REPORT ON LABORATORY TESTING OF THE SEDIMENT-SEALING METHOD

Part One

By

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SEALING EFFECTS OF DISPERSED AND FLOCCULATED BENTONITE SUSPENSIONS IN A DUNE SAND

Department of Civil Engineering

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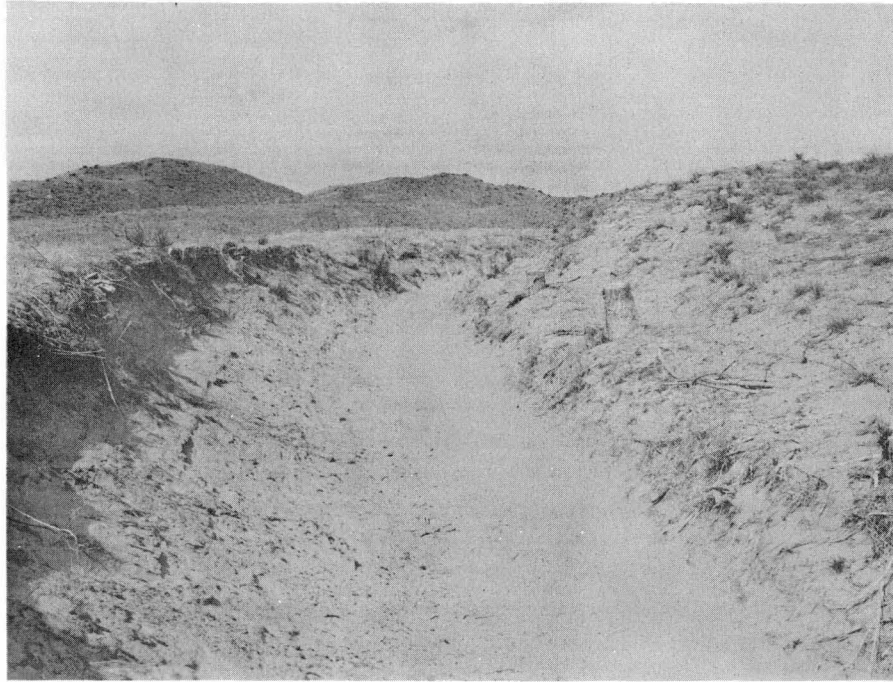
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View showing a sandy reach of Lateral No. 1,
Interstate Canal, North Platte Project, Tor-
rington, Wyoming -- USBR Photo No. 20-703-2593
by W. K. Lundgreen.

ACKNOWLEDGMENTS

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I. INTRODUCTION

In the past few years over twenty experimental installations of sedimenting with bentonite suspensions have been made in western United States. Most of these have been successful in reducing seepage. The actual mechanism of sealing is at present not fully understood. It is known that a filter cake formed on the surface of the soil will reduce seepage considerably. Such a filter cake is, however, susceptible to erosion, especially after an initial period of drying. It is also liable to be damaged by cattle and other animals.

It is therefore important to find out whether the sediment can enter the soil and can provide sealing in depth. An initial laboratory study of this problem was made by Curry (8) who found that stable colloidal bentonite suspensions would pass through chemically inert sands without retention unless the pores were so fine that the particles were filtered out at the surface. In the latter case no penetration was obtained.

In the present study a dune sand is used. The problems to be considered are:

1. What is the upper limit of hydraulic gradient for which a significant sealing effect can be obtained in the sand placed at constant density and without layering?

2. What is the lower limit of hydraulic gradient at which penetration of the sample is possible?

3. What is the effect of the non-colloidal fraction found in commercial bentonites on the penetration and sealing?

4. How does the state of flocculation or dispersion of bentonite affect penetration and sealing?

Delimitations

It is evident that there are a multitude of factors that affect field conditions in the control of canal seepage. A complete duplication of field conditions in the laboratory, besides being impracticable, would lead to results of doubtful validity in the formation of a general theory. The experiments described herein were intended to further basic understanding of some aspects of the sediment sealing method, and therefore many variables of importance in the field were either rigidly controlled or eliminated.

1. Only one commercial Wyoming bentonite was used in a one per cent suspension.

2. The study was restricted to one dune sand.

3. All tests were carried out on sand columns, 5 in. in diameter and approximately 24 in. in length.

4. The sand was compacted to a constant density without layering effects.

5. The sample was saturated throughout each test.

6. The hydraulic gradient was varied from 0.03 to 0.9.

Symbols Used

The nomenclature adopted in this report is tabulated below.

Table 1-- LIST OF SYMBOLS

Symbol	Description	Dimensions	Units
A	Cross-sectional area	L^2	cm^2
g	Gravitational acceleration	L/T^2	cm/sec^2
i	Hydraulic gradient	--	--
K	Hydraulic conductivity	L/T	cm/sec ft/year
K'	Intrinsic permeability	L^2	cm^2 $micron^2$
Q	Discharge	L^3/T	cm^3/sec
Q'	Specific discharge	L^2	$micron^2$
η	Dynamic viscosity	M/LT	poise
μ	Micron	L	$10^{-4}cm$
ρ	Density	M/L^3	gm/cm^3 lb/ft^3

Definition of Terms

1. Fines - Particles of silt and clay, and of organic materials in the same size range.

2. Hydraulic conductivity - The value of K in the formula

$$\frac{Q}{A} = Ki \quad .$$

3. Hygroscopic coefficient - The gain of moisture of a thin layer of soil subjected to a relative humidity of 90 per cent at 20°C and 1 cm of mercury absolute pressure for five days, expressed as a dry weight percentage.

4. Hygroscopic moisture ratio - The ratio of the hygroscopic coefficient of a sample of sand taken after a test to that of a check sample taken before the test.

5. Intrinsic permeability - The value of K' in the formula

$$\frac{Q}{A} = \frac{K'\rho\, gi}{\eta} \quad .$$

6. Specific discharge - The value of Q' in the formula

$$K' = \frac{Q'}{i} \quad ,$$

i.e.,

$$Q' = \frac{Q\eta}{A\rho g} \quad .$$

7. Thixotropy - The property of some gels of becoming fluid when disturbed. The change is reversible.

8. Uniformity coefficient - The ratio of the screen sizes which respectively permit the passage of 60 per cent and 10 per cent of a sample.

II. EQUIPMENT

The apparatus used consisted of five permeameters equipped with constant-head feeding devices, a mixing plant, a water supply tank and several items of auxiliary equipment. A general view is shown in Fig. 1.

Permeameters

In view of the nature of the problem to be studied, the permeameters had to satisfy the following requirements:

1. Flow had to be downward through the sand.

2. The cross-sectional area had to be sufficiently large so that the effect of flow at the sand-wall interface and the influence of any irregularities in the surface of the sand would be negligible.

3. The columns had to be transparent so that the sand and the suspensions above the sand could be observed.

4. The suspensions had to be in direct contact with the sand surface.

5. The capacity of the column above the sand had to be sufficiently large so that the flow for maintaining the constant head would not disturb the suspensions.

6. Permeability determination had to be made near the surface and also sufficiently far removed from surface interference.

7. Hydraulic gradients from 0.03 to 0.9 had to be measured.
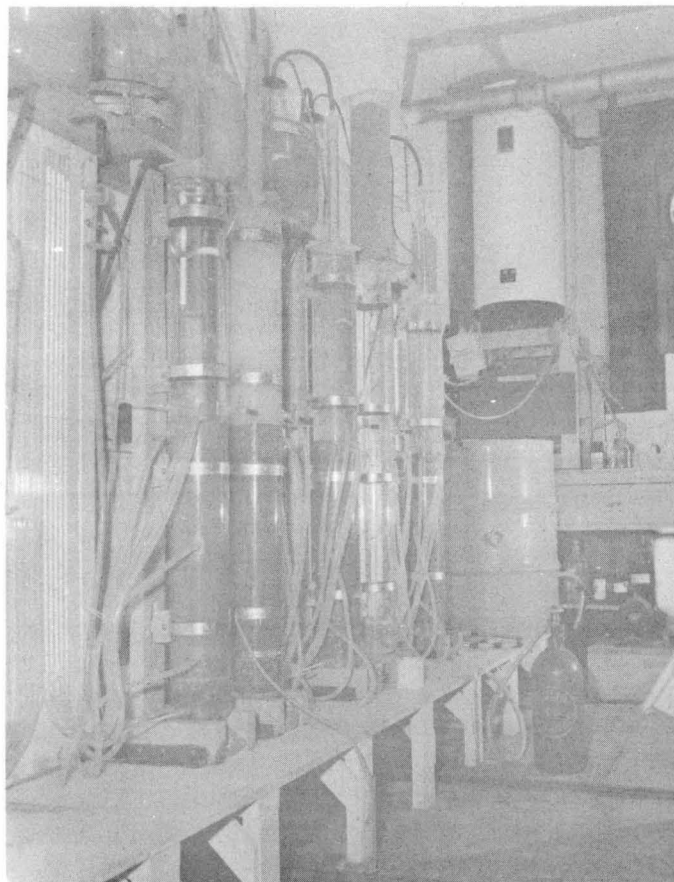
Fig. 1   General view showing the five permeameters. The mixing tank and the heated tank are in the background. One permeameter is ready for filling, with the sand dispenser in position.

8. The flow through the sand had to be arranged so that the absolute pressure gradient was positive at all times in order to prevent air from coming out of solution.

9. The upper portions of the columns had to be easily removable.

10. Because of the possibility of chemical reaction, metal in contact with the sand or the suspensions had to be avoided.

The columns were constructed almost entirely of lucite and plexiglass. The term "plastic" will be used for these two materials. Each column consisted of three sections of 5-in. internal diameter cast plastic cylinder with $\frac{1}{4}$-in. walls. (See Fig. 2)

The sections were connected by means of the male and female slip joints. Before assembly a little vaseline was put on the joints, which were then simply pushed together. They were generally watertight under a maximum head of 4 feet.

The lowest section (see Fig. 3) was approximately $4\frac{1}{2}$ in. long. A $\frac{1}{2}$-in. plastic plate drilled with nineteen $\frac{1}{2}$-in. diameter holes supported a graded sand and gravel filter. It rested on four lugs to maintain a clear space of $\frac{3}{4}$-in. below the filter. A drain and a connection to the outlet control were provided. A mercury thermometer was mounted into the clear space.

The middle section (see Fig. 4), approximately 24 in. long, held the sand sample. It was provided with seven manometer tappings, numbered from 1 through 7 from the top downwards. The locations of the tappings are given in Table 2.
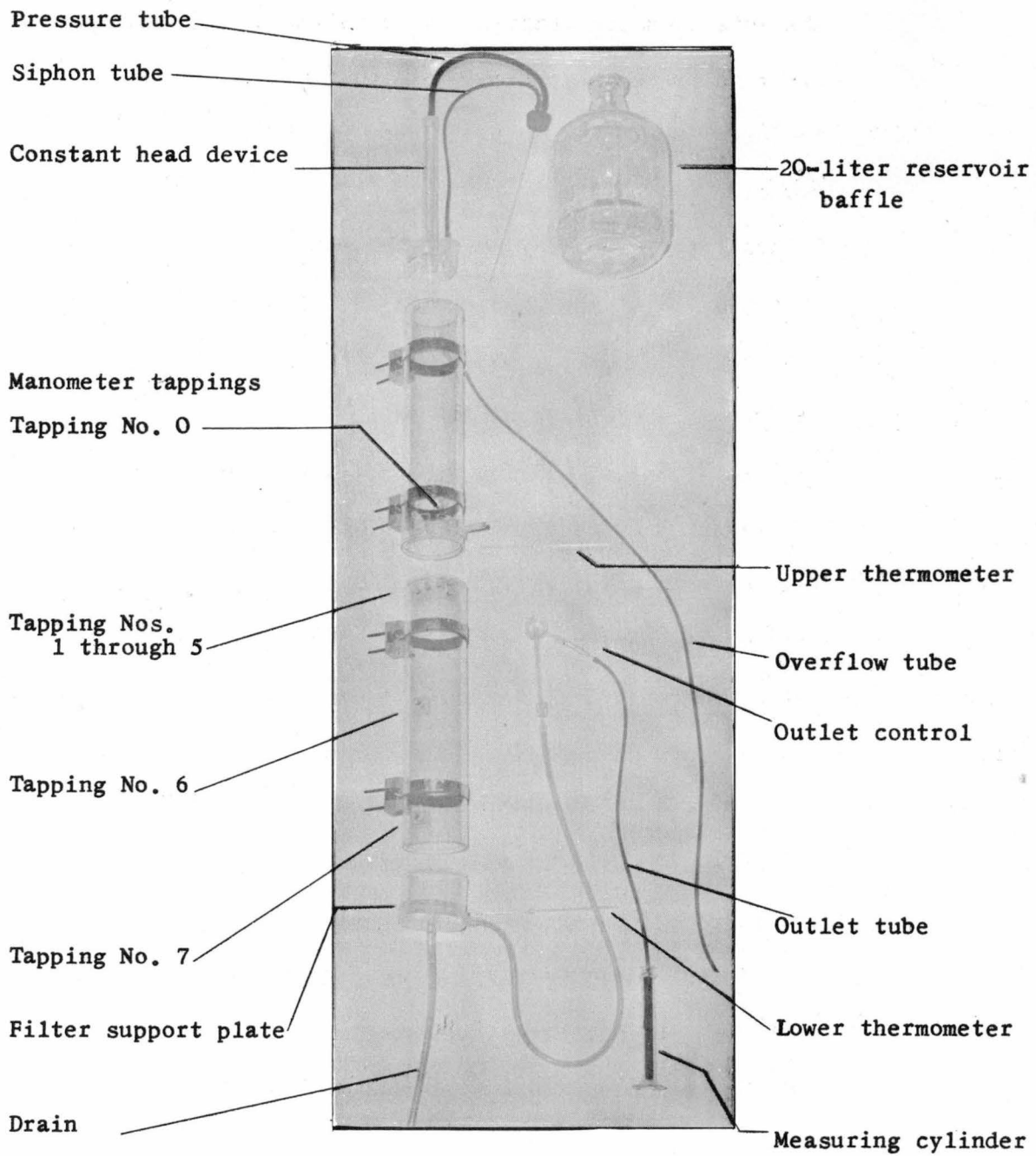
Fig. 2   Exploded view of a permeameter.

Pressure tube

Siphon tube

Constant head device

20-liter reservoir
baffle

Manometer tappings

Tapping No. 0

Tapping Nos.
1 through 5

Tapping No. 6

Tapping No. 7

Filter support plate

Drain

Upper thermometer

Overflow tube

Outlet control

Outlet tube

Lower thermometer

Measuring cylinder
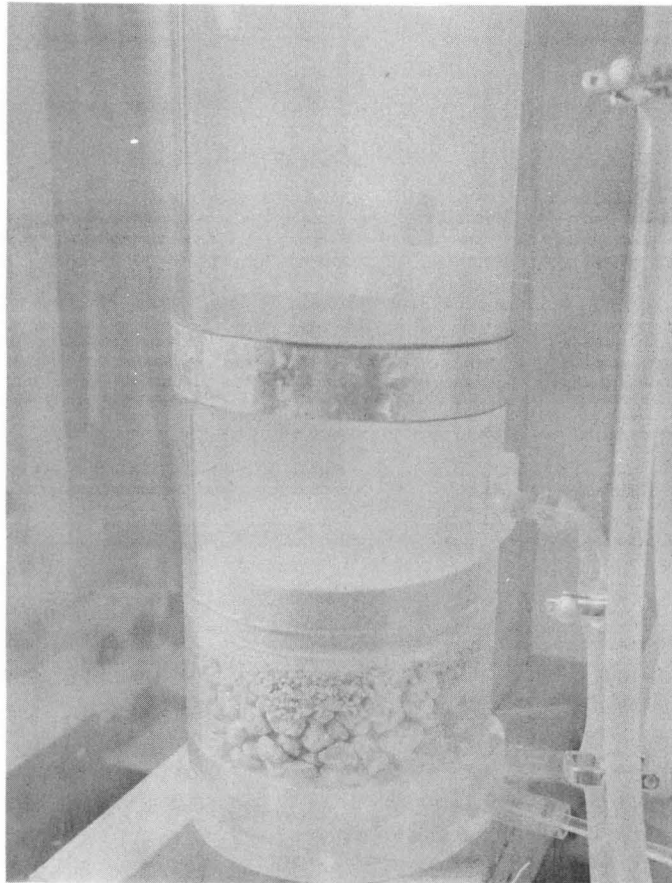
Fig. 3   View of bottom of section during filling. Six
streams of sand fall to form an even surface.
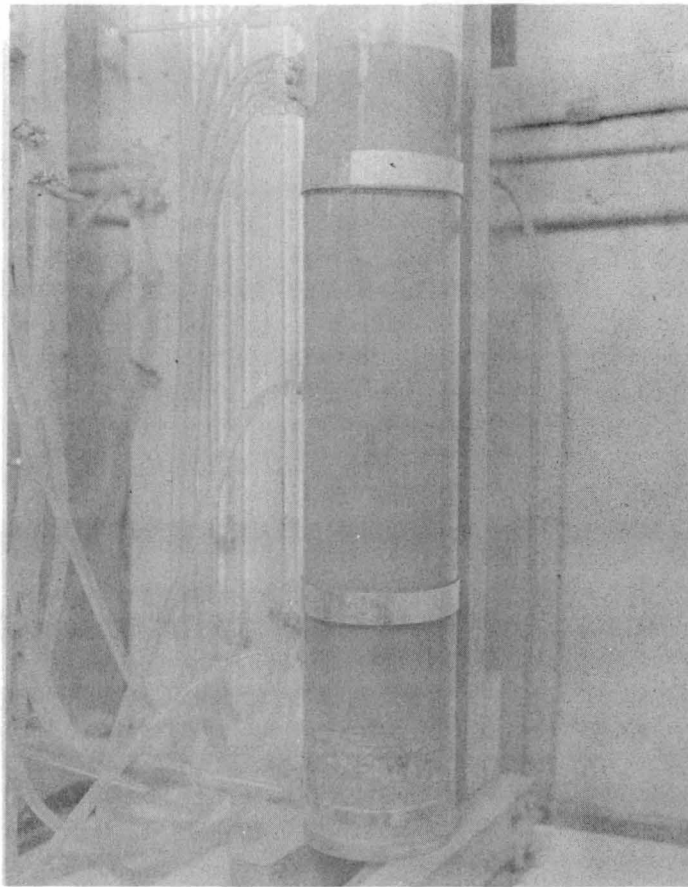
Fig. 4   View of middle section showing the even packing of
          the sand. Bentonite is visible in the bottom sec-
          tion below the graded filter pack.

