABRICS

by

JACK DAVID ROSE

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Approved by:

Harry L Manges
Major Professor

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INTRODUCTION

Today the growing population and the advancement in agricultural technology has resulted in a greatly diminished supply of potable water. In many agricultural areas of the West and Midwest the groundwater level is declining each year due mainly to the increased use for irrigation. In the coastal areas the lowering water table allows the intrusion of salt water into heretofore fresh water aquifers. The reason the water table is being lowered is that the increased use has surpassed the capacity of natural recharge resulting in the "mining" of water.

Surface reservoirs have been built to store irrigation water. These artificial detention structures increase the amount of groundwater recharge and are able to supply water for a limited amount of irrigation. However, storage reservoirs often cover some of the best agricultural soils in the area and have a large loss of water to evaporation. A loss of water occurs in transporting it through canal systems from the storage reservoir to the irrigated area. Surplus water is dumped into major streams and transported out of the area, thus losing its economical value to the area.

The last twenty-five years has brought about what could be the answer to the groundwater problem--artificial recharge of surplus water into the groundwater reservoir. This eliminates evaporation losses, allows the Earth's surface to be used for other purposes, and maintains most of the water in the area because the rate of flow in the groundwater reservoir is less than one-half mile per year.

As of 1963, artificial groundwater recharge was being practiced in twenty-six states. Three states were using it to prevent salt water intrusion, seven states to conserve water, thirteen to solve specific problems, and three to improve the quality of groundwater (42). Basically artificial recharge is done by three major methods: 1) water spreading; 2) digging detention reservoirs down to the aquifer and backfilling with sand and gravel; and 3) recharging through wells.

Individuals such as J.R. Hutchens (26) have successfully recharged water through an irrigation well for over ten years at an average yearly cost of $500 per year. Mr. Hutchens has raised his water table 15 feet and has noticed no detrimental effect even though he has no pre-treatment, i.e. clarification, of water before recharging other than the use of a detention reservoir. This, however, is rarely successful. Research by Sniegocki at al. (40) and Hauser and Lotspeich (19) indicates that untreated raw water plugs the pore spaces in the aquifer and ruins the well. They have found that if the water is treated before recharging through wells, there is no detrimental effect. Whetstone (44) adds that water carrying silt should not be used even in water spreading since the silt filters out, narrowing the "necks" in the percolation tubes and reducing the total voids by lodging in the interstices. Sniegocki et al. (40) and Hauser and Lotspeich (19) are not in complete agreement regarding the amount of treatment necessary. Sniegocki et al. feel that the recharged water should have 5 or fewer ppm of suspended solids while Hauser and Lotspeich used 10 to 30 ppm in their work. This discrepancy can probably be attributed more to a limiting size of the suspended solids than to the amount of turbidity in the water. The higher turbidity readings, 10 to 30 ppm, were used in research work done in Texas on the Ogallala formation

which has a very high clay content while Sniegocki et al. did their studies in Arkansas where the clay content was lower.

It is the goal of this type of research to see if an economical, easily operated pre-treatment system for raw water can be developed so that recharge operations through wells can be established on an individual farm level.

PURPOSE OF STUDY

The purpose of this study was to evaluate the filtration efficiency of various filter cloths. This was done by:

1. Designing and building an apparatus for measuring the amount of flow and turbidity removal obtained through a filter cloth while maintaining constant pressure and concentration.
2. Analyzing the data from several cloths for filtration and performance.

REVIEW OF LITERATURE

It is generally agreed that some form of pre-treatment must occur before excess surface water is artificially recharged into the groundwater. The degree and type of treatment varies, but Sniegocki et al. (40) found that "the tests with the greatest degree of treatment had the least plugging." There has to be a limit to the amount of treatment that is both practical and economical. With these two factors in mind a review of the literature was first conducted on the primary clarification techniques.

Water Clarification Methods

The simplest form of clarifying turbid water is the use of a settling basin. In these basins the fluid is allowed to come to rest so that the suspended particles, which have a greater density than water, will settle out. Ehlers and Steel (14) give recommendations for designing such a structure, and they point out that the clay fraction will not settle out because of the natural convection currents that occur in a reservoir. Normally this method is used ahead of a filter operation and is expedited by the use of coagulants and flocculants. Hansen and Culp (17) and Camp (5) tried to apply the sedimentation theory to shallow trays. These attempts met with only limited success. Later Hansen et al. (18) developed shallow settling tubes which are now produced commercially.

Another technique often used is the addition of a coagulating or flocculating compound. As mentioned before, this is used in conjunction with a sedimentation chamber and usually with a filter. The time necessary for detention is controlled by the design of the detention structure (18). In a series of research papers (9, 19, 20) a polyelectrolyte polymer was used for removing sediments from playa lake water for groundwater recharge. These polyelectrolyte polymers act as flocculating agents. They are compounds of high molecular weight and differ from other polymers in that they have an electrical charge. With a dose of 0.5 ppm of a cationic polyelectrolyte and 5 ppm of alum, laboratory tests showed a reduction in suspended solids from 210 to 20 ppm (19).

The necessity of using two compounds for the removal of turbidity is probably best explained by Riddick (35). He states that the zeta potential (ZP) is a measure of the electrokinetic charge that surrounds suspended particulate matter and that raw turbid water is predominantly electronegative. The coarse fraction (1mm-1μ) may be removed by an alum dosage because of a low zeta potential. However, the fine fraction (1μ -10Å) cannot be removed by the alum dosage because its electronegative ZP (15-25mv) prevents agglomeration. This ZP must be lowered to 0 $\pm$ 5 mv by an inorganic coagulant and an organic polyelectrolyte.

Other studies (28) show that flocculation is also effective in removing virus, bacteria, and larger micro-organisms. In general, the virus and bacteria removal parallels the removal of turbidity.

The final filtration process is usually done with a porous media, normally sand. It is characterized as being either slow sand filtration or fast sand filtration (14). Slow sand filters are used to clarify

water up to 50 ppm with no additional treatment. Flow rates are low (100-700 gal/day ft^2), but the period of operation is from three weeks to several months (14, 24) before the filter needs to be cleaned.

Fast sand filtration consists of coagulation, sedimentation, and filtration (14). The rate of filtration is from 1-6 gal/min ft^2 of surface area, but the length of run is only around twenty-four hours. When the system becomes plugged, some means of backflushing is necessary.

The explanation of the mechanisms by which the suspended particles are removed in a porous media varies from author to author. Catlin (8) feels that most removal is by sedimentation; however, Curry et al. (11) state that a filter removes suspended particles by mechanical sieving or interstitial straining near the surface, but lower in the filter, removal is a combination of diffusion and gravitational settling. Ehlers (14) states further that the small voids between grains act as sediment chambers and that organic slimes and films that form on the grains are sticky so that the particles become attached. He also says that the sand has a charge opposite that on the colloidal particles so that they are attracted to the sand grains. Craft (10) gives eight methods for particle removal:

1. Direct sieving.
2. Sedimentation.
3. Inertial impingement and centrifugal collection—as water bends to pass an obstacle, the heavier suspended particles are forced to the outside.
4. Brownian movement.
5. Diffusion caused by suspended particle concentration gradient—diffusion to sinks where there is no flow.

6. Chance contact caused by convergence of fluid stream lines.

7. Van der waal effects.

8. Electrokinetic effects.

These various methods of removal and the problems caused by backwashing have resulted in a number of different designs for the optimum filter (2, 13, 21, 25, 31, 33, 36, 38).

A relatively new method of removing colloids from suspension is electrophoresis. Hiler et al. (23) successfully removed kaolinite and bentonite from suspension by this method. They found that the effluent concentration decreased with an increasing electric field strength, but the electrolysis of the water molecules and the heat transfer losses caused a reduction in the efficiency of turbidity removal at the higher field strengths. The main problem with this method was one of cost and operation.

Straining suspended particles from a viscous fluid by a septum having very small openings, while maintaining a high porosity, will be the last clarification technique discussed.

A microstrainer is one system that employs straining as a means of removal. Microstrainers are usually stainless steel mesh screens ten feet wide and ten feet in diameter and are limited structurally to removing particles greater than 30μ (7). These large drums are continually rotated at approximately 3 RPM so that the only removal is done by straining at the screen. These filters have been used in England ahead of slow sand filters and at plants in Denver, Colorado (43). The initial cost ($25,000) is very high, and they have an application in a range where sedimentation is still quite rapid.

During World War II the U.S. Army Engineer Research & Development Laboratories along with private industry developed diatomite filter units (27). These units use various diatomaceous earth materials as a precoat on a wide variety of septum materials. The selection of the septum material depends upon the nature of the contaminants of the water to be filtered and the design of the filter used. In all cases, however, a good septum is characterized by the following:

1. The ability to take an even precoat.
2. A minimum tendency to allow blinding or fouling, that is, blocking of the septum openings.
3. The ease of complete removal of the filter cake upon cleaning.
4. The proper size and shape of the septum openings (27).

For the higher flow rate filter aids, the maximum safe spacing of the filter septum openings is about 0.005 of an inch (127μ) (3, 27). The initial precoat forms on the septum analogous to snow collecting on a snow fence. After the precoat has been applied, it may or may not be necessary to apply more filter aid along with the turbid fluid (3). This depends upon the characteristics of the particles to be removed, such as the porosity, size distribution, shape, et cetera. This type of filtration produces a high quality effluent because particles down to 1μ may be removed by this method (4).

Other filter fabrics are used for the complete removal operation. In most cases a filter aid is used to keep up the porosity in the filter cake, but if the suspended particles are rigid and have a porosity of their own, this process may not be necessary. The theory, application, and selection of filter cloths will be reviewed in detail.

Filter Fabric Theory

For discussion purposes the filtration process can be considered under three headings: 1) the filter medium, 2) the solid-liquid suspension, or slurry, and 3) the filter cake. None of these factors, of course, can be considered in complete isolation since the filtration process involves the interaction of all three (34).

The Filter Medium

Perry (34) points out that in operation the resistance of the medium to fluid flow is changed as particles in the slurry are deposited on or in it. Rushton et al. (37) state further that in many applications the resistance of the filter medium is considered to be negligible, but evidence is available which suggests that the effective flow resistance of the cloth after deposition is several times its clean value (6). Hermans and Bredée (22) were the first to study this problem. They suggested two possible mechanisms responsible for clogging of the filter media: 1) complete blocking in which single particles somewhat larger than the holes in the filter medium plug up individual holes and 2) standard blocking in which particles smaller than the holes are attached to the fibers along or within holes or to other particles previously retained. They showed that for constant pressure filtration the inverse of the flow rate of the filtrate was proportional to the volume of the filtrate raised by an exponent. The exponent for complete blocking was 2.0, for standard blocking 1.5, and for cake filtration 1.0. Grace (16) studied the increase in the resistance of a variety of types of filter media for very low concentrations of solutions in the feed and showed that standard blocking could

account for the clogging of the filter media in his work. Smith (39) states that the porosity and the twist of the yarns and the size distribution of the solid particles undergoing filtration probably determine what fraction is standard blocking. He states that it is likely that the mechanism of complete blocking dominates the clogging of the small passages between elements, while the mechanism of standard blocking dominates the clogging of the large passages between yarns.

In the work of Kehat et al. (29) they used ground polystyrene in water and tested the flow through filter cloths. They found that at the beginning of the cycle, clogging of the filter cloth and bridging of cake over the filter cloth occur. After bridging is completed, no further clogging takes place and filtration begins. From their work two types of experimental curves were obtained. For the case where no bleeding occurs, the rate of flow decreases while clogging takes place, but after a certain amount of filtrate has passed through the filter, cake filtration begins. The rate of flow continues to decrease but does so at a lower, straight line rate. For the case where bleeding of particles through the filter occurs, the flow rate decrease was slower during the clogging, bridging, and bleeding stage than during the subsequent cake filtration stage.

The Slurry

According to Perry (34) there seems to be no published work which predicts the way various properties such as the degree of flocculation, size distribution, and crystal form of the precipitates affect the filtration process. No information regarding this could be found by this writer either.

The Filter Cake

The major resistance to flow is due to the filter cake which is built up on the supporting medium (34). The earliest description of a relation between throughput and pressure difference in a porous bed was given by Darcy (1, 34). He carried out experiments on water seepage through fine sand beds and developed the equation:

$$Q = KA\frac{\Delta P}{L} \qquad (1)$$

where Q = Volume of water flowing in unit time

A = Area of the porous bed normal to the flow

ΔP = Pressure difference across the bed

L = Depth of the bed

K = Darcy's law coefficient.

By analogy with Poiseuille's Law for fluid flow through circular channels, it was realized that the viscosity of the fluid was also an important parameter. The more general equation is:

$$Q = K_1 A\frac{\Delta P}{\eta L} \qquad (2)$$

where K_1 = Permeability coefficient

η = Fluid viscosity.

If Q is replaced by V/θ, where V is the volume passed in time θ and L by vV/A, where v is the volume of cake formed per unit volume of slurry, the rate of flow can be expressed as:

$$\frac{dV}{d\theta} = \frac{K_1 A^2 \Delta P}{\eta v V}$$

Integration of the preceeding equation gives:

$$\theta = \frac{\eta v}{2K_1 \Delta P A^2} V^2 \qquad (3)$$

However, practical plant and experimental work found the agreement with this equation to be poor. Sperry (41) found the disagreement to be due to neglecting the resistance to flow caused by the filter medium.

From the design viewpoint the modified equation 3 is of limited use because the permeability coefficient K_1 is not an easily measured property of the system. Kozeny (37) solved the Navier-Stokes equation and found:

$$K_1 = \frac{C\epsilon^3}{S^2}$$

where C = Dimensionless number, the Kozeny Constant

ϵ = Porosity of the bed, fraction of volume of voids to total volume

S = Surface area of solids per unit volume of the bed.

