

PERCOLATION CHARACTERISTICS
OF VARIOUS SEDIMENTS

By

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B. S., Kansas State College
of
Agriculture and Applied Science, 1950

A THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Geology and Geography

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1952

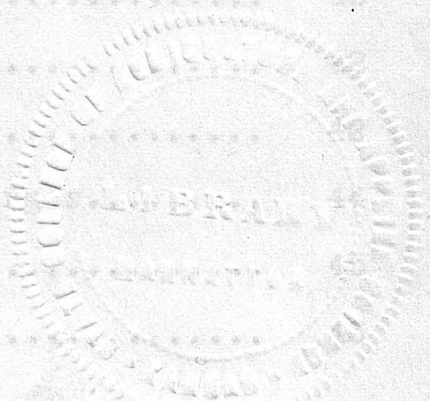


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INTRODUCTION

Purpose of the Investigation

An attempt was made to determine a few of the hydrologic characteristics and properties of two homogeneous structureless sediments that differed in grain size only. With this accomplished, comparisons could be made as to the effect of grain size on the hydrologic properties when all other factors are controlled.

The characteristics of percolation of the two sediments were of primary interest. The manner of investigation was controlled by the desire to obtain the maximum information on the rate as well as the quantity of water moved through the sediment or retained by it.

The hydrologic properties such as porosity, permeability, specific retention, specific yield, and the various points between saturation and the moisture equivalent were determined as a method to check and compare the results indicated by the use of the electrodes and voltage.

Previous Work

There has been a great deal of research to determine the hydrologic properties of various unconsolidated sediments. Most of this work has been done in the interest of agriculture, especially for the purpose of improving the methods of crop irrigation along with the soil conservation properties that would be involved.

However, this research performed to serve an objective in agriculture is almost entirely limited to very fine sands, silts, and clays as well as the colloids and organic matter that make up the soil.

The methods used for determining the hydrologic properties of the finer sediments are numerous. Three of the more common methods includes one direct and two indirect methods. (Slater and Bryant, 1946, pp. 142-148; and Scofield, 1945, pp. 375-402.)

The tensiometer method involves the direct measurement of the tension existing between the soil and its water by the use of a mercury manometer. The two indirect methods include the gravimetric method, in which soil samples are weighed and then dried to a constant weight (from the loss of weight the water content is computed) and the electrometric method, in which the measurement of the electrical resistance between two electrodes embedded in a block of gypsum placed in the soil.

One of the less common devices for determining soil moisture is the stabilometer. (Allyn, 1942, pp. 302-313.) This is a soil probe which consists of a diamond-shaped blade mounted on a shaft. The shaft and blade are driven to the desired depth and the resistance of the soil to the rotation of this point is termed the "soil stability" and is evaluated in terms of torque in inch-pound units by use of an especially designed handle. This stability measurement, when correlated with corresponding moisture content, shows a consistent relationship by means of which soil moisture content may be estimated for

any given soil type.

The research on coarse sediments, such as fine to medium sand, is more limited.

There has been considerable work done on the determination of porosity and permeability as well as the determination of specific yield for some of the water-producing aquifers.

(Stearns, 1927, pp. 121-176; and Meinzer, 1923, Paper 494.)

This work, although performed in laboratories, deals with sediments in their natural state. One exception to the laboratory work is the work performed by Theis which has to do with field determination of permeability and the determination of the "coefficient of transmissibility" for any given aquifer. (Theis, 1935, pp. 519-525.)

Material

The material used for this investigation was limited to a homogeneous sand and water to which an electrolyte had been added.

Sand of two grain sizes was used, one size being 40-60 sand. That is the sand charge composed of grains that would pass through a U.S. Standard Sieve of 40 holes to the inch (0.480 mm) and be retained on a sieve of 60 holes to the inch (0.250 mm). The second sand charge was size 60-80. That is, all the sand grains were between 0.25 mm to 0.195 mm in diameter. Each charge required 6 cubic feet of sand.

The sand used was deposited as glacial outwash and was

obtained from an area in southwestern Pottawatomie County (Sec. 36; T. 9 S.; R. 8 E.). This sand, before grading, ranged in size from coarse sand to very fine sand. The ungraded sand produced on an average of 22 pounds of size 40-60 sand and 15 pounds of size 60-80 sand for each 100 pounds processed.

The average mineral count for the graded sand, in percent, as determined by the use of a binocular microscope is as follows; quartz, 91 percent; orthoclase, 6 percent; mica, 1 percent; and the remainder (2 percent) was made up of granite, magnetite, calcite, glauconite, gypsum, pyrite, and chert.

The water used was obtained from two sources, natural precipitation (i.e., rain or snow), when it was available, and water collected from the atmosphere by a commercial dehumidifier. Water from both sources was collected and stored in glass containers to prevent possible contamination.

The electrolyte used was a commercial grade of white vinegar. For the preliminary test a commercial grade of rock salt (halite) was used as the electrolyte.

EQUIPMENT

Equipment for Grading Sand

The grading machine used to obtain the size 40-60 sand was designed and built by John D. Wells while enrolled at Kansas State College. Plates I and II give dimensions as well as details of design.

EXPLANATION OF PLATE I

Mechanical sand grader

Frame of grader

All material $3/4$ x 2 inch pine

Scale: $1/8$ inch equal 1 inch

EXPLANATION OF PLATE II

Mechanical sand grader

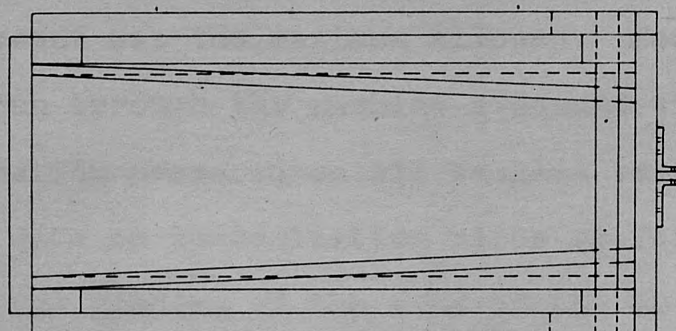
Shaker for grader
with
sieve positions

Sieves are 10 x 22 inches outside measurements
Sieve area is 160 square inches

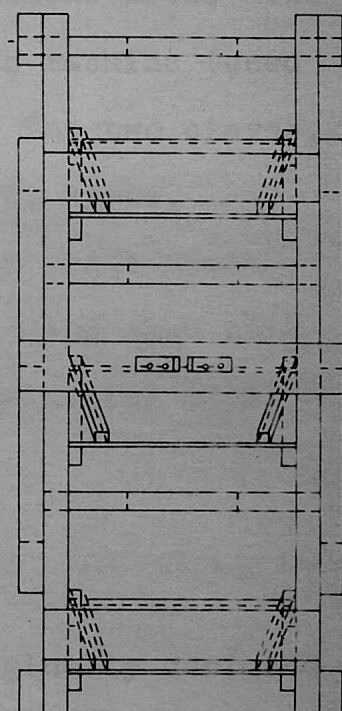
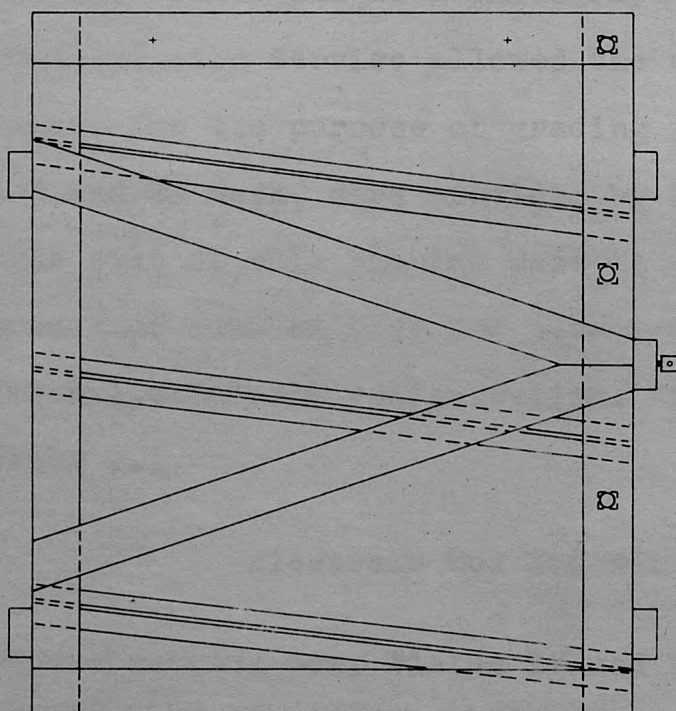
All material of construction is $\frac{3}{4}$ inch pine
Sieves are U. S. Standard Nos. 18, 40, and 60

Scale: $\frac{1}{8}$ inch equal 1 inch

PLATE II



Metal fitting



This machine was very satisfactory for the grading of the size 40-60 sand. The capacity of this device was between 5 and 6 pounds of size 40-60 sand an hour. A contamination of 3 percent was the maximum allowed. However, all graded sand was run through the machine a second time and the maximum contamination measured on all samples tested was 1.19 percent. (For data on contamination refer to Table 1.)

The grading of the sand of the 60-80 grain size was first attempted on the machine used for the 40-60 sand. However, the contamination averaged about 7 to 10 percent after the second run through the machine. The desire to keep the contamination less than 3 percent required a better and more efficient method of grading. Plate III is a photograph of the machine used. The Soil Conservation Service allowed the use of this machine (seed separator) for the purpose of grading the sand. The two sieves, size 60 and 80 mesh, were provided by Dr. Frank E. Byrne.

The size of this machine made it possible to grade about 150 pounds of sand an hour and obtain 25 pounds 60-80 sand with less than 1.5 percent contamination. (For contamination data see Table 2.)

Electrode Box and Wiring

The electrode box, Plates IV and V, was originally designed and built by Dr. Frank E. Byrne and Harry Pierce, a student in the Department of Geology, Kansas State College. Modifications in the design of the box were made by James M. Perdue and the author. The electrodes and drainage were modified by the author.

EXPLANATION OF PLATE III

Mechanical separator

(Seed Separator. Soil Conservation Service.)

Sieves are 30 by 42 inches

Fig. 1. Seed Separator viewed
from right hand corner

Fig. 2. Seed Separator showing
close-up view of upper
sieve. Viewed from top

PLATE III

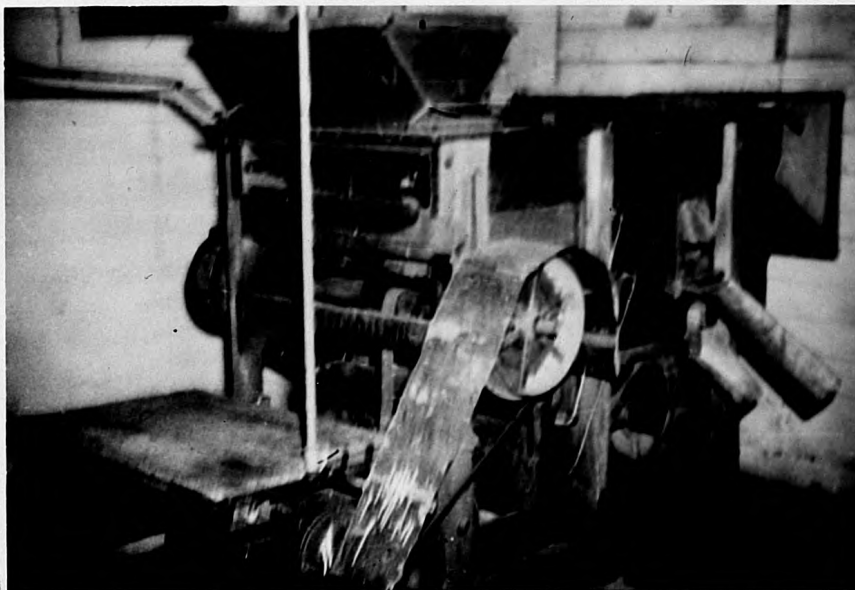


Fig. 1.



Fig. 2.

EXPLANATION OF PLATE IV

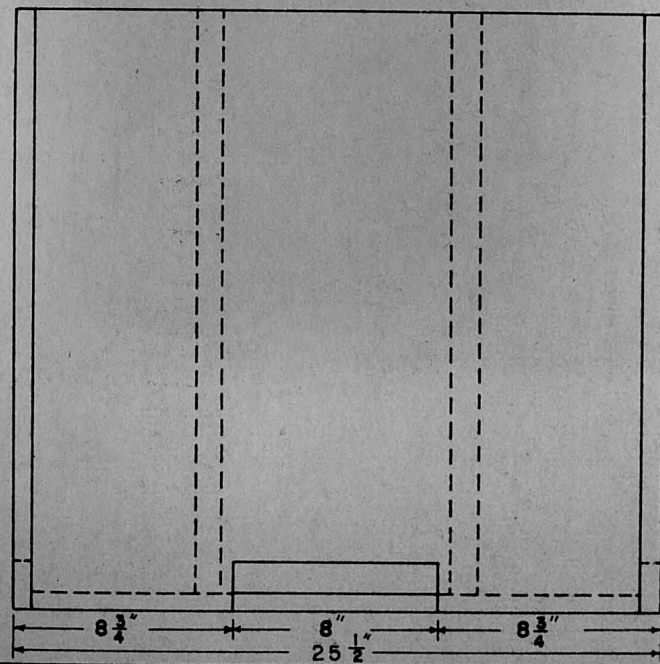
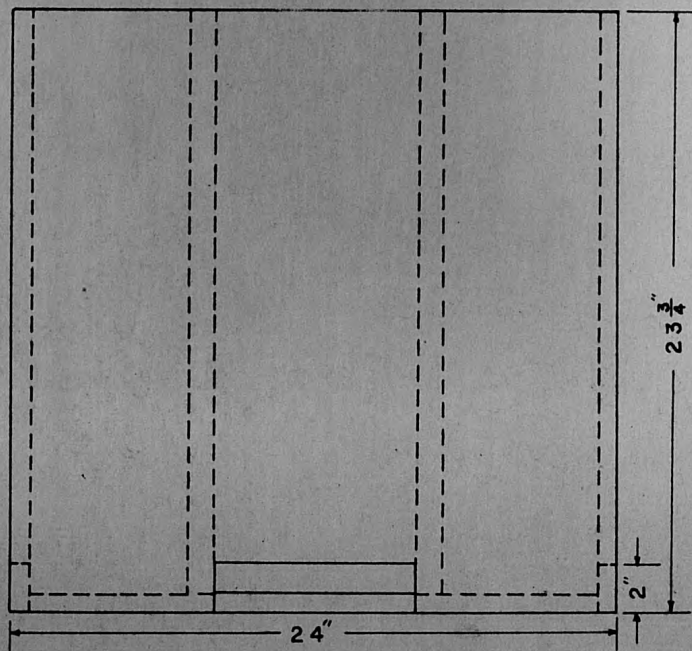
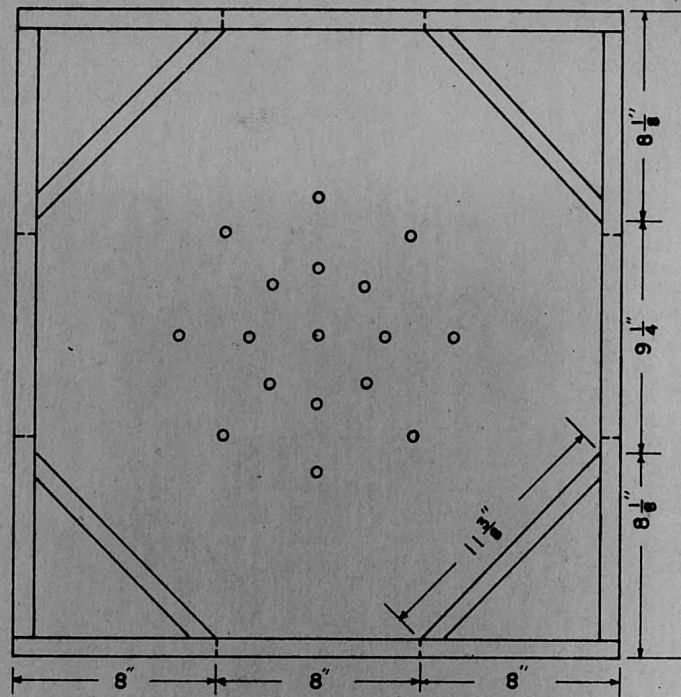
Electrode Box

All material $\frac{3}{4}$ inch stock
All fittings are 2 inch wood screws

All surfaces painted with water-proof
marine paint and caulked with paraffin

Scale: $\frac{1}{8}$ inch equal 1 inch

PLATE IV

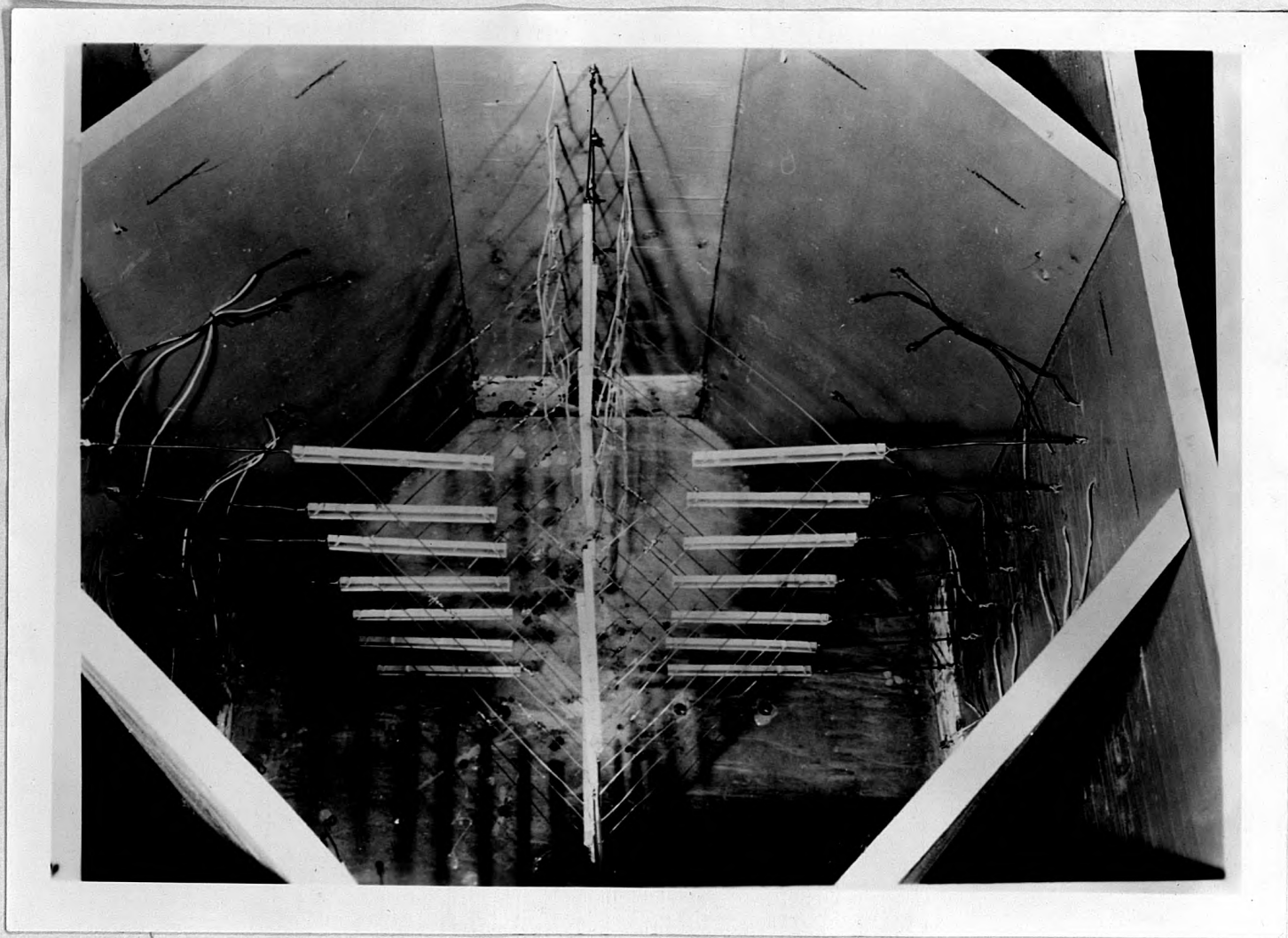


EXPLANATION OF PLATE V

Electrode box

View from top looking down.

Seven electrodes and drainage shown.