Table 2-- LOCATIONS OF MANOMETER TAPPINGS

Tapping No.	Distance Below Initial Sand Surface (in.)	
	Maximum	Minimum
1	0.69	0.64
2	0.93	0.89
3	1.18	1.16
4	1.44	1.36
5	1.68	1.65
6	11.72	11.68
7	21.69	21.66

Note: Tapping No. 0 was located in the upper section of the permeam-
eter, above the surface of the sand.

The upper section (see Fig. 5) was also approximately 24 in.
long. It was provided with two overflows, 6 in. and 23 in. above the
initial sand surface respectively, consisting of 3/8-in. internal diam-
eter, 1/16-in. wall, plastic tubes. The overflows were mounted at 45°
pointing downwards. In this way the water level in the cylinder was
not affected by surging in the overflow tubes. A manometer tapping
(Tapping No. 0), a mercury therometer and a drain were built in near
the lower end of this section.

The manometer tappings were made from 3/8-in. diameter cast
plastic rod. Details of a tapping are shown in Fig. 6. Bentonite
particles could pass through the nylon filters so that the manometers
continued to operate during sedimentation.

Six 11-mm outside diameter glass manometer tubes were pro-
vided for each permeameter. They were connected to selected tappings
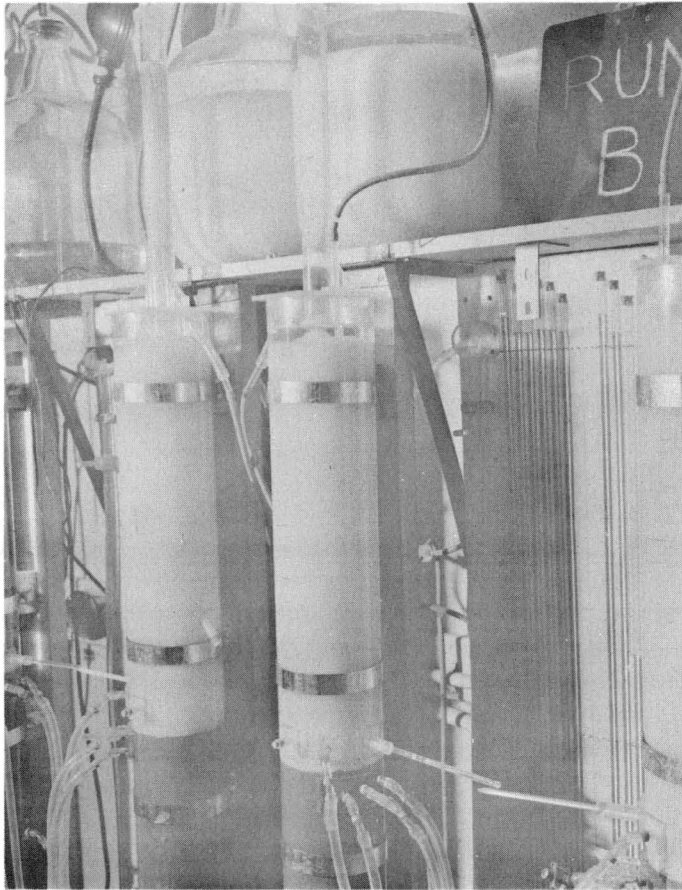
Fig. 5   View of upper sections during sedimentation with
flocculated bentonite suspension.
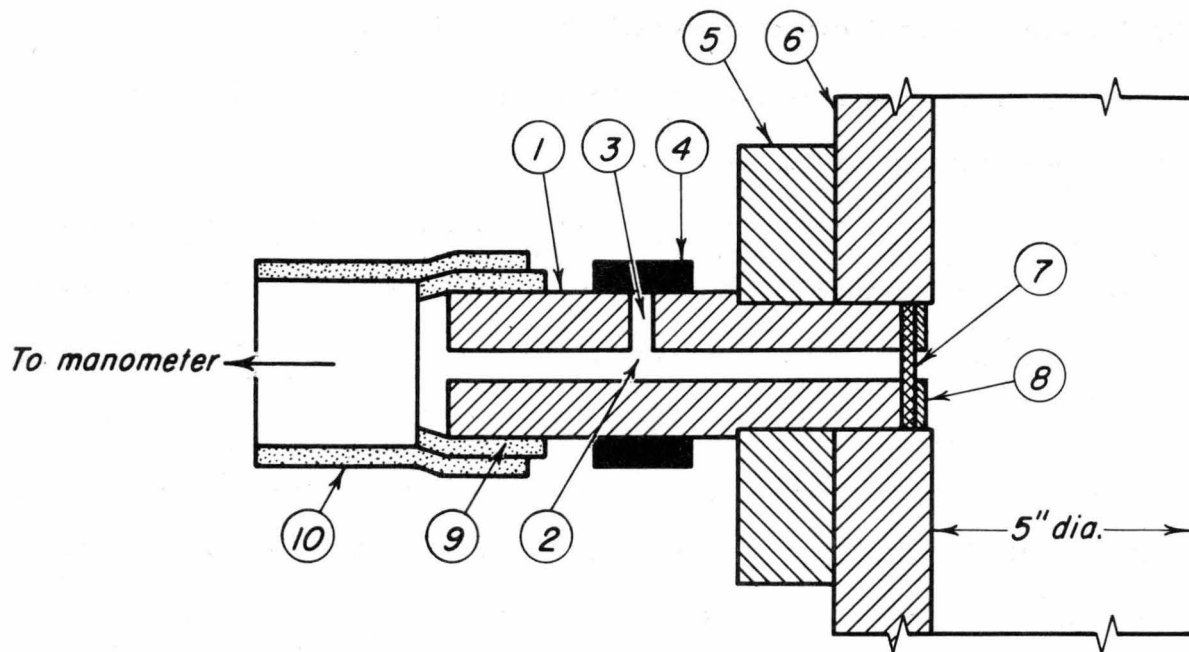
1 3/8" dia cast plastic rod, turned to fit 5/16" dia hole in cylinder wall
2 3/32" dia hole
3 1/16" dia air hole
4 Rubber tubing
5 Reinforcing patch (cast plastic)
6 Cylinder wall
7 Heavy nylon material
8 Acetate washer, 0.010 thick
9 5/16" interior dia, 1/16" wall mayon tubing
10 7/16" interior dia, 1/16" wall mayon tubing

Note: The nylon material is first glued to the washer and trimmed. The complete filter is then glued into the recess.

Fig. 6   Detail of manometer tapping.

by 7/16-in. internal diameter mayon[1] tubes. Air bubbles, bentonite and other impurities could be seen within the tubes. Large diameter tubes were chosen throughout to facilitate cleaning.

The overflow method of providing a constant head was found to be inconvenient because of the relatively large volume of prepared water or suspensions that had to be wasted. The permeameters were therefore equipped with constant head devices, (see Fig. 7). The flow through the siphon tube was controlled by a partial vacuum in the 20-liter feeding bottle. When the water level in the column dropped, air was admitted through the large tube permitting flow through the siphon until equilibrium was reached again.

The outlet level was adjusted by a control mounted on the manometer board. (See Fig. 4).

Water Supply

Tap water for the initial and final permeability determinations was stored in an electrically heated, glass-lined 30-gallon tank, open to the atmosphere. (See Fig. 1).

Mixing Plant

The mixing tank was made from a 55-gallon steel drum. It was painted with several coats of rubber base paint and sprayed with clear plastic enamel. The paint work was unsatisfactory and had to be patched frequently. This was probably due to the corrosive nature of the suspensions which also contained some grit and to the agitation of the mixer.

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[1] Mayon is a transparent, fully flexible plastic material.

High pressure
rubber tubing

Siphon tube

Partial vacuum

Partial vacuum

Feeding
bottle

Overflow
tube

Atmospheric pressure

Thinly coated with
parafin on the end

Upper section of permeameter
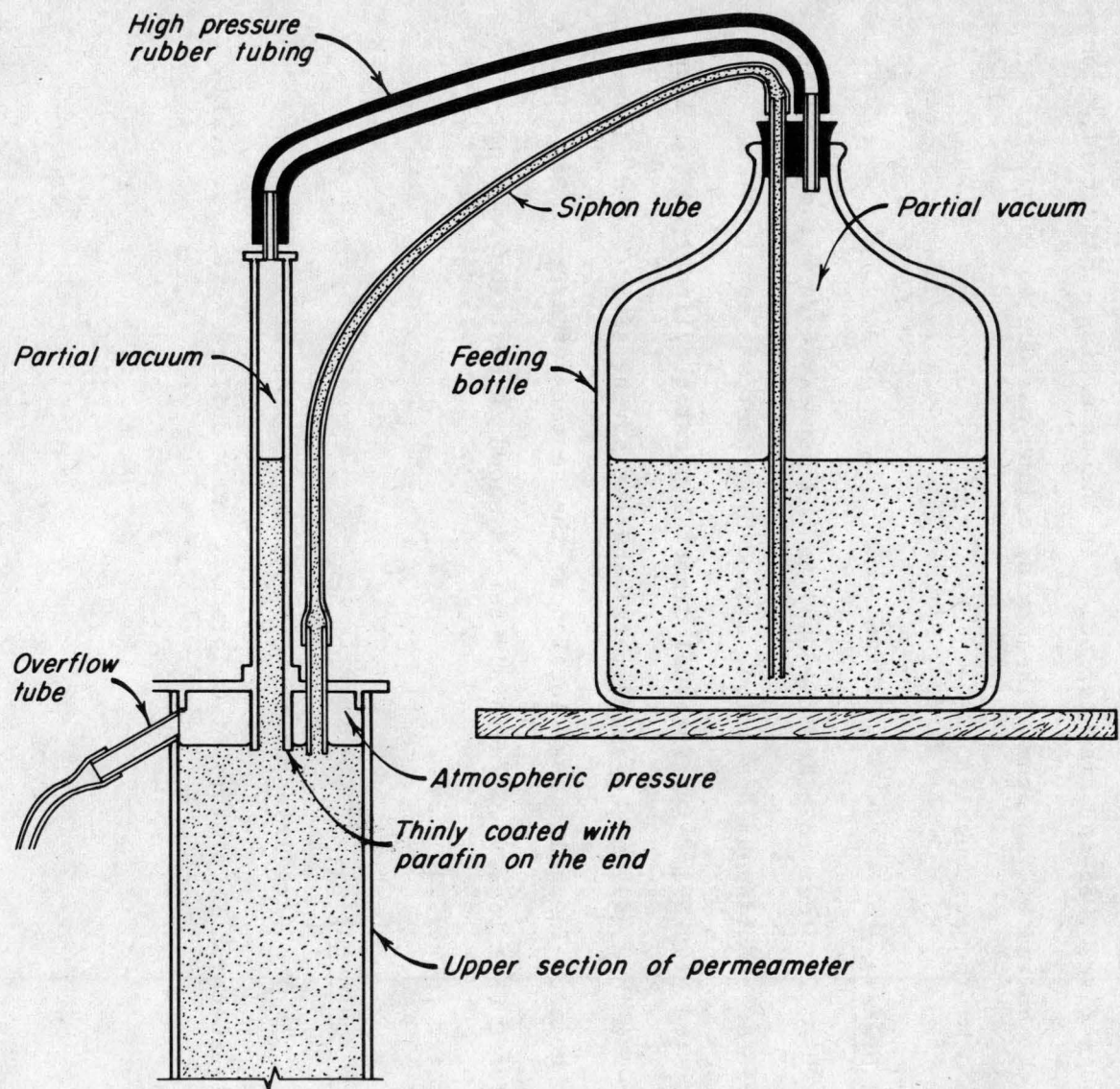
Fig. 7   Detail of constant-head device.

The tank was provided with an outlet 10 in. above the bottom in addition to a drain.

The mixer (see Fig. 8) consisted of a coil of 5/8-in. diameter stainless steel tube placed in the drum. Air from a compressor was forced through five 0.055-in. diameter holes in the underside of the coil, scouring the bottom of the drum. The mixing action was due to turbulence caused by the air bubbles.

Sand Dispenser

In order to place the sand in the permeameters without layering in one continuous operation, a sand dispenser was constructed. This consisted of a 5 3/8-in. internal diameter plastic cylinder 24 in. long, fitted with a galvanized sheet metal shutter having six 7/32-in. diameter holes. The holes were located at the centers of area of six equal sectors, (see Fig. 9). The dispenser is shown in position on a permeameter in Fig. 1.

Other Equipment

The facilities of the Soil Mechanics Laboratory and of the Soils Research Laboratory of Colorado A and M College were also available.

Fig. 8   The mixing plant.
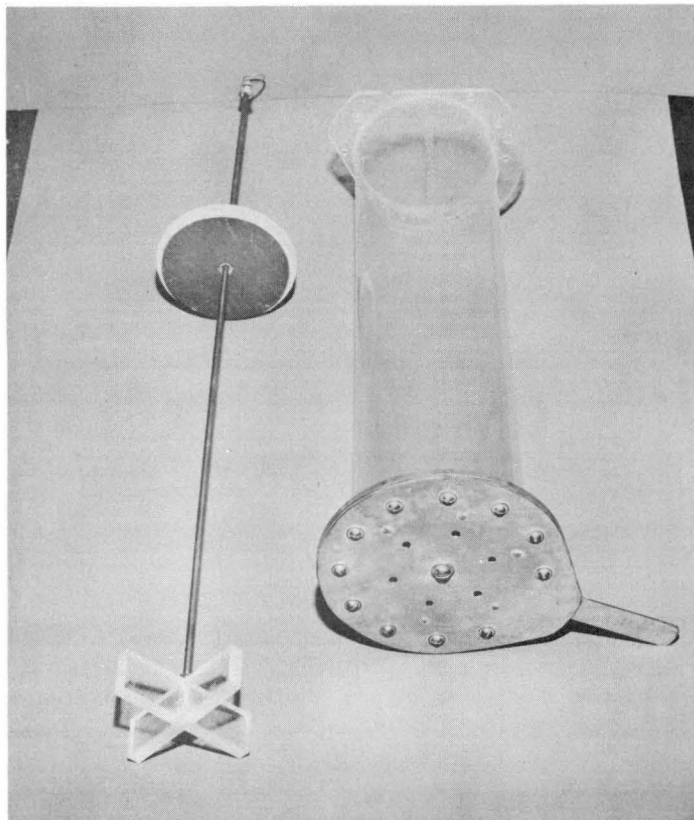
Fig. 9   Instrument for smoothing sand surface (left)
and sand dispenser.

III. MATERIALS

Sand

The sand used was taken from a dune adjacent to Mile 2 of
Lateral No. 1, Interstate Canal, North Platte Project, Torrington,
Wyoming. Tests made by the Bureau of Reclamation on this material are
described in the Appendix. Size distribution curves from mechanical
analysis are shown in Figs. 10 and 11.

Water

Tap water from the Fort Collins city mains was used. The
total hardness varied from 24 to 28 ppm as calcium carbonate.

Dispersing and Flocculating Agents

For dispersing agent, commercial anhydrous, granular, sodium
tripolyphosphate, $Na_5P_3O_{10}$, was used. For flocculating agent, calcium
acetate, $Ca (C_2H_3O_2)_2$, was used.

Bentonite

A commercially produced powdered high-swell, Wyoming bentonite
was used. It contained 5.8 per cent grit and 8.2 per cent moisture.
The quantities of bentonite used to obtain suspensions of the required
concentration and maximum sediment size for the different series are
given in Table 3. The proportions of bentonite, dispersant and floccu-
lating agent were obtained empirically.