Carman (6) later developed the well known Kozeny-Carman equation:

$$K_1 = \frac{\epsilon^3}{5S_0^2(1-\epsilon)^2} \qquad (4)$$

where S_0 = Specific surface of the solid, surface area per unit volume of solid.

Darcy's equation can now be written:

$$Q = \frac{\epsilon^3 \Delta P}{(1-\epsilon)^2 K_1 S_0^2 \eta L} \qquad (5)$$

In general it is assumed that the value of K_1 is constant and equal to 5, but this value is only approximate and is acceptable where the porous medium has a mean porosity and is made up of isometric particles. Actually, if the particles show plane surfaces, some of these surfaces will be able to touch and are no longer exposed to the flow (45).

McGregor (32) found that in the porosity range of $0.5 < \epsilon < 0.8$, K_1 has an average value of 5.5, but at higher porosities K_1 increases rapidly.

Both Baird et al. (1) and Lee (30) worked on the variation of porosity within the filter cake. Baird says that most filter cakes show some degree of compressibility, and that in general, the porosity is greater near the slurry-cake interface than it is near the medium. Various explanations have been given for this effect, but if the particles themselves are considered incompressible, the cake compressibility is most likely to be a result of particle re-arrangement into a more closely packed array. Baird's results showed that the compressibility of a filter cake is affected by the overall pressure drop and that a collapse occurs in the cake after a certain critical height has been reached. Therefore, the porosity variation is not uniform as had been previously assumed. Baird also found that the minimum porosity in a filter cake is not always adjacent to the medium.

Selection of Filter Medium

Most of this will be based on an article by French (15). The purpose of his report was to show what is available in the field of filter media and to give some guidelines that will aid in the selection of the best medium for the filtration problem.

Filter fabrics consist of three forms of yarn (15):

1. Monofilament - a synthetic fiber made in a single continuous filament;
2. Multifilament - a yarn made by twisting two or more continuous monofilaments;

3. Spun-staple - a yarn made by twisting short lengths of natural or synthetic fiber into a continuous strand.

Some of the major comparisons between the three cloths are that the monofilament has the highest flow rate, allows minimum blinding within the cloth, and has good cleaning and excellent cake-discharge characteristics. The multifilament has the greatest tensile strength of any of the yarns and has better flow and cake-discharge than spun yarns. The spun-staples have the best particle retention because of hairy filaments and offer the best gasketing, or sealing, properties.

Another factor to consider in filter selection is the weave of the filter fabrics. The plain weave is the lowest in price, has the least porosity, and has the greatest particle retentivity. This weave, however, is susceptible to blinding, or plugging, of the filter cloth by solids. The chain weave has a lower tensile strength and less retentivity than the plain weave but offers greater resistance to blinding. The twill weave has medium retentivity and blinding properties, offers high resistance to abrasion, and has good flow rates. The satin weave has the least particle retentivity of the basic weaves but offers superior cake-release and the best resistance to blinding. A knit weave is usually used behind a tight medium (one which has small pore openings) to provide drainage and to prevent the build-up of solids beneath the medium.

Some of the most commonly used filter fabrics are: cotton, polyester, dynel, glass, nylon, acrylic, polyethylene, polypropylene, saran, teflon, and polyvinyl chloride.

Cotton is the leader in the field because of its low price. It also has good abrasion resistance and offers good particle retention because

of its hairy filaments. Next to cotton, nylon claims the greatest usage in the field because it has exceptionally good abrasion resistance and has a smooth surface for good cake-discharge. Polypropylene, although relatively new in the field, is felt to be an important synthetic in the filter fabric field. It has the lowest density of any synthetic filter cloth which results in greater cloth yield per pound of yarn used. This is reflected not only in lower initial cost but also in shipping charges. It presents a very sleek fiber for cake-discharge and retardation of blinding. It also has good resistance to acids and has a moisture absorption value rated at less than 0.03%.

There are various important characteristics that need to be known in order to make the proper selection of the filter medium:

1. The type of equipment the cloth will be used on--this determines the tensile strength needed, abrasion resistance required, resistance to failure caused by flexing, and the ability to conform to the shape of the unit;
2. The pH, temperature, and chemical composition of the slurry to be filtered;
3. A knowledge of the particle size distribution of the slurry and the maximum particle size that can be allowed to pass through the medium--this helps in determining the porosity of the fabric;
4. The nature of the solids, e.g. crystalline, granular, slimy, gelatinous--this affects the porosity and weave selection also.

Normally it is the user's preference for either maximum flow rate or maximum filtrate clarity or some compromise of these two factors that leads to the final filter selection.

Rating of the Filter Medium

For filter cloths the Frazier air-porosity test is used to measure the porosity of a weave (15). For this test the Frazier Permeameter measures the air flow in cubic feet per minute that passes through one square foot of fabric at one-half inch of water pressure. Fabrics with ratings of 1-10 cfm are considered very tight, whereas cloths that test at 450-500 cfm are extremely porous. There is no correlation between the Frazier ratings and micron size retention, but the classification is useful for specifying either a more open or tighter cloth as desired.

In the work by Rushton et al. (37) the porosity was found by:

$$\epsilon = 1 - \frac{\text{Bulk Density}}{\text{Solid Density}} \qquad (6)$$

The bulk density was found by weighing a known area of cloth after drying to constant weight. The solid density can be supplied by the manufacturer. Rushton then found that the permeability as predicted by the Davie's Equation, which is for air flow through random beds of fibrous materials of widely varying physical dimensions, satisfactorily predicted the permeability of filters composed of smooth, monofilament fibers of simple weave and for multifilaments of tight weave which exhibit no interyarn pores. This equation is:

$$B = \frac{d^2}{64(1-\epsilon)^{1.5}\ 1+56(1-\epsilon)^3} \qquad (7)$$

where B = Permeability

d = Fiber diameter.

MATERIALS AND METHODS

Equipment

Test Apparatus

The experimental apparatus, shown by a block diagram in Plate I and schematically in Plate II, consisted of a feed tank, centrifugal pump, pressure regulating valve, by-pass line, filter column, filter cloth and support system, pressure gauge, and effluent tank in which the water level was recorded by time. The system was used as a laboratory model to evaluate various filter cloths under simulated field conditions.

The feed tank was an oblong galvanized steel tank which was 36 inches long by 22 inches wide by 22 inches deep. The water in this tank was continuously agitated by a paddle and re-cycled water. The paddle consisted of two wood slats 2.75 inches wide and mounted on a 10.5 inch radius. The paddle was rotated at 10 1/2 RPM by an electric motor. Sufficient agitation was desired to prevent any settling in the feed tank. Water from the tank was both withdrawn and re-cycled near the bottom.

A Dempster centrifugal pump rated at 1/2 H.P. was used for circulating the water. The intake line was 3/4 inch galvanized pipe, and the discharge line consisted of 1 inch pipe and 3/8 inch flexible hosing.

A type E-41 series 3 inch Cash Acme pressure regulating valve was used to maintain a constant pressure on the filter ($\pm$1 psi). The valve

had a delivery pressure range from 20 to 70 psi. Lower pressures could be obtained by varying the amount of by-pass.

The filter column was designed to satisfy the following requirements:

1. To hold the filter cloth in place across the face of the flow.
2. To by-pass the water through the filter column with sufficient velocity to prevent settling in the lines and in the column itself as much as possible.
3. To have sufficient length so that the velocity would not disturb any cake build-up.
4. To provide a means for the water to be removed above the cake after a run.

The last point is necessary so that the filter and cake could be removed without being disturbed. Also, the design had to include provisions for obtaining representative samples of the flow both above and below the filter. The column used for the tests is shown schematically in Plate II.

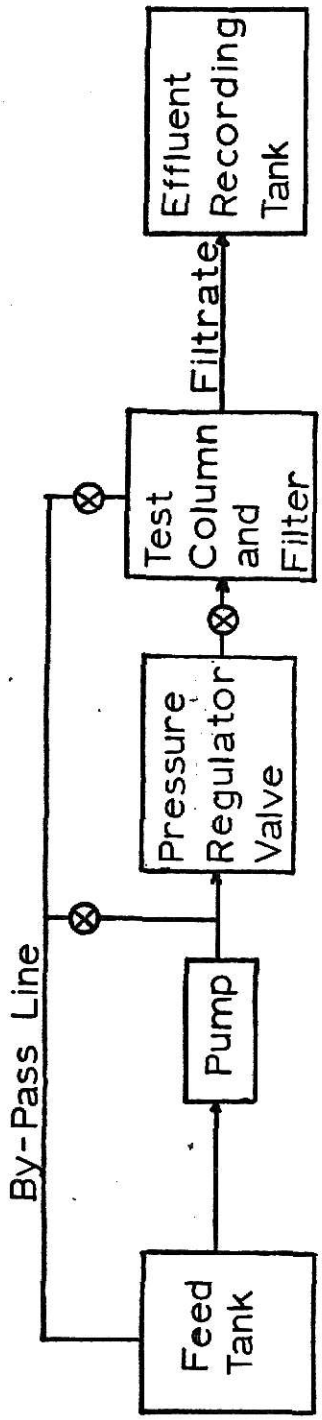
A 34 inch long galvanized pipe with a 2 inch diameter was used for the column. The top was capped and the inlet hose was attached at this point. A pressure gauge was put in the center of the column, and a by-pass line was attached at a point 4 inches below the pressure gauge and at a 90° offset to the left. This line consisted of a flow rate valve, 3*; a small draw-off valve, 4; a lead line to the first by-pass valve, 1; and a by-pass line to the feed tank. The lead line from by-pass valve, 1, not only made it easier to begin a run while the water was being circulated

* The number indicators refer to the parts and locations as referred to on Plate II.

EXPLANATION OF PLATE I

A block diagram of the filter test unit.

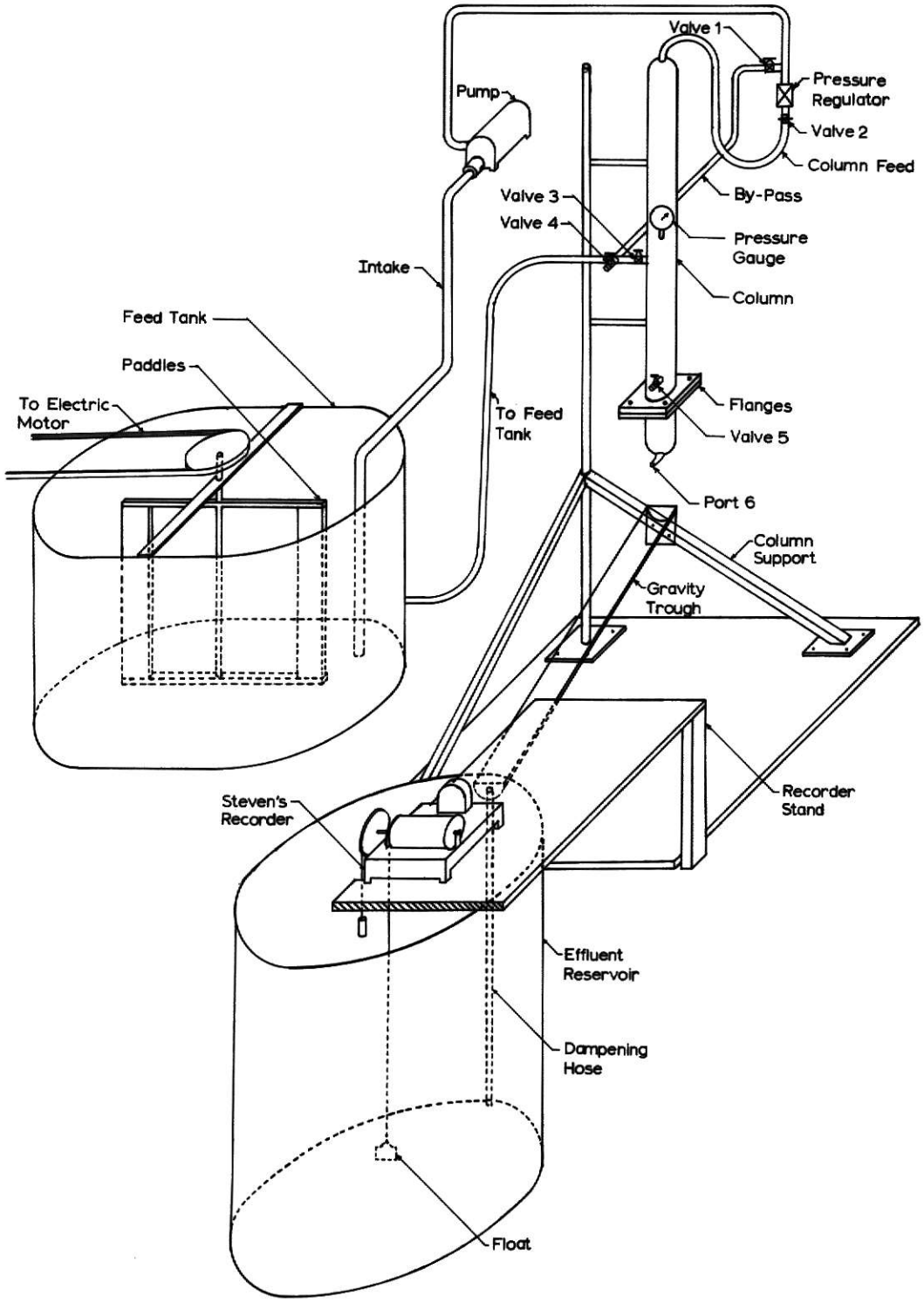
PLATE I


Effluent Recording Tank
Filtrate
Test Column and Filter
Pressure Regulator Valve
Pump
By-Pass Line
Feed Tank

EXPLANATION OF PLATE II

A schematic diagram of the filter test unit.