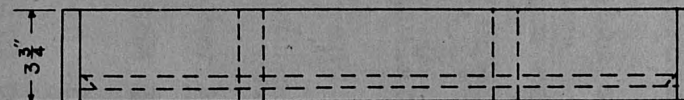
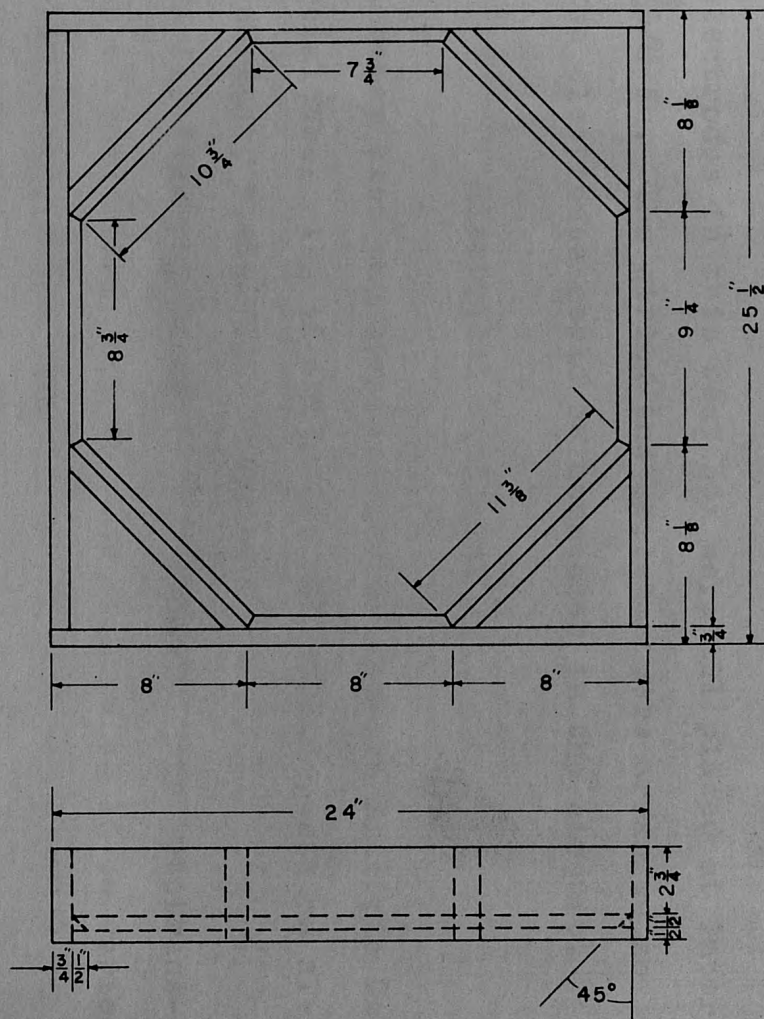
EXPLANATION OF PLATE VI

Water spreader

Material of construction is $\frac{3}{4}$ inch pine
Wire screen, 16 lines to the inch, covers
the lower side

Scale: $\frac{1}{8}$ inch equals 1 inch

PLATE VI



The electrodes were wired in 7 separate circuits, each electrode having a separate switch to complete the circuit to a variac and ammeter. (See Fig. 1.) The seven electrodes were spaced at a 0.2-ft interval starting at the bottom of the box. The electrodes (See Fig. 2) consisted of 0.35 mm copper wire. They were suspended in the box by plexi-glass. The glass suspenders acted as a spacer as well as the insulator between the two wires of each electrode pair, Plates V and VI show dimensions and design of the box.

A small test box (1.2 x 1.0 x 0.4 ft) was constructed and electrodes installed for the purpose of determining the lateral distance between electrodes with a given concentration of an electrolyte. Both factors were limited by the capacity of the ammeter and variac.

The electrodes in this test box were all placed at intervals of $\frac{1}{4}$ to $1 \frac{5}{8}$ in. The wiring and switches were arranged so that any two electrodes could be connected in the circuit.

Electrical Equipment

The ammeter used was manufactured by Western Electric Co. for commercial use. Its capacity was 240 milliamperes on alternating current, Plate VII.

The Variac (General Electric Variable Voltage Autotransformer) was of commercial design. The voltage could be varied from 0 to 140 volts, Plate VII.

The voltage stabilizer used was of General Electric patent.

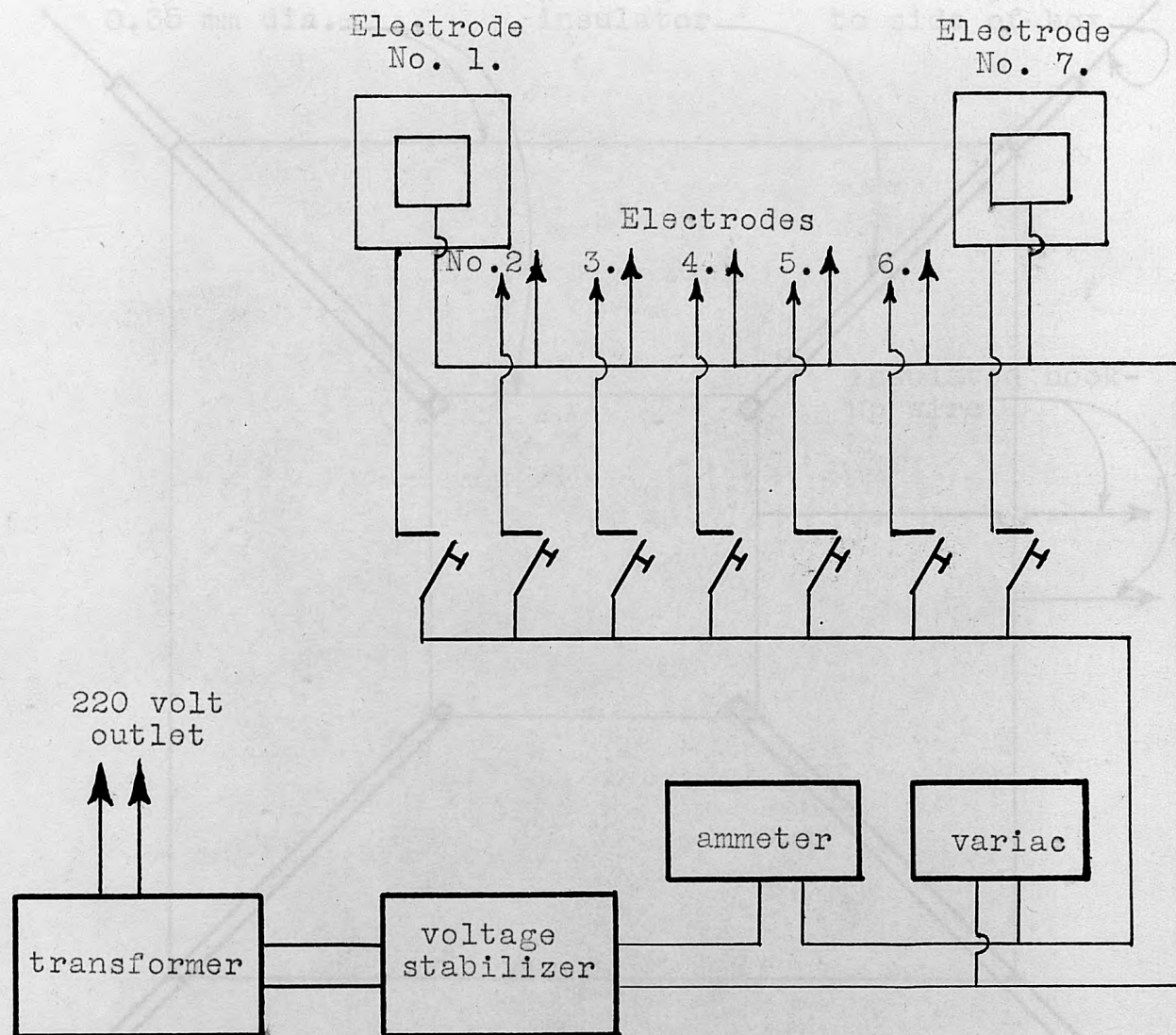
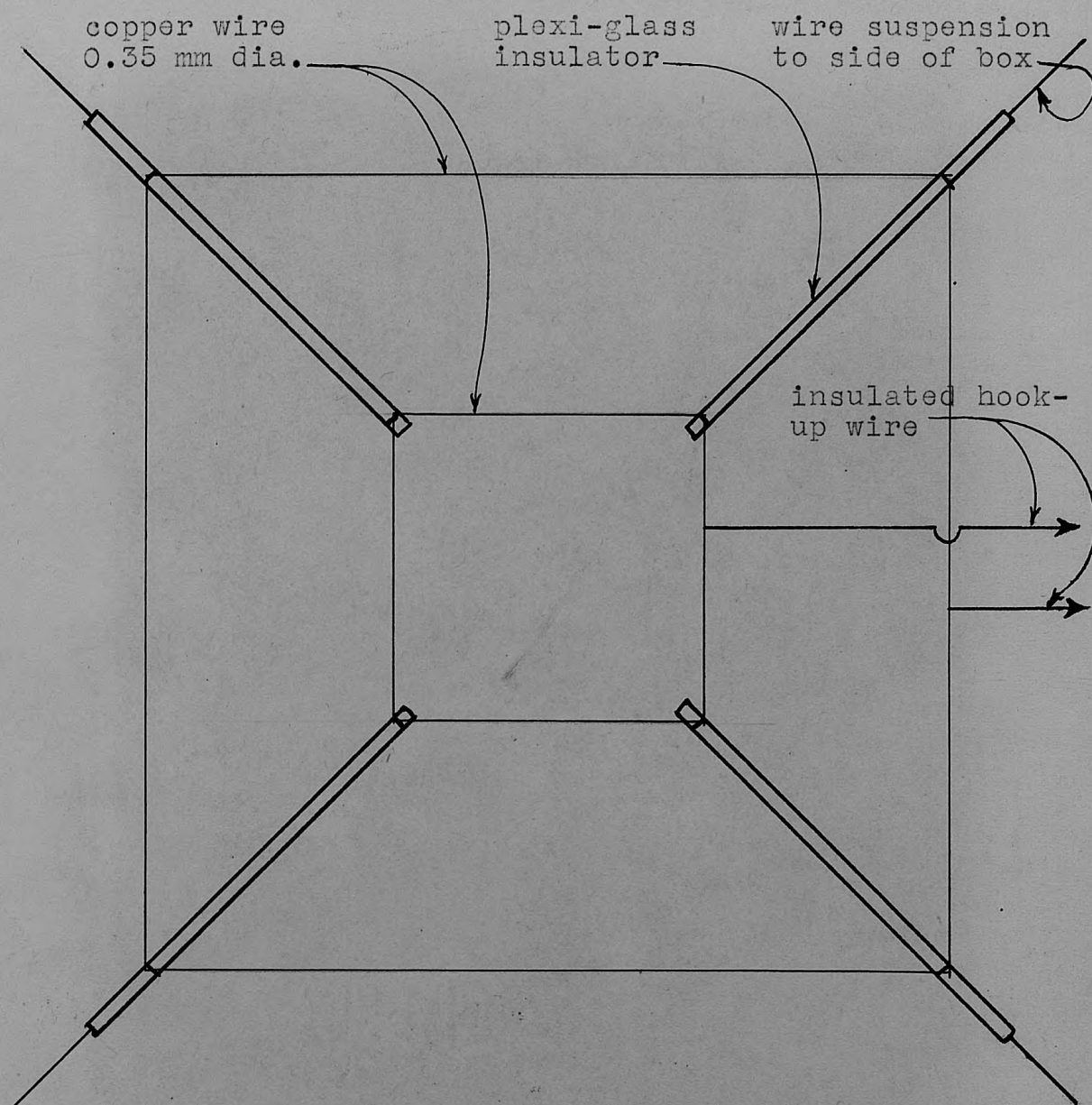


Figure 1. Wiring diagram of electrode system with switches, ammeter, variac, voltage stabilizer, and transformer in circuit.



Scale $\frac{1}{2}$ in equal 1 inch

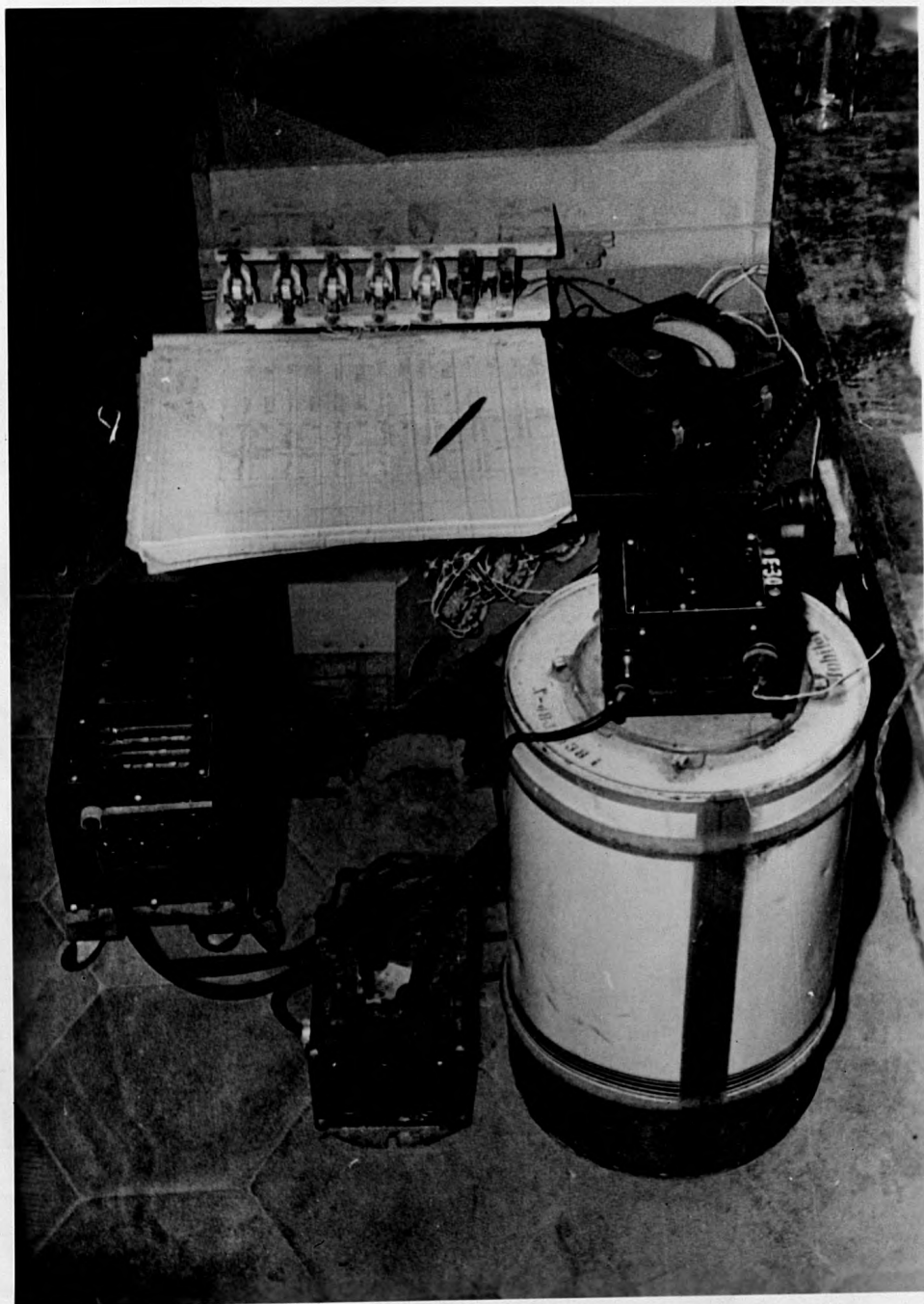
Figure 2. Electrode pair showing design and specifications.

EXPLANATION OF PLATE VII

Electrical equipment

- A. Voltage stabilizer
- B. Transformer (220 volts)
- C. Variac
- D. Milliammeter

PLATE VII



Its output was stabilized to 60 cycles 110 volts for an input of 102 to 125 volts, Plate VII.

INVESTIGATION PROCEDURE

The type of information desired, the rate and quantity of percolation, limited the procedure to recording the time and voltage as rapidly as possible for each of the seven electrode positions after the water was applied. Voltage reading being correlated to degree of wetness.

Combined results of time, wetness, and electrode position made it possible to determine the rate at which a given amount of water moved through the sediment.

The determination of porosity and permeability along with the known gradient made it possible to use Darcy's formula for computing the rate and quantity of flow and to compare these results with those obtained by the electrode box. (Tolman, 1937, pp. 200-213.)

The procedure of investigation for both sand charges were kept as near alike as possible. This included the preparation of the sand charge, the method of water application along with the volume used, and the recording of the voltage readings.

The sand used was first graded to a contamination of less than 1.16 percent for the 40-60 grain size and 1.5 percent for the 60-80 grain size. The two sand charges were thoroughly washed to remove possible clay-size particles that might adhere to the sand grains. The sand charge of 40-60 grain size was washed twice since this charge was used for the preliminary test.

The second washing was to remove any traces of the electrolyte use in the preliminary test.

The sand charges were oven dried after washing. The length of time required for the sand to reach a constant weight varied. The 40-60 sand required 6 hours at 110°C and the weight of the 60-80 sand became constant after 7 hours 30 minutes. The coarser sand was oven dried for 8 hours to insure complete dryness. The 60-80 sand was kept in the oven for 10 hours for the same reason.

The capacity of the oven, about 60 pounds of sand, made it necessary to store the oven-dried sand in metal containers (i.e., 100 pound grease drums) until the entire 600 pounds of sand of each charge could be dried.

The electrode box was filled with the oven-dried sand. The sand was added in 0.2-ft lifts and compacted with a 5.5-pound compaction hammer between each lift. The box was filled to a depth of 1.6 ft.

A swing psychrometer was used to obtain the wet-and dry-bulb temperatures for humidity determination at the start and finish of the filling of the electrode box. This was for the purpose of determining the hygroscopic moisture content of the sand. However, inasmuch as the humidity was approximately the same for both occasions during the filling of the box, the results were not used in later calculations. (Tables 3a and 3b for humidity data.)

The water with the electrolyte (i.e., commercial white vinegar) was applied to the sand charge by means of a container

9 inches in diameter and perforated with 1/16-inch holes. A greater dispersion of the water was insured by the use of the water-spreader built to fit the top of the electrode box, The Plate VI. and fourth water charges were applied after the

The water containing the electrolyte was applied as rapidly as possible. The first water charge applied to both sand charges was 22 quarts (20,817 ml) with 104 ml of vinegar. The second water charge was 18 quarts (17,024 ml) with 86 ml of vinegar. The third and fourth charges respectively were 14 quarts (13,238 ml) with 66 ml of vinegar and 6 quarts (5,678 ml) with 28 ml of vinegar.

The temperature of the sand and water were the same. Both were at room temperature which averaged about 79°F.

Immediately upon the start of application of water the first electrode switch was closed. The time and voltage were recorded as soon as the water reached this electrode. The second electrode switch was closed, the first switch being opened immediately upon taking the voltage reading (i.e., the voltage required to cause 20 milliamperes of current to flow in the circuit), and the process repeated for the second electrode. This procedure continued as rapidly as possible for all electrodes. The minimum time was 5 to 6 seconds between readings. The interval between readings was increased when the required voltage for 20 MA of current did not change from the previous reading. Usually about 30 minutes would account for the greatest, at least the most rapid, changes of voltage. The time and

voltage readings were continued until the voltage remained constant over a 36-hour period.

Both sand charges received 4 applications of water. The second, third, and fourth water charges were applied after the previous charge had stabilized. Usually about 150 to 170 hours were required for near-constant voltage readings. However, the time of re-charging the box took place from 1 to 10 days after the moisture content at the various levels had not changed one volt over a 36-hour period.

A record of the wet and dry bulb temperatures was kept during the percolation tests. (Tables 3a and 3b.)

THE PRELIMINARY PERCOLATION TESTS

A test was made previous to the actual percolation tests. This preliminary test was carried out with the electrode box to determine the quantity of water needed for a charge and to become familiar with the equipment. However, this test proved that most of the equipment as well as the electrolyte should be changed. The quantity of water used was satisfactory.

The electrode box in this test had 28 electrodes arranged in sets of 4 at 7 levels. The manual operation of this number of positions on 3 gang switches made it difficult to obtain rapid readings of any one electrode.

The need of a very weak electrolyte was obvious since the electrodes corroded very rapidly. This same corrosion could be reduced even more by keeping the current flow at the very mini-

mum and for the shortest possible time.

The need of drainage holes for the center area of the box, along with the side drainage, was found necessary. In addition to these center drainage holes, a thin layer (0.05 ft) of 18-35 sand was placed at the bottom of the electrode box to prevent the small amount of contamination of sand charges from accumulating in the drainage areas and sealing them. The 40-60 sand size did not cause the sealing of these drainage areas. However, it was anticipated that the 60-80 sand was of sufficient fineness to result in the partial sealing of these drains.

An Electrode Test Box

Rather than use the entire sand charge for determining a satisfactory electrode arrangement, as well as a suitable electrolyte, a small test box was constructed. The electrode system used in the preliminary test measured wetness at four positions on each level. The results were averaged together for one reading. To eliminate the need of four switches for each level, an areal electrode system was designed. Using electrodes with a greater exposed surface accomplished two things. It greatly reduced the necessary concentration of the electrolyte and still allowed the minimum of voltage to cause 20 MA current to flow. Both of these factors aided greatly in reducing the corrosion of the electrodes.

The test box had the electrodes arranged in one plane. The electrodes were square in plan and one square was placed inside

the other at varying intervals of $\frac{1}{4}$ to $1 \frac{5}{8}$ inches between parallel sides. The outside and larger square was $9\frac{1}{2}$ inches on a side, and the smaller square was $3\frac{1}{4}$ inches on a side. A total of 5 electrodes was arranged in this manner and by various combinations of two electrodes the distance between electrodes and the exposed surface of electrodes could be varied to 10 combinations.

Several concentrations of electrolytes were tried. The concentration of 0.5 percent white vinegar was found to be satisfactory for two electrodes spaced $2 \frac{3}{8}$ inches apart, $8\frac{1}{2}$ and $3 \frac{3}{4}$ inches on a side. This arrangement allowed the use of the full scale on the variac (i.e., 0 to 140 volts) for a minimum of 20 MA of current. The 20 MA current was the minimum that could be read rapidly and accurately on the ammeter. The saturated 40-60 and 60-80 sand (water with 0.5 percent vinegar used for saturation) gave a reading of 2+ volts with 20 MA of current. The full 140 volts would register 20 MA when the sand was about air dry, that is, the sand contained less than 0.5 percent moisture. The oven-dry sand would cause only the slightest deflection of the ammeter needle. (The sand was oven-dry when placed in this test box, however, during the process of pouring it in the box it would necessarily absorb some moisture from the atmosphere.)