The particle size distribution in suspensions used for Series
III (maximum sediment size 44 microns) is given in Fig. 12. The curves
indicate 30 to 40 per cent of the bentonite particles larger than one
micron.
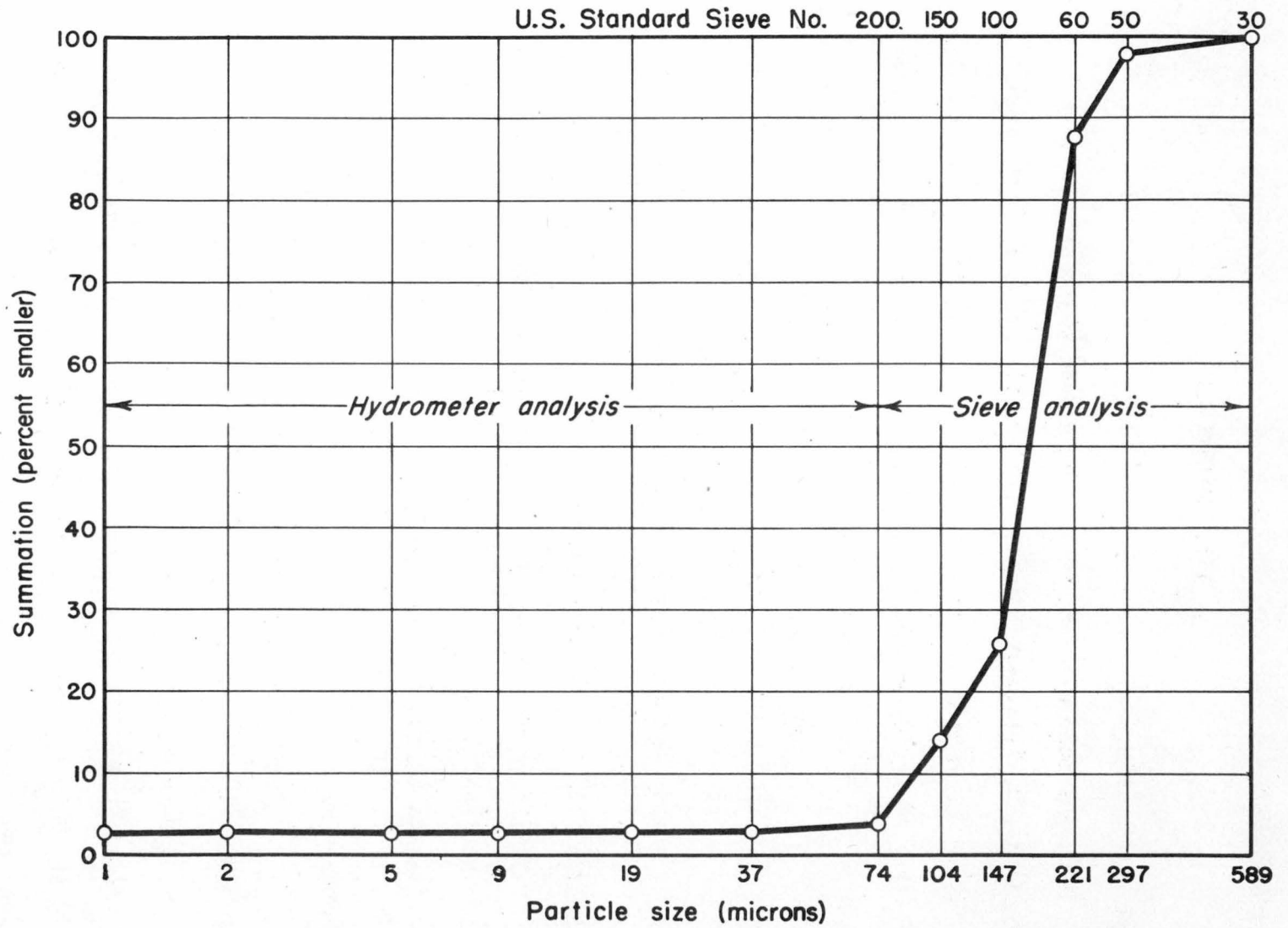
Fig. 10   Particle size distribution curve for pre-treated sand.
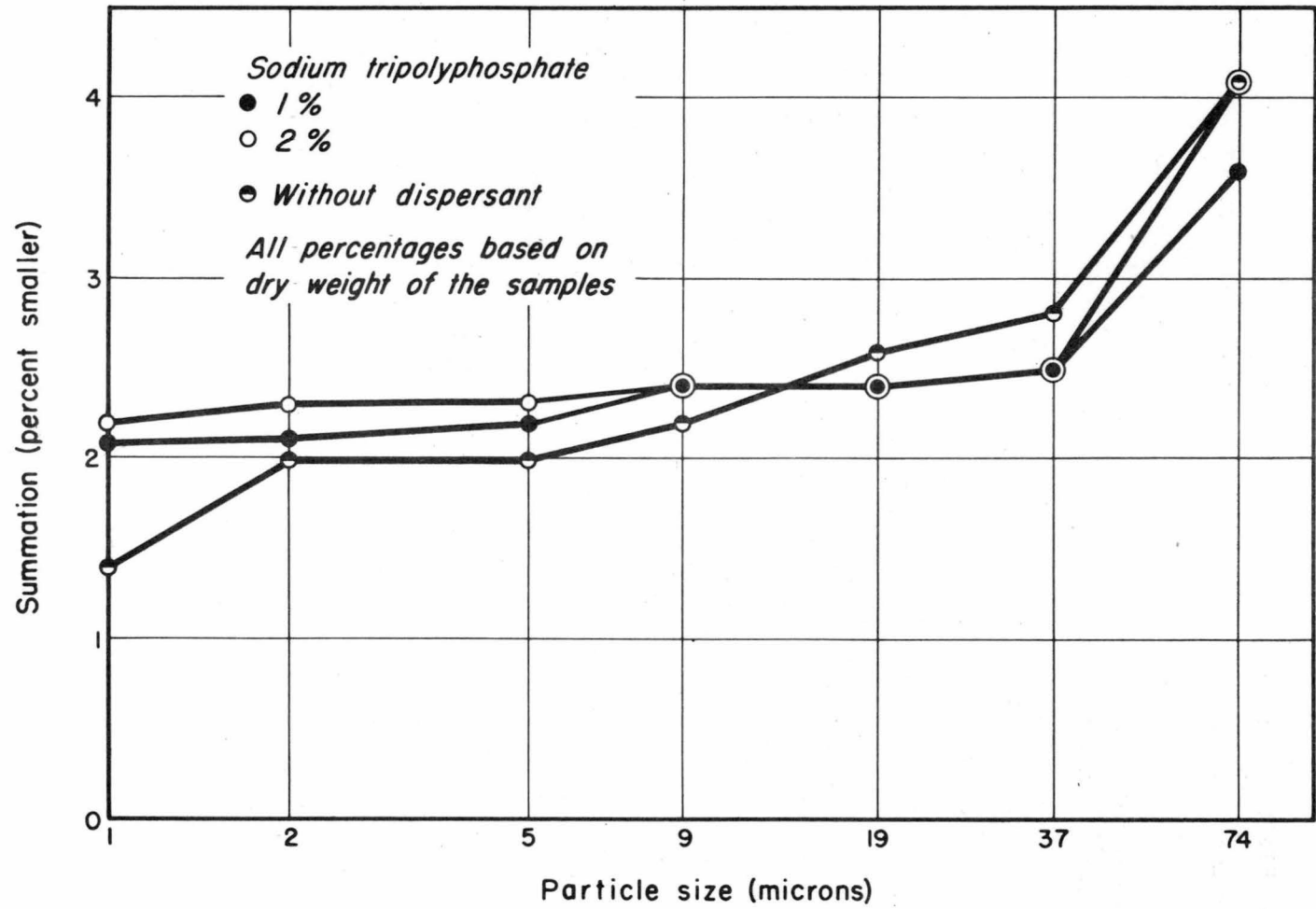
Fig. 11   Particle size distribution curve for pre-treated sand -- fines only.

Table 3-- BENTONITE SUSPENSIONS USED

Series	Bentonite[1] gm/liter	Dispersing Agent gm/liter	Flocculating Agent gm/liter	Maximum Sediment Size (micron)	Sediment Concentration (%) (nominal)
I	18.4	0.667	0	1.0	1.0
II	18.4	0.667	2.0	1.0*	1.0**
III	12.0	0.667	0	44	1.0
IV	0	0.667	0	0	0

*   As received
**   Before flocculation
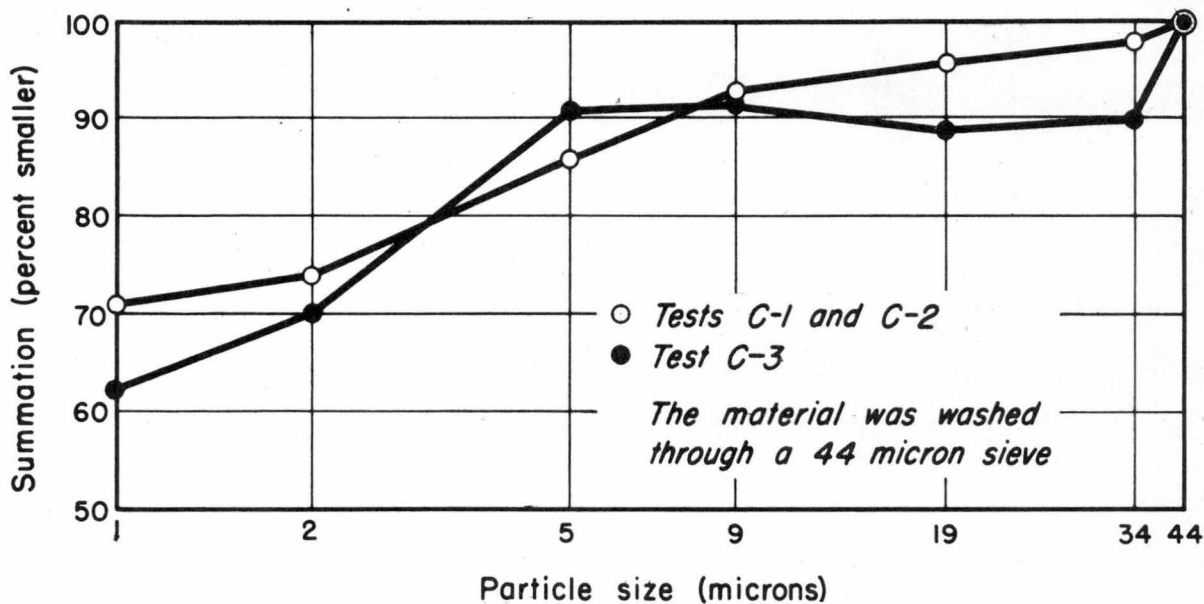
Fig. 12   Particle size distribution in bentonite suspensions
containing non-colloidal materials -- Series III.

IV. PROCEDURE

The general procedure may be outlined as follows:

1. Sand was placed in the permeameters in an atmosphere of carbon dioxide.

2. The initial clear-water permeability was determined.

3. The sand column was treated with sediment suspension.

4. The filter cake was removed and clear water was introduced for determination of after treatment permeability.

The procedures used for the various auxiliary tests are described in the Appendix.

Preparation of the Sand

The sand was washed through a U. S. No. 20 sieve and then dried in an oven heat of 110°C for several days. The sand was again passed through No. 20 sieve. The dispenser was then filled with a predetermined weight of sand. Samples of the sand were retained for hygroscopic moisture determination.

Preparation of the Tap Water

Tap water was passed into the heating tank together with a little thymol solution. In order to expel the air present in solution, the water was heated to 120°F. The 20-liter glass bottles were then filled from the tank. In the runs where the flow was sufficiently small so that the water could cool to room temperature before reaching the sand, the bottles were connected to the constant-head devices. The water

was thus subjected to a weak vacuum at once. In the other runs the bottles were corked tightly and the water was allowed to cool over night before being used.

Preparation of Bentonite Suspensions

The mixing tank was filled with about half the required quantity of tap water. An empirically determined amount of dry bentonite (see Table 3), together with 0.667 gm/liter of sodium tripolyphosphate and several crystals of thymol were added to the tank while the air mixer was working. The mixture was then allowed to hydrate for at least 24 hours. The mixer was then run again for one hour to complete the dispersion and the water was made up to the required quantity.

For use in Series I (dispersed suspensions) the suspension was allowed to stand until the maximum sediment size of any particle above the outlet of the tank was one micron. The suspension was then drawn off and used to fill the permeameter and reservoir bottles.

In Series II (flocculated suspensions) the procedure was the same, except that the flocculating agent was added, after the suspension was drawn from the tank.

In Series III (dispersed suspensions) a smaller amount of dry bentonite was required as the final suspension contained part of the coarser material. Otherwise the initial preparation was identical. When the permeameters were to be filled the mixer was started and any material sticking to the bottom of the tank was scraped off by hand. The suspension was run through a No. 325 sieve (44-micron opening) and was immediately pumped into the permeameters and bottles.

Preparation and Assembly of a Permeameter

All parts of the permeameter were thoroughly washed and allowed to dry. The manometer tubes were flushed out and filled to within about 6 in. of the ends of the mayon connecting tubes.

The bottom section of the permeameter was placed on the stand and the outlet control clamped to the manometer board at the required level. The gravel to sand filter was placed layer by layer. After the male part of the slip joint had been coated with vaseline, the middle section was slipped on and fixed to the stand. This was repeated for the upper section. Excess vaseline was wiped from the inside of the upper joint.

The manometer tubes were connected to selected tappings. The lower thermometer was placed in position. The opening for the upper thermometer was closed with a rubber stopper.

Filling a Permeameter

The filled sand dispenser was placed on top of the permeameter (see Fig. 1). A tank of carbon dioxide was connected to the drainage outlet in the lowest section through a regulating valve.

Carbon dioxide was passed into the permeameter. After all air had been displaced, the outlet pipe was clamped off and the shutter of the sand dispenser was opened. The flow of carbon dioxide was regulated so that no large bubbles of gas would disturb the sand after it had fallen. There was no absolute regulation of the flow.

Hot water drawn from the tank was allowed to flow directly onto the sand surface through a diffuser. The outlet tube was opened so that excess carbon dioxide could escape.

After the sand had been saturated, air in the ends of the mano-meter connecting tubes was driven out through the "air holes" provided in the tappings (see Fig. 6). The permeameter was then filled to the top and allowed to stand for 24 hours. At the end of this period the drain was opened and the sand was washed until tests on the effluent showed that it contained no excess carbon dioxide. (For test method see Appendix B).

The surface of the sand was then smoothed over with the instru-ment shown in Fig. 9. The sand was compacted to the desired density by hitting the back of the permeameter stand with a mallet, while the drain was open, i.e., the compaction was due to a combination of an applied hydraulic gradient of about 2 to 1 and the vibration.

Determination of Initial Permeability

After the flow had reached equilibrium minor adjustments to the outlet control were made to obtain the desired hydraulic gradient. Permeability determinations were carried out in duplicate. The efflu-ent was collected in a graduated cylinder. Manometer readings, temper-atures and time were recorded at the beginning and end of each deter-mination.

It was observed that the sand surface started to seal period-ically. A disproportionately high loss of head across the surface was caused, which was indicated clearly by the manometers. The surface also had a matted or crusted appearance. To keep the surface open when this occurred, about 1/16 in. of sand was siphoned off from the surface one hour before readings were taken.

Permeability measurements were continued until the results remained reasonably constant. At this stage the steepest portion of the permeability versus time relationship described by Christiansen and others (6) had been passed.

Sedimentation

After the initial permeability had been established the column of clear water above the sand was replaced by the suspension. The feeding bottles were filled with suspension and the test was continued at the same applied hydraulic gradient until the flow became negligible.

In the runs with flocculated suspensions the flow was not started again until a definite clear water break had developed in the column, simulating dead ponding conditions.

Permeability measurements were made at frequent intervals and visible phenomena were noted. If bentonite or other materials appeared in the effluent the concentration was determined. On completion of sedimentation the suspension was drawn off and the filter cake which had formed on the surface of the sand was siphoned off. The column was then filled with water for the final permeability determination.

Determination of Final Permeability

The procedure was similar to that for the initial determinations. The surface was kept open by periodic siphoning as before. The concentration of dissolved and suspended materials in the effluent was determined. The test was stopped after the final permeability had reached a maximum and had begun to decrease again. (See Fig. 15 at 415 hours).

The permeameter was then dismantled. Samples from various levels of the sand column were retained. The rest of the sand was discarded.

V. RESULTS

Four series of experiments were conducted as listed in Table 4.