PLATE II


Valve 1
Pump
Pressure Regulator
Valve 2
Column Feed
By-Pass
Valve 3
Valve 4
Pressure Gauge
Intake
Column
Feed Tank
Paddles
To Electric Motor
To Feed Tank
Flanges
Valve 5
Port 6
Column Support
Gravity Trough
Recorder Stand
Steven's Recorder
Effluent Reservoir
Dampening Hose
Float

for mixing, but it also made the control of the initial inlet water much easier. This aided in the prevention of surging across the filter which was necessary to allow the initial cake to deposit uniformly. Entering the water first at this point also limited undue stresses on the cloth. The small draw-off valve, 4, was used to obtain samples of the influent. It was thought that this location would allow very representative samples of the water going through the filter to be taken.

At the bottom of the column, a 5 inch square flange was attached. An identical flange was then fastened to another short column. These two flanges were used to hold the filter cloth across the column. A 10 mesh galvanized screen was placed below the cloth for support, and soft rubber on both sides of the filter and screen served as a gasket. The soft rubber molded around the screen to get a water-tight seal. The two flanges were then coupled by bolts at each corner.

At a point 1 1/2 inches above the flange a small draw-off valve, 5, was attached. The only purpose of this valve was to drain the water above the filter after a run.

The short column below the filter was capped and had a 3/8 inch outlet port at the bottom. This port was used to take samples on the effluent side of the filter. Normally though, the water left the port and fell into a trough where it flowed by gravity to the effluent recording tank.

The test column was held in place by a vertical 3/4 inch steel rod that was attached to a 3 foot square of 3/4 inch plywood.

The effluent reservoir consisted of a fifty gallon barrel and a Stevens Type F water level recorder. The Stevens recorder was placed on a platform above the barrel to give a reading of the rise in the water

level with time. The barrel was calibrated so that the amount of rise could be converted to usable units. This information could then be used to determine the flow rate at any time during the test.

Turbidity Monitor

The turbidity was measured by a Hoch turbidity meter. This meter is an absorptometer, which means that the turbidity is a measure of the amount of light absorption by the particles. The turbidity is measured in Jackson Turbidity Units (JTU). This type of meter does not work well for turbidities less than 2 JTU.

Test Materials

Filter Cloths

Original filter cloth samples were obtained from Uniroyal Fiber and Textile, Division of Uniroyal, Inc. The samples contained information on the fiber weight, weave, porosity, gauge, and grab strength. These samples were evaluated for two important parameters: 1) the permeability of the fabric and 2) the sleekness of the fibers, which indicates that the cloth will discharge the filter cake well.

The filter cloths selected for use in the analysis had the following permeabilities:

1. 5.1×10^{-9} feet^2 for monofilament polypropylene 224 003 01;
2. $.53 \times 10^{-9}$ feet^2 for multifilament nylon 150 009 01;
3. $.51 \times 10^{-9}$ feet^2 for multifilament polypropylene 220 005 00;
4. $.42 \times 10^{-9}$ feet^2 for multifilament polypropylene 220 012 02.

Both the nylon and polypropylene filter cloths meet the second requirement

since they have good cake-discharge characteristics.

The cloths used in the filtration study were obtained from the National Filter Media Corporation, Salt Lake City, Utah.

Test Soil

The soil used for the experiment was topsoil obtained from the Sandyland Experiment Field of Kansas State University. Only the portion of the soil that passed a 325 mesh (44 μ) sieve was used for the tests. A standard hydrometer analysis was used to find the size distribution of the soil to be filtered. The average distribution is shown on Plate III.

Test Water

Kansas State University tap water was used as the slurry liquid.

Chlorine

Chlorox, a commercial bleach, was added to the water in the feed tank by drip flow from an inverted bottle. The rate was adjusted so that a positive chlorine residual was maintained in the slurry to be filtered. The chlorine was added to eliminate bacterial growth in the feed water.

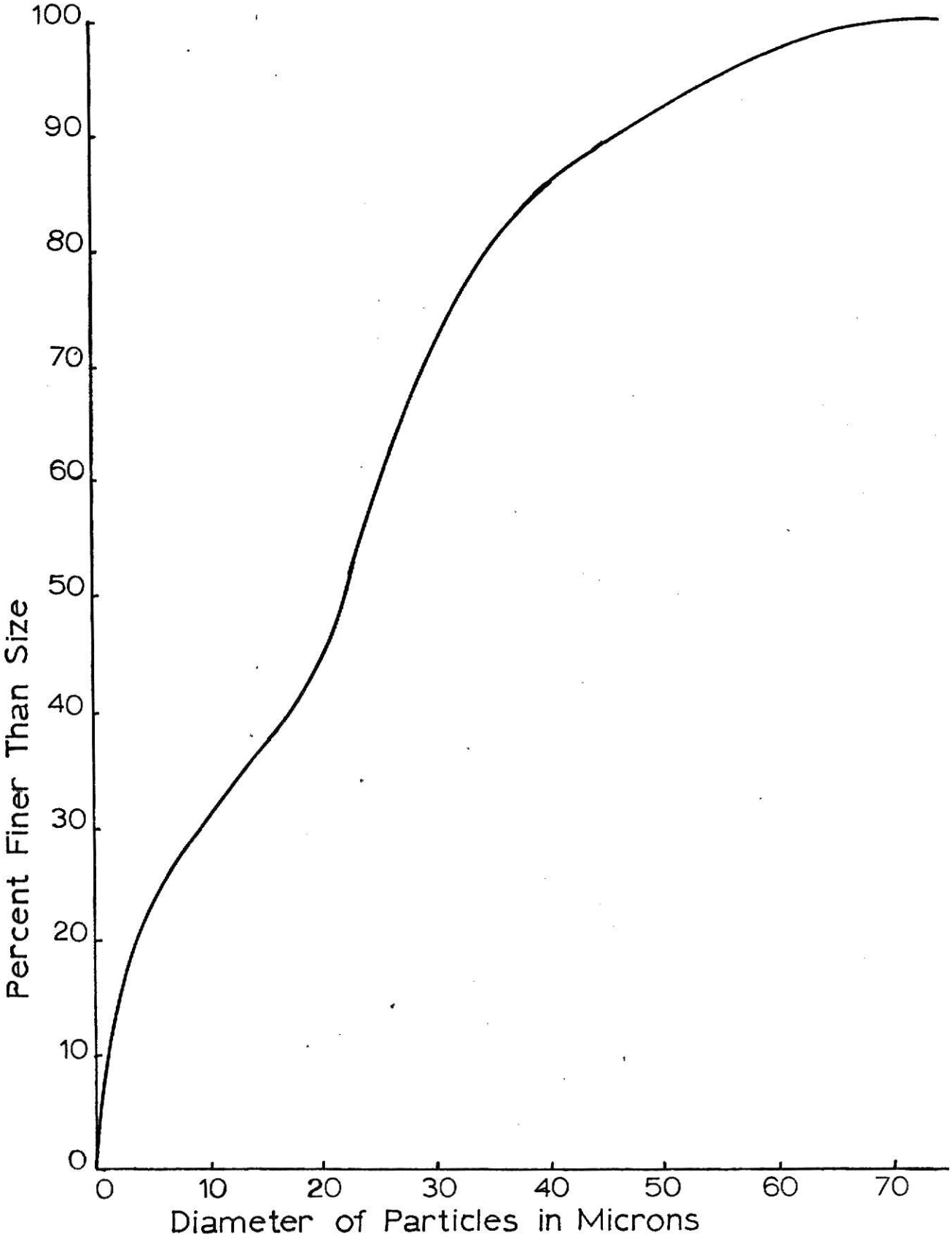
Calgon

For the early runs, Calgon, a commercially prepared water-softener, was added to the feed tank solution at 0.1% concentration. The Calgon was added as an aid in keeping the solids in the feed tank solution in suspension since the sodium ions in the Calgon would replace any calcium ions surrounding the particles. The sodium reduced agglomeration of the particles

EXPLANATION OF PLATE III

The average size distribution of the soil used as suspended solids in the filtration tests.

PLATE III


100
90
80
70
60
50
40
30
20
10
0
Percent Finer Than Size
0
10
20
30
40
50
60
70
Diameter of Particles in Microns

by increasing the amount of electrical repulsion between the particles. The use of Calgon was discontinued after several tests showed it caused unsatisfactory results.

PROCEDURE

Run Preparation

The soil used for the slurry was prepared for a run by collecting the fines that passed a 325 mesh (44 μ) U.S. Standard Sieve. The soil was sieved for a period of 5 minutes through a series of nested sieves with a RoTap, a mechanical shaking device. The low sieving time was used to limit the number of particles having a diameter approximately the size of the sieve openings of 44 μ. The collected fines were weighed and added to the fifty gallons of water in the feed tank at the rate of 0.6505 grams of soil for each ppm of turbidity desired. Runs were made with 32.50 and 65.05 grams of soil to obtain approximately 50 and 100 ppm turbidity respectively. The upper limit value was later adjusted to 80.0 grams. The soil was dispersed first by stirring it in 500 ml of tap water. This solution was then poured slowly into the water in the feed tank. Both recycling and stirring were started before the solution was added. Care was taken to add the solution directly in front of the rotating paddles so that the particles would not settle to the bottom of the feed tank before becoming dispersed. The slurry was then re-cycled and stirred for an hour before the beginning of a run. This was done to allow the particles to become uniformly distributed in the feed tank solution.

After the solution had been prepared, the filter cloth to be used for the run was weighed dry, and the weight was recorded. The filter

cloth was then placed over the 10 mesh screen and fixed in place between the two flanges on the test column. Each run was started with a clean, dry filter cloth.

The effluent tank was then filled with tap water to a level 4 inches above the bottom of the barrel. The hose from the gravity flow pipe was placed down to the bottom of the barrel to dampen surface motion in the tank as water flowed from the gravity trough into the tank. The float from the Stevens recorder was then placed in the water, and the recording pen was placed at the beginning of the chart.

After completion of these preliminary steps, the system was ready to begin a run.

The Run

Immediately prior to the beginning of a run, a feed tank sample was taken at the draw-off valve, 4, Plate II. The flow rate valve, 3, Plate II, was then slowly opened to allow water into the filter column. The water was first admitted slowly to reduce surging and possible air binding across the filter. At the moment water started flowing on the effluent side of the filter, a stop watch was used to begin timing the test. Once the conditions in the column had become somewhat stabilized, valve 2 was opened and valve 1 was closed. The regulating valve and valve 3 were then adjusted so that the desired pressure on the influent side was obtained for the test. Effluent samples were taken at port 6 at time intervals of 0.5, 2, 5, 10, 20, 30, and 60 minutes from the start of a run. After this, samples were taken from both points 4 and 6 at one hour intervals for the first three to four hours. Samples were obtained at random throughout the

duration of the run after the initial four hours. The samples were collected in two ounce, wide-mouth bottles. Temperature measurements were taken immediately after collection of the effluent sample, and both the influent and effluent samples were used for turbidity measurements. All of the samples were labeled as influent or effluent, and the time that the sample was taken was recorded.

The total flow passing through the filter was collected in the effluent tank where the Stevens recorder plotted the rise in the water level with time. This plotting was used to show clearly what was happening to the flow during the run.

Run Completion

The pump was shut off after nearly twenty-four hours of filtration. A short time was allowed after a run for particles kept in suspension above the filter to settle out on the cake. It was necessary to do this because a high concentration of particles formed above the cake, which possibly was a result of a small amount of turbulence in the column. Valve 4 was opened to allow air into the column, and then valve 5 was opened to drain the water above the filter and filter cake. After this stage was completed, the filter cloth was removed from the column. Care was taken at this point to slowly disassemble the flanges in order to drain any water remaining above the cake without carrying a significant amount of cake with it. The filter cloth and cake were then air dried and weighed to obtain the amount of soil removed.

The chart on the Stevens recorder was removed. Several points from the chart were plotted on linear graph paper in converted units of gallons

per foot squared of filter cloth versus time in minutes.

Both the feed tank and the effluent reservoir were emptied and washed at this point. They were re-filled with water in the manner discussed previously to prepare them for the next run.

RESULTS AND DISCUSSION

A total of twenty-five tests were run in this study; however, some of the tests were affected by various extraneous factors and could not be used for a filtration analysis. These factors and the reasons they occurred will be explained.

For the tests in which Calgon was added to the feed tank as an aid in keeping the suspended solids dispersed, a sudden drop in the flow occurred after a few hours. Beyond this point essentially no flow was obtained through the cloth. It was felt initially that the sodium ions from the Calgon were causing the collected solids to remain dispersed after forming on the cake. This factor would increased the tortuosity of the water flowing through the cake and decrease the amount of flow. This was found to be an unjustifiable conclusion by several observations. First, the Calgon was added prior to beginning a run, and the sudden drop occurred a few hours after the test had begun. This factor indicates that is was not a result of dispersion in the cake. If it had been, the flow rates would have continually decreased during the run rather than dropping off suddenly.

Second, clean filters were put into the system using a feed tank slurry which had already reached this state from a previous run. Again "no flow" conditions resulted, but this time they occurred before any cake was able to form on the filter septum. This indicates that it was not a property of the suspended solids in the cake. It was thought that perhaps

bacteria were causing the filter cake to clog. To eliminate this, Chlorox was added to the feed tank solution, but again the condition persisted.

Finally, it was observed that a white precipitate had formed on the cakes when Calgon was used. These precipitates were not analyzed as to chemical composition.

It is not known why the condition did occur and whether or not the precipitate formed had sufficient strength to plug the pores both in the cake and on the filter or whether the "no flow" condition that resulted was even a by-product of the precipitate. This affect on the filtration process resulted in discontinuing the use of Calgon in the feed tank because it entered an artificial, unaccountable factor into the filtration analysis.