Correlation of Volts to Percent Moisture

The test box was used for the purpose of determining the correlation data (see Table 4) of volts to percent moisture. The

data from saturation down to 1.25 percent moisture (60 volts) were obtained by wetting the sand and taking two samples from between the electrodes at a given voltage reading. The sand was weighed, oven-dried, and weighed again to determine the percent moisture for a given voltage.

The accuracy of reading the scale on the variac for the determination of voltage was limited because of mechanical design. The indicator on the scale was not designed to read the voltage within plus or minus 0.5 volt. This inaccuracy in reading the scale, in addition to the slight amount of backlash between the variable hand control knob and the rheostat, allowed a possible difference of nearly plus or minus one volt.

A difference of one volt in readings in the higher moisture percentages amounted to 5 to 8 percent moisture. Therefore, the saturated range was considered to be 2 to 4 volts instead of exactly 2 volts as shown in the correlation table.

DISCUSSION OF 40-60 SAND CHARGE

General

The data on the four water charges applied to the 40-60 sand size charge are recorded in Tables 5, 6, 7, and 8. These data of voltage, time, and electrode position are also developed graphically on several bar and line graphs which will be referred to in later discussions.

The First Water Charge

The application of the water charge to the air-dry sand began the initial percolation test. The rate of movement and degree of wetness were graphed on semi-log coordinate paper, Plate VIII. By using the logarithm to base 10 of the time in minutes it was possible to graph 166 hours (10,000 minutes) on 3-cycle log paper. The units (volts) for indicating wetness were plotted on a linear scale.

This graph, Plate VIII, gives a complete and continuous record of the wetness (percent by volume of water correlated with the voltage) along with the time from 10 minutes after the initial application of water up to 166 hours. The depth or distance the water has percolated is likewise recorded for each of the seven electrode positions.

The limit of 166 hours shown on the graph was not necessarily the termination of collecting time and voltage data. After that length of time, the moisture content of the sand changed but the time required for a change of one volt was usually from 48 to 72 hours or longer. The readings between the range of 50 to 60 volts indicated a moisture loss of only 0.02 percent. The loss measured per volt of change became even less for the higher voltage readings. In all water charges the upper electrode position registered more than 91 volts (0.84 percent moisture); the lower three electrodes, that is from a depth of 1.0 ft to a depth of 1.6 ft, remained near saturation or at least retained some gravity water at the end of the 166 hours.

EXPLANATION OF PLATE VIII

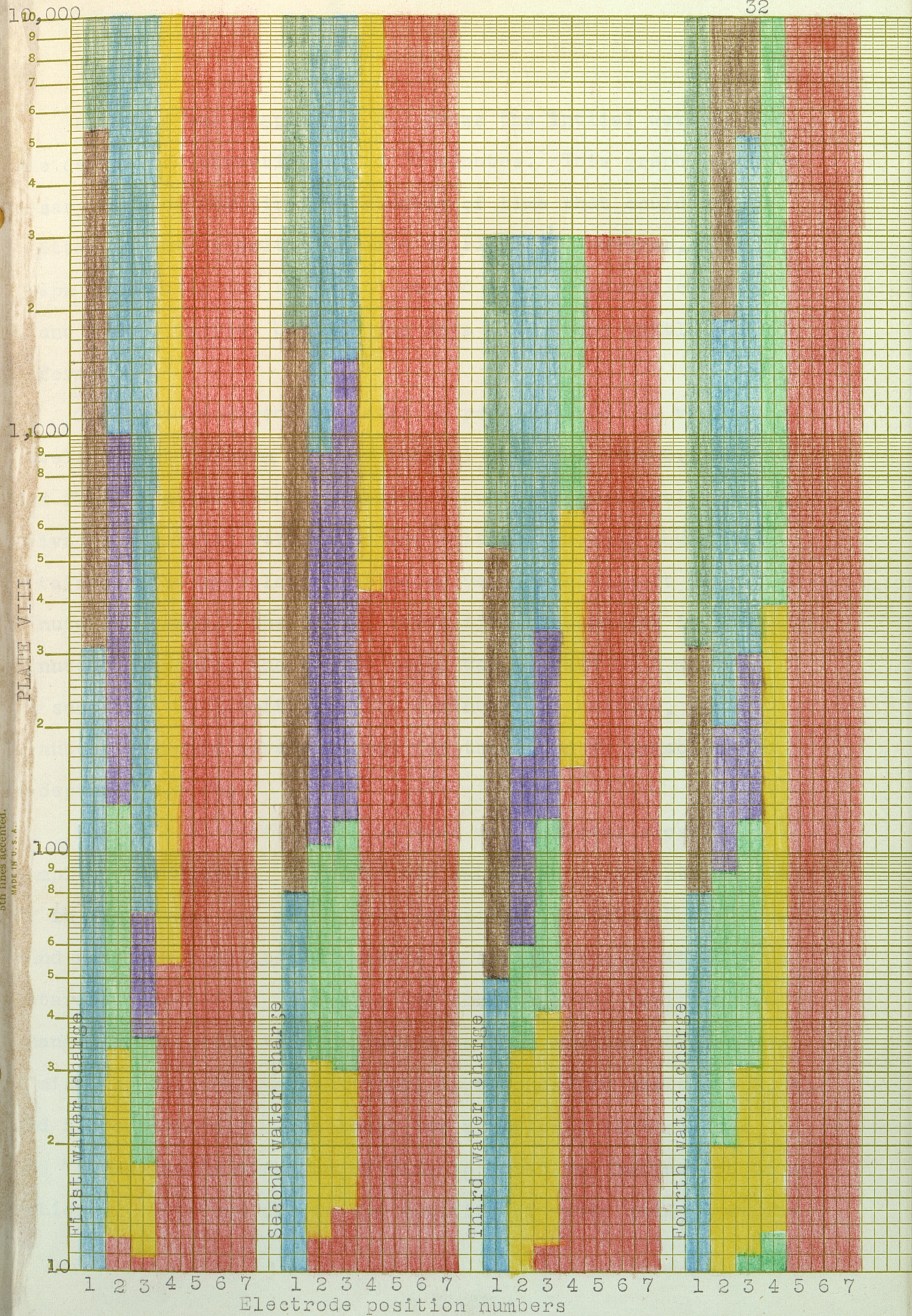
40-60 sand size

Four water charges

Log_{10} of time in minutes

KEY

(saturation)		0-5 volts
		6-10
		11-15
		16-20
		21-50
		51-90
(air-dry)		91-140



A second bar graph (Fig.3.) shows the initial wetting and the degree of saturation up to 30 minutes. This graph was necessary to show the first 10 minutes of time that could not be plotted on the logarithmic scale of Plate V. However, this graph shows only the first and second water charges; charges 3 and 4 were omitted because the data added very little new information.

The time required for water to percolate to the various levels is not uniform for the initial wetting. The 0.2 ft and 0.4 ft levels (electrode position 1 and 2, respectively) received the initial wetting before voltage readings could be obtained. The percolation of water penetrated 0.6 ft in 1 minute 3 seconds. The 0.8-ft level first became wet in 1 minute 57 seconds, the 1.0-ft depth was reached in 2 minutes 15 seconds, the 1.2-ft level in 4 minutes 48 seconds, and 6 minutes 5 seconds were required for the water to percolate to a depth of 1.4 ft.

The initial wetting of the sand was followed closely by complete saturation. The sand was saturated to a depth of 0.4 ft in 2 minutes. At this depth (electrode position No. 2) the sand required 1 minute 43 seconds to change from an air-dry to saturated condition. The time for the remaining positions to change from air-dry sand to saturation are 1 minute 57 seconds, 2 minutes 0 seconds, and 1 minute 58 seconds for positions 3, 4, and 5, respectively. The lower two positions, electrodes 6 and 7, required a much longer time interval for saturation to be achieved. This was due to the quantity of water being insuffi-

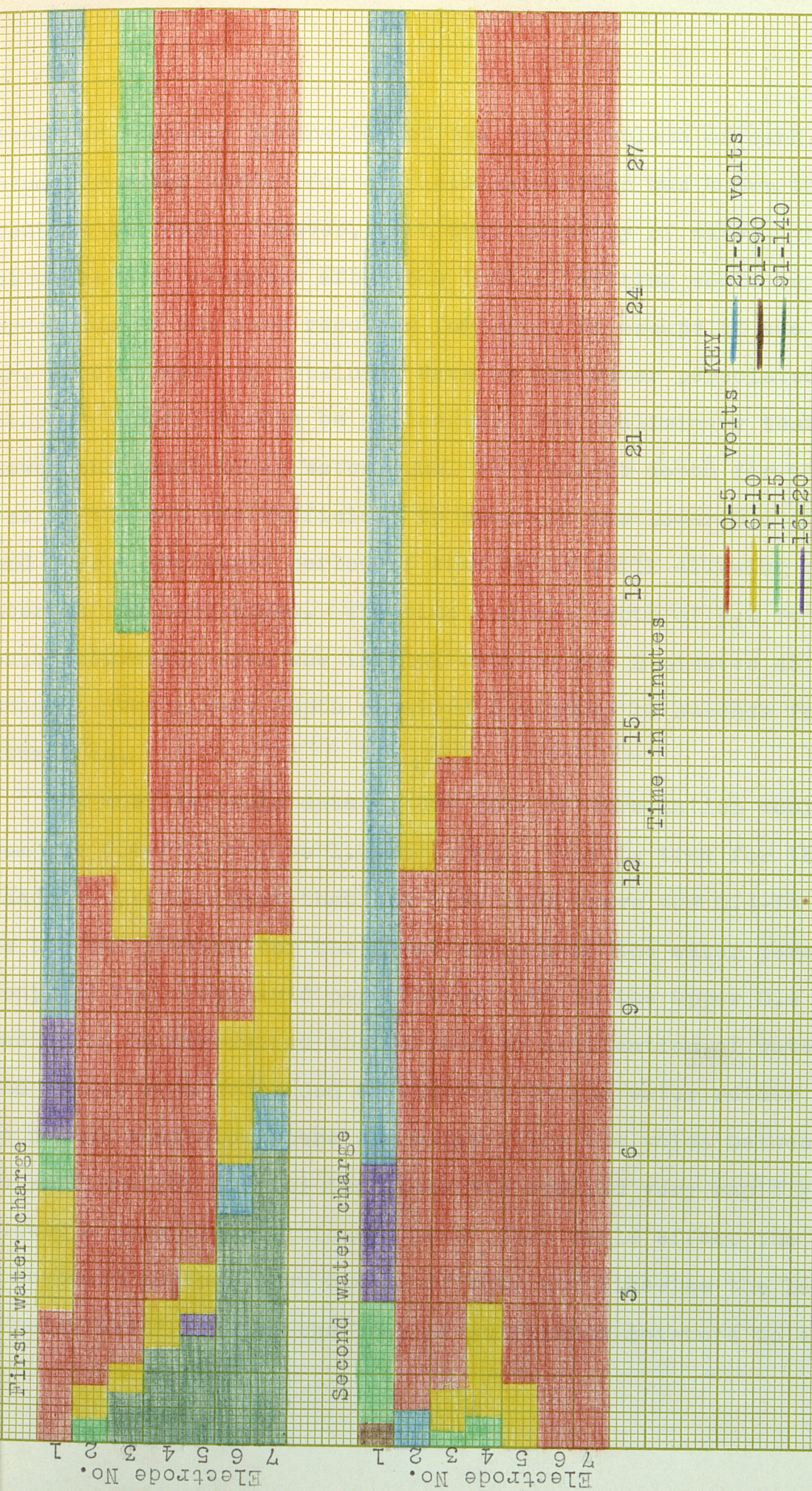


Fig. 3 40-60 sand size. Voltage plotted against time.

cient for complete saturation of the entire volume of sand. The volume of water needed for complete saturation was known to be about 18 gallons. However, with this quantity of water, the actual rate of movement after the initial wetting would be retarded due to the time required for water to escape at the bottom. The process of obtaining data as the water percolated downward would likewise be prolonged. The preliminary test showed the quantity of water equal to a 0.2-ft depth for the area of the box was sufficient to saturate the lower 0.6 ft of sand over a prolonged period of time while still allowing gravity water in the sand above. The time for the depth of 1.2 ft to reach saturation from the initial wetting was 2 minutes 45 seconds. The 1.4-ft depth required 5 minutes 10 seconds for saturation.

The most reliable data on the rate of percolation would be from the 0.4-ft level to 1.0-ft level. This is true for three reasons: (1) the fact that the time data above the 0.4-ft level are all but lacking for the first seconds of the water percolation; (2) the very rapid percolation rate in the upper 0.4 ft of sand could be attributed to the rate of application of water; the sand grains were suspended or floating in the water rather than the normal condition where the water fills the voids between the sand grains; and (3) the water was applied very rapidly and allowed a possible additional 'head' that would effect the rate of movement in the first 0.4 ft of sand and likewise the loss of this 'head' or even the lack of sufficient moisture to contin-

ue the downward progress would effect the rate of movement in the lower part below 1.0 ft. A line graph (see Fig. 5) with time plotted against depth on a linear scale for two moisture percentages will bear out the above statement.

The Second Water Charge

The second water charge applied to the 40-60 sand was reduced in volume because the lower third of the sand still remained near saturation. This second charge was applied 8 days after the time of the first application. A moisture percentage of 12 to 23 percent remained in the sand below the 1.0-ft mark.

The upper four electrode positions were of primary interest for the second set of data. During this test the point of saturation was not recorded for the upper electrode.

As the graph (Fig. 3.) indicates, the sand contained less than 1.5 percent of moisture and upon application of the water the moisture percentage reached the maximum and began receding within 1 minute. The moisture reading at 1 minute was 15.0 percent; at three minutes it had dropped to 7 percent. The first water charge required twice the length of time (6 minutes) to reach a condition of 7 percent moisture. The rapid percolation of the second water charge is attributed to the moist condition of the sand which differed from the air-dry condition present in the first water charge.

The second water charge, as before mentioned, differed from the first in quantity. Despite the lesser amount, the rate of percolation was very rapid as the above paragraph indicates. The

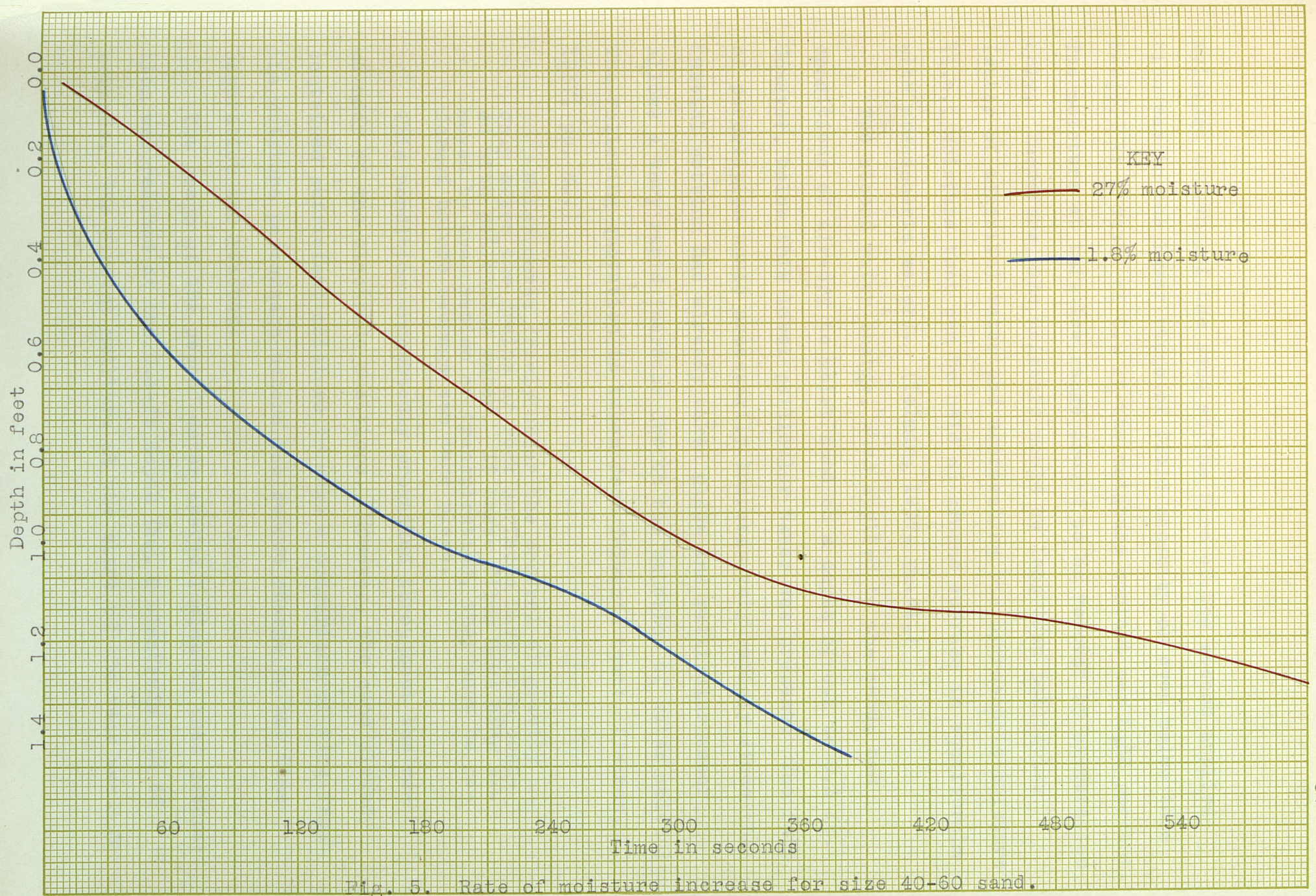


Fig. 5. Rate of moisture increase for size 40-60 sand.

moisture content of the sand at the time of the second application was in the lower range of field capacity or even below this range. At a depth of 0.2 ft the moisture content was 0.66 percent. The moisture at this low range proved to be removed by evaporation only. Therefore, the moisture would be less than pellicular (water of adhesion) water and approaching the hygroscopic moisture (i.e., moisture that can be held at ground surface in equilibrium with atmospheric water). (Tolman, 1937, pp.41.)

The second water charge, when applied to the sand, had conditions of air-dry to moist sand to a depth of 0.2 to 0.3 ft. However, below this level pellicular water was present. The rate of percolation would necessarily increase very rapidly since the initial wetting had already taken place and pellicular water allows a very rapid increase due to the cohesion of water molecules. The following quotation is taken from Tolman's text: (Tolman, 1937, pp. 41.)

Water moves freely under the control of gravity only after the grains or rock surfaces have been coated with pellicular water. If these films have been removed by evaporation or transpiration, they must be reformed before seepage can take place.

This condition undoubtedly prevailed throughout the remainder of the electrode positions. However, the sand already contained sufficient moisture to make a comparison of time from the moisture percentage before the second charge to the time saturation was reached.

The graph of the second water charge indicates that saturation was reached at the 0.4-ft depth (No. 2 electrode) in 45 seconds. The percent moisture at the start of the test was 1.8

percent; therefore, a gain of about 22 percent moisture took place in 27 seconds. Assuming 18 seconds were required for the second wetting front to reach the 0.4-ft position. Using the same position of the first water charge, a time of 1 minute 3 seconds was required for an increase of 25 percent moisture (from air-dry to 3 volts). (Tables 5 and 6 for voltage and time data.)

The Third and Fourth Water Charges

At the time the tests were being carried out it was thought that further tests with a smaller water charge would prove the percolation rate to be partly dependent on the amount of the water charge. However, because the electrode box retained water at or near the saturated condition in the lower 0.6 ft of the box, these two tests do not offer information that can be used at this time. The results of the third and fourth water charges are graphed, Plate VIII, and the data appear in Tables 7 and 8.

Rate and Quantity of Percolation

These two characteristics of percolation, rate and quantity, of the 40-60 sand were of primary interest. The method of obtaining this information was from the electrode box and then comparing the results with those obtained by the use of the permeability and gradient substituted in Darcy's formula for computing velocity of flow in gallons per day per square foot of area. (Tolman, 1937, pp. 203.)

$V = \left(\frac{231}{34 \times 8} \right) = 8.5$ Calculations
(based on experimental data)

$k = 924$ (Minimum) 940 (Maximum)

Percent moisture increase, Plate VIII 25.2%
(Effective porosity)

Time for moisture increase, Plate VIII

Electrode position No. 2. 103 sec.
No. 3. 117 sec.
No. 4. 120 sec.
No. 5. 118 sec.

Percolation Rates for the First Water Charge.

Electrode No. 2

Percent moisture increase from 1.8% to 27%

Time for increase 103 seconds

Vol. in cu in per min. $= \left(\frac{25.2\% \times 1728}{103} \times 60 \right) = 252.0$

Electrode No. 3

Percent moisture increase from 1.8% to 27%

Time for increase 117 seconds

Vol. in cu in per min. $= \left(\frac{25.2\% \times 1728}{117} \times 60 \right) = 221.0$

Electrode No. 4

Percent moisture increase from 1.8% to 27%

Time for increase 120 seconds

Vol. in cu in per min. $= \left(\frac{25.2\% \times 1728}{120} \times 60 \right) = 216.0$

Electrode No. 5

Percent moisture increase from 1.8% to 27%

Time for increase 118 seconds

Vol. in cu in per min. $= \left(\frac{25.2\% \times 1728}{118} \times 60 \right) = 220.0$

Computed values (based on Darcy's law) (Tolman, 1937, pp.201)

$$V = \frac{kh}{l} \text{ or } V = k \sin \phi$$

V = gallons per day per square foot of area

k = permeability constant

h = height of head-difference in two ends of material

l = length of column of water

ϕ = angle of water table slope

$$V = \left(\frac{231}{24 \times 60} \right) = \text{cu in min. SAND CHARGE}$$

$$k = 924 \text{ (Minimum)} \quad 940 \text{ (Maximum)}$$

$$h = 9.6 \text{ ft}$$

$$l = 0.6 \text{ ft}$$

$$\phi = 1 \text{ (Sin)} \quad \text{the four water charges applied to the 40-60}$$

$$V = k \text{ Sin } \phi \quad \text{is recorded in Tables 11, 12, 13, and 14.}$$

$$V = 924 \times 1 = 924 \text{ gals./sq ft}$$

$$\text{Minimum } V = \frac{924 \times 231}{24 \times 60} = 147.66 \text{ cu in/min.}$$

$$\text{Maximum } V = \frac{940 \times 231}{24 \times 60} = 150.78 \text{ cu in/min.}$$

Comparison of Results

The water charge (22 quarts) applied initially to the air-40-60 sand charge supplied the best information for the by the electrode readings do not agree with the calculations based on Darcy's law. However, the average percolation for the collected (Table 11) are shown as two bar graphs. The entire time span of the experiment is shown on the upper graph. The maximum using Darcy's formula was 150.8 cubic inches per minute. This lack of agreement with Darcy's formula when used on a maximum gradient has some support from previous investigators. The following quotation is taken from Tolman: (Tolman, 1937, pp. 203.)