Table 4-- TESTS CONDUCTED ON TORRINGTON (WYOMING) DUNE SAND

Series No.	Applied Hydraulic Gradient				Maximum Sediment Size (microns)	Material Used in Treatment
	0.03	0.10	0.30	0.90		
			Run			
I	A	E	J	-	1.0	Dispersed bentonite
II	B	-	-	N	1.0	Flocculated bentonite
III	C	-	-	O	44	Dispersed bentonite
IV	Q	-	-	-	-	Dispersant only

Series I (Dispersed suspensions - maximum sediment size one micron)

Tests A-1 and A-2 were conducted without the benefit of the carbon dioxide atmosphere to eliminate air during the loading. They are therefore excluded from the summary table (Table 5).

In Tests A-3 and A-4 (Fig. 14) the effluent remained substantially clear at all times. The results of an X-ray diffraction analysis on two samples taken after the tests are given in the Appendix, where the samples are identified as Nos. 5 and 6.

Some bentonite appeared in manometer Tapping No. 6 in Test E-1, indicating a penetration of at least 12 in. In Test E-3 the same was true, and some bentonite passed through the entire column after the filter cake was removed. The effluent color changed from cream to buff,

Table 5-- SUMMARY OF DATA - Series I (Dispersed suspensions -- maximum sediment size one micron)

	Run	A[4]	A	E	E	E	J	J
	Test	3	4	1	2	3	1	2
Average hydraulic gradient (5-7)[1]		0.0263	0.0278	0.101	0.100	0.102	0.302	0.305
Initial dry density of sand lb/ft^3		96.6	97.0	96.8	97.0	97.0	97.0	97.0
Sediment concentration (per cent)		0.996	0.996	1.128	1.128	1.081	1.128	1.128
Initial specific discharge Q' (μ^2)		0.514	0.527	2.09	1.94	1.79	6.33	6.18
Minimum Q' during sedimentation (μ^2)		0.0023	0.0034	0.0073	0.0275	0.0038	0.0085	0.0076
Maximum Q' after sedimentation[3] (μ^2)		0.307	0.343	0.0502	0.471	0.112	2.04	2.23
Sedimenting time (hours)		61	61	72	72	48	220	220
Initial permeability K' (5-7)[1] (μ^2)		18.2	18.7	20.7	19.4	17.7	19.9	20.2
Maximum K' after sedimentation[3] (μ^2)		10.8	11.5	0.048[2]	4.17	0.080[2]	6.31	6.97
Reduction of permeability (per cent)		41	39	100[2]	78	99[2]	68	65
Settlement of sand column during test		Not observed	Not observed	None	Yes	None	Yes	Yes
Visible penetration of bentonite during sedimentation (in.)		None	None	12	22	12	Complete	Complete
Bentonite in effluent following sedimentation		None	None	None	Yes	Yes	Yes	Yes
Hygroscopic moisture ratio	Top	0.792	0.744	See Table No. 6			0.536	0.530
	Middle	0.944	0.907	See Table No. 6			0.515	0.477
	Bottom	0.895[5]	0.901[5]	See Table No. 6			0.574	0.568

[1] The numbers in parentheses refer to the manometer tappings between which the measurements were made.
[2] Values at the time the test was stopped (see Fig. 15).
[3] After removal of filter cake.
[4] The results of Tests A-1 and A-2 are not reported (see text).
[5] Identified as Samples 5 and 6 in Appendix A, Section 1.

indicating the leaching of some fines from the sand. Complete penetration was observed in Test E-2; after the removal of the filter cake, bentonite and, later, fines leached from the sand until the maximum final permeability was reached (see Figs. 15 and 16).

Run J (Figs. 17 and 18) yielded complete penetration early during the sedimentation. The settlement of sand columns during sedimentation was about 1.5% of the initial height; further settlement occurred subsequently.

Table 6-- HYGROSCOPIC MOISTURE RATIOS - Series I - Run E

Distance Above Filter (in.)	Test 1	Test 2	Test 3
Top of column	0.552	*	0.595
18-19	1.131	0.710	0.715
15-16	1.101	1.027	1.040
12-13	1.063	0.958	0.974
9-10	0.950	1.062	1.068
6-7	0.895	0.856	1.031
3-4	0.869	1.060	1.022
0-1	0.780	1.120	0.974

* Sample spilled.

Series II (Flocculated suspensions)

In this series no visible penetration of flocculated bentonite particles was noted and no settlement of the sand columns occurred. The effluent remained clear at all times. The density of the flocculated

suspension increased markedly as the sand surface was approached, merging into an indistinct filter cake. The results are summarized in Table 7.

No permeability determinations were possible during the sedimentation phase in Run B (Fig. 19) because of the great manometer lag, which was later remedied by the nylon filter shown in Fig. 6.

Some time after the sedimentation phase began in Run N, calculation of permeability value was discontinued as almost the entire loss of head occurred at the surface and the difference of head between Tapping Nos. 5 and 7 soon became negligible (see Fig. 20).

Series III (Dispersed suspensions - maximum sediment size 44 microns)

The results of Run C are given in Fig. 21 and are summarized in Table 8. Permeability determinations were not possible during the sedimentation phase for the same reason as in Run B. The effluent remained clear throughout the tests. The filter cakes formed during these tests consisted of a dark gray layer overlain by a pink layer, which in turn was overlain by a cream layer. The total thickness of each filter cake was about 2 mm at the end of sedimentation. Residual sealing effects were small.

Test 0-2 had to be abandoned. The results of Tests 0-1 and 0-3 are given in Fig. 22 and 23 and are summarized in Table 8. The sand columns were penetrated completely by the suspension during sedimentation. The color of the effluent gradually changed from cream to buff, indicating that fines were being removed from the sand. Settlement was observed.

Table 7-- SUMMARY OF DATA - Series II (Flocculated suspensions)

	Run Test	B 1	B 2	B 3	N 1	N 2	N 3
Average hydraulic gradient (5-7)[1]		0.0297	0.0329	0.0347	0.895	0.907	0.906
Initial dry density of sand lb/ft^3		97.2	97.2	97.5	97.0	97.2	97.4
Sediment concentration (per cent)		0.994	0.994	0.994	1.050	1.018	1.050
Initial specific discharge Q' (μ^2)		0.484	0.453	0.485	15.5	15.2	16.1
Minimum Q' during sedimentation (μ^2)		0.0140	0.0136	0.0137	0.0226	0.0260	0.0226
Maximum Q' after sedimentation[3] (μ^2)		0.540	0.437	0.401	15.5	14.9	15.6
Sedimenting time (hours)		67	67	67	96	97	96
Initial permeability K' (5-7)[1] (μ^2)		16.3	13.8	14.5	17.4	16.7	17.8
Maximum K' after sedimentation[3] (μ^2)		15.4	13.6	16.3	17.2	16.0	17.2
Reduction of permeability (per cent)		5.5	1.4	(12.4)[2]	1.1	4.2	3.4
Settlement of sand column during test		None	None	None	None	None	None
Visible penetration of bentonite during sedimentation (in.)		None	None	None	None	None	None
Bentonite in effluent following sedimentation		None	None	None	None	None	None
Hygroscopic moisture ratio	Top				1.002	0.895	
	Middle				0.965	0.900	
	Bottom				0.942	0.928	

[1] The numbers in parentheses refer to the manometer tappings between which the measurements were made.
[2] Increase.
[3] After removal of filter cake.

Table 8-- SUMMARY OF DATA - Series III (Dispersed suspensions - maximum sediment size 44 micron)

	Run Test	C 1	C 2	C 3	O 1	O 2^2	O 3
Average hydraulic gradient (5-7)[1]		0.0315	0.0318	0.0312	0.937	0.908	0.909
Initial dry density of sand lb/ft^3		97.1	97.3	97.0	97.1	97.1	97.3
Sediment concentration (per cent)		0.954	0.954	0.899	1.071	1.071	1.071
Initial specific discharge Q' (μ^2)		0.450	0.580	0.594	14.5	14.6	15.9
Minimum Q' during sedimentation (μ^2)		0.0021	0.0028	0.0023	0.0066	–	0.0093
Maximum Q' after sedimentation[3] (μ^2)		0.461	0.531	0.553	6.41	–	4.88
Sedimenting time (hours)		50	50	49	144	–	144
Initial permeability K' (5-7)[1] (μ^2)		14.2	18.4	19.1	15.6	16.1	17.5
Maximum K' after sedimentation[3] (μ^2)		14.1	15.5	16.9	7.97	–	6.07
Reduction of permeability (per cent)		1	16	11	49	–	65
Settlement of sand column during test		Not observed	Not observed	None	Yes	–	Yes
Visible penetration of bentonite during sedimentation (in.)		None	None	None	Complete	Complete	Complete
Bentonite in effluent following sedimentation		None	None	None	Yes		Yes
Hygroscopic moisture ratio	Top				0.695		0.652
	Middle				0.920		0.545
	Bottom				0.849		0.693

[1] The numbers in parentheses refer to the manometer tappings between which the measurements were made.
[2] Test O-2 not completed.
[3] After removal of filter cake.

Filter cakes, 4 mm thick, consisting of a thin dark gray layer overlain by a thicker white layer, formed quickly. On top of these an additional cream layer formed more slowly, becoming 3 mm thick at the end of the sedimentation phase. The results of an X-ray diffraction study of the filter cakes are given in the Appendix A, (sample Nos. 3 and 4).

Series IV (Treatment with dispersant solution)

In this series, permeabilities were determined separately for the upper (K'_{5-6}) and lower (K'_{6-7}) portions of the column. The reductions of permeability were 62 per cent and 75 per cent respectively. Fines were leached from the column both during and after the treatment. The test was stopped before the movement had ceased. The values of effluent concentration given in Fig. 24 have been corrected for the dissolved solids entering the column.

Leaching action could be observed in this test. The sand in the column above a clearly defined level looked bright, while below it the sand was darker. This level moved downward until it reached the middle of the column, where it began to lose distinction. Results of this run are given in Tables 9 and 10.

Table 9-- SUMMARY OF DATA - Series IV - Run Q
        (Treatment with dispersant)

Manometer Tappings Between Which Measurements Were Made	5-6	6-7
Average hydraulic gradient (initial value)	0.0291	0.0261
Hydraulic gradient (final value)	0.0339	0.0411
Initial permeability K' (μ^2)	16.5	18.5
Minimum permeability during treatment K' (μ^2)	3.21	2.02
Maximum permeability following treatment K' (μ^2)	8.24	4.74
Final permeability K' (μ^2)	5.49	4.57
Reduction of permeability (per cent)	62	75

Notes: 1. Settlement occurred during and following the treatment.
        2. The effluent contained fines during and following treatment.
        3. Initial dry density of the sand was 97.0 lb/ft^3.
        4. The hydraulic gradient applied to the column was kept constant throughout the experiment.
        5. Only one test was made.

Table 10-- HYGROSCOPIC MOISTURE RATIOS - Series IV - Run Q

Distance above Filter (in.)	Coefficient
Top of Column	0.120
18-19	0.391
15-16	0.372
12-13	0.391
9-10	0.382
6-7	0.635
3-4	0.625
0-1	0.601

VI. DISCUSSION

In the tests described here the sand was placed in a reason-
ably homogeneous body with all air excluded and a steady flow condition
initially. Because of these idealized conditions the results of such
tests cannot be applied directly to any field site. This study was di-
rected toward the establishment of some basic principles that can be
used to further the understanding of what happens in the field.

Permeability and specific discharge were computed by assuming
that the density and viscosity of the permeating fluid were those of
clear water at the same temperature. Sediment and effluent concentra-
tions, and hence, the error involved in using clear water density, did
not exceed two per cent (see effluent concentration curves on Figs.
17 and 22).

The error involved in using the viscosity of water was however
very large. The viscosity of suspensions, particularly of bentonite
suspensions, is affected by the properties and concentration of suspended
solids and dissolved salts, as well as by temperature and the applied
shearing stress (see Hoppler (15). Viscosity measurements on effluent
samples under identical stress and temperature conditions would have
been required to make the calculated values of K' and Q' comparable
at all times. To overcome this difficulty the tests were run until the
effluent was clear, in order to obtain final values of permeability.

Time was chosen as the most convenient basis for the presen-
tation of results. The cumulative volume of discharge would probably

have provided a more realistic basis, which would have prevented the distortion at the ends of the curves, particularly noticeable in Figs. 20 and 22. The total effluent was, however, not collected during this study.

Series I (Dispersed suspensions)

In Tests A-3 and A-4 the hygroscopic moisture ratios (see Table 5) were all less than unity, implying that there had been a reduction of surface, especially near the top of the columns. Two interpretations are possible:

1. No bentonite entered the sand and natural fines were leached out.

2. The increase of surface due to retention of bentonite was smaller than the loss of surface due to the loss of fines initially present in the sand.

The natural clay present in the sand used was mainly montmorillonite (see Appendix - Samples 1, 2, 5, and 6), which had, however, an X-ray diffraction pattern differing from that of the montmorillonite in the bentonite sample. This difference led to the conclusion that no bentonite from the suspension reached the bottom of the columns in Tests A-3 and A-4.

The curves of permeability and specific discharge (see Fig. 14) are similar in shape, indicating that only part of the total sealing effect took place at the surface. After the removal of the filter cake both permeability and specific discharge increased fairly rapidly to about half the final maximum values. Further increases were more gradual.

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The reduction of permeability in the main body of the sand columns and its subsequent gradual recovery may have been due to one or more of the following causes:

1. Colloidal particles present in the sand originally were enabled to swell because of sodium saturation.

2. Rearrangement of clay particles into new positions, more effectively blocking pore spaces.

3. Migration and subsequent accumulation of particles in thin layers relatively impermeable to water having a high sodium content took place (see also Kemper (18)).

The residual sealing in Tests A-3 and A-4 is of limited significance. There is no evidence that penetration of bentonite is possible in the sand used and under the given test conditions, at a hydraulic gradient of 0.03.

In Tests B-1 and B-3 the permeability and specific discharge decreased following the removal of the filter cake, after an initial recovery (see Figs. 15 and 16). The tests were stopped when the flow through the columns had become negligible. The hygroscopic moisture ratios (see Table 6) exceeded unity in the upper half of the column in Test B-1 and in the lower half of the column in Test B-3. The increases of surface showed that there had been a net retention of bentonite in those regions. This conclusion is in agreement with visual observations of bentonite penetration made during the tests (see Chapter V).

Several factors, in addition to those already discussed, could have contributed to the sealing:

4. Bentonite particles accumulated at some irregularity in the packing of the sand, forming a barrier where more particles were filtered out.

5. The velocity of the bentonite particles was less than that of the water carrying them, leading to a gradual increase in viscosity and, eventually, the formation of a thixotropic gel.

6. When the softened suspending liquid was replaced by the relatively hard tap water, flocculation of bentonite occurred within the soil.

It was shown in Tests B-1 and B-3 that both penetration and retention of bentonite is possible in the sand used and under the given test conditions, at a hydraulic gradient of 0.10. The sealing was practically complete.

Test B-2 showed considerable divergence from the other two tests in the same run, although there was no difference in the technique employed. The recovery of permeability was initially slower but more continuous (see Fig. 15).

The residual sealing in Test B-2 was greater than that obtained in any of the other experiments made during this study, except Tests B-1 and B-3. The divergence of Test B-2 cannot be explained satisfactorily in view of the limited number of tests made.

In Run J the hygroscopic moisture ratios indicated that there had been a considerable reduction of soil colloids in both tests (see Table 5). The effluent concentration curve (see Fig. 17) shows clearly

that leaching began soon after the start of the sedimentation phase, when the effluent concentration exceeded the concentration of the suspension used (1.128 per cent).

The permeability remained steady during sedimentation, after an initial drop, recovering only slightly when the filter cake was removed (see Fig. 17). The specific discharge continued to decrease at a reduced rate (see Fig. 18) as the filter cake was formed. The second sharp dip in the curve of specific discharge was due to sealing at or near the surface.

The removal of 1/4 in. of sand from the surface was intended to show whether there had been any concentrated bentonite penetration for a short distance. However, this effect may have been caused by suspended solids being filtered out at the surface. The nature of such extraneous materials was not determined. Hydroxides of iron or aluminum are two possible sources. In view of these remarks no definite interpretation can be placed on any particular response, as the causes cannot be separated.

Sedimentation of the sand columns, under the given test conditions, caused considerable leaching at a hydraulic gradient of 0.30. The resulting settlement was probably a major factor in effecting partial sealing in Run J.

Series II (Flocculated suspension)

In every test of this series the permeability and specific discharge returned substantially to their initial values, immediately after the removal of the filter cake (see Figs. 19 and 20). The values

of hygroscopic moisture for Tests N-1 and N-2 showed no significant reduction of surface (see Table 7). The permeability curves for Run N (see Fig. 20) indicate that there was no reduction of permeability in the body of the columns during sedimentation.

In Series II sealing was restricted to the surface. There was no evidence that any of the flocculated bentonite entered the sand under hydraulic gradients of up to 0.90. Tests were started after the suspensions had been at rest for some time to allow the flocs to develop.