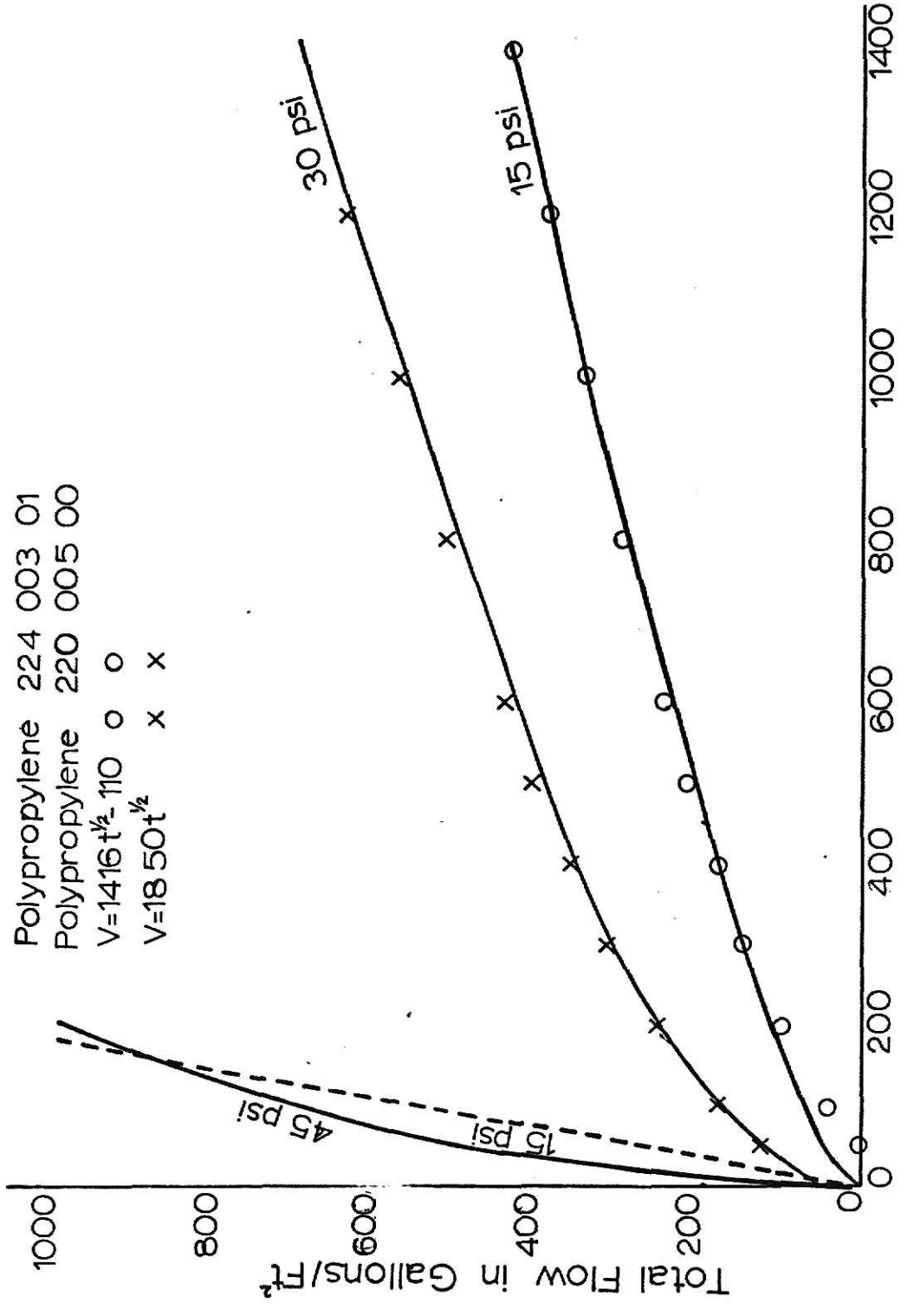
Two other factors also made it unjustifiable to use the test runs in the filtration analysis. The first factor was that the monofilament polypropylene 224 003 01 was not able to remove the suspended solids from the slurry for the size distribution of particles used in the tests. This is shown in Plate IV where the flow continues at a nearly constant rate throughout the duration of a run and again in Plate VI where it can be noted that little turbidity removal occurred. The use of this cloth was discontinued because the pore openings were too large for the particles to bridge and block and thus establish a base for forming a cake.

The second factor is that the 45 psi pressure stressed the fibers in the cloths so that again the openings between the fibers became too large for a cake to form. This is apparent from Plates IV and VI for the multifilament polypropylene 220 005 00. After eliminating the test runs for the aforementioned reasons, ten test runs remained for filtration analysis.

EXPLANATION OF PLATE IV

The total flow through the monofilament polypropylene 224 003 01 at 15 psi and the multifilament polypropylene 220 005 00 at 15, 30, and 45 psi is plotted against time. The mathematical equations that were developed in the analysis are also shown for the multifilament polypropylene 220 005 00 at 15 and 30 psi.

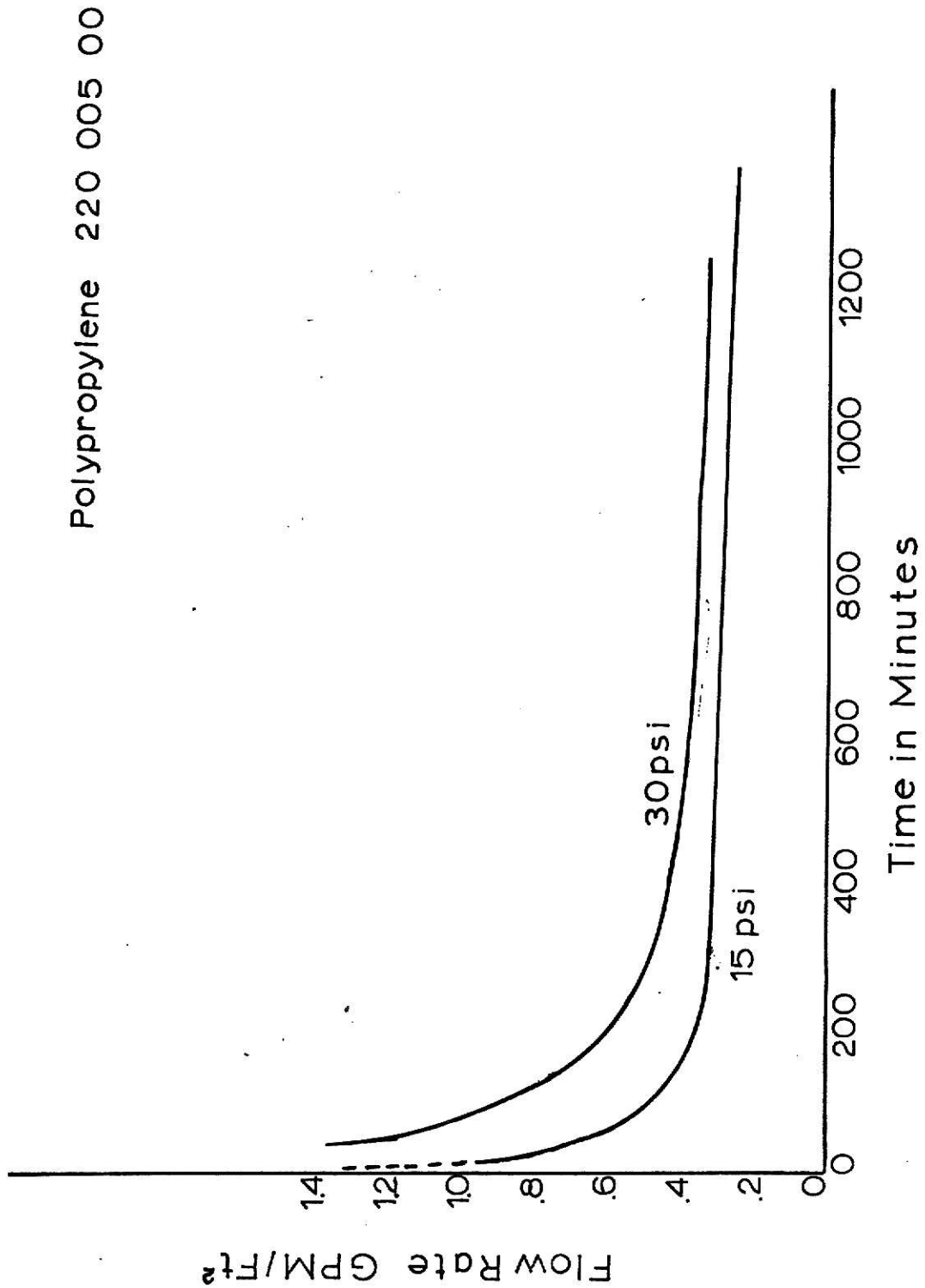
PLATE IV


Polypropylene 224 003 01
Polypropylene 220 005 00
V=1416t½-110 o o
V=1850t½ x x
30 psi
15 psi
45 psi
15 psi
Total Flow in Gallons/Ft²
Time in Minutes
0
200
400
600
800
1000
1200
1400

EXPLANATION OF PLATE V

The variation in the flow rate through the filter for the multifilament polypropylene 220 005 00 at 15 and 30 psi is plotted against time.

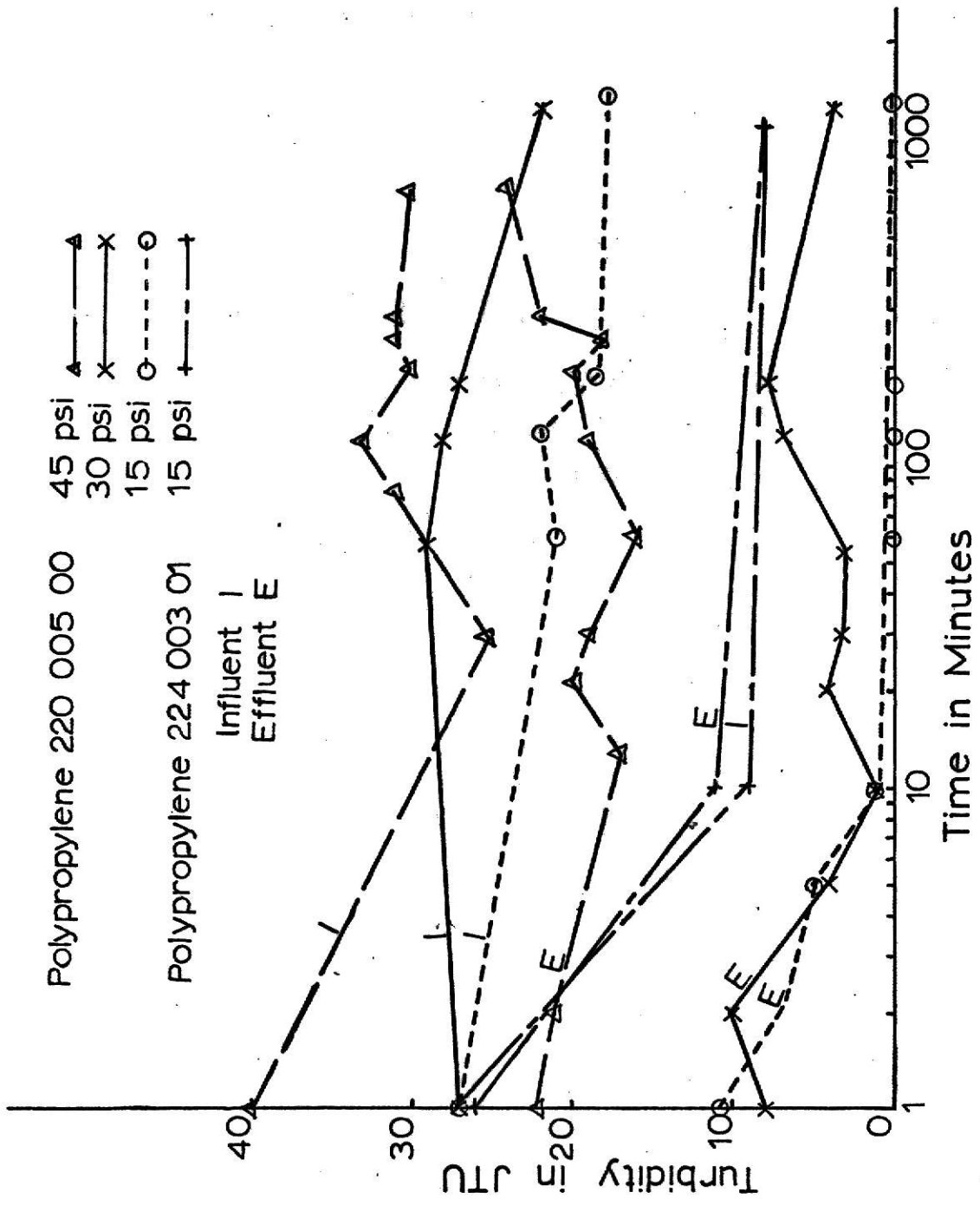
PLATE V


Polypropylene 220 005 00
Flow Rate GPM/Ft²
1.4
1.2
1.0
.8
.6
.4
.2
0
0
200
400
600
800
1000
1200
Time in Minutes
30psi
15 psi

EXPLANATION OF PLATE VI

The influent and effluent turbidities for the monofilament polypropylene 224 003 01 at 15 psi and the multifilament polypropylene 220 005 00 at 15, 30, and 45 psi are plotted against the log of time.