The validity of Darcy's law at very low and very high gradients has been questioned by many investigators. Recent experimental work at the hydrologic laboratory in Washington, D.C., proves that the Darcy law holds for gradients as low as 2 or 3 inches to the mile. Experimental work has shown that Darcy's law holds for all gradients up to the critical velocity and the inception of turbulence.--

DISCUSSION OF 60-80 SAND CHARGE

General

The data on the four water charges applied to the 60-80 size sand charge is recorded in Tables 11, 12, 13, and 14. These data on voltage, time, and electrode positions are further developed graphically and these graphs will be referred to in the following discussion.

The First Water Charge

The water charge (22 quarts) applied initially to the air-dry 60-80 sand charge supplied the best information for the determination of rate and quantity of percolation. The data collected (Table 11) are shown as two bar graphs plotted on semi-log paper. The entire time span of the experiment, 166 hours, appears on the upper bar graph, Plate IX. The first 10 minutes of the first charge, as well as the remaining three water charges, do not appear on this graph. The graph of the first 2 hours and 46 minutes appears in Figure 6. The scale of time is in seconds ($\log_{10}$ of time in seconds).

The time required for water to percolate to the various levels is as follows: 15 seconds for the first 0.2 ft; 40 seconds from the surface to 0.4 ft; 72 seconds to a depth of 0.6 ft; 5 minutes 30 seconds to penetrate 0.8 ft; 16 minutes 35 seconds for 1.0 ft; 41 minutes for 1.2 ft, and 1 hour 32 minutes for 1.4 ft.

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Electrode position

KEY

- 0 to 5 volts
- 6 to 10
- 11 to 15
- 16 to 20
- 21 to 30
- 31 to 50
- 51 to 90
- 91 to 140

Fig. 6. 60-80 sand size. First water charge.
Voltage plotted against time in seconds.

The upper 0.2 ft of 60-80 sand remained saturated for only $11\frac{1}{2}$ seconds. The percent moisture declined to about 4 percent within the first minute. The depth of 0.4 ft reached a 4 percent moisture content in about 38 hours. The lower 0.8 ft remained near saturation for more than 180 hours. At the time of recharge (260 hours) the lower four positions contained moisture of 7 to 12 percent.

The Second, Third, and Fourth Water Charges

These water charges were applied to determine the effect on percolation rate in sand that was other than air-dry. However, the water retained under specific retention did not allow sufficient moisture increase to obtain the desired information.

The quantity of water added on each charge was varied from 18 quarts to 6 quarts. The results of these applications are indicated on the graphs. The time required for the sand to return to the more stable point ranges from 53 hours for the first charge, to 30 hours for the second, to 26 hours for the third, and to 13 hours for the fourth charge.

The lower 0.6 ft of sand remained above 9 percent moisture for 8 days (192 hours). A sample of sand was taken at the lower three electrode positions after 6 months (183 days). The moisture percentages were 5.13 percent for the 1.0-ft depth, 5.98 percent for the 1.2-ft depth, and 7.39 percent for the lowest electrode. (see Table 15.)

Table 15. Percent moisture retained after 183 days in 60-80 sand.

Depth in feet	Weight of sample	Sand plus can: oven dry, in grams	Wt. of moisture: in grams	Weight of can	Vol. of Sand in cu in	Percent moisture by volume
					($\frac{\text{Oven-dry sd.}}{\text{S.G.}}$)	
1.0	62.6	60.7	1.9	13.0	37.0	5.13
1.2	67.2	65.2	2.0	12.8	33.5	5.98
1.4	69.3	66.3	3.0	13.1	40.6	7.39

The high moisture percentages retained in these electrode positions indicate that the bottom of the electrode box acted as an impermeable barrier to the water held near the point of gravity water and field capacity.

Rate and Quantity of Percolation

The percolation rate for the seven electrode positions is highly variable. The time required for the sand to reach a point of near saturation from 2 percent moisture ranges from about 11 seconds to 1 hour and 23 minutes. Two positions (0.4 and 0.6 ft depths) required 38 and 39 seconds for an increase of 17.6 percent moisture. However, this rate is much greater than the rate of percolation in the 40-60 sand charge.

Calculations

Darcy's formula (Tolman, 1937, pp. 201.)

$$V = \frac{k l}{h} \sin \phi$$

V = gal. per day per sq ft area
k = permeability 380 (Table 9.)

l = distance between surface and bottom of sand

h = height of water column

ϕ = angle of gradient

$$k = 380$$

$$l = 1.4 \text{ ft}$$

$$h = 1.4 \text{ ft}$$

$$V = \frac{380 \times 1.4}{1.4} = 380 \text{ gal/day/sq ft}$$

$$V = \frac{380 \times 231}{1440} = 60.96 \text{ cu in/min}$$

Water Charge No. 1 (See Fig. 6 and Table 11.)

Electrode No. 1

Percent moisture increase (19.6 - 2%) 17.6%

(See Fig. 6.)

Time for moisture increase 11 seconds

Electrode No. 2 and No. 3

Percent moisture increase (19.6 - 2%) 17.6%

Time for moisture increase 38 seconds

Percolation rate = $\left(\frac{17.6\% \times 1728}{38} \times 60 \right) = 480 \text{ cu in/min/sq ft}$

Electrode No. 4

Percent moisture increase (19.6 - 2%) 17.6%

Time for moisture increase 73 seconds

Percolation rate = $\left(\frac{17.6\% \times 1728}{73} \times 60 \right) = 250 \text{ cu in/min/sq ft}$

Electrode No. 5

Percent moisture increase (19.6 - 2%) 17.6%

Time for moisture increase 295 seconds

Percolation rate = $\left(\frac{17.6\% \times 1728}{295} \times 60 \right) = 61.8 \text{ cu in/min/sq ft}$

Electrode No. 6

Percent moisture increase (19.6 - 2%) 17.6%

Time for moisture increase 900 seconds

Percolation rate = $\left(\frac{17.6\% \times 1728}{900} \times 60 \right) = 20.3 \text{ cu in/min/sq ft}$

Electrode No. 7

Percent moisture increase (19.6 - 2%) 17.6%

Time for moisture increase 5000 seconds

Percolation rate = $\left(\frac{17.6\% \times 1728}{5000} \times 60 \right) = 3.64 \text{ cu in/min/sq ft}$

Surface to 1.0 ft depth

Percent moisture increase 19.5%

Time for increase 1200 seconds

Percolation rate = $\left(\frac{19.5 \times 1728}{1200} \times 60 \right) = 16.8 \text{ cu in/min/sq ft}$

COMPARISON OF Results AND CONCLUSIONS

The calculated rate of percolation in 60-80 sand by Darcy's law is 60.96 cu in/min for 1 sq ft area. The 17.6 percent of moisture for 38 seconds would be 480 cu in/min for 1 sq ft area. The percolation rates for the other electrode positions: 0.8 ft, 250 cu in/min; 1.0 ft, 61.3 cu in/min; for 1.2 and 1.4 ft, 20.3 and 3.64 cu in/min, respectively. The average rate of percolation from the surface to 1.0 ft was 16.8 cu in/min/sq ft of area. Escape of air, however, should not have affected the

The electrode box at the 1.0-ft level had a percolation rate which agrees with the calculations based on Darcy's formula. However, the percolation rate never appeared uniform while the moisture content increased. The rates obtained from the upper electrodes are undoubtedly due to turbulent flow implemented by flotation of sand grains. *Plot the log₁₀ of time in minutes. (The*

A few of the electrode positions were checked for the rates of percolation after saturation was reached and the percent moisture was decreasing. These rates were either very high, 142 to 300 cu in/min, or they were extremely low, 2 to 10 cu in/min. *retained away and after the rate of downward movement of water*

The rates obtained during the second water charge were of equal disagreement with the calculated results. These rates were obtained on both the increase and decrease of moisture percentages. *Journal of Geology, 1933, pp. 121.) These two line*

graphs would seem to indicate that the rates of percolation were similar with the only difference being the percentages of moisture

COMPARISON OF RESULTS AND CONCLUSIONS.

The two sand charges used compare favorably in many respects. However, the rate of percolation for the 60-80 sand size as indicated by the available data are in error in one way or another. The fact that other characteristics of this sand compare to those of the coarser sand indicates the fault must be in the rate of application of the water charge along with the ease the air could escape from the drainage areas at the bottom of the electrode box. The escape of air, however, should not have affected the rate of percolation for the second water charge and should have allowed uniform percolation rates. This was not the case.

A graph (Fig. 7) shows a comparison of the percentage of moisture for the two sand charges. The two sections of each line graph are similar in most respects. The percentage of moisture by volume is plotted against the $\log_{10}$ of time in minutes. (The data were obtained from Tables 5, 11, and 4.)

The red area on each graph indicates the range of field capacity. The field moisture capacity is defined as the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased. (Johnstone & Cross, 1949, pp. 121.) The green area on the graph is the range of gravity water. By definition, gravity water is water in excess of the field moisture capacity. (Johnstone & Cross, 1949, pp. 121.) These two line graphs would seem to indicate that the rates of percolation were similar with the only difference being the percentages of moisture

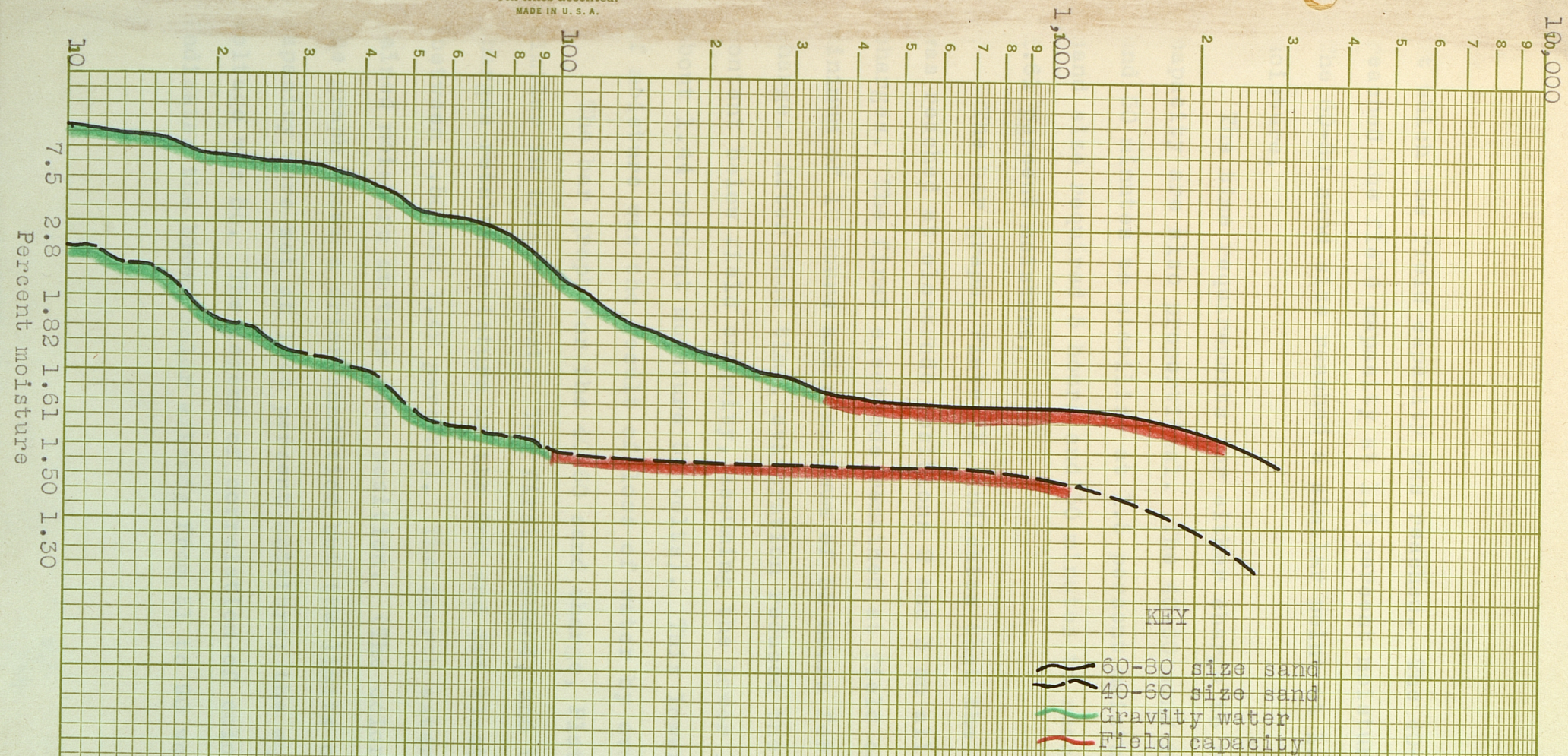


Fig. 7. Comparison of percent moisture to time in minutes for two sand charges.

at which the field capacity was reached. The 40-60 sand size reached the field capacity at 1.5 percent moisture by volume. The 60-80 sand size reached a similar point at 1.61 percent moisture.

The time requirements for either charge to reach field capacity are also proportional. The 40-60 sand required 1 hour and 50 minutes to stabilize at 1.5 percent moisture. The 60-80 sand size required 5 hours and 50 minutes to reach stability at 1.61 percent moisture.

The bar graph, Plate IX, indicates that the field capacity was reached at electrode positions 2 and 3 on all four water charges. The first electrode remained at field capacity for a minimum of 10 hours and a maximum of 53 hours for the 60-80 charge. After that time, evaporation reduced the moisture content below field capacity, assuming the lower limit to be about 1.44 percent moisture (55 volts). This lowered percentage of moisture was the result of loss of water by evaporation.

The bar graph for the 40-60 sand charge, Plate VIII, was similar in this respect. The first, second, and third water charges retained moisture at the 2nd and 3rd electrode positions (between 1.50 and 1.49 percent). The fourth water charge retained moisture at this same position. (The color indicated on the graph shows a drier condition but the limits of the field capacity were set at 1.44 percent moisture; the equivalent voltage was 55. The legend of correlation of color to volts indicates the brown color extends from 51 to 90 volts.)

EXPLANATION OF PLATE IX

60-80 sand size

Four water charges

Log_{10} of time in minutes

KEY

(saturation)		0-5	volts
		6-10	
		11-15	
		16-20	
		21-50	
		51-90	
(air-dry)		91-140	

1,000

PLATE IX

100

10

First water charge

Second water charge

Third water charge

Fourth water charge

Electrode position numbers

EVALUATION OF TECHNIQUE

The basis for the method used in determining the rate of percolation is that after the initial wetting (1.4 to 1.6 percent, 44 to 58 volts) of the sand has taken place, the time between this initial wetting and the point of near saturation is equivalent to the same percolation rate as would be obtained from saturated sand that was allowed to drain freely with a continuous supply of water for saturation.

The technical controls were satisfactory. However, the use of a variac as a voltage scale is an inherent weakness. A better method would be either to use a voltmeter in conjunction with the variac and read the voltage from the voltmeter scale or determine a concentration of electrolyte that would permit the reading of milliamperes of current for a pre-determined voltage.

The data collected appear to be satisfactory and no appreciable corrosion was evident except possibly for the last readings recorded for the 60-80 sand during the fourth water charge. The electrodes were new at the start of each sand charge and were removed and tested for amount of corrosion at the end of the fourth charge. The maximum noted for the 40-60 sand size was 1 volts for the lower two electrodes. The 60-80 sand size showed about 2 volts for the No. 6 electrode and 1 volts for the No. 7 electrode. This corrosion did not effect the results since this area was near saturation at all times.

ACKNOWLEDGEMENTS

Sincerest thanks are expressed to Dr. Frank E. Byrne for the interest, the help and encouragement which he expended almost without limit.

Appreciation is extended to Professor A. B. Sperry for the use of the facilities and equipment of the Geology Department; to the Electrical Engineering Department and Professor Ward and Hewson for the use of the electrical equipment; and to the Soil Conservation Service and Messrs. Eschbough and Ficke for the use of the equipment for grading sand.

My special thanks go to James M. Perdue who contributed a great deal of his time in the preparation of one sand charge and the information recorded on the preliminary percolation test.

Sincerest appreciation and thanks are extended to my wife for her encouragement and help and to my brother, Warren, for his interest and time spent in helping with the many details he attended to in my absence from the College.

Others that contributed time and effort to make possible the application of the water charges and recording of data are Clarence Harr, Michael E. Davis, Kenneth Parish, Larson Drake, George Priddy, and Rex Archer.

Mr. John D. Wells constructed the mechanical grading device used to grade the 40-60 sand size.

LITERATURE CITED

- Allyn, R. B.
Soil Science. U. S. Dept. of Agr. Vol. 53. No. 4. April 1942.
- Johnstone & Cross.
Elements of Applied Hydrology. Ronald Press Co. New York: 1949.
- Meinzer, O. E.
U. S. Geol. Survey Water-Supply Paper 494. 1923.
- Scotfield, C. S.
Jour. Agr. Research. U. S. Dept. of Agr. Vol. 71. No. 9. 1945.
- Slater, C. S. and Bryant, J. C.
Soil Science. U. S. Dept. of Agr. Vol. 61. No. 2. Feb. 1946.
- Stearns, N. D.
Water-Supply Paper 596. U. S. Geol. Survey. 1927.
- Theis, C. V.
Am. Geophys. Union Trans. 1935.
- Tolman, C. F.
Ground Water. New York and London. McGraw-Hill Book Co. Inc. 1937.

Wt. of Original Sample Plus Dish	Wt. of Sample after Mixer Test	Wt. of Sample after Test	Wt. of Con.	Percent
grams	grams	grams	grams	Weight
273.2	252.0	155.3	1.2	0.77
273.5	271.2	134.0	1.5	0.97
267.1	237.0	155.7	2.1	1.34
273.0	273.1	130.1	1.9	1.19
268.5	263.1	157.0	1.4	0.85
271.7	259.4	153.4	2.3	1.45
273.5	271.5	155.7	2.0	1.32
270.3	233.2	157.4	1.6	1.10

APPENDIX

Table 1. Contamination tests on size 40-60 sand. Test samples were oven-dried and placed in a Mizner vibrator for five minutes each. The contamination was made up of sand grains smaller than a No. 60 sieve.

Wt. of Original Sample Plus Dish grams	Wt. of Sample Plus Dish : Mizner Test : grams	Wt. of Sample After Mizner Test, grams :	Wt. of Con- tamination grams :	Percent by Weight :
283.60	282.98	174.10	1.3	0.74
275.40	274.90	197.53	2.0	1.02
289.80	289.10	165.10	1.9	1.14
290.20	289.70	175.30	2.1	1.19
286.70	286.40	169.90	1.5	0.84
288.60	288.10	173.50	1.8	1.03
278.20	277.70	164.80	1.6	0.97

Table 2. Contamination tests on size 60-80 sand. Test samples were oven-dried and placed in a Mizner vibrator for five minutes each. The contamination was made up of sand grains smaller than a No. 80 sieve.

Wt. of Original Sample Plus Dish grams	Wt. of Sample Plus Dish : Mizner Test : grams	Wt. of Sample After Mizner Test, grams :	Wt. of Con- tamination, grams :	Percent by Weight :
270.2	269.0	155.3	1.2	0.77
273.5	271.9	164.0	1.6	0.97
269.1	267.0	155.7	2.1	1.34
275.0	273.1	160.1	1.9	1.19
266.5	265.1	157.0	1.4	0.88
271.7	269.4	158.4	2.3	1.45
273.6	271.6	158.7	2.0	1.26
270.8	269.2	157.4	1.6	1.10

Table 3a. Relative humidity data. Size 40-60 sand.

Charge	Time	Deg. F Dry bulb	Deg. F Wet bulb
Sand-charge	Initial	80.4	60.2
	Final	80.0	61.7
1st water-charge	0 hrs.	83.1	65.8
	2 hrs.	83.0	65.8
	8 hrs.	80.5	66.0
	15 hrs.	81.0	66.2
	34 hrs.	80.2	65.0
	62 hrs.	80.5	66.0
2nd water-charge	0 hrs.	80.5	68.0
	2 hrs.	80.8	68.7
	8 hrs.	79.2	67.0
	15 hrs.	79.0	65.5
	40 hrs.	79.3	66.2
3rd water-charge	0 hrs.	76.5	68.7
	2 hrs.	77.1	69.0
	14 hrs.	80.1	73.0
	38 hrs.	79.3	68.0
	48 hrs.	80.0	68.5
4th water-charge	0 hrs.	80.0	68.5
	2 hrs.	80.4	71.2
	8 hrs.	79.5	70.0
	19 hrs.	80.2	69.0
	47 hrs.	79.9	68.7
	72 hrs.	79.4	68.8

Table 3b. Relative humidity data. Size 60-80 sand.