The minimum specific discharge during sedimentation in Run B of Series II (see Table 8) was about six times larger than that in Run C of Series III (see Table 9). Both runs were carried out at a hydraulic gradient of 0.03, and in both cases sealing was restricted mainly to the surface (see Figs. 19 and 21). This indicates that dispersed suspensions form tighter filter cakes than flocculated suspensions. Flocculated suspensions of the type used in this study would therefore seem to have a limited range of application in sediment lining operations, unless flocculation can be delayed until after the suspensions have penetrated the soil (see Curry (8)). The flocs do not penetrate into small pores and do not form an efficient filter cake when lining larger voids. Flocculated bentonite suspensions are very viscous. It may be possible to make use of this property to seal very open soils and gravels.

The tests reported herein simulated dead ponding conditions. Penetration of flocculated bentonite may be possible if turbulence near the suspension-soil interface prevents the formation of effective flocs.

Series III (Dispersed suspensions)

In Run C the specific discharge (see Fig. 21) decreased rapidly to a minimum during sedimentation and increased to its final value immediately after the removal of the filter cake. The final reduction of permeability was small (see Table 8). Run A (Series I) was carried out at the same hydraulic gradient of 0.03 as Run C. In both cases dispersed suspensions were used, the only difference being in the maximum sediment size (see Table 4). In run A (see Fig. 14 and Table 6) the decrease in specific discharge during sedimentation and the subsequent increase were more gradual than in Run C. The final reduction of permeability was greater in Run A. The coarser materials present in the suspension used in Run C accelerated the formation of the filter cake. The total volume of filtrate which entered the soil during sedimentation was therefore limited. This probably accounted for the reduction in final sealing effects.

In Run O the decrease of permeability and specific discharge (see Figs. 22 and 23) was rapid at the beginning of the sedimentation phase and then continued at a decreasing rate. After the removal of the filter cake, the permeability increased to its final value relatively quickly. The hygroscopic moisture ratios (see Table 9) indicated that there had been no net retention of bentonite and that a significant proportion of soil colloids had been leached from the columns.

In Test O-3 the filter cake was damaged accidentally so that the sand column was subjected to effective sedimentation for a longer period. This was reflected in the curve of effluent concentration (see)

Fig. 22). The filter cake contained a slightly smaller amount of mont-morillonite (see Appendix A - Samples 3 and 4) and the final reduction of permeability was greater than in Test O-1. The hygroscopic moisture ratios (see Table 8) indicate, however, a relatively greater reduction of surface in Test O-3.

In view of the above remarks it may be concluded that settlement was the major factor causing sealing in Run O.

Series IV (Treatment with dispersant solution)

In Run Q the permeability in the upper part of the column, K'_{5-6} , decreased more quickly at the beginning of the treatment with dispersant solution, than in the lower part, K'_{6-7} (see Fig. 24). At 210 hours K'_{5-6} again became larger than K'_{6-7} and remained so for the rest of the test. This sequence, when considered together with the observations made during the test (see Chapter VI) and the hygroscopic moisture ratios (see Table 11), may be explained thus:

At the start of the treatment a relatively large proportion of the effect of the dispersant was used up in the upper part of the column, enabling soil colloids to disperse and migrate. At 90 hours the effect of the removal of fines became predominant and the permeability began to increase in the upper part. In the lower part the permeability continued to decrease probably because the density and, consequently, the viscosity of the permeating suspension increased. This may be deduced from the response to surface cleaning at 380 hours. The specific discharge increased as may be expected, but the increase in permeability

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in the upper part of the column was much smaller than the corresponding increase in the lower part, indicating that the fluid there had a more sensitive stress-viscosity relationship.

After the end of the treatment the permeability in the upper part continued to decrease, possibly because of additional settlement. In the lower part the permeability remained substantially steady, although leaching continued.

The hygroscopic moisture ratios showed that a considerable loss of surface had occurred in this run, particularly in the upper part of the column. The difference in the residual sealing effect (see Table 9) may be attributed to the difference in clay content. In Run A, carried out at the same hydraulic gradient of 0.03, both the loss of surface and the reduction of permeability were significantly smaller (see Table 6). It may therefore be concluded that the predominant factor causing partial sealing in Run Q was the compaction of the sand.

This conclusion was of considerable importance in improving the interpretation of the results of Runs E and J (see Table 5) and of Run O (see Table 8).

Run Q can also be regarded as an accelerated illustration of a phenomenon occurring in nature, where in some older soils the clay content is found to increase with depth.

VII SUMMARY

Permeability measurements were made on columns of a natural dune sand from eastern Wyoming which were treated with one per cent bentonite suspensions or with a dispersant solution, in order to study some factors which may contribute to penetration and sealing in sediment lining installations.

It was found that the hydraulic gradient was one factor affecting the entry of dispersed bentonite suspensions into the sand and the retention of bentonite. There was apparently a critical value of hydraulic gradient when both penetration and retention could occur. Under those conditions complete or almost complete sealing of the sand columns could be effected. In the system studied this critical value fell somewhere between the hydraulic gradients of 0.03 and 0.30. If the hydraulic gradient was less than critical the bentonite was filtered out at the sand surface. Under hydraulic gradients larger than critical, bentonite was not retained in the sand in significant quantities.

The sand used contained initially a small proportion of clay in the form of coatings around the grains. It therefore had a slight cation exchange capacity (see Appendix A). In an earlier study, Curry (8) found that retention of bentonite from a dispersed suspension was not possible if the permeated medium was chemically inert.

Natural colloidal materials were leached from the columns by dispersed suspensions or their filtrates. Where the leaching was limited, the rearrangement and swelling of soil colloids, as well as the formation

of denser layers by accumulation of particles, may have contributed to the sealing.

Considerable leaching caused settlement of the sand, which in turn contributed materially to the reduction of permeability. This may have been of relatively greater importance than the loss of soil colloids, which would be expected to cause an increase of permeability.

Non-colloidal materials contained in the bentonite accelerated the formation of the filter cake.

Flocculated suspensions did not enter the sand under dead ponding conditions, even at hydraulic gradients of up to 0.90.

When one of the sand specimens was treated with a dispersant solution, instead of a bentonite suspension, in-place colloids were leached from the column and settlement of the sand occurred.

It was demonstrated that colloids present in a soil can become mobile in a dispersant environment. Application of this principle in the field may lead to the development of a sealing method by in-place sedimentation under suitable conditions.

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APPENDIX

A. TESTS CARRIED OUT AT THE ENGINEERING LABORATORIES,
U. S. BUREAU OF RECLAMATION, DENVER, COLORADO.

Tests on the Sand and Bentonite Used in the
Experiments at Colorado A and M College

The following is a copy of memoranda written by Mr. E. J.
Benton and by Mr. D. Ramaley reporting results of petrographic examina-
tions, and of chemical analysis data. Sample Nos. 5 and 6 were taken
from the bottom of the columns (see Table 6).

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Division of Engineering Laboratories
Petrographic Memorandum No. 56-49
Denver, Colorado
June 28, 1956

Subject: Examination of materials from sediment lining tests made at
Colorado A and M laboratories, Sediment Lining Project,
Lower Cost Canal Lining Program

INTRODUCTION

Materials from the sediment lining tests at Colorado A and M
were brought into the Petrograpic Laboratory by Engineer C. W. Jones
of the Earth Laboratory and Mr. Clive Newman of Colorado A and M Col-
lege, Fort Collins, Colorado, for examination by x-ray diffraction and
differential thermal analysis. The samples were obtained in connection
with experiments being performed at the College to ascertain the extent
to which bentonite in water suspension will penetrate sand. These ma-
terials were identified as follows:

No. 1   Sand as placed
No. 2   Sand as placed
No. 3   Filter cake, Run O-1
No. 4   Filter cake, Run O-3
No. 5   Sand after sedimenting, Run A-3
No. 6   Sand after sedimenting, Run A-4
No. 7   Bentonite

The samples were examined by x-ray diffraction. From these
results it was evident that differential thermal analysis would not
contribute additional information. Brief observations were made with
the stereoscopic microscope but a complete petrographic study was not
made. Since the clay content of the sand materials was very low, it
was necessary to concentrate the clay fraction from a relatively large
sample to make identification possible.

DESCRIPTION OF THE SAMPLES

Sands, No. 1, 2, 5 and 6

The sand samples were practically identical and will be des-
cribed together. The sand grains are subangular to well rounded and

range in size from about 0.1 to 0.3 mm for the most part. A very small proportion of coarser and finer sand is present in the samples. The grains are predominately quartz; grains of feldspars are subordinate; and a very few percent of other minerals and miscellaneous rock fragments are present. The feldspars appear sound. No argillaceous particles were observed in any of the samples under the stereoscopic microscope.

X-ray diffraction patterns on Samples No. 1 and No. 2 were similar and showed a composition of 70 to 80 percent quartz and 20 to 30 percent feldspars, the miscellaneous minerals being of too low concentration to permit identification by x-ray in the bulk sample. No diffraction study was made of Samples No. 5 and No. 6, the treated sands. They appeared to be in their original condition and the clay content is below the minimum detectable by x-ray diffraction.

The clay fraction of the sand samples No. 1, No. 5 and No. 6 was concentrated by the following procedure: 20 g of the sand was placed in a beaker and distilled water added to a total volume of 500 ml. The fine fractions were dispersed by agitation in a high speed electric mixer for 5 minutes. The samples were allowed to stand over a weekend to insure complete hydration of clays, and again were dispersed briefly by the mixer. After settling for 1 hour, a 50 ml portion of each was withdrawn from a depth of 4 cm and placed in a tared centrifuge tube. Approximately 0.2 g of $FeCl_3 \cdot 6H2O$ was added to each tube to flocculate the clay. A drop of 1:1 HCl was added to each tube to prevent precipitation of ferric hydroxide. The tubes were heated in a water bath until the suspended material became flocculent, then centrifuged for 5 minutes, after which the perfectly clear supernatant liquid was decanted. The residues were washed once with 40 ml of 95 percent ethyl alcohol and again centrifuged and decanted. The tubes were dried briefly in an oven at 105°C, then allowed to cool in the room air and weighed. The amounts of this material recovered from each sample were as follows:

> Sample No. 1   15.3 mg
> Sample No. 5   10.8 mg
> Sample No. 6   11.2 mg

No attempt is made here to calculate the total amount of this material present in the samples since the procedure is somewhat arbitrary. However, since identical treatment was received by each sample the recovered quantities of these clay-size materials should be fairly good indices of the relative amounts present in the sands. The x-ray diffraction patterns show the three clay materials to be identical, and to consist of montmorillonite clay and very minor amounts of quartz and feldspars. The samples cause a fluorescent darkening of the diffraction pattern from some iron compound which contributes no identifiable lines to the pattern. The iron is possibly either extremely fine metallic

dust abraded from the mixer blades by the sand or residual $FeCl_3 \cdot 6\ H_2O$
not washed out by the alcohol rinse. The 14A spacing on these materials
is very diffuse and is accompanied by low angle scattering, quite dif-
ferent from the sharp 14A line from the bentonite sample (No. 7) and the
filter cakes (No. 3 and No. 4). All three specimens were medium buff
when pulverized. Each produced a greenish blue color with benzidine,
indicating the presence of montmorillonite-type mineral.

Bentonite and filter cakes, No. 3, 4 and 7

The bentonite (Sample No. 7) is a very light buff, finely
pulverized material, showing rapid reaction with benzidine solution
with development of a sky blue color. The two filter cakes (Samples
No. 3 and 4) are very light gray, hard, cracked crusts of bentonite
with silt inclusions and patches of adhering sand. They react to ben-
zidine as does Sample No. 7. The x-ray diffraction patterns of these
materials show their compositions to be approximately as follows:

Mineral	Filter Cake No. 3	Filter Cake No. 4	Bentonite No. 7
Montmorillonite	50 percent	45 percent	70 percent
Quartz and chalcedony	45 percent	50 percent	25 percent
Feldspars and misc.	5 percent	5 percent	5 percent

CONCLUSIONS

Practically no newly introduced bentonite is present in the
treated sands. Indeed, the data suggest that the sedimentary treat-
ment washed out part of the small amount of montmorillonite originally
present in the sand. The x-ray diffraction patterns show a difference
between the montmorillonite mineral originally present in the sand and
that in the bentonite used in the sedimentation treatment. The latter
is a normal montmorillonite giving a sharp 14A line, whereas the former
gives a very diffuse band corresponding to d spacings between 10 and
14A, suggesting that it may be a mixed layer clay.

(signed)
Elton J. Benton

Division of Engineering Laboratories
Petrographic Memorandum No. 56-60
Denver, Colorado
July 26, 1956

Subject: Petrographic examination of materials from sediment lining tests made at Colorado A and M Laboratories, Sediment Lining Project, Lower-cost Canal Lining Program

INTRODUCTION

This memorandum is a supplement to Petrographic Memorandum No. 56-49, same subject, and comprises a microscopical description of the samples. No conclusions reported in the previous memorandum have been altered by microscopical study.

The samples are designated as follows:

No. 1 Sand as placed
No. 2 Sand as placed
No. 3 Filter cake, Run O-1
No. 4 Filter cake, Run O-3
No. 5 Sand after sedimenting, Run A-3
No. 6 Sand after sedimenting, Run A-4
No. 7 Bentonite

RESULTS OF EXAMINATION

Sand Samples No. 1, 2, 5, and 6

These samples are similar to each other and may be discussed simultaneously. The sands are fine and very little material is retained on a No. 30 sieve. Sieve analyses of these sands are as follows:

| | Percent by weight | | | |
Size fraction	Sample No. 1	Sample No. 2	Sample No. 5	Sample No. 6
+No. 30	0.1	0.1	0.4	0.2
-No. 30 and +No. 50	2.3	3.2	2.0	1.6
-No. 50 and +No. 100	80.8	85.8	80.7	84.8
-No. 100 and +No. 200	15.8	10.0	15.7	12.6
-No. 200	1.0	0.9	1.2	0.8
	100.0	100.0	100.0	100.0

Nearly all of the sand particles range in diameter from 0.045 to 0.36 mm. The particle shapes range from angular to round.

The sands are composed predominantly of quartz and feldspars (both plagioclase and alkalic varieties). Small proportions of cherts, micas, amphiboles, iron oxides, garnets, miscellaneous minerals, and fine-grained weathered rock fragments are present also. Very small amounts of clay were detected in the fine sand fractions.

Bentonite (Sample No. 7)

Under the microscope the bentonite is seen to be moderately pure montmorillonite clay of medium refractive index (n about 1.535) and fairly high birefringence. Particles range in diameter from sub-microscopic to about 0.1 mm. The sample contains also angular and sub-angular quartz and feldspar grains in moderate abundance. These range in size up to about 0.1 mm. Calcium carbonate crystals are sparsely scattered throughout the sample.

When treated with water, the bentonite exhibits the high swell and slippery feel characteristic of bentonites.

Filter Cakes (Samples No. 3 and 4)

The samples are composed of dried, shrunken, and curled fragments composed of bentonite and silty sand in about equal proportions. These fragments contain alternating layers or lenses of relatively concentrated sand and relatively concentrated bentonite.

The materials with particle diameters less than 50 microns consist predominantly of bentonite but include also a moderate proportion of silt particles of the types occurring in the sand samples (Nos. 1, 2, 5, and 6) and the bentonite (No. 7).

(signed)

D. Ramaley

LCCL--Sediment Lining Program

Lab No.	Material*	Milliequivalents per 100 grams of soil							Exchangeable percentage			Saturation percentage
		Exchangeable salts				Soluble salts						
		Exchange capacity	Na	K	Ca + Mg	Na	K	Total	Na	K	Ca + Mg	
A-6455	Sand	3.75	0.83	0.00 0	2.91	0.01	0.00	0.01	22.2	0.00	77.8	30.0
A-6456	Sand	3.88	0.84	0.00	3.03	0.01	0.00	0.01	21.5	0.00	78.5	30.0
A-6457	Bentonite	70.0	16.7	14.8	38.5	10.5	0.22	11.7	23.8	21.1	55.1	420

* Description of samples

A-6455   Sample No. 2 -- Colorado A and M College -- sand as placed
A-6456   Composite of Samples No. 5 and 6 -- Colorado A and M College -- sand after sedimenting runs A-3 and A-4
A-6457   Sample No. 7 -- Colorado A and M College

Tests on Canal Bed Material from
Lateral No. 1, North Platte Project

The following information was included in unpublished data received under cover of a letter, dated February 3, 1956, to the Dean of Engineering, Colorado State University, from the Chief, Division of Engineering Laboratories, U. S. Bureau of Reclamation, Denver, Colorado. Subject: Pre-installation test data - Sediment Lining Project - Lower-cost Canal Lining Program.

"Soil samples were obtained from Lateral No. 1 (North Platte) at Miles 1.1, 4.2, and 61. . . . .

"From petrographic examination, bentonite was found to be present in the soils predominantly in the form of strongly attached coatings on the surfaces of the grains. An estimate of the quantity of bentonite resulted in an average of 5 or 6 percent by volume . . .

"Table 2.--CHEMICAL ANALYSES OF CANAL BED MATERIALS - SEDIMENT LINING TESTS[1].