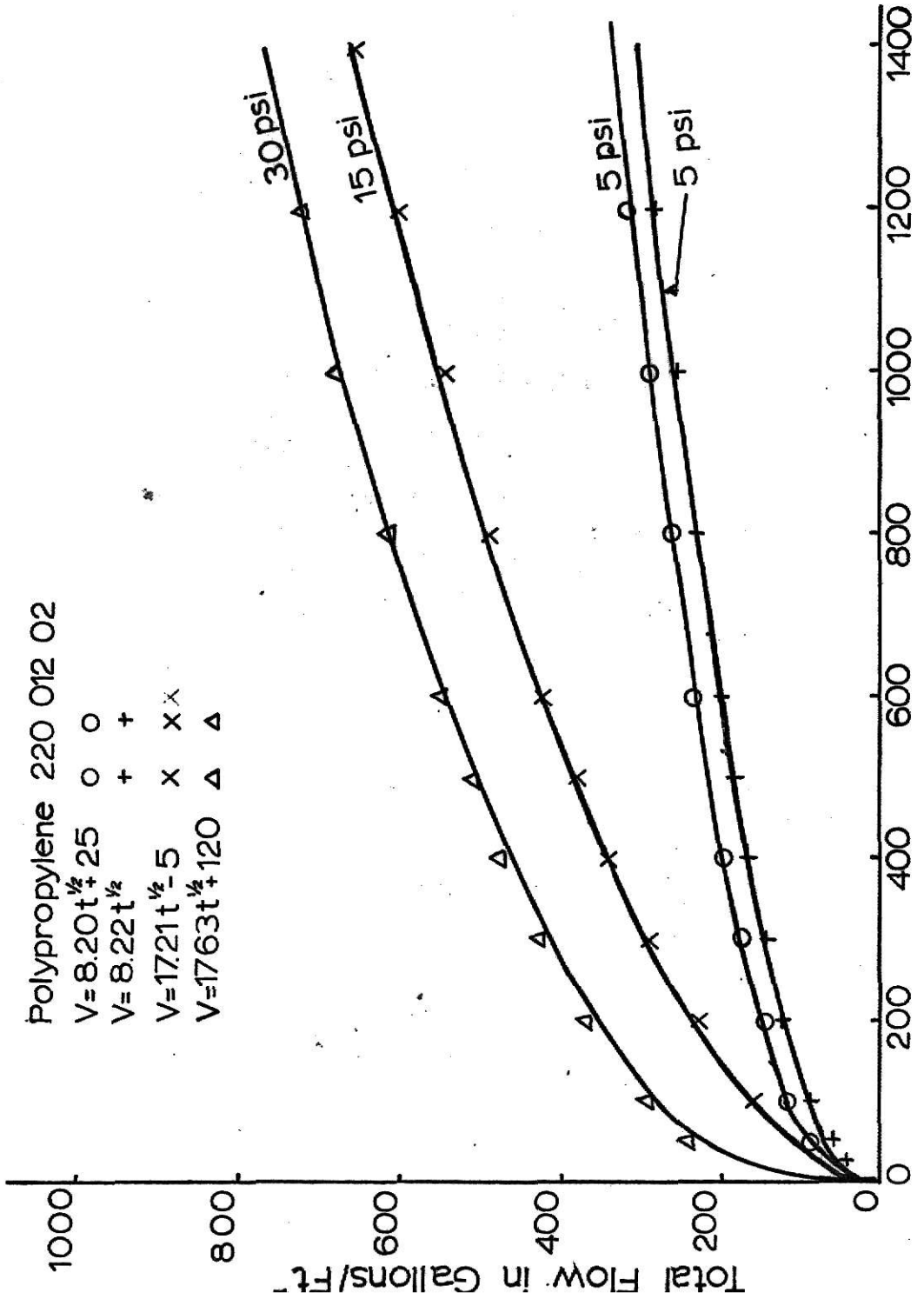
PLATE VI


Polypropylene 220 005 00
45 psi
30 psi
15 psi
Polypropylene 224 003 01
15 psi
Influent I
Effluent E
Turbidity in JTU
Time in Minutes
0
10
20
30
40
1
10
100
1000

EXPLANATION OF PLATE VII

The total flow through the multifilament polypropylene 220 012 02 filter fabric at 5, 15, and 30 psi is plotted against time. The mathematical equations developed in the analysis are also shown for each pressure level.

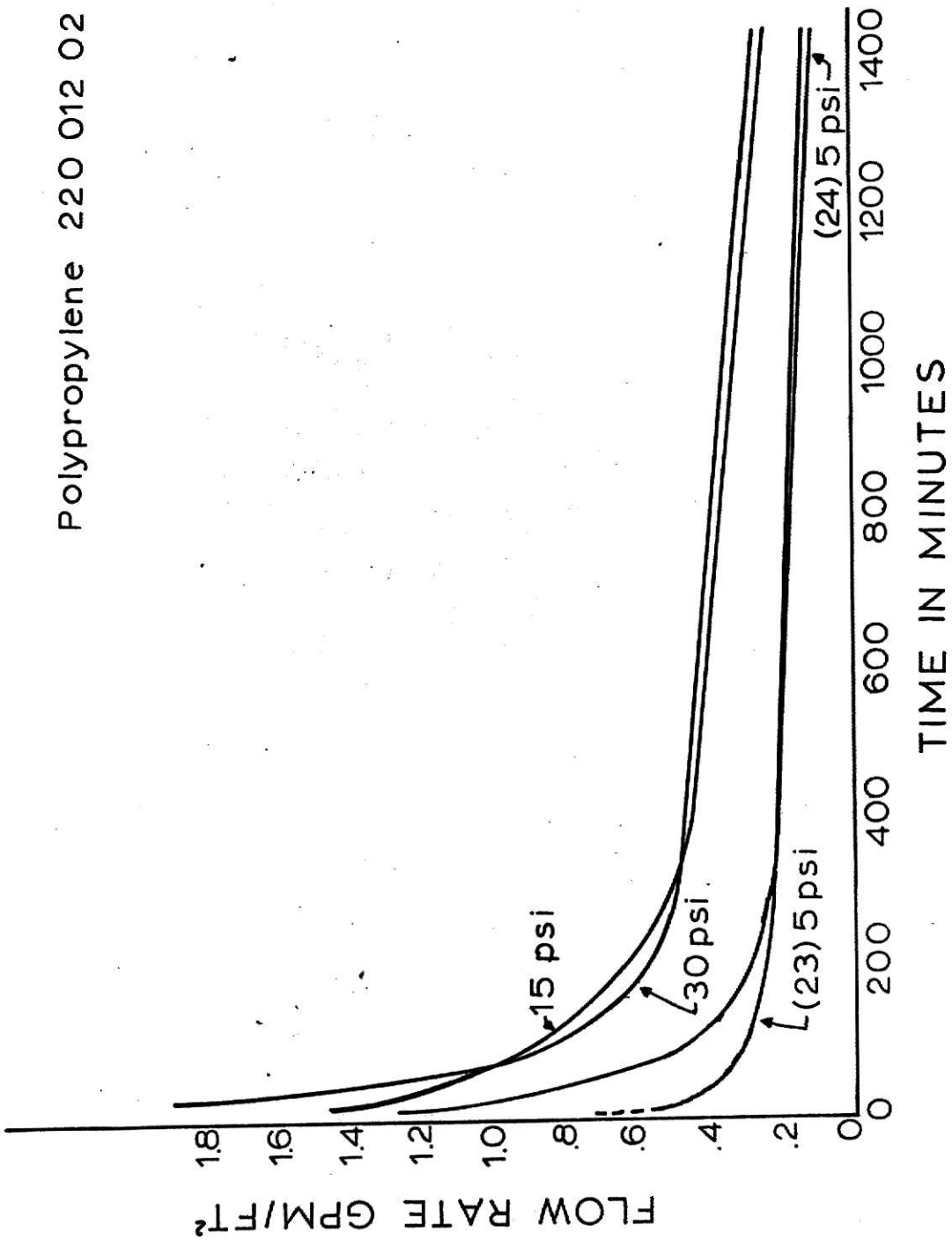
PLATE VII


Polypropylene 220 012 02
V=8.20t^½+25 o o
V=8.22t^½ + +
V=17.21t^½-5 x x
V=17.63t^½+120 Δ Δ
30 psi
15 psi
5 psi
5 psi
Total Flow in Gallons/Ft²
Time In Minutes
0
200
400
600
800
1000
1200
1400

EXPLANATION OF PLATE VIII

The variation in the flow rate through the filter for the multifilament polypropylene 220 012 02 at 5, 15, and 30 psi is plotted against time.

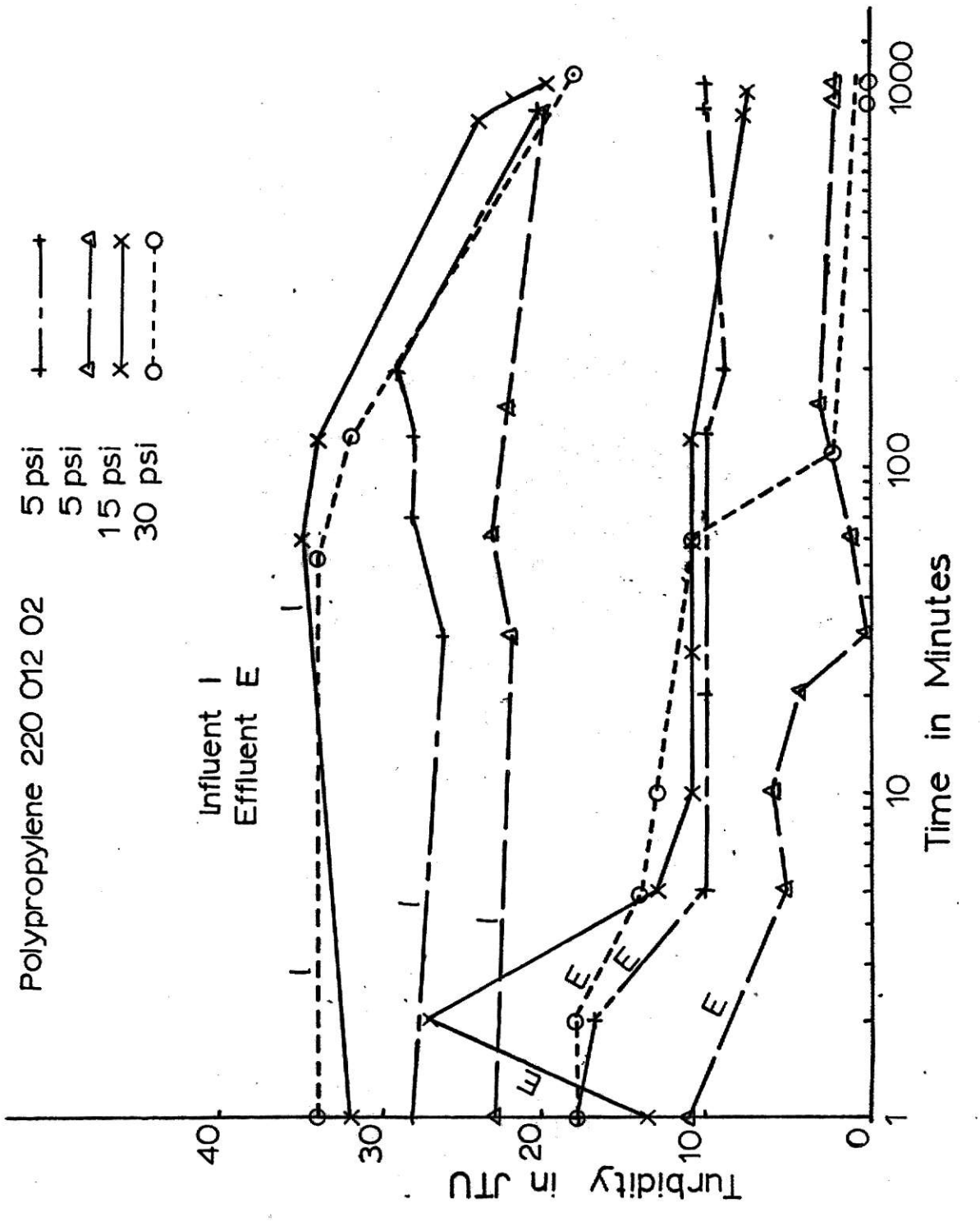
PLATE VIII


Polypropylene 220 012 02
FLOW RATE GPM/FT²
TIME IN MINUTES
15 psi
30 psi
(23) 5 psi
(24) 5 psi
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
0
200
400
600
800
1000
1200
1400

EXPLANATION OF PLATE IX

The influent and effluent turbidities for the multifilament polypropylene 220 012 02 at 5, 15, and 30 psi are plotted against the log of time.