Charge :	Time :	Deg. F : Dry bulb :	Deg. F Wet bulb
Sand-charge	Initial	79.9	59.0
	Final	79.5	58.9
1st water-charge	0 hrs.	80.5	58.0
	3 hrs.	79.0	58.0
	11 hrs.	77.5	55.5
	29 hrs.	78.0	56.0
	45 hrs.	78.0	57.0
	153 hrs.	79.0	58.0
2nd water-charge	0 hrs.	80.0	62.0
	3 hrs.	78.0	61.5
	10 hrs.	76.0	58.0
	35 hrs.	76.0	58.0
	71 hrs.	81.0	68.0
	129 hrs.	79.0	62.0
3rd water-charge	0 hrs.	78.0	62.0
	6 hrs.	77.0	61.0
	16 hrs.	76.5	62.0
	21 hrs.	80.0	60.3
	52 hrs.	76.0	62.0
	96 hrs.	75.5	61.0
4th water-charge	0 hrs.	75.0	62.2
	2 hrs.	75.0	63.0
	9 hrs.	77.0	62.0
	34 hrs.	76.0	60.0
	52 hrs.	79.0	61.3
	76 hrs.	79.0	59.5
	180 hrs.	79.0	61.5

Table 4. Correlation data for volts to percent moisture by volume. (*-percent moisture computed with test box, tables 16 & 17 show calculations; remaining percentages interpolated from the graph, figure 4.)

Volts	: Equivalent in percent moisture	:	Volts	: Equivalent in percent moisture
2 *	38.23	:	22	2.3
3	30.0	:	23	2.1
4	23.0	:	24	2.0
5 *	19.50	:	25 *	1.95
6	15.0	:	26	1.92
7	12.0	:	27	1.89
8	10.0	:	28	1.86
9 *	8.65	:	29	1.84
10	7.5	:	30 *	1.82
11	7.0	:	35 *	1.67
12 *	6.00	:	40	1.61
13	5.4	:	45	1.56
14	5.0	:	50	1.50
15	4.4	:	55 *	1.44
16 *	4.17	:	60	1.30
17	3.7	:	70	1.15
18	3.2	:	80	1.0
19	3.0	:	90	0.84
20	2.8	:	100	0.67
21 *	2.49	:	120	0.33
		:	140	0.0

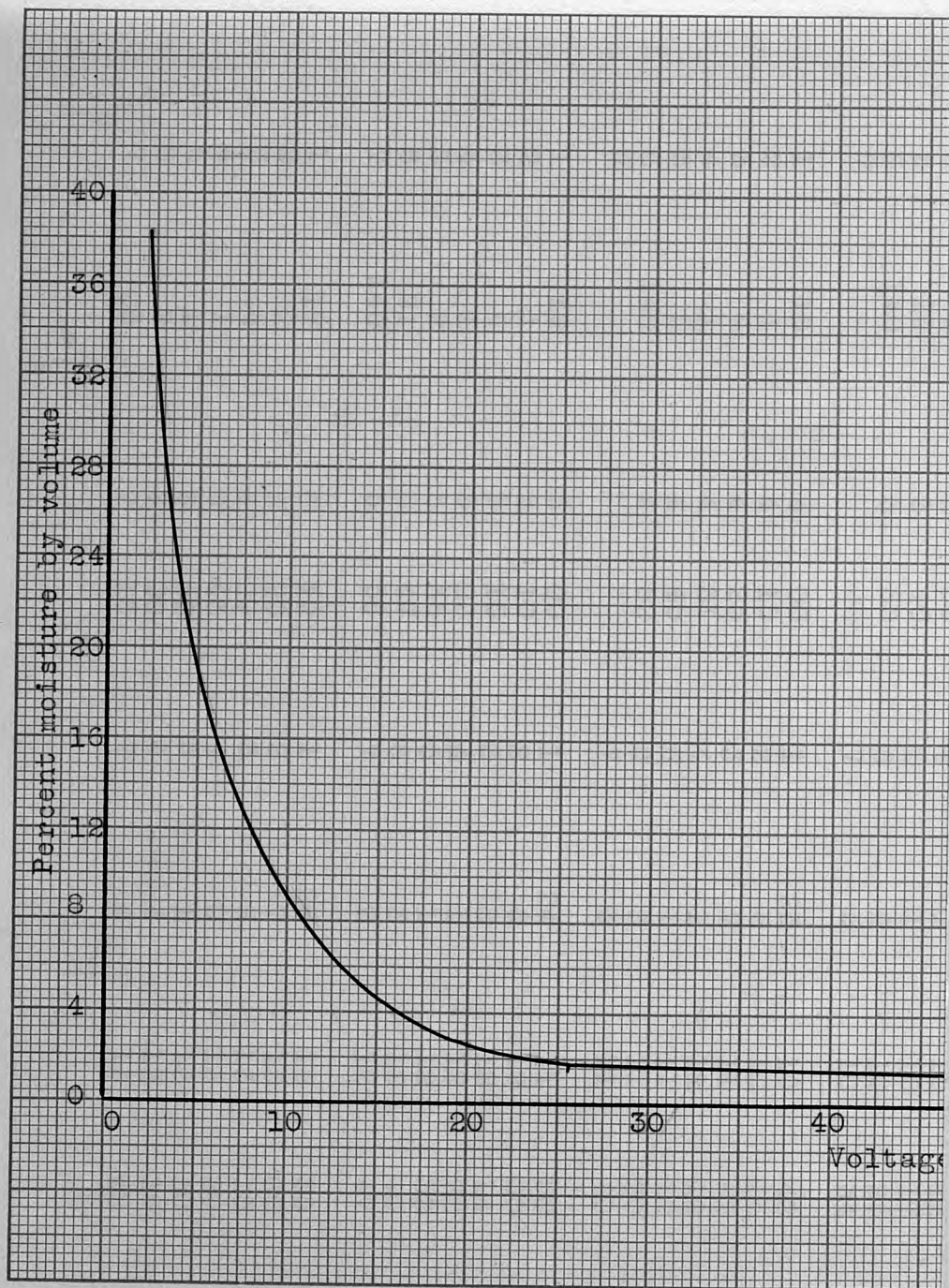


Fig. 4. Correlation of voltage to percent moisture.

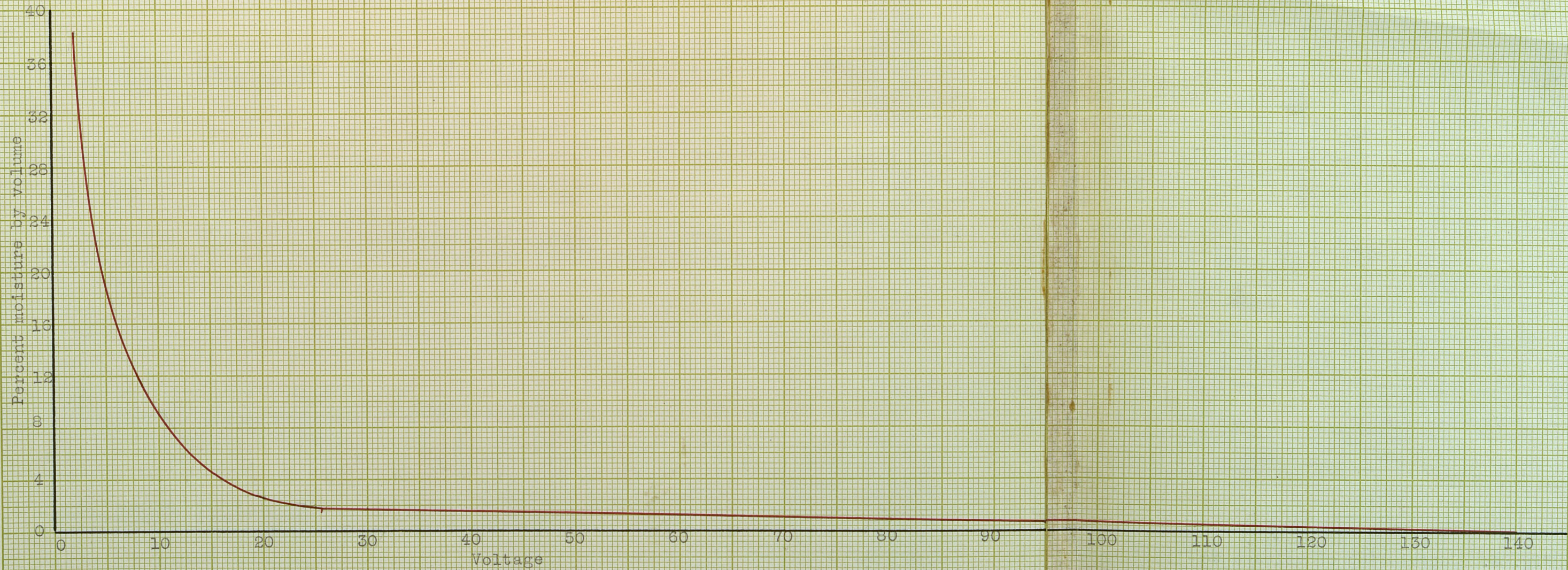


Table 5. Voltage and time data for water charge No. 1.
40-60 sand-size.

Electrode: : Time				Electrode: : Time			
level	:Voltage:	Hr.	Min. Sec.:	level	:Voltage:	Hr.	Min. Sec.
1	5		15	1	16	7	28
2	12		27	2	4	7	35
3	140		45	3	5	7	45
4			33	4	1	8	00
5			40	5	1	8	12
6			50	6	6	8	25
7			00	7	6	8	35
1	5	1	05	1	20	8	45
2	4	1	20	2	5	8	55
3	9	1	35	3	5	9	05
4	6	2	05	4	1	9	15
5	25	2	15	5	1	9	20
6	140	2	25	6	4	9	30
7		13	00	7	6	9	35
1	5	2	40	1	22	9	47
2	2	3	00	2	5	9	55
3	2	3	20	3	5	10	00
4	1	3	35	4	1	10	12
5	10	3	40	5	1	10	17
6	140	3	50	6	2	10	25
7		17	00	7	5	10	34
1	10	4	00	1	23	10	42
2	1	4	15	2	5	10	55
3	4	4	25	3	7	11	02
4	1	4	31	4	1	11	12
5	5	4	45	5	1	11	18
6	140	4	52	6	3	11	30
7		17	00	7	3	11	40
1	12	5	00	1	24	11	50
2	1	5	10	2	6	12	00
3	4	5	15	3	8	12	14
4	1	5	25	4	1	12	22
5	2	5	35	5	1	12	32
6	21	5	47	6	3	12	40
7	140	5	58	7	2	12	47
1	17	6	12	1	26	12	55
2	2	6	20	2	7	13	06
3	4	6	29	3	9	13	15
4	1	6	43	4	2	13	20
5	1	6	52	5	1	13	30
6	7	7	00	6	4	13	35
7	23	7	15	7	4	13	42

Table 5. (Cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time	level	Voltage	Hr.	Time
			Min. Sec.				Min. Sec.
1	27		14 00	1	33		20 10
2	7		14 13	2	29		20 20
3	10		14 22	3	11		20 26
4	2		14 32	4	3		20 35
5	2		14 40	5	2		20 43
6	3		14 50	6	4		20 55
7	4		15 00	7	4		21 00
1	26		15 17	1	35		21 05
2	7		15 25	2	10		21 15
3	10		15 33	3	12		21 25
4	3		15 40	4	3		21 30
5	3		15 46	5	2		21 40
6	4		15 54	6	5		21 45
7	3		16 00	7	4		21 55
1	27		16 12	1	33		22 00
2	7		16 22	2	10		22 15
3	10		16 30	3	13		22 22
4	2		16 38	4	4		22 30
5	1		16 45	5	2		22 40
6	4		16 52	6	4		22 48
7	4		17 00	7	4		22 55
1	29		17 10	1	34		23 00
2	8		17 20	2	9		23 15
3	10		17 25	3	13		23 25
4	3		17 32	4	4		23 32
5	2		17 40	5	2		23 40
6	4		17 45	6	5		23 48
7	4		17 53	7	4		23 54
1	32		18 10	1	36		24 00
2	9		18 18	2	10		24 15
3	11		18 25	3	13		24 20
4	3		18 32	4	3		24 28
5	2		18 40	5	2		24 38
6	4		18 45	6	4		24 46
7	3		18 50	7	4		24 55
1	30		19 05	1	37		25 05
2	8		19 15	2	10		25 15
3	12		19 25	3	14		25 20
4	3		19 35	4	4		25 30
5	2		19 45	5	5		25 40
6	4		19 50	6	4		25 45
7	3		19 55	7	4		25 50

Table 5. (Cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	36		26 05	1	37		34 20
2	10		26 15	2	11		34 30
3	14		26 25	3	15		34 45
4	4		26 30	4	4		34 58
5	2		26 38	5	2		35 05
6	4		26 45	6	4		35 15
7	4		26 50	7	3		35 30
1	35		27 00	1	37		35 45
2	10		27 20	2	11		35 55
3	14		27 25	3	15		36 05
4	4		27 30	4	4		36 15
5	2		27 36	5	2		36 28
6	4		27 40	6	4		36 40
7	4		27 48	7	4		36 55
1	38		28 00	1	38		37 12
2	10		28 15	2	11		37 25
3	14		28 22	3	16		37 38
4	4		28 30	4	5		37 50
5	2		28 40	5	2		38 00
6	4		28 45	6	4		38 12
7	4		28 50	7	3		38 25
1	36		29 30	1	39		38 40
2	10		29 40	2	11		38 55
3	15		29 55	3	17		39 09
4	4		30 09	4	5		39 20
5	2		30 25	5	3		39 35
6	4		30 35	6	4		39 48
7	4		30 45	7	4		40 00
1	37		31 05	1	39		40 12
2	10		31 20	2	12		40 25
3	15		31 30	3	17		40 35
4	4		31 40	4	5		40 45
5	3		31 55	5	2		40 55
6	4		32 05	6	4		41 10
7	4		32 12	7	3		41 20
1	37		32 30	1	40		41 45
2	10		32 40	2	12		41 55
3	15		32 50	3	17		42 05
4	4		33 02	4	5		42 25
5	2		33 12	5	2		42 35
6	4		33 23	6	4		42 50
7	4		33 35	7	3		43 00

Table 5. (Cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	40		43 15	1	44		51 30
2	12		43 30	2	13		51 45
3	17		43 45	3	18		51 55
4	4		43 55	4	5		52 10
5	2		44 05	5	2		52 20
6	4		44 20	6	4		52 32
7	3		44 35	7	3		52 45
1	40		44 50	1	44		53 00
2	12		45 05	2	13		53 12
3	17		45 20	3	18		53 20
4	5		45 28	4	5		53 35
5	2		45 38	5	2		53 45
6	4		45 45	6	4		53 55
7	3		45 58	7	3		54 05
1	41		46 15	1	45		54 20
2	12		46 25	2	14		54 35
3	17		46 35	3	19		54 45
4	5		46 45	4	6		54 55
5	2		46 55	5	3		55 09
6	4		47 05	6	4		55 15
7	3		47 15	7	3		55 25
1	42		47 30	1	45		55 30
2	12		47 45	2	14		55 45
3	18		47 55	3	18		55 58
4	5		48 05	4	6		56 15
5	3		48 15	5	3		56 28
6	4		48 25	6	5		56 35
7	3		48 40	7	4		56 55
1	42		48 50	1	45	1	00
2	13		49 05	2	15		00
3	18		49 15	3	20		00
4	5		49 25	4	6		00
5	3		49 35	5	3	1	01
6	4		49 45	6	4		01
7	3		49 58	7	3		01
1	43		50 05	1	46	1	05
2	13		50 22	2	15		05
3	18		50 35	3	20		05
4	5		50 45	4	6		05
5	3		50 55	5	3		05
6	4		51 05	6	4	1	06
7	3		51 15	7	3		06

Table 5. (Cont.)

Electrode:				Electrode:			
level	Voltage	Time	Time	level	Voltage	Time	Time
		Hr.	Min. Sec.			Hr.	Min. Sec.
1	46	1	10	1	48	1	50
2	15		10	2	15		50
3	21		10	3	22		50
4	6		10	4	6		50
5	3	1	11	5	2	1	51
6	4		11	6	4		51
7	3		11	7	3		51
1	47	1	15	1	48	2	00
2	15		15	2	16		00
3	21		15	3	22		00
4	6		15	4	6		00
5	3		15	5	2	2	01
6	4		15	6	4		01
7	3	1	16	7	3		01
1	47	1	20	1	47	2	10
2	15		20	2	16		10
3	21		20	3	22		10
4	5		20	4	6		10
5	3		20	5	2		10
6	4	1	21	6	4	2	11
7	4		21	7	4		11
1	47	1	25	1	48	2	20
2	15		25	2	16		20
3	21		25	3	22		20
4	6		25	4	6		20
5	3	1	26	5	2	2	21
6	4		26	6	3		21
7	3		26	7	4		21
1	47	1	30	1	48	2	40
2	15		30	2	16		40
3	21		30	3	23		40
4	6		30	4	6		40
5	2		30	5	2	2	41
6	4	1	31	6	3		41
7	3		31	7	3		41
1	48	1	40	1	48	3	00
2	15		40	2	17		00
3	22		40	3	23		00
4	6		40	4	6		00
5	2		40	5	2	3	01
6	4	1	41	6	3		01
7	3		41	7	3		01

Table 5. (Cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time	level	Voltage	Hr.	Time
			Min. Sec.				Min. Sec.
1	48	3	20	1	51	15	40
2	17		20	2	18		40
3	23		20	3	26		40
4	7		20	4	6		40
5	2	3	21	5	2	16	40
6	3	9	21	6	3	5	41
7	3		21	7	3		41
1	49	13	40	1	51	16	10
2	17		40	2	18		10
3	24		40	3	26	18	10
4	7		40	4	6		10
5	2	10	40	5	2		10
6	3	3	41	6	3		10
7	3		41	7	3	16	11
1	50	14	00	1	52	26	40
2	17		00	2	18		40
3	25		00	3	25		40
4	7		00	4	7		40
5	2	14	01	5	2	26	41
6	3		01	6	3		41
7	3		01	7	3		41
1	50	14	20	1	52	27	10
2	17		20	2	19		10
3	27		20	3	27		10
4	6		20	4	7		10
5	2	14	21	5	2	27	11
6	3		21	6	3		11
7	3		21	7	3		11
1	50	14	40	1	52	27	40
2	17		40	2	19		40
3	27		40	3	27		40
4	6	13	40	4	6		40
5	2		40	5	2	27	41
6	3	4	41	6	3		41
7	3		41	7	3		41
1	50	15	10	1	52	28	40
2	17	14	10	2	19		40
3	25		10	3	30		40
4	6		10	4	7		40
5	2		10	5	2	28	41
6	3	15	11	6	3		41
7	3		11	7	2		41

Table 5. (Cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	52	9	40	1	52	16	40
2	19		40	2	21		40
3	31		40	3	35		40
4	8		40	4	9		40
5	2		40	5	3	16	41
6	3	9	41	6	3		41
7	3		41	7	3		41
1	52	10	40	1	53	18	39
2	20		40	2	21		39
3	33		40	3	35	18	40
4	9		40	4	9		40
5	2	10	41	5	4		40
6	3		41	6	3		40
7	2		41	7	3	18	41
1	52	11	40	1	53	20	40
2	20		40	2	23		40
3	34		40	3	35		40
4	9		40	4	9		40
5	2	11	41	5	4	20	41
6	3		41	6	3		41
7	2		41	7	3		41
1	52	12	40	1	53	22	45
2	20		40	2	24		45
3	34		40	3	36		45
4	9		40	4	9		45
5	2	12	41	5	3	22	46
6	3		41	6	3		46
7	2		41	7	3		46
1	52	13	40	1	55	26	40
2	20		40	2	37		40
3	34		40	3	36		40
4	9	13	41	4	9		40
5	2		41	5	3	26	41
6	3		41	6	3		41
7	2		41	7	3		41
1	42	14	40	1	57	30	35
2	20	14	41	2	37		35
3	35		41	3	36		35
4	9		41	4	10		35
5	3		41	5	4	30	36
6	3	14	42	6	3		36
7	3		42	7	3		36

Table 5. (Concl.) and time for water charge No. 2.
40-50 sand-size.

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	61	34	32	1	87	62	48
2	28		32	2	31		48
3	38		32	3	40		48
4	10	34	33	4	10		48
5	4		33	5	4	62	49
6	4		33	6	4		49
7	3	34	34	7	3		49
1	66	38	45	1	87	70	38
2	29		45	2	30		38
3	38		45	3	39		38
4	10	38	46	4	10	70	39
5	4		46	5	4		39
6	4		46	6	4		39
7	3		46	7	3		39
1	68	42	41	1	88	90	00
2	29		41	2	30		00
3	38		41	3	40		00
4	10		41	4	10		00
5	4	42	42	5	5		00
6	4		42	6	4		00
7	3		42	7	3		00
1	72	46	42	1	96	138	00
2	30		42	2	31		00
3	38		42	3	40		00
4	10	46	43	4	10		00
5	4		43	5	5		00
6	4		43	6	4		00
7	3		43	7	3		00
1	76	50	40	1	102	184	30
2	30		40	2	31		30
3	39		40	3	40		30
4	10	50	41	4	10		30
5	4		41	5	5		30
6	4		41	6	4		30
7	3		41	7	3		30
1	81	54	45	1	103	190	15
2	30		45	2	31		15
3	40		45	3	40		15
4	10		45	4	10		15
5	4	54	46	5	5		15
6	4		46	6	4		15
7	3		46	7	3		15

Table 6. Voltage and time for water charge No. 2.
40-60 sand-size.