Description	North Platte[2]
pH	7.3
Exchange capacity (M.E./100 gm)	2.90
Total sodium	0.50
Soluble sodium	0.03
Exchangeable sodium	0.47
Total potassium	0.25
Soluble potassium	0.00
Exchangeable potassium	0.25
Exchangeable (calcium + magnesium)	2.18
Total soluble salts	0.11
Saturation percent	28.6

Notes: [1] Only the relevant portion of Table 2 is reproduced here.
[2] Sample 2OF-130 from Mile 4.2 of Lateral No. 1, of the Interstate Canal."

Petrographic Analyses of Bentonite

The following information is reproduced from "Results of Laboratory Tests on Soils and Water for Sediment Lining Demonstrations" (30). The two bentonite samples described were supplied by the company which also supplied the bentonite used in the tests at Colorado A and M College.

Earth Materials Laboratory No.	20 F - 3	20 F - 4
Description	Bentonite	Bentonite
Location	Wyoming	Wyoming
Na-, Ca-montmorillonite	62%	60%
Quartz	25%	25%
Calcite	2%	3%
Feldspar	4%	3%
Acidic volcanic glass	1%	1%
Muscovite, biotite	1%	1%
Gypsum	5%	5%
Iron oxides, zircon, apatite	Trace	Trace

B. DESCRIPTION OF AUXILIARY TESTS

Determination of the Hygroscopic Moisture Ratio

Samples of the sand in its pre-treated condition and samples taken from the permeameters were oven dried at 110°C. They were then broken up in a mortar and passed through a No. 20 sieve. Approximately 20 gm of each sample was placed in a weighed aluminum dish and returned to the oven for 24 hours. The samples were then cooled in a dessicator over calcium chloride.

The dry weights were determined. The dishes were then placed in a dessicator over a saturated solution of zinc sulphate, $ZnSO_4 \cdot 7H_2O$, in distilled water. The dessicator was evacuated to approximately 1 cm of mercury absolute pressure and kept in a constant temperature room at 20°C. Under these conditions the relative humidity in the dessicator was 90 per cent. After five days the moist weights of the samples were determined.

The hygroscopic moisture ratios were then calculated:

$$\text{Ratio} = \frac{\text{Moisture per cent of dry weight of sample}}{\text{Moisture per cent of dry weight of original sample}} \cdot$$

Mechanical Analysis of Sand Samples

A sample of 100 gm of the oven dry material was placed in a 1000 ml hydrometer jar with about 150 ml of water. Various proportions of dispersant were added (see Fig. 11). The air mixer (see Fig. 13) was put into the jar and was run for 10 minutes. Details of an air mixer of the same type are given by Davidson and others (9). The mixer was
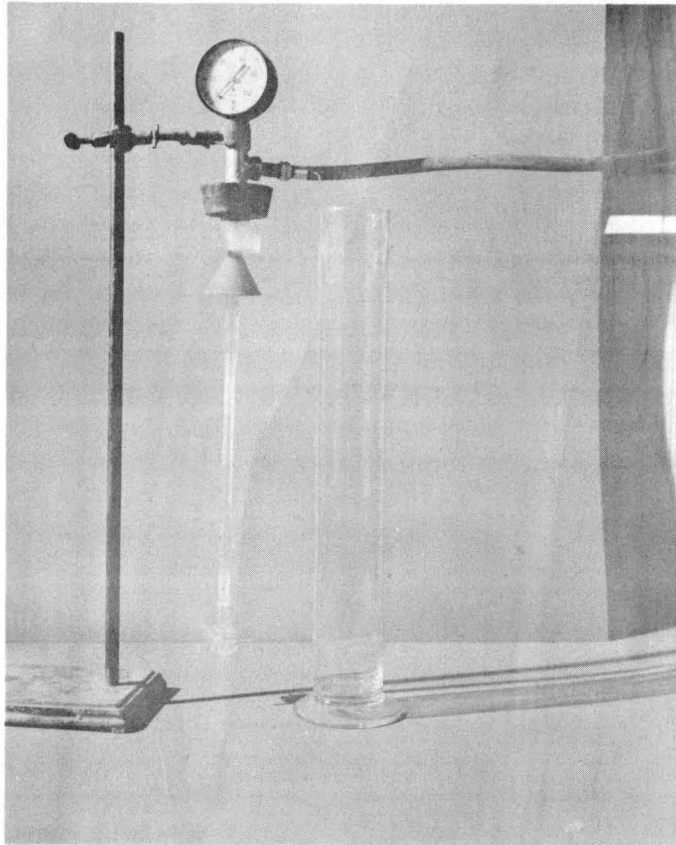
Fig. 13   View of air mixer for soil samples.

removed, the contents of the jar were made up to 1000 ml and allowed to stand for 24 hours. The mixture was then shaken up by hand and the hydrometer test was run. After this the contents of the jar were washed through a No. 200 sieve (74-micron opening). The material retained was dried and analysed by dry sieving.

Determination of the Concentration of Samples of the Suspension or Effluent

Samples of 25 ml were taken with a pipette and dried in weighted aluminum dishes at 110°C. The dry weight was determined to within one milligram and the concentration calculated from:

$$C = \frac{100(W_d - D)}{25}$$

where 	C = 	concentration (per cent)

W_d = 	dry weight of sample (gm)

D = 	correction for dispersing agent if applicable (gm)

The concentration determined by this method agreed, to within one per cent, with values obtained in several check tests in which the original weight of the wet sample was recorded.

Determination of Carbon Dioxide in the Effluent

Samples of 100 ml of the effluent and of water from the heating tank were titrated with an $N/22$ solution of sodium carbonate, Na_2CO_3, using phenolthalein as indicator. It was assumed that all excess carbon dioxide had been washed from the column when the end points were reached in both samples with equal quantities of the titrating solution.

Grit Content Test on Bentonite

This test has been adapted from one described by Fisk (13).

Samples of 20 gm of oven dry bentonite were dispersed in water by means of the air mixer (see Fig. 13). The resulting suspension was washed through a No. 325 sieve (44-micron opening), with as much water as necessary. The grit retained on the screen was washed into a dish and dried at 110°C. The grit content was calculated from:

$$\text{Grit Content } (\%) = \frac{\text{Dry weight of fraction larger than 44 microns x 100}}{\text{Dry weight of original sample}}$$
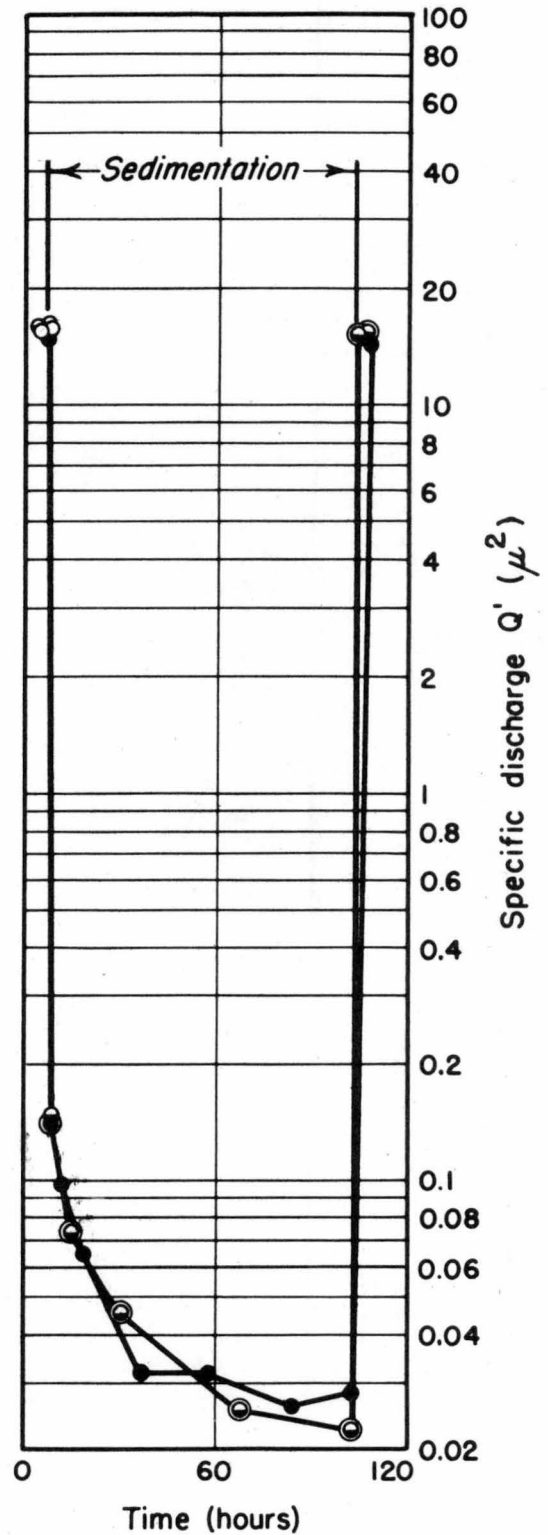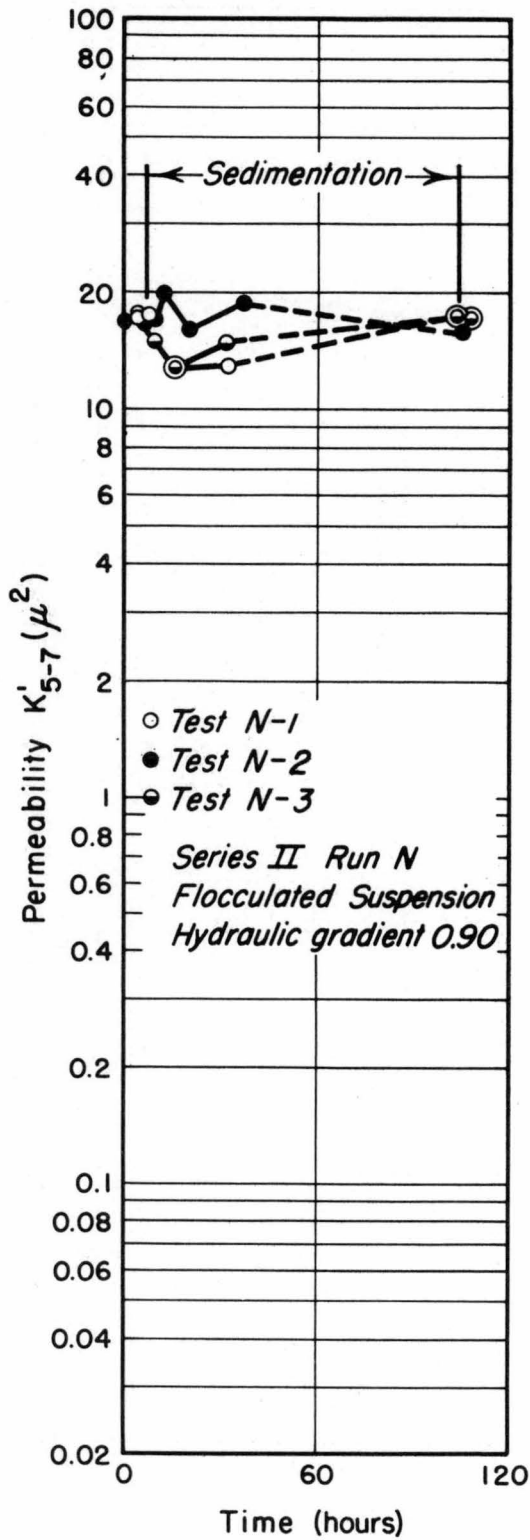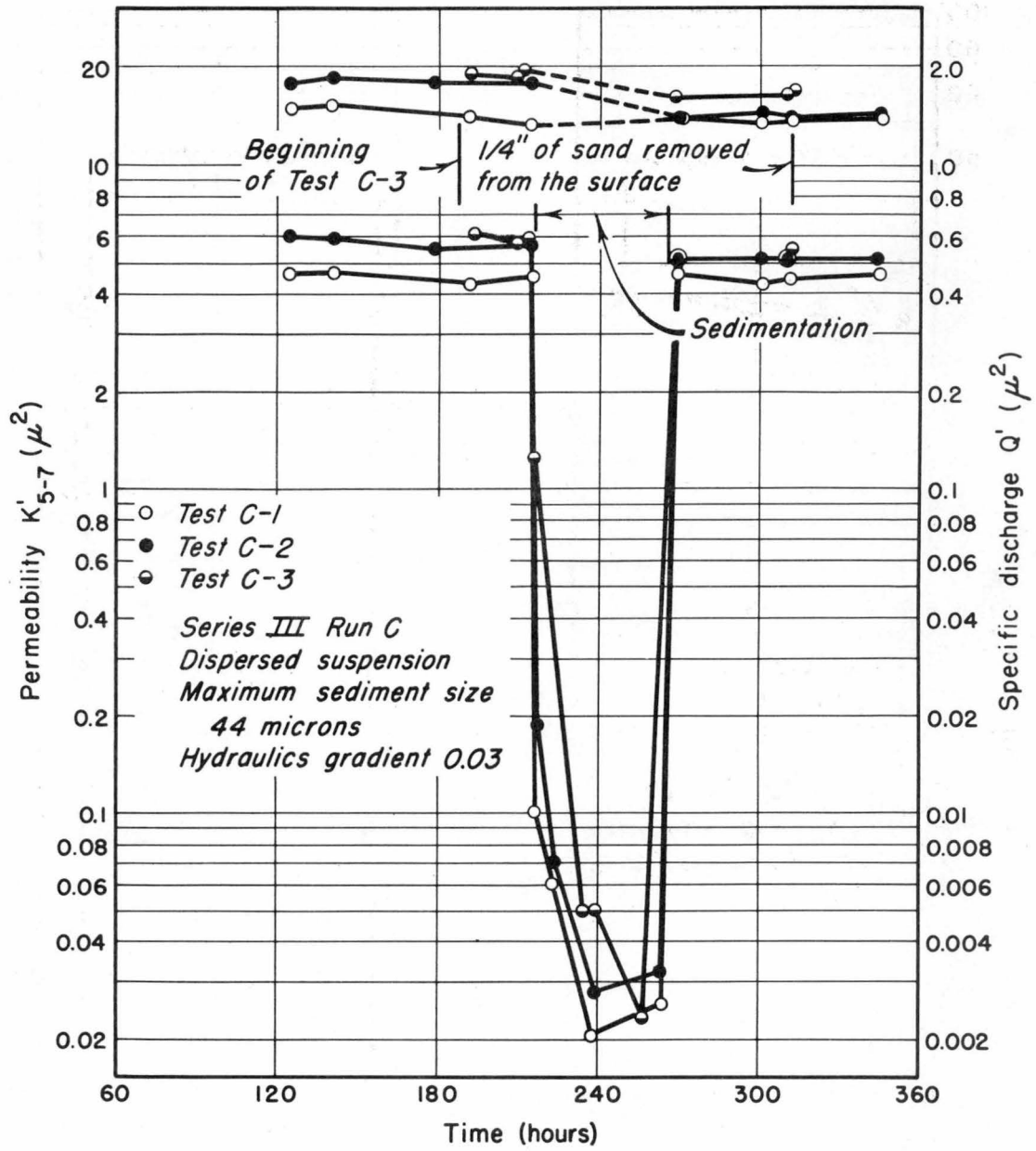
C. GRAPHICAL REPRESENTATION OF TEST RESULTS
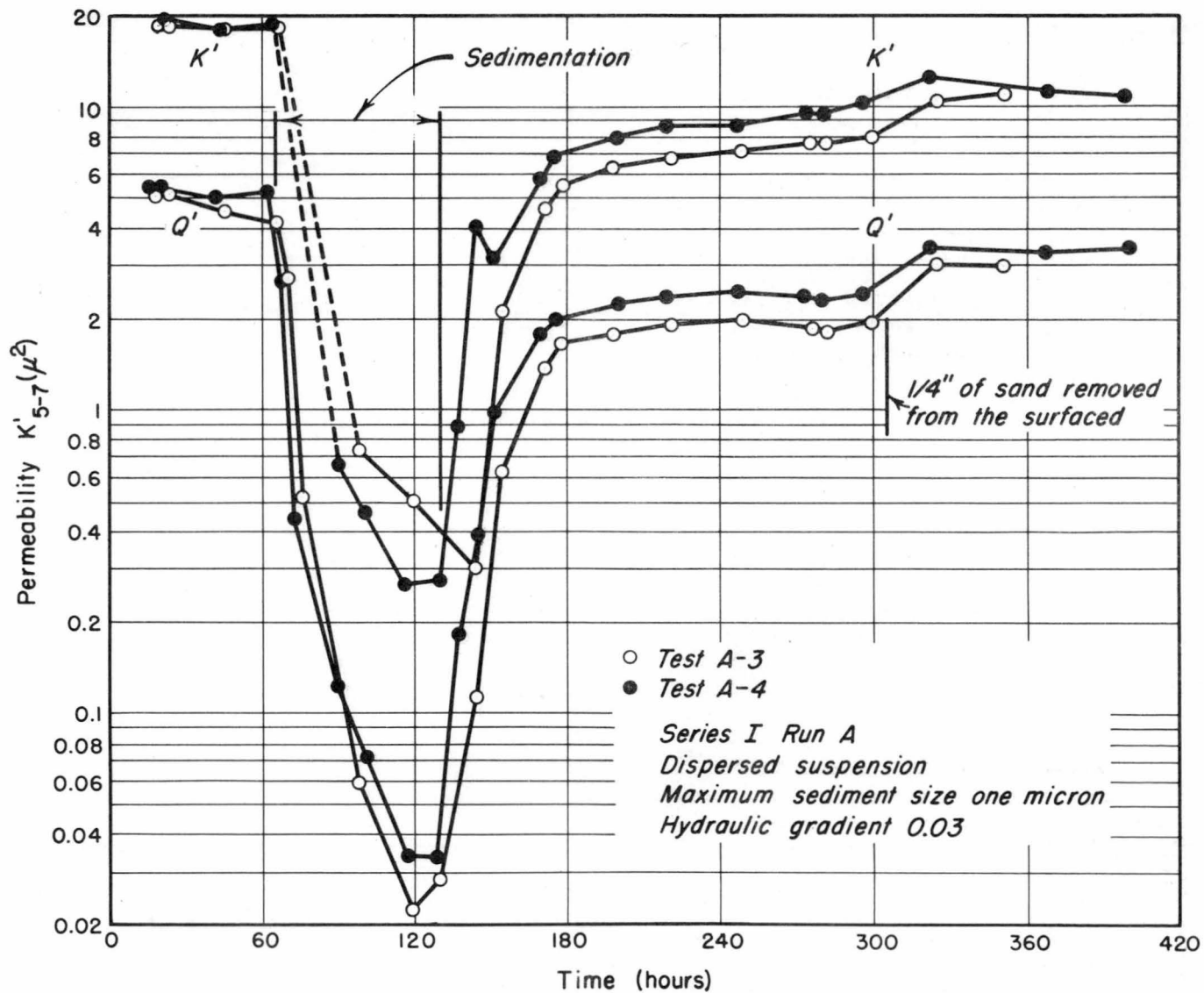
Fig. 14 Variation of permeability and specific discharge with time -- Series I Run A.
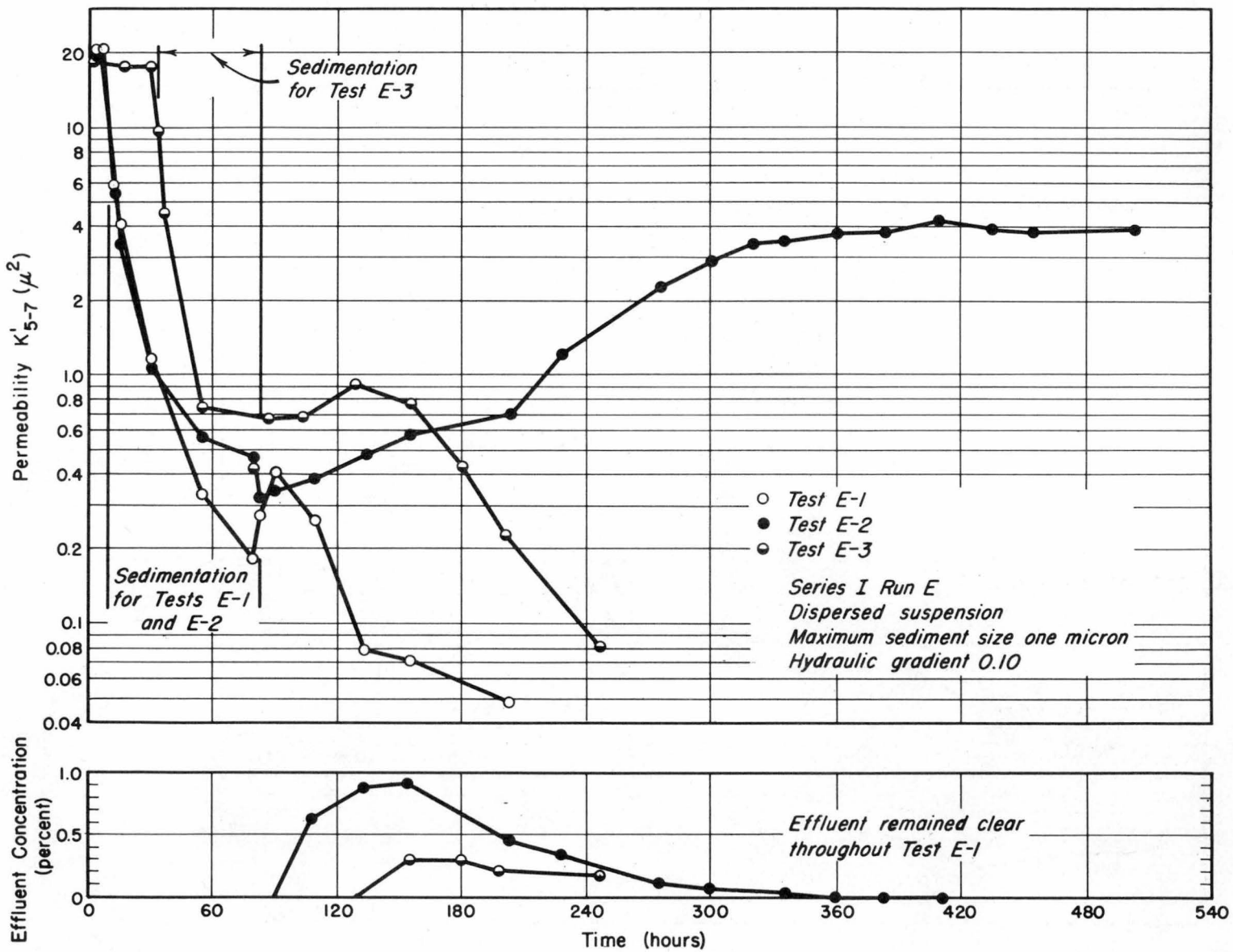
Fig. 15   Variation of permeability and effluent concentration with time -- Series I Run E.
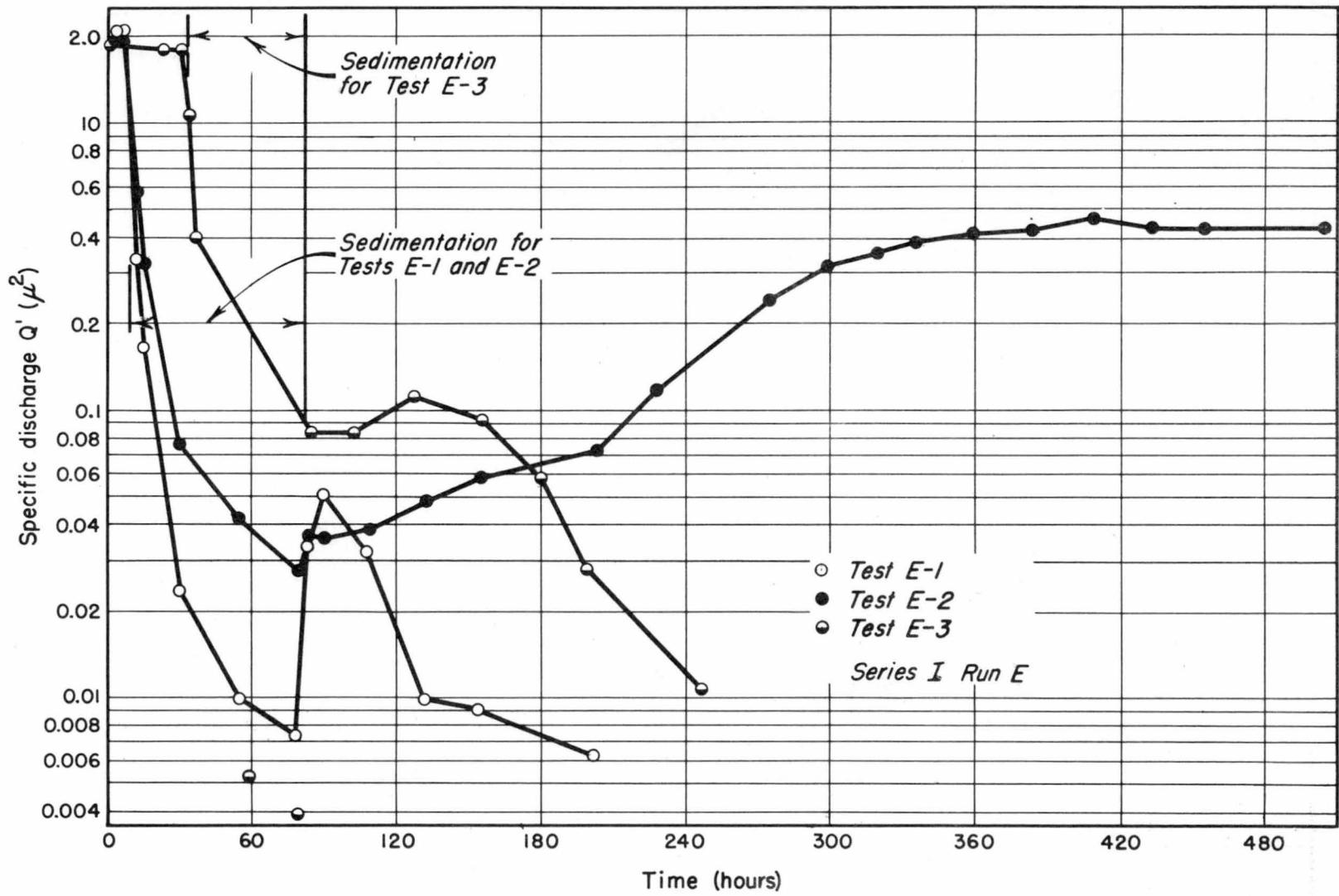
Fig. 16   Variation of specific discharge with time -- Series I Run E.
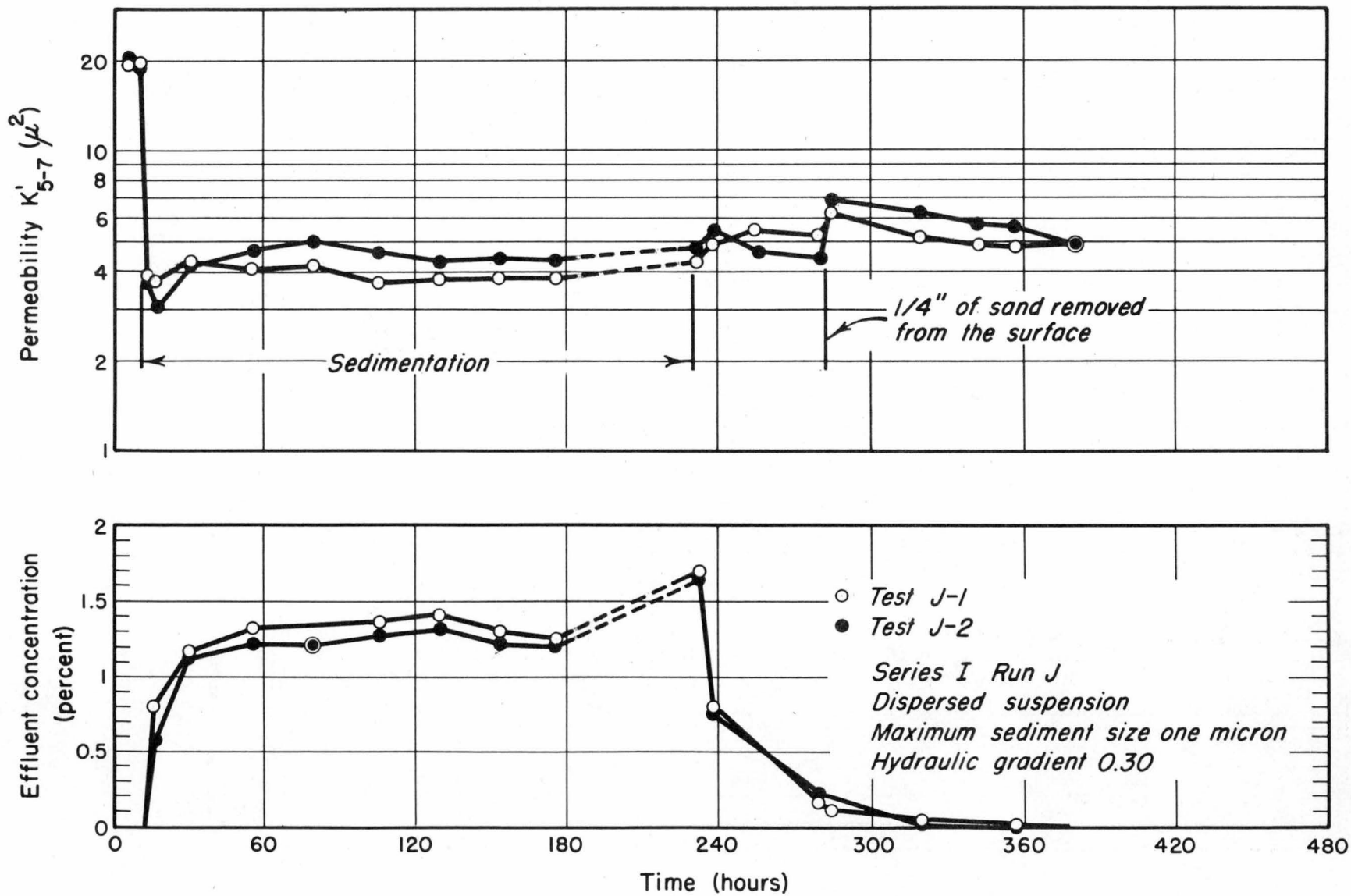
Fig. 17   Variation of permeability and effluent concentration with time -- Series I Run J.
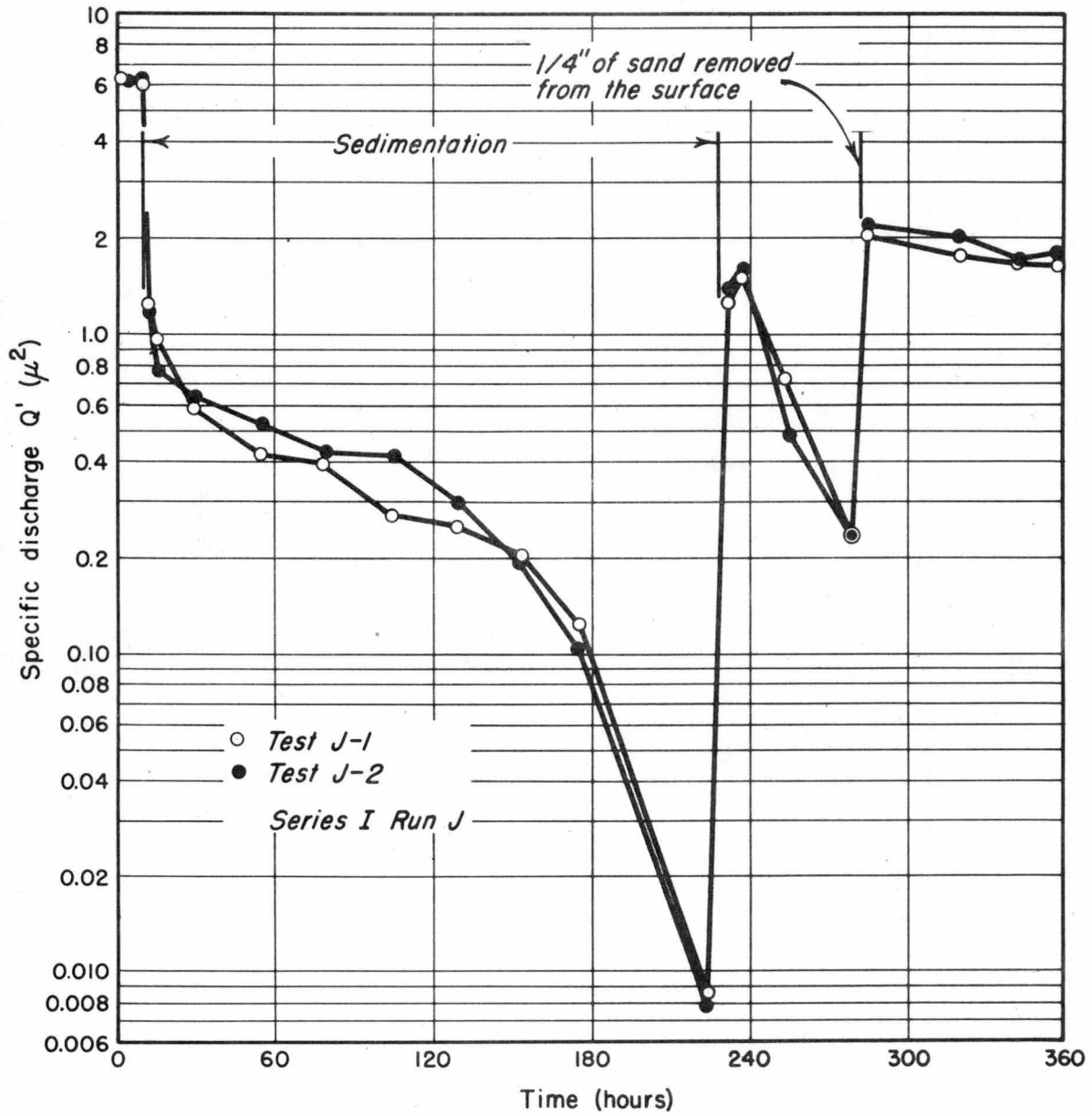
Fig. 18   Variation of specific discharge with time -- Series I Run J.
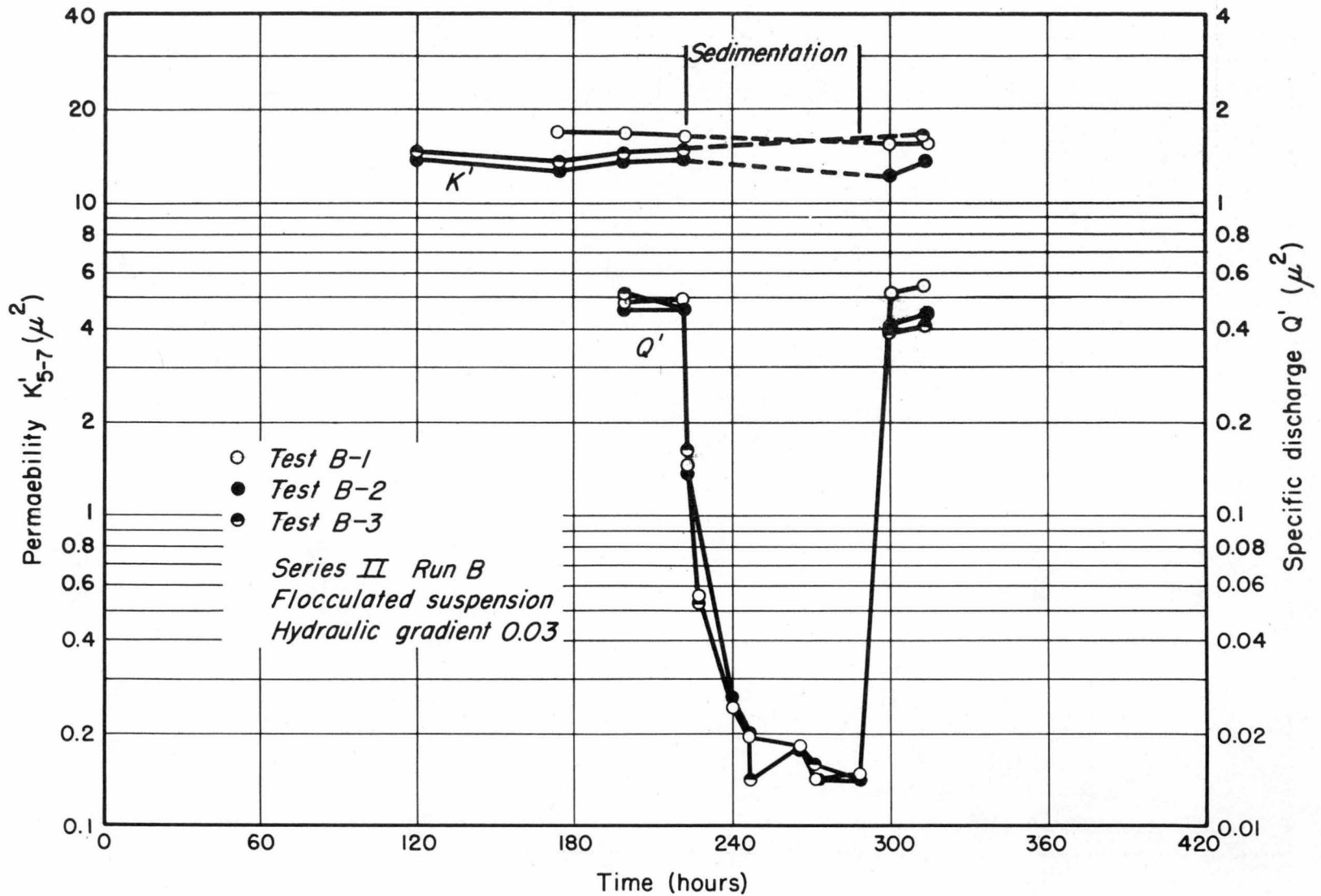
Fig. 19   Variation of permeability and specific discharge with time -- Series II Run B.