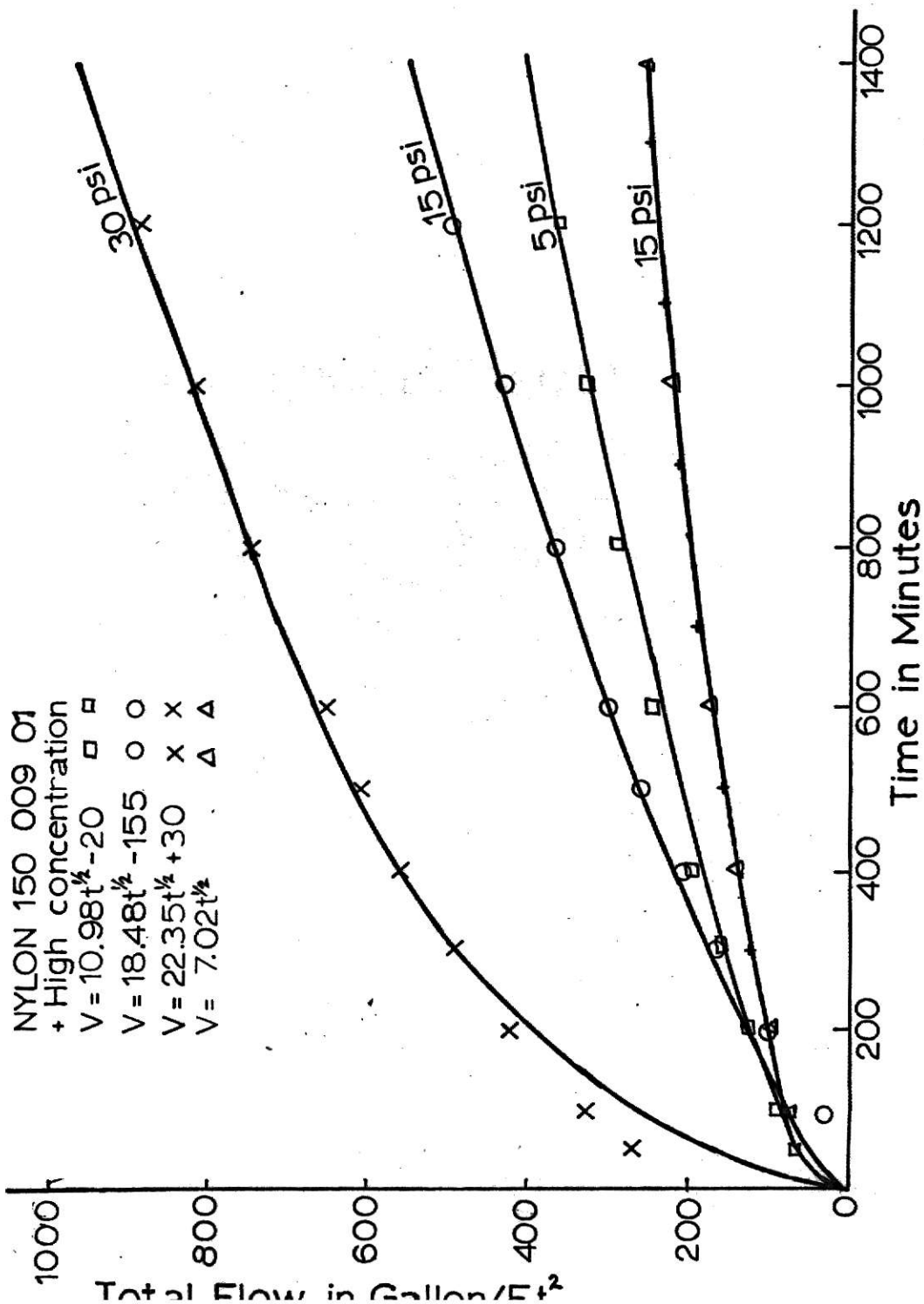
PLATE IX


Polypropylene 220 O12 O2
5 psi
5 psi
15 psi
30 psi
Influent I
Effluent E
Turbidity in JTU
Time in Minutes
0
10
20
30
40
1
10
100
1000

EXPLANATION OF PLATE X

The total flow through the multifilament nylon 150 009 01 filter fabric at 5, 15, and 30 psi is plotted against time. The mathematical equations developed in the analysis are also shown for each pressure level.

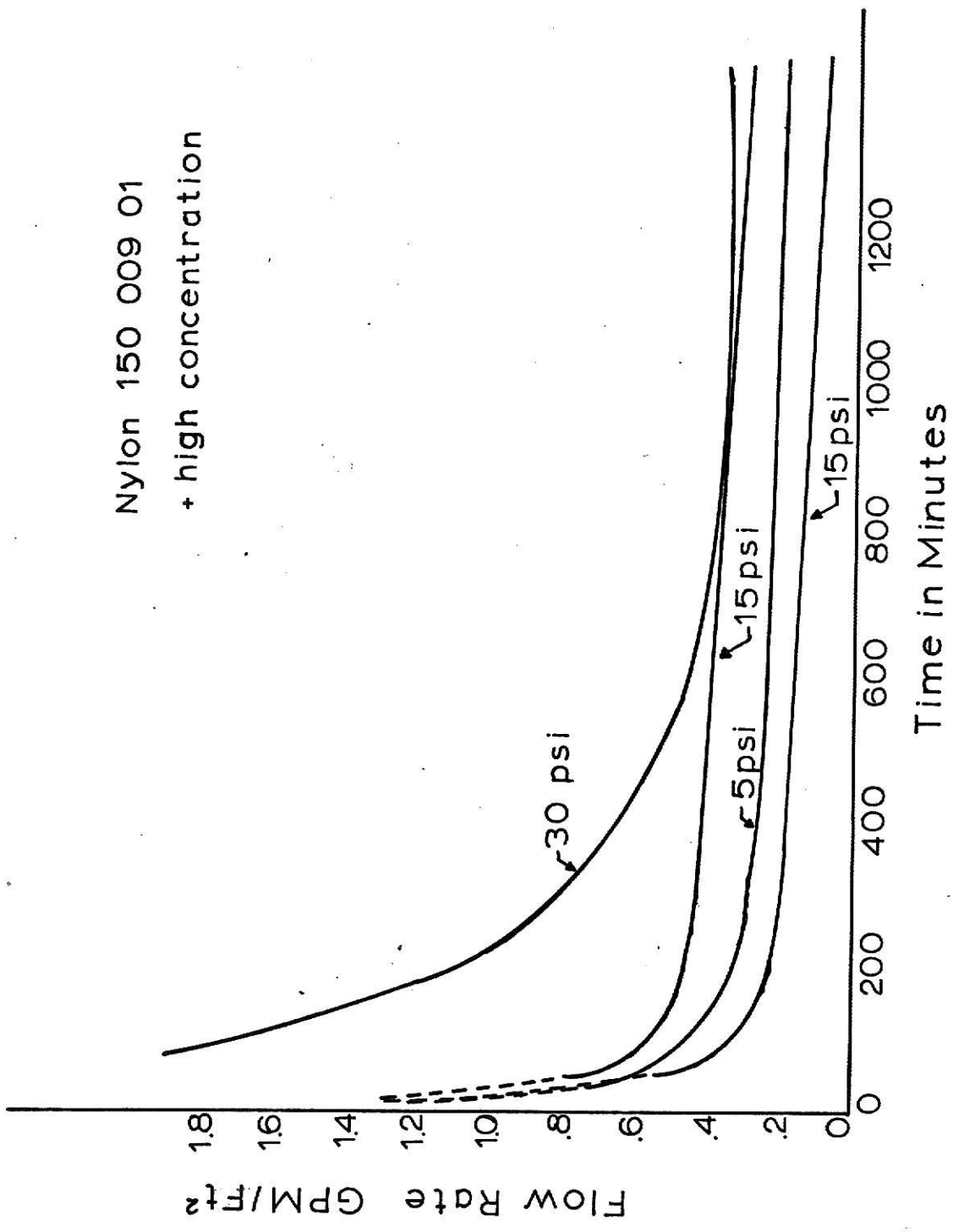
PLATE X


NYLON 150 009 01
+ High concentration
V = 10.98t^½ -20
V = 18.48t^½ -155
V = 22.35t^½ +30
V = 7.02t^½
30 psi
15 psi
5 psi
15 psi
Total Flow in Gallon/Ft²
Time in Minutes
0
200
400
600
800
1000
1200
1400

EXPLANATION OF PLATE XI

The variation in the flow rate through the filter for the multifilament nylon 150 009 01 at 5, 15, and 30 psi is plotted against time.

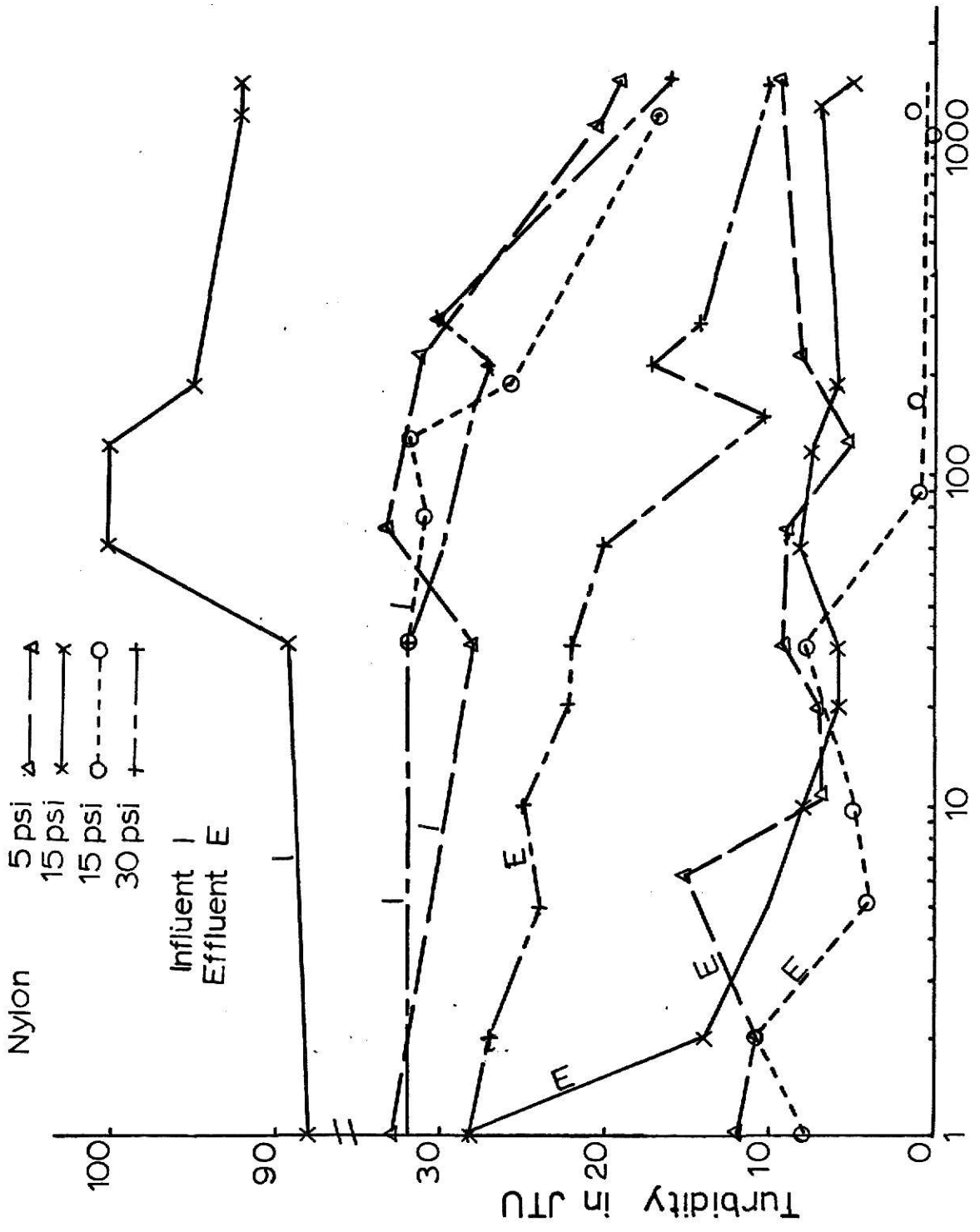
PLATE XI


Nylon 150 009 01
+ high concentration
30 psi
15 psi
5psi
15psi
Flow Rate GPM/Ft²
Time in Minutes
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
200
400
600
800
1000
1200

EXPLANATION OF PLATE XII

The influent and effluent turbidities for the multifilament nylon 150 009 01 at 5, 15, and 30 psi are plotted against the log of time.

PLATE XII


Nylon
5 psi
15 psi
15 psi
30 psi
Influent I
Effluent E
Turbidity in JTU
100
90
30
20
10
0
1
10
100
1000
Time in Minutes

Filtration Analysis

Rushton et al. (37) and Kehat et al. (29) used the general form of the classical filtration equation:

$$V^2 + aV - b = 0 \qquad (8)$$

where $a = \frac{2AR}{C_1 \alpha}$

$$b = \frac{2A^2 \theta \Delta P}{C_1 \alpha \mu}$$

for the case of constant pressure drop accross the growing filter cake. The variables are defined as:

A = Surface area of cloth, cm^2

ΔP = Pressure drop, $dynes/cm^2$

θ = time, seconds

C_1 = Concentration of solids in slurry, gm/cm^3

α = Cake resistance, cm/gm

μ = Viscosity of fluid, gm/cm sec.

R = Resistance of cloth, cm^{-1}.

Rushton states further that the resistance of the filter medium is considered negligible in many applications. His work indicates that filter cloths similar to those used in this work have a maximum value of $R = 51.51 \times 10^{-6}$ cm^{-1} which would be insignificant for the accuracy obtainable in most work.

If the resistance of the cloth is assumed negligible, equation 8 now becomes:

$$V^2 = b \qquad (9)$$

and when converted to the units used in this study, it is:

$$V^2 = 5.868 \times 10^7 \frac{A^2 \Delta P}{C_1 \alpha \mu} \theta \qquad (10)$$

where A = Area, ft^2

ΔP = Pressure drop, $pound/in^2$

C_1= Concentration of solids in slurry, gm/gal

θ = Time, minutes

α = Cake resistance, ft/pound

μ = Viscosity, pound sec/sq. ft.

R = Resistance of cloth, ft^{-1}.

Defining equation 3 further, we find that a unit area A of filter cloth was used with a constant pressure drop ΔP for a run. The flow through the cloth was also adjusted to a standard temperature (68°F) to set μ equal to a constant. Now if it is assumed that C_1 and α remain constant, equation 10 takes on the form:

$$V^2 = K\theta$$

which can be written:

$$V = K_1\theta^{\frac{1}{2}} \qquad (11)$$

where

$$K_1 = (5.868 \times 10^7 A^2 \Delta P / C_1 \alpha \mu)^{\frac{1}{2}} \qquad (12)$$

The assumption that C_1 and α are constant is valid if the concentration of suspended solids in the slurry impinging upon the cake and filter remain constant and if the porosity of the formed cake is uniform. The validity of these assumptions will be discussed later.