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	72		18	1	18	4	28
2	25		22	2	4	4	35
3	14		27	3	4	4	42
4	11		32	4	3	4	50
5	6		38	5	5	5	00
6	5		45	6	5	5	10
7	3		52	7	4	5	20
1	11	1	00	1	20	5	25
2	3	1	08	2	4	5	32
3	8	1	13	3	4	5	40
4	10	1	18	4	4	5	50
5	5	1	24	5	4	6	00
6	5	1	30	6	5	6	05
7	3	1	35	7	3	6	15
1	14	1	42	1	21	6	30
2	3	1	50	2	4	6	40
3	5	1	55	3	4	6	50
4	9	2	00	4	3	7	00
5	5	2	05	5	3	7	10
6	5	2	07	6	5	7	18
7	3	2	15	7	3	7	29
1	14	2	20	1	21	7	40
2	4	2	25	2	4	7	50
3	4	2	28	3	4	7	55
4	7	2	32	4	3	8	05
5	5	2	40	5	3	8	12
6	5	2	45	6	5	8	25
7	3	2	50	7	3	8	40
1	16	3	00	1	22	8	50
2	4	3	05	2	4	9	00
3	4	3	10	3	4	9	15
4	4	3	15	4	3	9	30
5	5	3	20	5	3	9	40
6	5	3	25	6	5	9	50
7	3	3	30	7	3	10	00
1	17	3	35	1	23	10	10
2	4	3	40	2	5	10	20
3	4	3	48	3	4	10	30
4	4	3	55	4	3	10	40
5	4	4	00	5	3	10	50
6	4	4	10	6	5	11	05
7	3	4	18	7	3	11	20

Table 6. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	25	11	35	1	32	19	30
2	5	11	45	2	7	19	35
3	4	11	55	3	6	19	40
4	3	12	05	4	2	19	45
5	3	12	20	5	2	19	50
6	5	12	35	6	4	20	00
7	3	12	50	7	4	20	05
1	27	13	00	1	33	20	15
2	6	13	10	2	7	20	25
3	5	13	18	3	6	20	30
4	3	13	29	4	2	20	35
5	3	13	42	5	2	20	40
6	5	13	55	6	4	20	50
7	3	14	08	7	4	20	55
1	29	14	20	1	34	21	00
2	6	14	30	2	7	21	10
3	5	14	40	3	7	21	15
4	3	14	55	4	2	21	25
5	3	15	05	5	2	21	30
6	5	15	18	6	4	21	40
7	3	15	30	7	4	21	45
1	30	15	45	1	36	21	55
2	6	15	55	2	8	22	05
3	6	16	00	3	7	22	15
4	3	16	10	4	2	22	25
5	3	16	20	5	2	22	30
6	5	16	35	6	4	22	38
7	3	16	50	7	4	22	49
1	31	17	05	1	36	23	00
2	6	17	15	2	8	23	10
3	6	17	25	3	7	23	20
4	2	17	35	4	2	23	30
5	3	17	45	5	2	23	35
6	5	17	58	6	4	23	45
7	4	18	12	7	4	23	52
1	32	18	20	1	36	24	08
2	6	18	30	2	8	24	16
3	6	18	35	3	8	24	25
4	2	18	45	4	3	24	32
5	2	18	58	5	2	24	47
6	4	19	08	6	4	24	50
7	4	19	20	7	4	24	54

Table 6. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time	level	Voltage	Hr.	Time
			Min. Sec.				Min. Sec.
1	36		25 00	1	41		40 10
2	8		25 10	2	11		40 20
3	8		25 15	3	12		40 30
4	3		25 25	4	3		40 42
5	2		25 40	5	2		40 55
6	4		25 52	6	4		41 05
7	4		26 05	7	4		41 15
1	37		26 16	1	43		45 10
2	8		26 25	2	12		45 20
3	8		26 30	3	12		45 30
4	3		26 38	4	3		45 40
5	2		26 45	5	2		45 55
6	4		26 55	6	4		46 05
7	4		27 02	7	4		46 15
1	38		27 15	1	45		50 00
2	9		27 25	2	12		50 10
3	9		27 30	3	13		50 20
4	3		27 35	4	3		50 32
5	2		27 45	5	2		50 45
6	4		27 55	6	4		50 55
7	4		28 05	7	4		51 02
1	38		28 15	1	46		55 00
2	9		28 25	2	13		55 10
3	9		28 30	3	14		55 20
4	3		28 39	4	3		55 30
5	2		28 50	5	2		55 40
6	4		29 00	6	4		55 50
7	4		29 10	7	4		55 58
1	38		29 20	1	47	1	00
2	9		29 30	2	13		00
3	10		29 40	3	15		00
4	3		29 50	4	3		00
5	2		29 55	5	2		00
6	4		30 05	6	3		00
7	4		30 10	7	4	1	01
1	39		35 12	1	48	1	05
2	10		35 25	2	14		05
3	11		35 35	3	16		05
4	3		35 45	4	3		05
5	2		36 55	5	2		05
6	4		36 05	6	3		05
7	4		36 10	7	4	1	06

Table 6. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	49	1	10	1	54	1	50
2	19		10	2	17		50
3	16		10	3	19		50
4	3		10	4	4		50
5	2		10	5	2		50
6	3		10	6	3		50
7	4	1	11	7	3	1	51
1	50	1	15	1	54	2	00
2	15		15	2	17		00
3	17		15	3	19		00
4	3		15	4	4		00
5	2	1	16	5	2		00
6	3		16	6	3		00
7	4		16	7	3	2	01
1	51	1	20	1	55	2	10
2	15		20	2	17		10
3	17		20	3	19		10
4	3		20	4	4		10
5	2		20	5	2		10
6	3	1	21	6	3		10
7	3		21	7	3	2	11
1	52	1	25	1	55	2	20
2	16		25	2	18		20
3	18		25	3	20		20
4	3		25	4	4		20
5	2		25	5	2		20
6	3		25	6	3		20
7	3	1	26	7	3	2	21
1	52	1	30	1	56	2	40
2	16		30	2	18		40
3	18		30	3	20		40
4	4		30	4	4		40
5	2		30	5	2		40
6	3		30	6	3	2	41
7	3	1	31	7	3		41
1	53	1	40	1	56	3	03
2	16		40	2	18		03
3	19		40	3	20		03
4	4		40	4	4		03
5	2		40	5	2		03
6	3		40	6	3		03
7	3	1	41	7	3	3	04

Table 6. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	56	3	21	1	59	6	02
2	19		21	2	20		02
3	21		21	3	23		02
4	4		21	4	5		02
5	2		21	5	2		02
6	3		21	6	4		02
7	3	3	22	7	3	6	03
1	57	3	39	1	59	6	35
2	19	3	40	2	20		35
3	21		40	3	23		35
4	4		40	4	5		35
5	2		40	5	2		35
6	3		40	6	4		35
7	3	12	40	7	3	6	36
1	57	4	00	1	60	7	00
2	19		00	2	20		00
3	21		00	3	23		00
4	4		00	4	5		00
5	2		00	5	2		00
6	3	15	00	6	3		00
7	3		00	7	3	7	01
1	57	4	31	1	60	8	02
2	19		31	2	20		02
3	22		31	3	23		02
4	4	18	31	4	6		02
5	2		31	5	2		02
6	3		31	6	3		02
7	3		31	7	3	8	03
1	58	5	00	1	61	9	03
2	19		00	2	20		03
3	22		00	3	23		03
4	5		00	4	6		03
5	2		00	5	2		03
6	3		00	6	3		03
7	3	21	00	7	3	9	04
1	59	5	30	1	61	10	00
2	20		30	2	20		00
3	23		30	3	23		00
4	5		30	4	6		00
5	2		30	5	2		00
6	4		30	6	3		00
7	3	5	31	7	3	10	01

Table 6. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	61	11	01	1	89	30	20
2	20		01	2	40		20
3	23		01	3	35		20
4	6		01	4	10		20
5	2		01	5	4		20
6	3		01	6	3		20
7	3	11	02	7	3	30	21
1	61	12	58	1	100	34	00
2	20		58	2	41		00
3	23		58	3	36		00
4	7		58	4	10		00
5	2		58	5	4		00
6	3		58	6	3		00
7	3	12	59	7	3	34	01
1	61	15	10	1	121	40	15
2	21		10	2	43		15
3	23		10	3	37		15
4	7		10	4	10		15
5	3		10	5	4		15
6	3	15	11	6	3		15
7	3		11	7	2	40	16
1	62	18	00	1	121	46	00
2	22		00	2	43		00
3	24		00	3	37		00
4	8	18	01	4	10		00
5	3		01	5	4		00
6	3		01	6	3		00
7	3		01	7	2	46	01
1	64	21	57	1	117	52	15
2	25		57	2	41		15
3	25		57	3	38		15
4	9		57	4	10		15
5	3		57	5	5		15
6	3		57	6	3		15
7	3	21	58	7	2	52	16
1	70	25	52	1	119	64	23
2	34		52	2	42		23
3	31		52	3	38		23
4	10		52	4	10		23
5	4		52	5	5		23
6	3		52	6	3		23
7	3	25	53	7	2	64	24

Table 6. (concl.) and time data for water charge No. 3.
40-60 sand-size.

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	120	88	00	1	10	4	38
2	42		00	2	5	5	08
3	39		00	3	4	6	13
4	10		00	4	3	6	23
5	5		00	5	3	5	29
6	3		00	6	3	5	33
7	2		00	7	2	5	40
1	122	118	00	1	21	5	50
2	43		00	2	3	5	58
3	39		00	3	3	5	05
4	11		00	4	3	6	12
5	5		00	5	4	6	20
6	3		00	6	4	6	25
7	3		00	7	2	6	30
1	123	142	00	1	25	7	00
2	43		00	2	3	7	03
3	40		00	3	5	7	15
4	11		00	4	4	7	22
5	5		00	5	4	7	30
6	3		00	6	4	7	45
7	3		00	7	2	7	55
1	125	170	00	1	25	8	05
2	43		00	2	3	8	15
3	41		00	3	3	8	22
4	12		00	4	4	8	30
5	5		00	5	4	8	40
6	3		00	6	4	8	50
7	3		00	7	2	9	00

Table 7. Voltage and time data for water charge No. 3.
40-60 sand-size.

Electrode: : Time				Electrode: : Time			
level	:Voltage:	Hr.	Min. Sec.	level	:Voltage:	Hr.	Min. Sec.
1	12		10	1	19	4	58
2	5		14	2	5	5	09
3	29		18	3	4	5	15
4	10		22	4	6	5	23
5	5		26	5	5	5	28
6	3		30	6	3	5	35
7	3		34	7	2	5	40
1	14		40	1	21	5	50
2	5		45	2	5	5	58
3	15		50	3	5	6	05
4	10		55	4	5	6	12
5	5	1	00	5	4	6	20
6	3	1	07	6	4	6	25
7	2	1	15	7	2	6	30
1	14	1	25	1	23	7	00
2	7	1	35	2	6	7	08
3	10	1	42	3	5	7	15
4	10	1	50	4	4	7	22
5	5	2	00	5	4	7	30
6	3	2	10	6	4	7	45
7	2	2	18	7	2	7	55
1	16	2	25	1	25	8	05
2	5	2	32	2	6	8	15
3	7	2	38	3	5	8	22
4	10	2	45	4	4	8	30
5	5	2	52	5	4	8	40
6	3	2	58	6	4	8	50
7	2	3	05	7	2	9	00
1	16	3	15	1	26	9	09
2	4	3	22	2	8	9	18
3	5	3	30	3	5	9	22
4	9	3	36	4	4	9	30
5	5	3	45	5	4	9	35
6	3	3	50	6	4	9	40
7	2	3	55	7	2	9	52
1	17	4	08	1	27	10	10
2	5	4	15	2	8	10	20
3	4	4	22	3	5	10	30
4	9	4	30	4	3	10	40
5	5	4	35	5	4	10	50
6	3	4	40	6	4	11	05
7	2	4	45	7	2	11	15

Table 7. (cont.)

Electrode:				Electrode:			
level	: Voltage:	Hr.	Time Min. Sec.	level	: Voltage:	Hr.	Time Min. Sec.
1	30		11 25	1	33		17 10
2	8		11 35	2	7		17 20
3	5		11 45	3	7		17 30
4	4		11 55	4	4		17 38
5	4		12 05	5	3		17 45
6	5		12 12	6	4		17 52
7	2		12 20	7	2		18 00
1	30		12 30	1	34		18 10
2	7		12 38	2	8		18 20
3	6		12 45	3	7		18 30
4	4		12 55	4	4		18 40
5	4		13 02	5	3		18 50
6	5		13 10	6	4		19 00
7	2		13 18	7	2		19 10
1	31		13 25	1	35		19 20
2	7		13 32	2	8		19 30
3	6		13 40	3	7		19 37
4	4		13 48	4	4		19 45
5	4		13 55	5	3		19 52
6	5		14 05	6	4		20 00
7	2		14 12	7	2		20 10
1	32		14 18	1	37		20 20
2	7		14 25	2	8		20 29
3	6		14 32	3	7		20 35
4	4		14 38	4	4		20 42
5	4		14 45	5	4		20 50
6	5		14 52	6	4		21 00
7	2		15 00	7	2		21 10
1	33		15 10	1	38		21 18
2	7		15 17	2	9		21 25
3	6		15 25	3	7		21 32
4	4		15 35	4	4		21 40
5	3		15 42	5	4		21 50
6	4		15 49	6	4		21 58
7	2		15 58	7	3		22 05
1	33		16 12	1	38		22 20
2	7		16 20	2	8		22 30
3	6		16 28	3	8		22 40
4	4		16 35	4	4		22 48
5	3		16 42	5	4		22 55
6	4		16 50	6	4		23 02
7	2		16 58	7	2		23 10

Table 7. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	39		23 22	1	42		30 25
2	8		23 30	2	10		30 32
3	8		23 40	3	9		30 40
4	4		23 50	4	4		30 48
5	4		24 00	5	4		30 55
6	4		24 10	6	3		31 05
7	2		24 18	7	3		31 12
1	40		24 30	1	42		31 20
2	9		24 40	2	10		31 28
3	8		24 50	3	9		31 35
4	4		25 00	4	4		31 42
5	4		25 10	5	4		31 50
6	4		25 20	6	3		32 00
7	2		25 30	7	3		32 08
1	40		25 45	1	42		32 15
2	9		25 55	2	10		32 25
3	8		26 05	3	10		32 45
4	4		26 15	4	4		32 42
5	4		26 18	5	4		32 50
6	4		26 25	6	4		32 58
7	3		26 35	7	3		33 05
1	40		27 25	1	42		33 15
2	9		27 45	2	10		33 22
3	8		28 00	3	10		33 30
4	4		28 12	4	4		33 38
5	4		28 20	5	4		33 45
6	3		28 30	6	4		33 52
7	3		28 38	7	3		34 00
1	41		28 45	1	43		34 10
2	9		28 52	2	11		34 20
3	8		29 00	3	10		34 30
4	4		29 05	4	4		34 38
5	4		29 11	5	5		34 45
6	3		29 20	6	4		34 55
7	3		29 28	7	3		35 05
1	42		29 40	1	46		40 00
2	10		29 38	2	12		40 10
3	9		29 45	3	10		40 18
4	4		29 52	4	4		40 25
5	4		30 00	5	5		40 35
6	3		30 08	6	4		40 45
7	3		30 15	7	3		40 55

Table 7. (cont.)

Electrode:				Electrode:			
level	:Voltage:	Hr.	Time Min. Sec.	level	:Voltage:	Hr.	Time Min. Sec.
1	48		45 02	1	56	1	15
2	13		45 12	2	17		15
3	11		45 20	3	14		15
4	4		45 30	4	5		15
5	5		45 40	5	5		15
6	4		45 50	6	5		15
7	4		46 00	7	5		15
1	49		50 02	1	56	1	20
2	15		50 15	2	17		20
3	11		50 25	3	14		20
4	5		50 35	4	5		20
5	5		50 45	5	5		20
6	4		50 55	6	5		20
7	4		51 05	7	5		20
1	51		55 09	1	57	1	30
2	15		55 20	2	17		30
3	12		55 30	3	15		30
4	5		55 40	4	5		30
5	5		55 50	5	5		30
6	5		56 00	6	5		30
7	4		56 10	7	5		30
1	53	1	00	1	58	1	40
2	16		00	2	18		40
3	12		00	3	16		40
4	5		00	4	5		40
5	5		00	5	5		40
6	5		00	6	5		40
7	5	1	01	7	5		40
1	54	1	05	1	59	1	50
2	16		05	2	18		50
3	13		05	3	16		50
4	5		05	4	5		50
5	5		05	5	5		50
6	5		05	6	5		50
7	5		05	7	5		50
1	55	1	10	1	61	2	10
2	17		10	2	19		10
3	13		10	3	16		10
4	5		10	4	5		10
5	5		10	5	5		10
6	5		10	6	5		10
7	5		10	7	5		10

Table 7. (cont.)

Electrode:				Electrode:			
level	:Voltage:	Hr.	Time Min. Sec.	level	:Voltage:	Hr.	Time Min. Sec.
1	62	2	30	1	70	5	00
2	20		30	2	24		00
3	17		30	3	20		00
4	5		30	4	7		00
5	5		30	5	4		00
6	5		30	6	5		00
7	5		30	7	5		00
1	64	2	50	1	72	5	30
2	21		50	2	26		30
3	17		50	3	20		30
4	6		50	4	7		30
5	5		50	5	4		30
6	5		50	6	5		30
7	5		50	7	5		30
1	64	3	10	1	73	6	00
2	21		10	2	27		00
3	18		10	3	21		00
4	6		10	4	8		00
5	5		10	5	4		00
6	5		10	6	5		00
7	5		10	7	5		00
1	65	3	30	1	75	6	30
2	22		30	2	28		30
3	18		30	3	22		30
4	6		30	4	8		30
5	4		30	5	4		30
6	5		30	6	5		30
7	5		30	7	5		30
1	69	4	00	1	77	7	00
2	22		00	2	29		00
3	19		00	3	23		00
4	7		00	4	8		00
5	4		00	5	4		00
6	5		00	6	5		00
7	5		00	7	5		00
1	69	4	30	1	79	7	29
2	23		30	2	30		29
3	19		30	3	23		29
4	7		30	4	9		29
5	4		30	5	4		29
6	5		30	6	5		29
7	5		30	7	5		29

Table 7. (cont.)

Electrode:				Electrode:			
level	:Voltage:	Hr.	<u>Time</u> Min. Sec.	level	:Voltage:	Hr.	<u>Time</u> Min. Sec.
1	83	8	00	1	112	14	00
2	31		00	2	41		00
3	24		00	3	31		00
4	9		00	4	11		00
5	5		00	5	5		00
6	5	8	01	6	5		00
7	5		01	7	5		00
1	89	9	01	1	115	16	03
2	34		01	2	41		03
3	28		01	3	32		03
4	10	9	02	4	11		03
5	5		02	5	5		03
6	5		02	6	5		03
7	5	43	02	7	5		03
1	101	10	03	1	119	20	05
2	37		03	2	42		05
3	30		03	3	33		05
4	10		03	4	11		05
5	5		03	5	5		05
6	5		03	6	5		05
7	5		03	7	5	20	06
1	109	11	02	1	118	24	02
2	38		02	2	42		02
3	30		02	3	34		02
4	11		02	4	11		02
5	5		02	5	5		02
6	5		02	6	5		02
7	5		02	7	5	24	03
1	112	12	08	1	118	27	50
2	39		08	2	42		50
3	30		08	3	34		50
4	11		08	4	11		50
5	5		08	5	5		50
6	5	12	09	6	5		50
7	5		09	7	5		50
1	114	13	00	1	119	32	05
2	40		00	2	42		05
3	31		00	3	34		05
4	11		00	4	11		05
5	5		00	5	5		05
6	5		00	6	5		05
7	5		00	7	5		05

Table 7. (concl.) and time for water charge No. 4.
40-60 sand-size.

Electrode:				Electrode:			
level	Voltage	Hr.	Time	level	Voltage	Hr.	Time
			Min. Sec.				Min. Sec.
1	120	38	02	1	81	3	40
2	42		02	2	13	3	45
3	35		02	3	13	3	50
4	12		02	4	12	3	55
5	5		02	5	4	4	00
6	5		02	6	4	4	05
7	5		02	7	4	4	10
1	121	48	00	1	22	4	40
2	43		00	2	12	4	45
3	38		00	3	12	4	50
4	12		00	4	12	4	55
5	5		00	5	4	5	00
6	5		00	6	4	5	05
7	5	48	01	7	4	5	10
1	20	1	30	1	22	3	45
2	11	1	35	2	11	3	50
3	13	1	40	3	12	3	55
4	13	1	45	4	12	3	00
5	6	1	50	5	4	3	05
6	5	1	55	6	4	3	10
7		2	00	7	4	3	15
1	20	2	05	1	22	3	20
2	11	2	10	2	11	3	25
3	13	2	15	3	12	3	30
4	12	2	20	4	12	3	35
5	5	2	25	5	4	3	40
6	5	2	30	6	4	3	45
7		2	35	7	4	3	50
1	20	2	40	1	21	3	55
2	11	2	45	2	10	3	00
3	13	2	50	3	12	3	05
4	12	2	55	4	12	3	10
5	5	2	00	5	4	3	15
6	5	3	05	6	4	3	20
7		3	10	7	4	3	25
1	21	3	15	1	20	3	30
2	12	3	20	2	10	3	35
3	13	3	25	3	11	3	40
4	11	3	30	4	12	3	45
5	5	3	35	5	4	3	50
6	5	3	40	6	4	3	55
7		3	45	7	4	3	00

Table 8. Voltage and time for water charge No. 4.
40-60 sand-size.