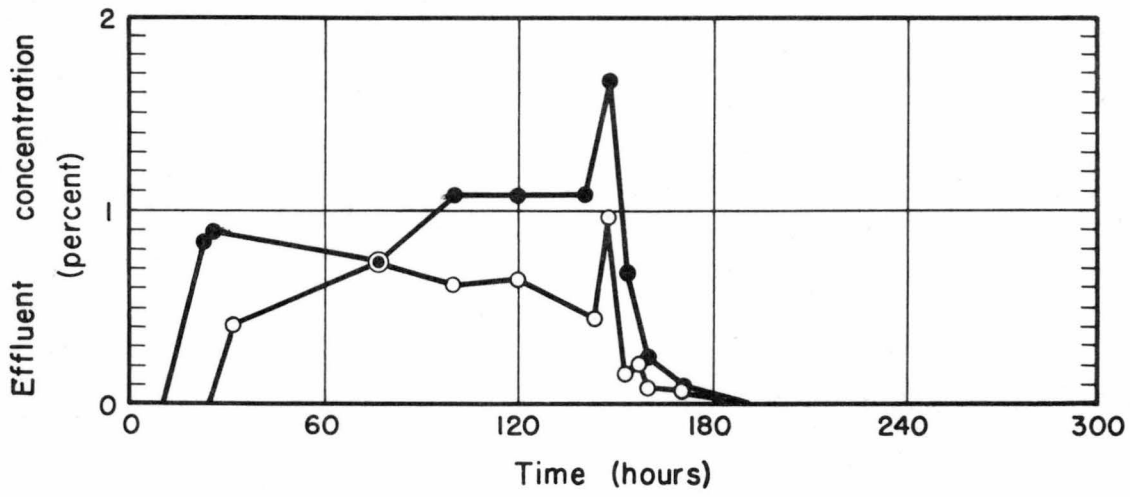Fig. 20 Variation of permeability and specific discharge with time -- Series II Run N.

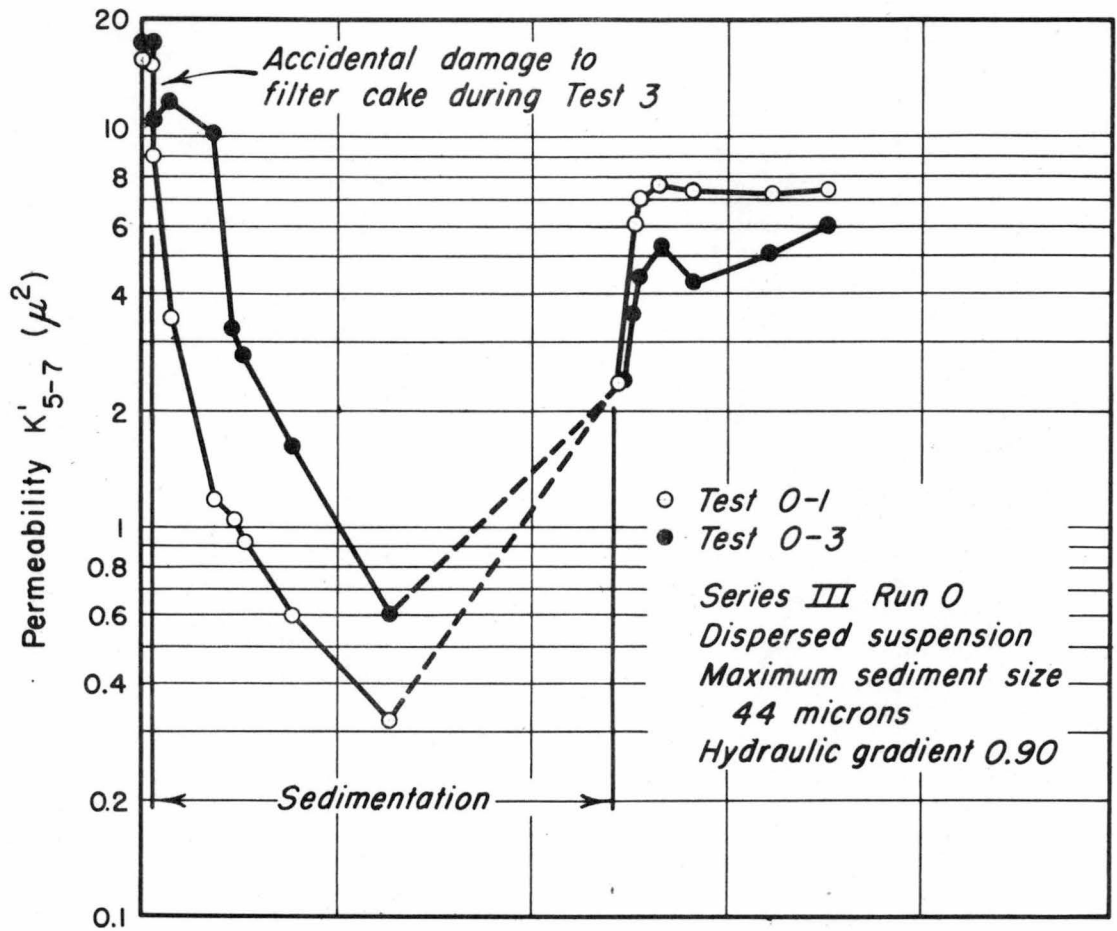Fig. 21   Variation of permeability and specific discharge with time -- Series III Run C.

Fig. 22 Variation of permeability and effluent concentration with time -- Series III Run O.
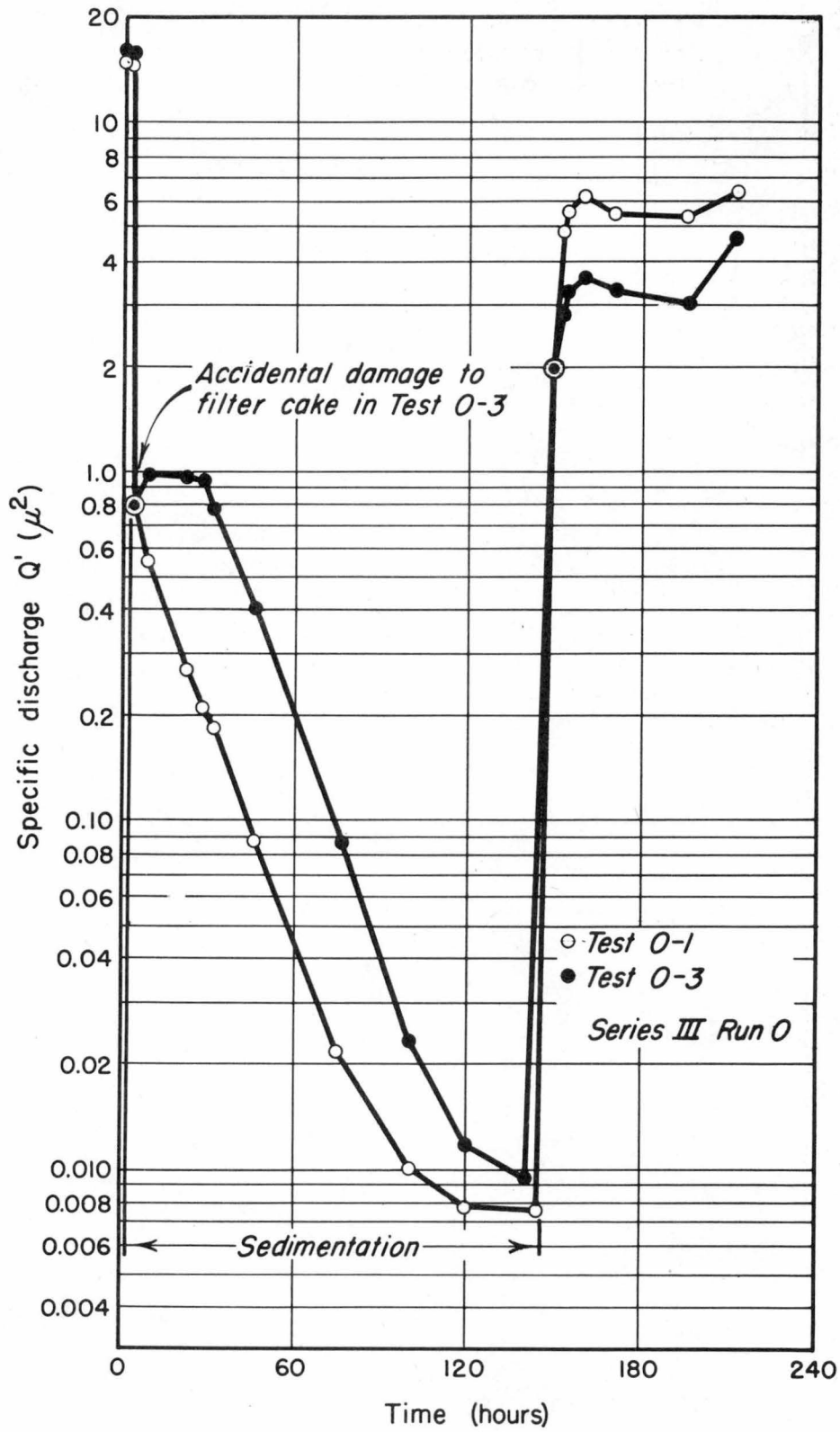
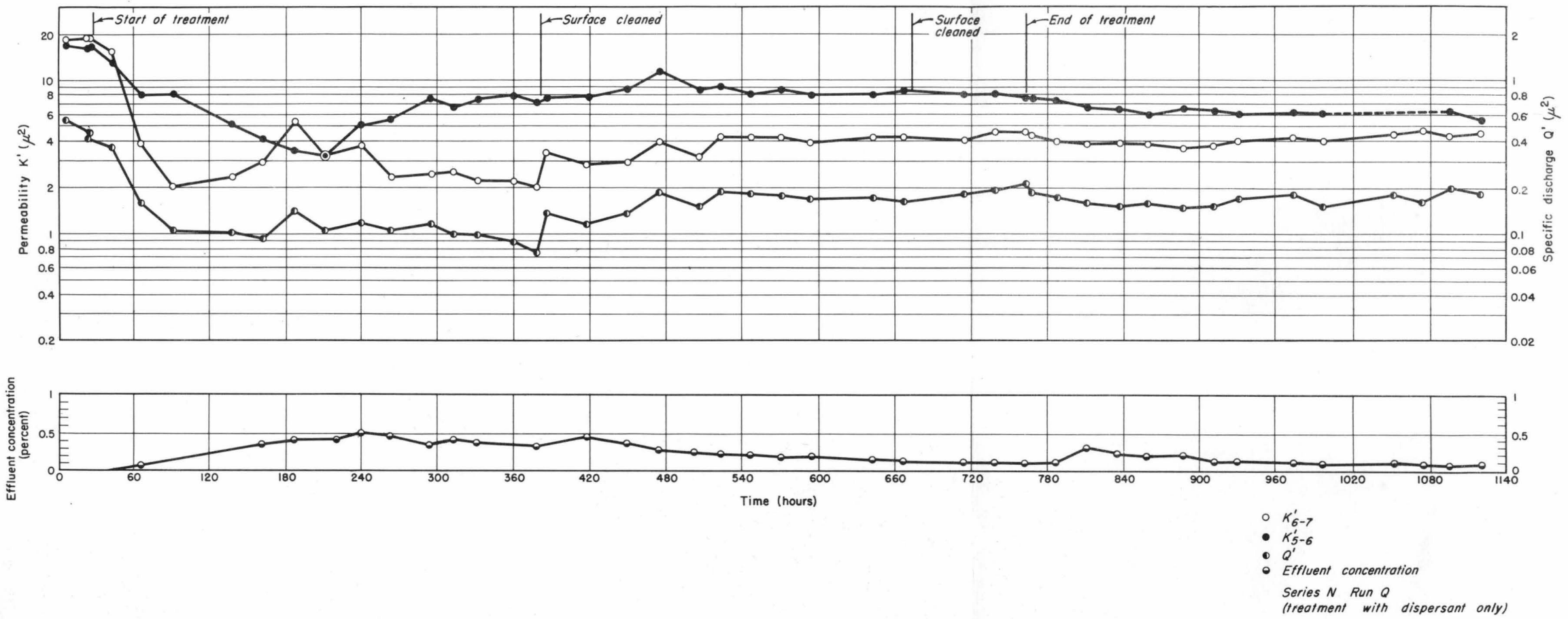Fig. 23   Variation of specific discharge with time -- Series III Run O.

Fig. 24 Variation of specific discharge, permeability and effluent concentration with time -- Series IV Run Q.

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