Values for K_1 were found by fitting equation 11 to the data plotted on log log paper of θ versus V. The equations obtained are shown on Plates IV, VII, and X along with point plots along the curves. In some cases, e.g. $V - 14.16t^{\frac{1}{2}} - 110$ on Plate IV, a constant was added at the end of the equation to shift the point plots up or down the abscissa. The use of a

constant at the end was felt to be justifiable to account for discrepancies occurring at the beginning of the filtration cycle. These discrepancies are two-fold: 1) they were a property of the system and operator for the run, thus being completely independent of the filter cloth; and 2) they were a property of the cloth during the blocking, bridging, and bleeding stage at the beginning of the filtration cycle. The first discrepancy resulted because the system was limited by design for the maximum flow that could be obtained. This created a time lag in bringing the system up to the pressure for which the test was to be run. The result is a loss of flow through the cloth before the cake filtration stage takes over. The operator also creates an error, the magnitude of which is proportional to the speed at which the valves are opened or closed while bringing the run up to the desired operating pressure.

The second discrepancy is dependent upon the cloth and is a function of the openings between the fibers, the weave, and the twist of the fibers (see page 9). All of these factors determine the rate at which cake filtration develops control over the filtration process.

By examination of Plates IV, VII, and X we can see that good agreement is obtained between theoretical and experimental values and that the assumption that R is negligible is sufficient for predicting the filtration process.

If the cake truly does control the filtration process, then any variable parameters in equation 10 which are not controlled or measured during testing should be the same between cloths. This relationship may not hold for the different pressures if the cake is compressible. This is based further on the assumption that the size distribution of suspended solids in the slurry is nearly the same between tests.

As stated previously, the area A, the pressure drop ΔP, and the viscosity μ are the same for runs at the same pressure. Therefore, these terms of equation 10 are controlled by the system. This leaves only the values C_1 and α to define.

If it is assumed that C_1 remains constant throughout a run, there are two methods by which a value for C_1 may be determined. The first of these was established before the run began when a known amount of soil and water was put into the feed tank. These two values could then be used to determine a value of C_1. The second method consisted of weighing the amount of soil collected on the filter and combining this with the data from the Stevens recorder for total flow. The values obtained for C_1 by both method I and method II are shown in Table 1. It can be seen from Table 1 that method I and method II sometimes differed by an order of magnitude. This is particularly true for the tests run at 5 psi.

This discrepancy between the methods can be explained. Plates VI, IX, and XII show that in most cases, particles bleed through the cloth throughout a run. This bleeding causes method I to be in error since no allowance is made for particles passing through the filter. Also, sedimentation occurred in the column as the water was being re-cycled above the filter. This is shown in Table 1 when the amount removed, measured by weighing the cake, has a value greater then theoretically predictable by method I. This can be verified also by the fact that the turbidity on the influent side decreased during a run, and that no noticeable sedimentation occurred in the feed tank.

Since $C_1 = f(\text{cake build-up})$, it was felt that the use of method II was more justifiable. Special note should be made that method I would

Table 1

Concentration of solids in feed tank slurry by two methods.

Cloth mat.	Cloth number	Test press.	Soil to 50 gal.	Method I C_1	Soil collected on filter	Total flow test	Method II C_1
		psi	grams	gn/gal	grams	gal	gn/gal
Poly	22001202	5	32.5	0.6505	11.93	8.2	1.32
Poly	22001202	5	30.2	0.6040	9.46	8.0	1.14
Poly	22001202	15	32.5	0.6505	——	17.4	——
Poly	22001202	30	32.5	0.6505	12.68	19.4	0.618
Nylon	15000901	5	32.5	0.6505	11.52	10.9	1.05
Nylon	15000901	15	80.0	1.60	26.10	6.5	4.02
Nylon	15000901	15	32.0	0.6400	15.83	28.2	0.580
Nylon	15000901	30	32.5	0.6505	11.55	24.4	0.424
Poly	22000500	15	——	——	3.76	11.6	0.323
Poly	22000500	30	32.5	0.6505	12.50	16.7	0.748

have been easier to use for defining the results since the value was nearly constant between runs.

After determining a value for C_1, α remains the only undefined term in equation 10 and should be the value that is comparable in the results of the different filtration tests. Solving equation 12 for α we have:

$$\alpha = \frac{5.368 \times 10^7 A^2 \Delta P}{C_1 \mu K_1^2}$$

The values determined for α are shown in Table 2. The results show that α increases with pressure as might be expected since some compression should occur with increased pressure. The values of α at the 15 psi level agree very well except for the multifilament polypropylene 220 005 00. The large discrepancy by this filter cloth resulted when the test was run using the slurry left in the feed tank from a previous run. The suspended solids left in the slurry would have a finer size distribution; larger particles settled out in the column during the previous run which would cause the resistance to flow in the cake (α) to increase.

The differences in the values obtained for α possibly are a result of variations in C_1 during a run and the averaging method applied to establish C_1. The variation at the 5 psi level could possibly be quite large because most of the sedimentation would occur in the early stages of the run; later the C_1 value would correspond more to the value determined by method I. These fluctuations would cause α to vary greatly also because the larger particles would tend to form on the cake early, and a finer distribution of particles would make up the latter stages of the cake.

At 30 psi, though, the discrepancy may be explained by observation of the cake once it had dried. At this high pressure level, it was par-

ticularly noticeable that pockets formed in the cake next to the cloth. These pockets formed when particles in this region were able to bleed through the cloth after they had once collected as cake. This results in weak points in the cake, and the degree of this factor could cause variations in the determined value of α.

Further analysis of α reveals that the mean values of α, at each pressure level shown in Table 2, become linear when plotted against the square of the absolute pressure as shown in Plate XIII. It follows that α can be predicted by the equation:

$$\alpha = 1.55 \times 10^{4} P_{ab}^{2} + 8.1 \times 10^{6} \qquad (13)$$

where α = Resistance, ft/lb

P_{ab}^{2} = Absolute pressure above filter cake, psi.

This result is significant if further testing shows that the resistance to flow for any soil can clearly be defined as an equation of the form:

$$\alpha = cP_{ab}^{2} + d \qquad (14)$$

where c and d = Constants dependent upon size distribution, the porosity, the state of agglomeration, et cetera.

This relationship would be useful in several fields other than in filtration since determining α at any two points would determine the value at any pressure.

As discussed previously, serious errors could have resulted in assuming C_1 and α to be constant throughout a run. However, these errors tend to complement one another so that the value $C_1\alpha$ remains fairly constant within the limits of these tests. For example, it is known that if the turbidity in the feed tank drops, this is a result of settling by the

Table 2

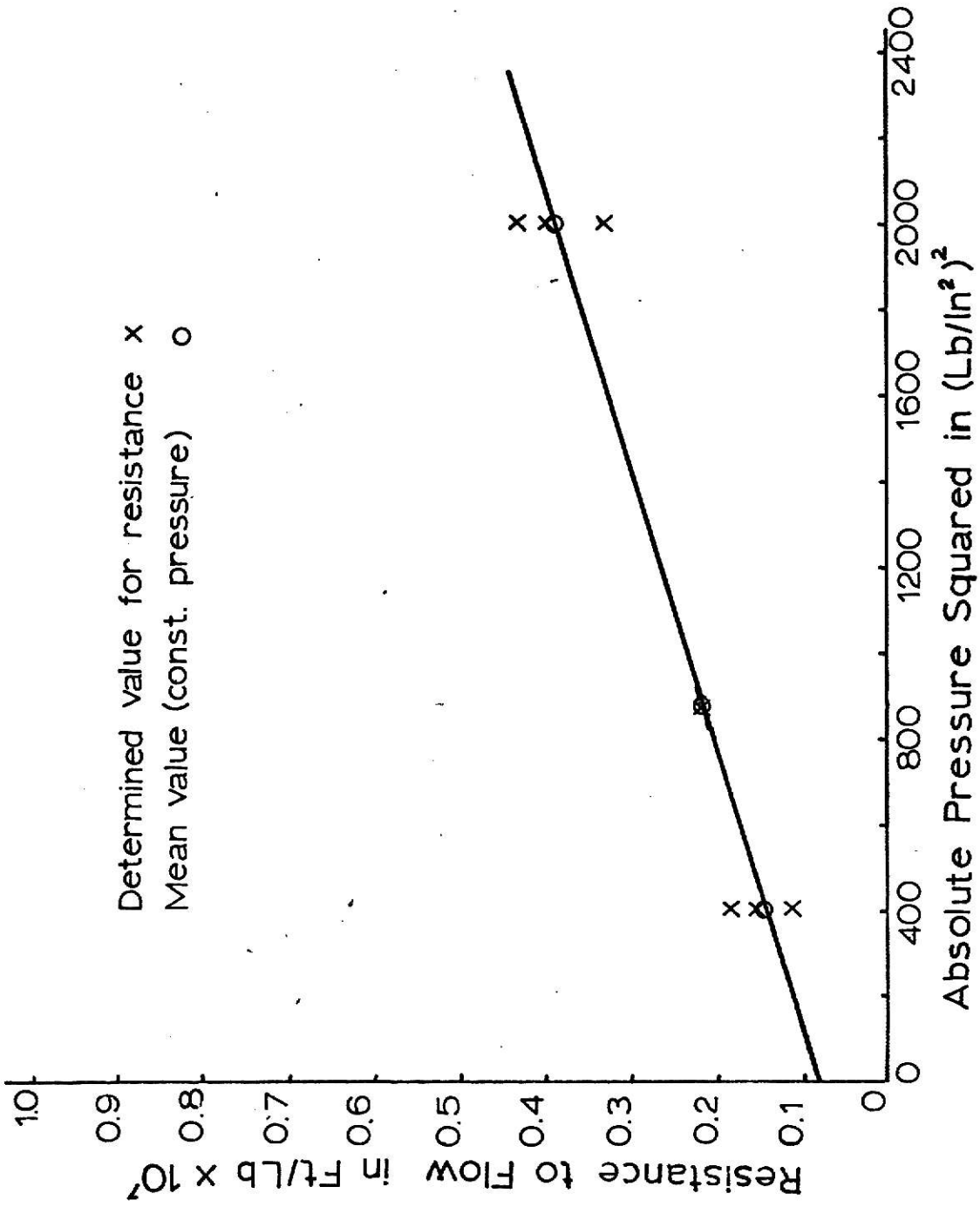
Comparison of values calculated from the filtration equation.

Cloth material	Cloth number	Filtration pressure	K_1	C_1		Correction
Poly	22001202	5	8.2	1.32	.156	+25
Poly	22001202	5	8.22	1.14	.180	———
Poly	22001202	15	17.21	.6505	.216	-5
Poly	22001202	30	17.63	.618	.433	+120
Nylon	15000901	5	10.98	1.05	.110	-20
Nylon	15000901	15	18.48	.580	.210	-155
Nylon	15000901	15	7.02	4.02	.210	———
Nylon	15000901	30	22.35	.424	.393	+130
Poly	22000500	15	14.16	.323	.643	-110
Poly	22000500	30	18.5	.748	.325	———

EXPLANATION OF PLATE XIII

A plot of the determined values for the cake resistance of the tests against the absolute pressure of the tests above the filter cake squared.

PLATE XIII


Determined value for resistance x
Mean value (const. pressure) o
Resistance to Flow in Ft/Lb x 10⁷
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
400
800
1200
1600
2000
2400
Absolute Pressure Squared in (Lb/In²)²

larger particles. This reduction in solids lowers C_1; however, since the solids left are finer, the cake formed will have a larger value for α. Control methods should be introduced into any further studies to nullify variations in C_1 and α.

The previous discussion leads to one important thought. If the entire filtration process is controlled by the cake, then it would be a relatively simple matter of describing C_1 and α or a combination of $C_1\alpha$ to predict the filtration rates of any raw-water for any soils.

Turbidity Removal and Flow Rates

From Plates VI, IX, and XII it can be seen that the filter cloths in this study are capable of removing much turbidity from the water. By visual observation of the cakes, it appears that nearly all of the suspended solids are removed by the cake, but turbidity is measured in the effluent because particles already formed as cake bleed through weak points in the filter septum as mentioned earlier. The amount of turbidity reduction is then dependent upon the number of weak points in the cloth. This factor varies with the cloth and the pressure. The greatest turbidity removal occurred at 15 psi. Greater turbidity in the effluent at 30 psi can be explained by stresses on the fibers of the cloth. At 5 psi no substantial explanation can be offerred for less turbidity reduction without further testing.

The flow rates through the cloths are shown on Plates V, VIII, and XI, and as would be anticipated they continue to decrease throughout the run. At the end of twenty-four hours the values vary from .10 to .34 gpm per square foot of filter. These values are all dependent upon the factors

mentioned earlier. These values of the flow rate would mean from 144 to 490 gallons per day per square foot which is within the flow range of slow sand filters.

SUMMARY AND CONCLUSIONS

Twenty-five tests were run in the filtration analysis of four different filter cloths. Some of the tests, however, could not be used in the analysis because of various extraneous factors. These factors consisted of using Calgon in the feed tank, testing a filter cloth in which the pores were too large to trap the particles, and using too high of a pressure which stressed the fibers in the filter cloths.

When Calgon was used as an aid to keep the particles in the feed tank in suspension, a sudden drop in the flow would occur after a few hours. These tests were not used in the filtration analysis because the Calgon added an artificial, undefined parameter to the filtration process. Other tests also were not used in the analysis including the tests involving the monofilament polypropylene filter 224 003 01 which had pore openings which were too large to permit clogging and bridging of the particles on the cloth. The tests run at 45 psi were not used because the cloths became stretched so that once again bridging and clogging could not occur.

In the ten tests used for the study, it was found that the filtration process could be explained by the equation:

$$V^2 + aV - b = 0$$

where $a = \frac{2 c_s A R}{c_1 \alpha}$

$$b = 5.366 \times 10^7 \frac{A^2 \Delta P}{c_1 \alpha \mu}$$

for which A = Area, square feet

θ = Time, minutes

C_1 = Concentration of solids in the slurry, gm/gal

ΔP = Pressure drop, lb/inch^2

α = Cake resistance, ft/lb

μ = Viscosity, lb sec/ ft^2

R = Resistance of cloth, ft^{-1}.