Electrode:				Electrode:			
level	Voltage	Hr.	Time	level	Voltage	Hr.	Time
			Min. Sec.				Min. Sec.
1	20		12	1	21	3	40
2	36		20	2	13	3	45
3	13		28	3	13	3	50
4	13		35	4	12	3	55
5	5		45	5	4	4	00
6			50	6	5	4	05
7			55	7	4	4	10
1	17	1	00	1	22	4	40
2	17	1	05	2	12	4	45
3	13	1	10	3	12	4	50
4	10	1	15	4	12	4	55
5	5	1	20	5	4	5	05
6	5	1	25	6	4	5	15
7		1	30	7	4	5	25
1	20	1	30	1	22	5	45
2	11	1	35	2	11	5	55
3	13	1	40	3	12	6	05
4	13	1	45	4	12	6	10
5	6	1	50	5	4	6	20
6	5	1	55	6	4	6	25
7		2	00	7	4	6	30
1	20	1	05	1	22	6	40
2	11	1	10	2	10	6	50
3	13	1	15	3	12	7	00
4	11	1	20	4	13	7	05
5	5	1	25	5	4	7	15
6	5	1	30	6	4	7	20
7		2	35	7	4	7	25
1	20	2	35	1	21	7	35
2	11	2	40	2	10	7	45
3	13	2	45	3	12	7	50
4	13	2	50	4	12	8	00
5	5	2	55	5	4	8	08
6	5	3	00	6	4	8	15
7		3	05	7	4	8	20
1	21	3	05	1	20	8	25
2	12	3	10	2	10	8	30
3	13	3	15	3	11	8	35
4	11	3	20	4	12	8	40
5	5	3	25	5	4	8	50
6	5	3	30	6	4	8	55
7		3	35	7	4	9	02

Table 8. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	21	9	12	1	24	14	07
2	10	9	22	2	10	14	15
3	11	9	27	3	8	14	21
4	12	9	35	4	10	14	30
5	4	9	45	5	5	14	35
6	4	9	50	6	5	14	40
7	4	9	55	7	3	14	50
1	22	10	05	1	25	15	00
2	10	10	12	2	10	15	10
3	11	10	18	3	7	15	18
4	12	10	25	4	10	15	23
5	5	10	30	5	5	15	30
6	4	10	38	6	4	15	35
7	4	10	43	7	3	15	42
1	22	10	50	1	25	15	54
2	10	11	00	2	10	16	00
3	10	11	05	3	7	16	10
4	12	11	15	4	10	16	18
5	5	11	22	5	5	16	25
6	4	11	28	6	4	16	30
7	4	11	32	7	3	16	35
1	23	11	40	1	26	16	45
2	10	11	48	2	10	16	53
3	9	11	53	3	8	17	00
4	11	11	59	4	9	17	08
5	5	12	05	5	5	17	13
6	4	12	10	6	4	17	18
7	4	12	15	7	3	17	23
1	24	12	25	1	26	17	32
2	10	12	32	2	10	17	40
3	8	12	40	3	8	17	45
4	10	12	47	4	9	17	55
5	5	12	52	5	5	18	05
6	4	12	58	6	4	18	15
7	4	13	03	7	3	18	20
1	24	13	15	1	26	18	30
2	10	13	22	2	10	18	40
3	8	13	29	3	8	18	48
4	10	13	35	4	8	18	53
5	5	13	42	5	5	19	00
6	4	13	47	6	4	19	05
7	4	13	52	7	3	19	10

Table 8. (cont.)

Electrode: : Time				Electrode: : Time			
level	Voltage	Hr.	Min. Sec.	level	Voltage	Hr.	Min. Sec.
1	25	19	20	1	28	25	00
2	10	19	30	2	11	25	10
3	8	19	35	3	10	25	15
4	8	19	40	4	6	25	25
5	5	19	45	5	5	25	32
6	4	19	50	6	5	25	40
7	3	20	00	7	4	25	50
1	25	20	10	1	29	26	00
2	11	20	20	2	11	26	09
3	9	20	25	3	10	26	15
4	7	20	30	4	6	26	25
5	5	20	40	5	5	26	30
6	4	20	50	6	5	26	35
7	4	21	00	7	4	26	45
1	26	21	20	1	30	27	00
2	11	21	30	2	11	27	09
3	9	21	35	3	10	27	18
4	7	21	40	4	6	27	25
5	5	21	45	5	5	27	32
6	4	21	55	6	4	27	40
7	4	22	00	7	4	27	50
1	26	22	15	1	31	28	00
2	11	22	23	2	11	28	10
3	9	22	30	3	10	28	17
4	7	22	35	4	6	28	29
5	5	22	40	5	5	28	37
6	5	22	45	6	4	28	45
7	4	22	55	7	4	28	50
1	27	23	05	1	31	29	00
2	11	23	10	2	11	29	12
3	10	23	15	3	10	29	20
4	6	23	25	4	6	29	30
5	5	23	30	5	5	29	37
6	5	23	35	6	4	29	43
7	4	23	45	7	4	29	50
1	27	24	00	1	31	30	02
2	11	24	06	2	11	30	13
3	10	24	12	3	10	30	20
4	6	24	20	4	6	30	27
5	5	24	30	5	5	30	34
6	5	24	35	6	4	30	45
7	4	24	45	7	4	30	45

Table 8. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	33		35 00	1	48	1	10
2	12		35 09	2	15		10
3	11		35 16	3	13		10
4	6		35 27	4	8		10
5	5		35 38	5	5	1	11
6	4		35 45	6	4		11
7	4		35 50	7	4		11
1	36		40 00	1	49	1	20
2	12		40 10	2	15		20
3	11		40 20	3	13		20
4	7		40 25	4	8		20
5	5		40 30	5	5		20
6	4		40 40	6	4		20
7	4		40 50	7	4		20
1	39		45 05	1	51	1	30
2	12		45 15	2	16		30
3	11		45 25	3	14		30
4	7		45 35	4	8		30
5	5		45 40	5	4		30
6	4		45 50	6	4		30
7	4		46 00	7	4		30
1	41		50 02	1	55	1	40
2	13		50 10	2	17		40
3	12		50 20	3	14		40
4	7		50 30	4	8		40
5	5		50 40	5	4		40
6	4		50 50	6	4		40
7	4		51 00	7	4		40
1	44		55 10	1	59	1	50
2	14		55 20	2	18		50
3	12		55 30	3	15		50
4	7		55 40	4	7		50
5	5		55 55	5	5		50
6	4		56 05	6	4		50
7	4		56 15	7	4		50
1	47	1	00	1	63	2	00
2	14		00	2	18		00
3	12		00	3	15		00
4	8		00	4	7		00
5	5		00	5	5	2	01
6	4		00	6	4		01
7	4		00	7	4		01

Table 8. (cont.)

Electrode: : Time				Electrode: : Time			
level	:Voltage:	Hr.	Min. Sec.:	level	:Voltage:	Hr.	Min. Sec.:
1	67	2	20	1	95	4	20
2	19		20	2	27		20
3	16		20	3	20		20
4	8		20	4	9		20
5	5		20	5	5	4	21
6	4		20	6	4		21
7	4		20	7	4		21
1	69	2	40	1	88	4	41
2	20		40	2	30		41
3	17		40	3	20		41
4	8		40	4	9		41
5	5		40	5	5	4	42
6	4		40	6	4		42
7	4		40	7	4		42
1	71	3	00	1	91	5	01
2	21		00	2	32		01
3	18		00	3	21		01
4	8		00	4	10		01
5	5		00	5	5	5	02
6	4		00	6	4		02
7	4		00	7	4		02
1	73	3	20	1	96	5	20
2	22		20	2	34		20
3	18		20	3	21		20
4	9		20	4	10		20
5	5		20	5	5		20
6	4		20	6	5		20
7	4		20	7	4		20
1	77	3	40	1	102	5	40
2	23		40	2	37		40
3	19		40	3	22	5	41
4	9		40	4	10		41
5	5	3	41	5	5		41
6	4		41	6	5		41
7	4		41	7	4		41
1	81	4	02	1	108	6	01
2	25		02	2	40		01
3	19		02	3	23		01
4	9		02	4	10		01
5	5	4	03	5	5	6	02
6	4		03	6	5		02
7	4		03	7	4		02

Table 8. (cont.)

Electrode:				Electrode:			
level	:Voltage:	Hr.	Time Min. Sec.	level	:Voltage:	Hr.	Time Min. Sec.
1	120	6	30	1	133	13	35
2	43		30	2	49		35
3	23		30	3	27		35
4	11		30	4	14		35
5	5		30	5	5		35
6	5		30	6	5		35
7	4		30	7	4		35
1	124	7	01	1	133	15	33
2	45		01	2	49		33
3	24		01	3	28		33
4	11		01	4	14		33
5	5	7	02	5	5	15	34
6	5		02	6	5		34
7	4		02	7	4		34
1	127	8	38	1	133	19	36
2	47		38	2	49		36
3	24		38	3	30		36
4	11		38	4	14		36
5	5	8	39	5	5	19	37
6	5		39	6	5		37
7	4		39	7	4		37
1	130	9	34	1	136	23	33
2	48		34	2	49		33
3	25		34	3	33		33
4	12		34	4	14		33
5	5	9	35	5	5		33
6	5		35	6	5		33
7	4		35	7	4		33
1	132	10	35	1	138	31	00
2	49		35	2	50		00
3	25		35	3	36		00
4	13	10	36	4	14		00
5	5		36	5	5	31	01
6	4		36	6	5		01
7	4		36	7	4		01
1	133	11	39	1	140	47	39
2	49		39	2	50		39
3	26		39	3	39		39
4	13	11	40	4	14		39
5	5		40	5	5	47	40
6	4		40	6	5		40
7	4		40	7	4		40

Table 8. (concl.) calculations for permeability determination.

Electrode:	:	Time	:	Electrode:	:	Time
level	:Voltage:	Hr. Min. Sec.:		level	:Voltage:	Hr. Min. Sec.
1	140	72 49		1	140	288 00
2	50	49		2	52	00
3	50	49		3	53	00
4	14	49		4	14	00
5	5	72 50		5	7	00
6	5	50		6	5	00
7	5	50		7	5	00
1	140	144 00		1	140	360 00
2	50	00		2	53	00
3	52	00		3	53	00
4	14	00		4	14	00
5	5	00		5	7	00
6	5	00		6	6	00
7	5	00		7	5	00
1	140	168 00				
2	50	00				
3	52	00				
4	14	00				
5	5	00				
6	5	00				
7	5	00				
1	140	192 00				
2	50	00				
3	52	00				
4	14	00				
5	6	00				
6	5	00				
7	5	00				
1	140	216 00				
2	50	00				
3	53	00				
4	14	00				
5	6	00				
6	5	00				
7	5	00				
1	140	240 00				
2	51	00				
3	53	00				
4	14	00				
5	7	00				
6	5	00				
7	5	00				

Table 9. Data and calculations for permeability determination.

$$\text{Coefficient of permeability} = \frac{Kl \left(\frac{D_m}{D_c} \right)^2 \log_{10} \frac{h}{h_o} k}{t}$$

K = 2.3026 (constant for permeameter)

l = 12.3 cm (length of cylinder)

D_m = 0.9 cm (diameter of manometer)

D_c = 3.55 cm (diameter of cylinder)

h = Terminal head in cm (30 cm)

h_o = Initial head in cm (35 cm)

k = 21,200 (constant for sand size grains)

t = Time in seconds for h_o to h

$$\text{Coef. of Pm} = \frac{2.3026 \times 12.3 \left(\frac{0.9}{3.55} \right)^2 \log_{10} \frac{h}{h_o} \times 21,200}{\text{time in seconds}}$$

$$\text{Coef. of Pm} = \frac{38425 \left(\log_{10} \frac{30}{35} \right)}{\text{time in seconds}} = \frac{11,550}{\text{time}}$$

40-60 sand size		60-80 sand size	
Time in seconds	Pm	Time in seconds	Pm
(average of 4)		(average of 4)	
12.4 sec.	933	30.65	377
12.5 sec.	925	31.00	373
12.3 sec.	940	31.38	368

Table 10a. Data and calculations for determination of porosity. Size 40-60 sand.

$$\text{Porosity} = \frac{\text{Vol. of water for saturation}}{\text{Vol. of oven dry sand}}$$

Wt. of oven dry sand plus can	Wt. of saturated sand plus can	Weight of : can	Wt. of water for : saturation	Vol. of : oven dry sand	Porosity : (percent by volume)
334.2	400.08	23.0	65.88	183.60	35.88
333.1	399.30	23.0	66.20	183.61	36.02
334.8	400.12	23.0	65.32	183.61	35.60

Table 10b. —Data and calculations for determination of porosity. Size 60-80 sand.

$$\text{Porosity} = \frac{\text{Vol. of water for saturation}}{\text{Vol. of oven dry sand}}$$

Wt. of oven dry sand plus can	Wt. of saturated sand plus can	Weight of : can	Wt. of water for : saturation	Vol. of : oven dry sand	Porosity : (percent by volume)
324.9	395.03	23.0	70.13	183.60	38.20
324.3	394.60	23.0	70.30	183.60	38.31
325.0	395.21	23.0	70.21	183.61	38.23

Table 11. Voltage and time data for water charge No. 1.
60-80 sand-size.

Electrode: : Time				Electrode: : Time			
level	Voltage	Hr.	Min. Sec.	level	Voltage	Hr.	Min. Sec.
1	10		20	1	4	5	00
2	1		40	2	2	5	10
3				3	2	5	20
4				4			
5				5			
6				6			
7				7			
1	1	1	30	1	5	5	40
2	1	1	40	2	2	5	55
3	3	1	50	3	3	6	10
4				4	15	6	25
5				5			
6				6			
7				7			
1	2	2	05	1			
2	1	2	15	2			
3	1	2	30	3			
4				4	5	7	00
5				5			
6				6			
7				7			
1	3	2	35	1			
2	1	2	45	2			
3	1	2	55	3			
4				4	3	7	15
5				5			
6				6			
7				7			
1	5	3	15	1	5	7	25
2	2	3	30	2	2	7	35
3	1	3	40	3	3	7	50
4				4	2	7	58
5				5			
6				6			
7				7			
1	5	4	00	1	5	8	10
2	2	4	10	2	2	8	22
3	2	4	20	3	3	8	35
4				4	2	8	50
5				5			
6				6			
7				7			

Table 11. (cont.)

Electrode: : Time				Electrode: : Time			
level	:Voltage:	Hr.	Min. Sec.	level	:Voltage:	Hr.	Min. Sec.
1	5	9	00	1	8	16	00
2	2	9	10	2	2	16	15
3	3	9	20	3	3	16	25
4	2	9	35	4	1	16	35
5				5	70	16	45
6				6			
7				7			
1	6	10	40	1			
2	2	10	55	2			
3	3	11	05	3			
4	1	11	25	4			
5				5	36	17	00
6				6			
7				7			
1	6	12	00	1			
2	2	12	15	2			
3	3	12	30	3			
4	1	12	45	4			
5				5	20	17	20
6				6			
7				7			
1	7	13	05	1			
2	2	13	17	2			
3	3	13	40	3			
4	1	13	55	4			
5				5	18	17	35
6				6			
7				7			
1	7	14	15	1			
2	3	14	30	2			
3	3	14	45	3			
4	1	14	58	4			
5				5	14	17	45
6				6			
7				7			
1	8	15	00	1			
2	2	15	15	2			
3	3	15	30	3			
4	1	15	45	4			
5				5	12	18	00
6				6			
7				7			

Table 11. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	8	18	10	1	9	24	15
2	2	18	20	2	3	24	30
3	3	18	25	3	3	24	45
4	1	18	32	4	1	24	55
5	8	18	40	5	2	25	00
6				6			
7				7			
1	8	18	50	1	10	25	30
2	2	19	05	2	3	25	40
3	3	19	20	3	3	25	55
4	1	19	35	4	1	26	00
5	5	19	45	5	2	26	20
6				6			
7				7			
1	8	20	05	1	10	26	45
2	2	20	15	2	3	26	55
3	3	20	25	3	3	27	10
4	1	20	35	4	1	27	20
5	3	20	45	5	1	27	30
6				6			
7				7			
1	9	21	00	1	10	28	00
2	3	21	10	2	3	28	05
3	3	21	20	3	3	28	15
4	1	21	30	4	2	28	30
5	2	21	45	5	1	28	45
6				6			
7				7			
1	9	22	15	1	11	30	00
2	3	22	27	2	3	30	05
3	3	22	35	3	4	30	15
4	1	22	45	4	2	30	20
5	2	22	55	5	1	30	40
6				6			
7				7			
1	9	23	15	1	11	35	00
2	3	23	25	2	2	35	10
3	3	23	35	3	3	35	20
4	1	23	45	4	2	35	30
5	2	23	55	5	1	35	42
6				6			
7				7			

Table 11. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	13		40 00	1			
2	2		40 10	2			
3	3		40 22	3			
4	2		40 35	4			
5	1		20 45	5			
6				6	12		46 45
7		1	31	7		1	
1		1	33	1	15	2	50 20
2			30	2	3		50 30
3			30	3	4		50 40
4			30	4	2		50 50
5			30	5	1		51 00
6	78		41 35	6	6		51 10
7		1	31	7		2	
1				1	16	2	55 05
2				2	3		55 15
3				3	4		55 25
4				4	2		55 35
5				5	1		55 40
6	50		42 35	6	5		55 50
7		1	23	7		2	
1				1	17	1	00
2				2	3		00
3				3	4		00
4				4	2		00
5				5	1		00
6	40		43 42	6	4		00
7		1	34	7		2	
1				1	18	1	05
2				2	3		05
3				3	4		05
4				4	2		05
5				5	1		05
6	27		45 00	6	4	1	06
7		1	39	7		2	
1	15		45 05	1	19	1	10
2	2		45 13	2	4		10
3	3		45 23	3	4		10
4	2		45 35	4	2		10
5	1		45 45	5	1		10
6	17		45 55	6	3	1	11
7		1	41	7		2	

Table 11. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	22	1	20	1	26	1	50
2	4		20	2	5		50
3	4		20	3	5		50
4	2		20	4	3		50
5	1		20	5	2		50
6	3		20	6	2		50
7	-	1	21	7	12	1	51
1	23	1	30	1	29	2	00
2	5		30	2	6		00
3	4		30	3	5		00
4	2		30	4	3		00
5	1		30	5	2		00
6	3		30	6	3		00
7	-	1	31	7	10	2	01
1	41	6	00	1	30	2	15
2	10		00	2	7		15
3	10		00	3	6		15
4	4		00	4	3		15
5	3		00	5	2		15
6	3		00	6	3		15
7	90	1	33	7	8	2	16
1	42	8	02	1	31	2	30
2	11		02	2	7		30
3	12		02	3	6		30
4	4		02	4	3		30
5	3		02	5	2		30
6	3		02	6	4		30
7	52	1	34	7	7	2	31
1	43	11	00	1	34	3	00
2	12		00	2	8		00
3	13		00	3	7		00
4	4		00	4	3		00
5	3		00	5	2		00
6	3		00	6	3		00
7	28	1	39	7	5	3	01
1	24	1	40	1	35	3	30
2	5		40	2	9		30
3	4		40	3	8		30
4	2		40	4	4		30
5	1		40	5	2		30
6	2		40	6	3		30
7	21	1	41	7	3		30

Table 11. (cont.)

Electrode:				Electrode:			
level	:Voltage:	Hr.	<u>Time</u> Min. Sec.	level	:Voltage:	Hr.	<u>Time</u> Min. Sec.
1	36	4	00	1	43	17	02
2	10		00	2	12		02
3	10		00	3	13		02
4	4		00	4	4		02
5	3		00	5	2		02
6	3		00	6	3		02
7	2	4	01	7	2	17	03
1	38	5	01	1	43	21	00
2	10		01	2	12		00
3	10		01	3	14		00
4	4		01	4	4		00
5	3		01	5	2		00
6	3	5	02	6	3		00
7	2		02	7	2		00
1	41	6	00	1	44	25	00
2	10		00	2	12		00
3	10		00	3	17		00
4	4		00	4	5		00
5	3		00	5	2		00
6	3		00	6	3		00
7	2	6	01	7	2		00
1	42	8	02	1	45	29	00
2	11		02	2	12		00
3	12		02	3	18		00
4	4		02	4	5		00
5	3		02	5	2		00
6	3		02	6	4		00
7	2	8	03	7	2		00
1	43	11	00	1	45	37	00
2	12		00	2	14		00
3	12		00	3	19		00
4	4		00	4	5		00
5	2		00	5	3		00
6	3		00	6	4		00
7	2		00	7	2		00
1	43	14	01	1	48	45	00
2	12		01	2	15		00
3	13		01	3	20		00
4	4		01	4	5		00
5	2		01	5	3		00
6	3		01	6	4		00
7	2		01	7	3		00

Table 11. (concl.) and time data for water charge No. 2.
sand-size.

Electrode:	:	Time	:	Electrode:	:	Time
level	:Voltage:	Hr. Min. Sec.	:	level	:Voltage:	Hr. Min. Sec.
1	50	53 00	:	1	71	105 00
2	17	00	:	2	20	00
3	22	00	:	3	26	00
4	6	00	:	4	7	00
5	3	00	:	5	3	00
6	4	00	:	6	5	00
7	3	00	:	7	4	00
1	53	61 00	:	1	72	129 00
2	18	00	:	2	20	00
3	22	00	:	3	27	00
4	6	00	:	4	7	00
5	3	00	:	5	3	00
6	4	00	:	6	5	00
7	4	00	:	7	4	00
1	58	69 00	:	1	73	153 00
2	19	00	:	2	20	00
3	23	00	:	3	28	00
4	6	00	:	4	7	00
5	3	00	:	5	4	00
6	5	00	:	6	5	00
7	4	00	:	7	4	00
1	65	81 00	:	1	73	177 00
2	20	00	:	2	20	00
3	23	00	:	3	28	00
4	6	00	:	4	7	00
5	3	00	:	5	4	00
6	5	00	:	6	5	00
7	4	00	:	7	4	00
1	67	89 00	:	1	74	201 00
2	20	00	:	2	20	00
3	24	00	:	3	30	00
4	7	00	:	4	8	00
5	3	00	:	5	4	00
6	5	00	:	6	6	00
7	4	00	:	7	5	00
1	69	97 00	:	1	76	225 00
2	20	00	:	2	20	00
3	25	00	:	3	31	00
4	7	00	:	4	8	00
5	3	00	:	5	4	00
6	5	00	:	6	6	00
7	4	00	:	7	5	00

Table 12. Voltage and time data for water charge No. 2.
60-80 sand-size.