The middle term of the preceeding equation was neglected when it was found justifiable to consider R to be insignificant. The equations developed took on the form:

$$V = K_1\theta^{\frac{1}{2}}$$

This means the complete filtration process is controlled by the cake. It was necessary for some of the equations to add or subtract a constant to adjust the theoretical curve up or down the abscissa. This was justified because of limitations in the system for testing and variations in the rate of blocking and bridging of particles upon which a cake could form.

Values for C_1 were obtained by weighing the soil that collected upon the filter cloth for a known quantity of water passing through the filter. Finding C_1 by this method was based upon the assumption that C_1 was constant throughout the run. This assumption was not completely met because settling occurred in the column above the filter.

The only undefined variable remaining was α. It was determined by the equation:

$$\alpha = 5.368 \times 10^7 \frac{A\ P}{C_1\ K_1^2}$$

The values obtained for α increased with pressure, which indicated that the filter cake was compressible, but differences occurred in α at

the same test pressures. At the lowest pressure (5 psi) the discrepancies were possibly a result of the large variations in C_1 that would occur due to settling in the column in the early stages, and a finer size distribution of particles in the latter stages of the run. Discrepancies occurred at the highest pressure (30 psi) because observation of the cake after drying revealed that pockets formed in the cake directly above the filter. These pockets were a result of particles bleeding through stressed areas of the cloth after once having formed as cake. They created variations in the cake and could account for variations in determined α.

When the increase of α with pressure was analyzed further, it was found that α could be predicted by the equation:

$$\alpha = 1.55 \times 10^4 P_{ab}^2 + 8.1 \times 10^6$$

where α = Resistance, ft/lb

P_{ab}^2 = Absolute pressure above filter cake, psi.

This equation would be significant if further testing would prove α varies in a manner analogous to it.

The following are some conclusions which can be drawn within the limits of these experiments:

1. For the filter cloths and pressure ranges tested, the filtration was controlled by the filter cake after bridging and blocking were completed. Thus, the resistance of the filter medium can be considered negligible.
2. The filter cloth is only a septum upon which a cake forms.
3. The initial flow through the filter cloths was dependent upon the bridging, blocking, and bleeding characteristic of the individual cloth and limitations in the system.

4. The mechanical straining of the filter cloth is capable of turbidity removal, but nearly all of the turbidity is removed in the cake. The turbidity on the effluent side is also subject to bleeding of particles through the filter cloth after they were once formed as cake.
5. The filter cake is compressible over the pressure ranges tested, and the increased resistance to flow in the cake varies linearly as a function of the absolute pressure squared.
6. The filtration process can be described mathematically if the values of the concentration of the particles in the solution (C_1) and the resistance to flow in the filter cake (α) are known.
7. The flow rates obtained for the cloths tested were comparable to slow sand filters.

SUGGESTIONS FOR FUTURE RESEARCH

The manner in which filter cloths can be used in filtration is quite versatile. It is suggested that any further testing of filter cloths be approached in either of the two following ways. The first would use a tight filter medium through which little, if any, bleeding of particles would occur. With this type of system the cloth could be exposed to the flow for short periods of time only before cleaning would be necessary. This type of filtration would be dependent upon the filter cloth alone since a cake would not have time to form. The second method of testing would involve the use of an open filter cloth with filter aids added to the slurry to be filtered. The filter aids would increase the porosity in the filter cake. This type of system would be used for longer periods of time.

It is further recommended that the relationship between the cake resistance and the absolute pressure above the filter cake be tested using various soils and size distributions.

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REFERENCES

1. Baird, R.L. and Perry, M.G. "The Distribution of Porosity in Filter Cakes," Filtration and Separation, pp. 471-475, Sept./Oct. 1967.

2. Baylis, John R. "Review of Filter Bed Design and Methods of Washing," Journal—American Water Works Association, Vol. 51, No. 11, pp. 1433-54, Nov. 1959.

3. Bell, George R. "Design Criteria for Diatomite Filters," Journal—American Water Works Association, Vol. 54, No. 10, Oct. 1962.

4. Buck, F.W. "Diatomite Filtration of Water Used for Secondary Recovery," Producers Monthly, June 1964.

5. Camp, T.R. "Sedimentation and the Design of Settling Tanks," ASCE Transactions, p. 895, 1946.

6. Carman, P.C. "Fundamental Principles of Industrial Filtration," Institute of Chemical Engineers Transactions, Vol. 16, pp. 168-183, 1938.

7. Carter, F.C., Ludwig, H.F., Ongerth, H.J., Harman, J.A., and Woody, S.H. "Behavior and Evaluation of Microstraining for a Supply in California," American Water Works Association Journal. Vol. 54, No. 5, pp. 606-620, May 1962.

8. Catlin, L.J. "Industrial Filtration," American Water Works Association Journal. Vol. 53, No. 4, April 1961.

9. Clyma, Wayne and Jensen, M.E. "Flocculent Used to Remove Sediments from Playa Lake Water Used for Groundwater Recharge," Progress Report #2144. Texas Agricultural Experiment Station, Texas A&M College. May 16, 1960.

10. Craft, T.F. "Review of Rapid Sand Filtration Theory," American Water Works Association Journal. Vol. 58, No. 4, pp. 428-439, April 1962.

11. Curry, R.B., Barker, G.L., and Strach, Z. "Interrelation of Physical and Chemical Properties in Flow of Colloidal Suspensions in Porous Media," ASAE Transactions. Vol. 8, No. 2, 1965.

12. Daniel, E.R. and Garton, J.E. "An Automated Upflow Filter for Domestic Water Supplies," Paper No. 67-213, Presented at 60th Annual Meeting of ASAE.

13. Diaper, E.W. and Ives, K.J. "Filtration through Size-Graded Media," ASCE Journal (San. Engr. Div.). Vol. 91, #SA 3, Part 1. June 1965.

14. Ehlers, V.M. and Steel, E.W. Municipal and Rural Sanitation. New York: McGraw-Hill Book Company, 1950. 4th edition.

15. French, R.C. "Filter Media," Chemical Engineering. Vol. 70, No. 21, pp. 177-192. Oct 14, 1963.

16. Grace, H.P. "Structure and Performance of Filter Media," Amer. Inst. Chem. Engr. Jrnl. Vol. 2, No. 3, pp. 307-336. Sept. 1956.

17. Hansen, S.P. and Culp, G.P. "Applying Shallow Depth Sedimentation Theory," Jrnl. Amer. Water Works Assoc. Vol. 59, p. 1134, 1967.

18. Hansen, S.P., Richardson, G.H., and Hsiung, A. "Some Recent Advances in Water Treatment Technology," Presented at the National Meeting of the Amer. Inst. of Chem. Engr. New Orleans, March 16-20, 1969.

19. Hauser, V.L. and Lotspeich, F.B. "Artificial Groundwater Recharge through Wells," Soil and Water Conservation Journal. Vol. 22, No. 1. Jan/Feb. 1967.

20. Hauser, V.L., and Signor, D.C. "Water Conservation and Groundwater Recharge Research," Texas Agricultural Experiment Station, Texas A&M University, MP-850, Sept. 1967.

21. Herbert, R.E. "Development of a New Type of Rapid Sand Filter," ASCE Journal (San. Engr. Div.). Vol. 92, #SA1, pp. 31-39. Feb. 1966.

22. Hermans. P.H. and Bredée, H.L. "Principles of Mathematical Treatment of Constant Pressure Filtration," Society of Chemical Industries Journal. Vol. 55T, pp. 1T-4T, 1936.

23. Hiler, E.A., Curry, R.B., and Schwab, G.O. "Electrokinetic Removal of Colloids from Suspension," ASAE Transactions. Vol. 8, No. 1, pp. 79-82. 1965.

24. Hill, R.D. "Characteristics of Slow Sand Filters for Pond Water Filtration," ASAE Transactions. Vol. 7, No. 3, 1964.

25. Hudson, H.E. "Declining-Rate Filtration," Amer. Water Works Assoc. Journal. Vol. 51, No. 11, pp. 1455-1463. Nov. 1959.

26. Hutchens, J.R. "Interview on a Groundwater Recharge Operation," Irrigation Age. Oct. 1968.

27. Johns-Manville Corporation. "The Filtration of Water," Johns-Manville Celite Filter Aids, 1964.

28. Kabler, P.W. "Microbial Considerations in Drinking Water," Amer. Water Works Assoc. Vol. 60, No. 10, pp. 1173-80. Oct. 1968.

29. Kehat, E., Lin, A., and Kaplan, A. "Clogging of Filter Media," Industrial and Engineering Chemistry, Process Design and Development Division, Vol.46, No. 1. Jan. 1967.

30. Lec, P.L. "The Compressibility of Filter Cakes and Its Influence on the Filtration Equation," Filtration and Separation. Pp. 114-123. Mar./Apr. 1964.

31. Ling, J.T. "Progress in Technology of Water Filtration," Water and Sewage Works. Vol. 109, No. 8, pp. 315-319. Aug. 1962.

32. McGregor, R. "Porosity in Filter Cakes," Society of Dyers and Colourers Journal. Vol. 81, pp. 429-444. 1965.

33. Oeben, R.W., Haines, H.P., and Ives, K.J. "Comparison of Normal and Reverse Graded Filtration," Amer. Water Works Assoc. Jrnl. Vol. 60, No. 4, pp. 420-439. April 1968.

34. Perry, M.G. "Filter Cakes—I," Filtration. Pp. 253-255. Sept./Oct. 1964.

35. Riddick, T.M. "Zeta Potential and Its Application to Difficult Waters," Amer. Water Works Assoc. Jrnl. Vol. 53, No. 8. Aug. 1961.

36. Roebeck, G.G., Dostal, K.A. and Woodward, R.L. "Studies of Modification in Water Filtration Systems—Double Layered," Amer. Water Works Assoc. Jrnl. Vol. 56, No. 2, pp. 198-213. Feb. 1964.

37. Rushton, A., Green, D.J., and Khoo, H.E. "Flow of Fluids in Filter Cloths," Filtration and Separation. Pp. 213-216. May/June 1968.

38. Smit, P. "Upflow Filter," Amer. Water Works Assoc. Jrnl. Vol. 55, No. 6, pp. 804-806. June 1963.

39. Smite, E.G. "Fabric Filter Media," Chem. Engr. Progress. Vol. 47, No. 11, pp. 545-549. Nov. 1951.

40. Sniegocki, R.T., F.H. Bayley III, K. Engler, and J.W. Stephens. "Testing Procedure and Results of Studies of Artificial Recharge in the Grand Prairie Region Arkansas," Geological Survey Water-Supply Paper #1615-G.

41. Sperry, D.R. "Principles of Filtration—II," Chemical Engineering. Vol. 17, p. 161. 1917.

42. Task Group Report, "Artificial Groundwater Recharge," Amer. Water Works Assoc. Jrnl. Vol. 55, No. 6, pp. 705-709. June 1963.

43. Turre, George J. "Use of Microstraining Unit at Denver," Amer. Water Works Assoc. Jrnl. Vol. 51, No. 3, pp. 354-362. March 1959.

44. Wheatstone, G.A. "Mechanism of Groundwater Recharge," ASAE Transactions. Vol, 35. 1954.

45. Wyllie, M.R. Jr. and Gregory, A.R. "Fluid Flow through Unconsolidated Porous Aggregates," Industrial and Engineering Chemistry. Vol, 47, No. 7, p. 1379. July 1968.

FILTRATION ANAYLSIS OF FOUR DIFFERENT FILTER FABRICS

by

JACK DAVID ROSE

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ABSTRACT

The purpose of this study was to analyze the filtration performance of four different filter fabrics. These filter cloths consisted of the following: one monofilament polypropylene cloth, two multifilament polypropylene cloths of different porosities, and one multifilament nylon cloth. For testing these cloths the apparatus was composed of a feed tank, a centrifugal pump, a pressure regulating valve, a pressure gauge, a column two inches in diameter to support the filter cloth, and an effluent tank in which the water level was recorded by time.

Top soil, which was obtained from the Sandyland Experiment Field of Kansas State University, was rotapped through a nested set of sieves for 5 minutes. The fines that passed the 325 mesh (44 μ) sieve were added to 50 gallons of water in the feed tank at concentrations of 32.5 or 80.0 grams. The soil was kept in suspension by mechanical agitation and re-cycling. Chlorox was added to retard bacterial growth.

Each cloth was tested in the system at constant pressures of 5, 15, and 30 psi for twenty-four hours. During the test, samples were taken ahead of and behind the filter to measure the temperature and turbidity while the total flow was measured in the effluent reservoir by a Steven's Type F water level recorder. At the end of the run the filter cloth and cake which had been formed by the removal of any suspended solids from the influent feed were dried and weighed.

The results of the tests showed that the flow through the filter could be mathematically predicted. This finding was significant because the filtration was found to be dependent upon the cake and independent of the filter cloth. Therefore, the only requirement in selecting the filter cloth is that the pore openings in the cloth be small enough to allow the formation of a cake.

The filter cake was found to be compressible as the pressure was increased, and the resistance to flow in the cake, a result of the compressibility, increased linearly as a function of the absolute pressure squared. Therefore, at increased pressure the flow through the filter is not directly proportional to the pressure drop but is also dependent upon the resistance to flow in the cake as described previously.

The samples taken ahead of and behind the filter showed that large amounts of turbidity could be removed by this filtration technique. The turbidity measurements, after cake filtration had begun, indicated that most of the turbidity is removed in the cake. Observation of the dried cake reveals that some particles bleed through the cloth after once having formed as cake.

Further study is suggested for using filter aids to increase the porosity in the filter cake. Additional research would also be valuable in testing the hypothesis that the resistance to flow in the cake is a function of the absolute pressure.