Electrode: : Time				Electrode: : Time			
level	Voltage	Hr.	Min. Sec.	level	Voltage	Hr.	Min. Sec.
1	42		35	1	6	5	40
2	25		40	2	3	5	50
3	53		50	3	5	6	05
4				4	10	6	15
5				5	10	6	25
6				6	11	6	35
7				7	10	6	50
1	6	1	00	1	7	7	20
2	12	1	15	2	3	7	30
3	50	1	20	3	5	7	40
4	18	1	30	4	9	7	55
5	11	1	40	5	10	8	00
6				6			
7				7			
1	6	1	45	1	7	8	30
2	3	1	55	2	3	8	45
3	12	2	00	3	5	8	55
4	16	2	10	4	8	9	10
5	11	2	20	5	10	9	23
6				6	11	9	40
7				7	10	9	55
1	5	2	45	1	7	13	30
2	3	2	55	2	3	13	45
3	7	3	05	3	4	13	55
4	15	3	12	4	7	14	05
5	11	3	24	5	10	14	15
6	11	3	35	6	10	14	25
7				7	10	14	35
1	6	3	45	1	8	15	00
2	3	3	55	2	3	15	10
3	6	4	05	3	4	15	20
4	14	4	15	4	7	15	30
5	11	4	25	5	10	15	40
6	11	4	35	6			
7				7			
1	6	4	45	1	8	17	00
2	3	4	55	2	3	17	10
3	6	5	05	3	4	17	21
4	13	5	12	4	6	17	29
5	10	5	20	5	10	17	40
6	11	5	30	6			
7	10	5	35	7			

Table 12. (cont.)

Electrode:				Electrode:			
level	: Voltage:	Hr.	Time Min. Sec.	level	: Voltage:	Hr.	Time Min. Sec.
1	9		18 00	1	12		30 00
2	3		18 15	2	4		30 10
3	4		18 25	3	6		30 18
4	5		18 35	4	5		30 35
5	10		18 48	5	5		30 50
6	10		19 00	6	5		31 05
7	10		19 10	7	6		31 20
1	9		20 10	1	13		31 30
2	4		20 18	2	4		31 40
3	5		20 35	3	6		31 48
4	5		20 45	4	5		31 55
5	6		20 55	5	4		32 05
6	9		21 05	6	4		32 10
7	10		21 15	7	5		32 18
1	10		22 00	1	15		35 00
2	4		22 10	2	4		35 10
3	5		22 25	3	6		35 18
4	5		22 40	4	4		35 28
5	6		22 52	5	5		35 40
6	7		23 05	6	4		35 50
7	10		23 15	7	5		36 02
1	10		24 00	1	16		40 00
2	4		24 10	2	5		40 10
3	5		24 20	3	7		40 20
4	5		24 30	4	4		40 33
5	5		24 45	5	4		40 45
6	6		24 55	6	4		40 55
7	9		25 10	7	5		41 10
1	11		26 00	1	16		50 00
2	4		26 10	2	5		50 10
3	5		26 20	3	7		50 21
4	5		26 35	4	4		50 28
5	5		26 45	5	4		50 35
6	5		26 58	6	4		50 45
7	7		27 10	7	5		50 58
1	11		28 00	1	18	1	00
2	4		28 12	2	6		00
3	5		28 25	3	8		00
4	5		28 40	4	5		00
5	5		28 50	5	4		00
6	5		29 05	6	4	1	01
7	6		29 15	7	5		01

Table 12. (cont.)

Electrode:				Electrode:			
level	:Voltage:	Hr.	Time Min. Sec.	level	:Voltage:	Hr.	Time Min. Sec.
1	20	1	10	1	27	2	15
2	6		10	2	7		15
3	8		10	3	9		15
4	5		10	4	5		15
5	4		10	5	4		15
6	4	1	11	6	4		15
7	4		11	7	5	2	16
1	22	1	20	1	28	2	30
2	6		20	2	7		30
3	9		20	3	10		30
4	5	1	21	4	5		30
5	4		21	5	4		30
6	4		21	6	4	2	31
7	4		21	7	5		31
1	24	1	30	1	29	3	00
2	7		30	2	8		00
3	9		30	3	10		00
4	5		30	4	5		00
5	4		30	5	4		00
6	4	1	31	6	4		00
7	4		31	7	5	3	01
1	26	1	40	1	30	3	30
2	6		40	2	8		30
3	9		40	3	10		30
4	5		40	4	5		30
5	4		40	5	4		30
6	4	1	41	6	4		30
7	4		41	7	5	3	31
1	27	1	50	1	30	4	00
2	7		50	2	8		00
3	9		50	3	10		00
4	5	1	51	4	6		00
5	4		51	5	4		00
6	4		51	6	4		00
7	4		51	7	5	4	01
1	27	2	00	1	31	5	00
2	7		00	2	9		00
3	9		00	3	10		00
4	5		00	4	6		00
5	4		00	5	4		00
6	4	2	01	6	4		00
7	4		01	7	5	5	01

Table 12. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	31	6	01	1	45	29	00
2	9		01	2	12		00
3	10		01	3	17		00
4	6		01	4	8		00
5	4		01	5	5		00
6	4		01	6	8		00
7	5	6	02	7	7		00
1	32	7	00	1	53	35	00
2	9		00	2	16		00
3	10		00	3	19		00
4	6		00	4	8		00
5	4		00	5	5		00
6	4		00	6	9		00
7	5	7	01	7	7		00
1	34	10	02	1	54	41	00
2	10		02	2	17		00
3	12		02	3	19		00
4	7		02	4	8		00
5	4		02	5	5		00
6	4		02	6	9		00
7	5	10	03	7	7		00
1	36	13	00	1	55	47	00
2	11		00	2	17		00
3	13		00	3	20		00
4	7		00	4	8		00
5	4		00	5	5		00
6	4		00	6	9		00
7	5		00	7	7		00
1	38	17	00	1	57	53	00
2	11		00	2	18		00
3	14		00	3	20		00
4	7		00	4	9		00
5	4		00	5	5		00
6	4		00	6	9		00
7	5		00	7	7		00
1	40	23	00	1	58	59	00
2	11		00	2	18		00
3	15		00	3	21		00
4	7		00	4	9		00
5	4		00	5	5		00
6	8		00	6	10		00
7	7		00	7	7		00

Table 12. (concl.)

Electrode:				Electrode:			
level	:Voltage:	Hr.	Time	level	:Voltage:	Hr.	Time
			Min. Sec.				Min. Sec.
1	57	71	00	1	5	7	10
2	19		00	2	4	7	10
3	21		00	3	14	7	23
4	9		00	4	11	7	23
5	5		00	5	9	7	20
6	5		00	6			
7	5		00	7			
1	59	105	00	1	6	7	10
2	19		00	2	4	7	10
3	23		00	3	13	7	23
4	9		00	4	11	7	23
5	5		00	5	9	7	20
6	5		00	6			
7	5		00	7			
1	61	129	00	1		7	10
2	21		00	2		7	10
3	24		00	3		7	23
4	9		00	4		7	23
5	5		00	5	9	7	20
6	5		00	6	8	7	20
7	5		00	7	7	7	20
1	64	153	00	1		7	10
2	22		00	2		7	10
3	25		00	3	12	7	23
4	10		00	4	11	7	23
5	5		00	5	9	7	20
6	5		00	6	8	7	20
7	5		00	7	7	7	20
1	70	177	00	1		7	10
2	22		00	2		7	10
3	27		00	3	10	7	23
4	11		00	4	11	7	23
5	6		00	5	9	7	20
6	5		00	6	8	7	20
7	5		00	7	6	7	20

Table 13. Voltage and time for water charge No. 3.
60-80 sand-size.

Electrode:				Electrode:			
level	Voltage	Hr.	Min. Sec.	level	Voltage	Hr.	Min. Sec.
1	60		28	1	8	4	00
2	35		40	2	4	4	10
3				3	14	4	20
4				4	11	4	30
5				5	9	4	35
6				6			
7				7			
1	26		50	1	8	5	00
2	19	1	00	2	4	5	10
3	28	1	15	3	13	5	20
4				4	11	5	25
5				5	9	5	35
6				6			
7				7			
1	9	1	20	1			
2	7	1	30	2			
3	26	1	40	3			
4				4			
5				5	9	6	00
6				6	8	6	10
7				7	7	6	20
1				1	9	7	10
2				2	4	7	18
3	24	1	50	3	12	7	25
4				4	11	7	35
5				5	9	7	40
6				6	8	7	45
7				7	7	7	50
1				1	9	8	00
2				2	3	8	10
3	19	2	05	3	10	8	18
4				4	11	8	22
5				5	9	8	30
6				6	8	8	35
7				7	6	8	40
1	8	2	15	1	9	8	45
2	5	2	25	2	3	8	50
3	15	2	35	3	8	8	55
4	11	3	45	4	10	9	00
5	9	3	55	5	8	9	05
6				6	8	9	10
7				7	6	9	15

Table 13. (cont.)

Electrode:				Electrode:			
level	:Voltage:	Hr.	Time Min. Sec.	level	:Voltage:	Hr.	Time Min. Sec.
1	9	9	25	1	10	16	00
2	4	9	30	2	4	16	08
3	6	9	38	3	5	16	15
4	7	9	45	4	5	16	20
5	6	9	55	5	5	16	30
6	8	10	05	6	5	16	40
7	6	10	12	7	5	16	45
1	9	11	00	1	11	17	00
2	4	11	10	2	4	17	08
3	5	11	18	3	5	17	15
4	6	11	25	4	5	17	25
5	5	11	35	5	5	17	30
6	8	11	45	6	5	17	38
7	6	11	50	7	5	17	45
1	9	11	55	1	12	17	50
2	4	12	05	2	5	17	55
3	5	12	15	3	5	18	05
4	5	12	25	4	5	18	15
5	5	12	35	5	5	18	22
6	6	12	45	6	5	18	28
7	6	12	55	7	5	18	35
1	9	13	00	1	12	18	50
2	4	13	10	2	5	19	00
3	5	13	20	3	5	19	10
4	5	13	30	4	4	19	15
5	5	13	40	5	5	19	22
6	5	13	50	6	5	19	29
7	6	13	55	7	5	19	35
1	10	14	00	1	13	19	50
2	4	14	10	2	5	20	00
3	5	14	20	3	5	20	10
4	5	14	30	4	4	20	18
5	5	14	40	5	5	20	25
6	5	14	50	6	5	20	33
7	6	14	55	7	5	20	40
1	10	15	00	1	13	20	45
2	4	15	08	2	5	20	55
3	5	15	15	3	6	21	05
4	5	15	22	4	4	21	15
5	5	15	30	5	4	21	22
6	5	15	40	6	5	21	22
7	6	15	45	7	5	21	40

Table 13. (cont.)

Electrode: level	: Voltage:	Hr.	Time Min. Sec.	:	Electrode: level	: Voltage:	Hr.	Time Min. Sec.
1	13	22	00		1	14	28	00
2	5	22	05		2	5	28	10
3	6	22	12		3	6	28	20
4	4	22	20		4	5	28	30
5	4	22	26		5	4	28	35
6	5	22	35		6	4	28	40
7	5	22	45		7	5	28	50
1	13	23	00		1	14	29	00
2	5	23	10		2	5	29	10
3	6	23	18		3	6	29	20
4	5	23	25		4	5	29	30
5	4	23	35		5	4	29	40
6	5	23	40		6	4	29	45
7	5	23	45		7	4	29	50
1	13	24	00		1	14	30	00
2	5	24	10		2	6	30	10
3	6	24	15		3	6	30	15
4	5	24	25		4	5	30	25
5	4	24	30		5	4	30	35
6	4	24	35		6	3	30	45
7	5	24	45		7	4	30	50
1	14	25	00		1	14	32	00
2	5	25	10		2	6	32	10
3	6	25	18		3	7	32	20
4	5	25	25		4	5	32	30
5	4	25	30		5	4	32	35
6	4	25	35		6	3	32	45
7	5	25	45		7	4	32	50
1	14	26	00		1	15	34	10
2	5	26	10		2	6	34	20
3	6	26	20		3	7	34	25
4	5	26	25		4	5	34	30
5	4	26	35		5	4	34	40
6	4	26	40		6	3	34	45
7	5	26	50		7	4	34	50
1	14	27	00		1	16	36	00
2	5	27	10		2	6	36	05
3	6	27	18		3	7	36	15
4	5	27	25		4	5	36	25
5	4	27	30		5	4	36	35
6	4	27	35		6	3	36	40
7	5	27	40		7	4	36	50

Table 13. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	16		38 00	1	23	1	45
2	6		38 05	2	7		45
3	8		38 15	3	10		45
4	5		38 25	4	5		45
5	4		38 30	5	4		45
6	3		38 38	6	4		45
7	4		38 55	7	3		45
1	16	12	40 05	1	26	2	15
2	6		40 15	2	8		15
3	7		40 25	3	10		15
4	5		40 33	4	5		15
5	4		40 40	5	4		15
6	3		40 45	6	4		15
7	3		40 50	7	3		15
1	16	18	45 00	1	30	3	15
2	6		45 10	2	8		15
3	9		45 20	3	10		15
4	5		45 30	4	6		15
5	4		45 40	5	4		15
6	3		45 48	6	4		15
7	3		46 00	7	3		15
1	16	20	50 00	1	32	4	15
2	6		50 10	2	9		15
3	9		50 20	3	10		15
4	5		50 30	4	6		15
5	4		50 35	5	4		15
6	3		50 45	6	4		15
7	3		50 50	7	3		15
1	18	1	00	1	34	5	15
2	7		00	2	9		15
3	9		00	3	10		15
4	5		00	4	6		15
5	4		00	5	5		15
6	3		00	6	4		15
7	3		00	7	3		15
1	21	1	15	1	35	6	15
2	7		15	2	10		15
3	9		15	3	10		15
4	5		15	4	6		15
5	4		15	5	5		15
6	4		15	6	4		15
7	3		15	7	3		15

Table 13. (concl.) and time data for water charge No. 4.
ap-50 sand-size.

Electrode:	:	Time	:	Electrode:	:	Time	:
level	:Voltage:	Hr. Min. Sec.	:	level	:Voltage:	Hr. Min. Sec.	:
1	37	9 15	:	1	52	40 45	:
2	10	15	:	2	17	45	:
3	12	15	:	3	18	45	:
4	6	15	:	4	7	45	:
5	5	15	:	5	5	45	:
6	4	15	:	6	4	45	:
7	3	15	:	7	4	45	:
1	40	12 45	:	1	55	52 00	:
2	11	45	:	2	17	00	:
3	14	45	:	3	19	00	:
4	6	45	:	4	7	00	:
5	5	45	:	5	5	00	:
6	4	45	:	6	4	00	:
7	3	45	:	7	4	00	:
1	46.	16 45	:	1	56	76 00	:
2	12	45	:	2	21	00	:
3	15	45	:	3	18	00	:
4	6	45	:	4	8	00	:
5	5	45	:	5	5	00	:
6	4	45	:	6	4	00	:
7	3	45	:	7	4	00	:
1	51	20 45	:	1	56	96 00	:
2	14	45	:	2	22	00	:
3	15	45	:	3	19	00	:
4	6	45	:	4	8	00	:
5	5	45	:	5	5	00	:
6	4	45	:	6	4	00	:
7	3	45	:	7	4	00	:
1	51	24 45	:	1	58	140 00	:
2	15	45	:	2	23	00	:
3	15	45	:	3	22	00	:
4	6	45	:	4	9	00	:
5	5	45	:	5	5	00	:
6	4	45	:	6	5	00	:
7	4	45	:	7	4	00	:
1	51	28 45	:	1	65	236 00	:
2	15	45	:	2	28	00	:
3	16	45	:	3	24	00	:
4	6	45	:	4	9	00	:
5	5	45	:	5	5	00	:
6	4	45	:	6	5	00	:
7	4	45	:	7	5	00	:

Table 14. Voltage and time data for water charge No. 4.
60-80 sand-size.

Electrode:				Electrode:			
level	Voltage	Hr.	Time	level	Voltage	Hr.	Time
			Min. Sec.				Min. Sec.
1	50		45	1	6		4 10
2			10	2	5		4 20
3			13	3	7		4 30
4			20	4			
5			25	5			
6			35	6			
7			45	7			
1	23	1	05	1	7		4 45
2	18	1	20	2	4		4 55
3			30	3	5		5 05
4			30	4	8		5 11
5			35	5	8		5 21
6			45	6			
7			50	7			
1	18	1	35	1	8		5 35
2	12	1	50	2	5		5 42
3	23	2	00	3	4		5 50
4	8	2	10	4	8		6 00
5			30	5	8		6 10
6			40	6			
7			45	7			
1	11	2	20	1	9		7 15
2	9	2	25	2	5		7 25
3	23	2	35	3	5		7 35
4			35	4	6		7 45
5			35	5	7		7 55
6			40	6			
7			45	7			
1	8	2	45	1	10		10 00
2	6	2	55	2	5		10 10
3	21	3	05	3	5		10 15
4	8	3	17	4	6		10 25
5	5	3	30	5	6		10 30
6				6	7		10 40
7				7	7		10 55
1	7	3	40	1	10		11 00
2	5	3	50	2	5		11 10
3	18	3	55	3	5		11 15
4				4	5		11 20
5				5	6		11 30
6				6	6		11 40
7				7	7		11 50

Table 14. (cont.)

Electrode:				Electrode:			
level	Voltage	Time		level	Voltage	Time	
		Hr.	Min. Sec.			Hr.	Min. Sec.
1	11	14	00	1	17	30	00
2	5	14	10	2	8	30	10
3	5	14	15	3	6	30	18
4	5	14	20	4	5	30	30
5	5	14	25	5	4	30	35
6	6	14	35	6	5	30	40
7	7	14	45	7	5	30	50
1	12	16	00	1	19	40	00
2	7	16	10	2	9	40	10
3	5	16	20	3	6	40	20
4	4	16	30	4	5	40	30
5	5	16	35	5	4	40	35
6	6	16	45	6	5	40	40
7	6	16	50	7	5	40	55
1	13	17	00	1	22	1	00
2	7	17	10	2	9		00
3	5	17	20	3	7		00
4	4	17	25	4	6		00
5	5	17	30	5	4		00
6	6	17	40	6	4		00
7	6	17	45	7	5		00
1	14	20	00	1	25	1	30
2	8	20	10	2	9		30
3	5	20	20	3	7		30
4	5	20	25	4	6		30
5	5	20	35	5	5		30
6	5	20	40	6	3		30
7	6	20	45	7	5		30
1	15	23	00	1	28	2	00
2	8	23	10	2	10		00
3	5	23	18	3	8		00
4	5	23	25	4	6		00
5	5	23	30	5	5		00
6	5	23	35	6	3		00
7	6	23	40	7	4		00
1	16	25	00	1	31	2	30
2	8	25	10	2	10		30
3	6	25	20	3	9		30
4	5	25	25	4	6		30
5	4	25	30	5	5		30
6	5	25	40	6	3		30
7	5	25	45	7	4		30

Table 14. (cont.)

Electrode:				Electrode:			
level	Voltage	Hr.	Time Min. Sec.	level	Voltage	Hr.	Time Min. Sec.
1	33	3	00	1	55	34	00
2	10		00	2	22		00
3	10		00	3	17		00
4	6		00	4	9		00
5	5		00	5	5		00
6	4		00	6	5		00
7	3		00	7	5		00
1	39	4	00 (days)	1	56	52	00
2	10		00	2	25		00
3	11		00	3	20		00
4	7		00	4	9		00
5	5		00	5	5		00
6	4		00	6	5		00
7	3		00	7	5		00
1	43	5	00 (days)	1	58	76	00
2	11		00	2	18		00
3	11		00	3	20		00
4	9		00	4	9		00
5	5		00	5	5		00
6	5		00	6	5		00
7	3		00	7	5		00
1	48	9	00	1	60	101	00
2	13		00	2	19		00
3	14		00	3	20		00
4	8		00	4	9		00
5	5		00	5	5		00
6	5		00	6	4		00
7	4		00	7	5		00
1	50	18	00	1	61	125	00
2	16		00	2	19		00
3	15		00	3	20		00
4	9		00	4	9		00
5	5		00	5	5		00
6	5		00	6	5		00
7	4		00	7	5		00
1	53	22	40	1	62	150	00
2	17		40	2	20		00
3	15		40	3	20		00
4	9		40	4	9		00
5	5		40	5	5		00
6	5		40	6	5		00
7	4		40	7	5		00

Table 14. (concl.)

Electrode:	:	Time	:	Electrode:	:	Time
level	:Voltage:	Hr. Min. Sec.	:	level	:Voltage:	Hr. Min. Sec.
1	65	180 00				
2	20	00				
3	21	00				
4	9	00				
5	5	00				
6	5	00				
7	6	00				
1	68	576 (24 days)				
2	28					
3	24					
4	10					
5	5					
6	6					
7	7					
1	105	912 (38 days)				
2	33					
3	35					
4	12					
5	6					
6	11					
7	10					

Table 15. Calculations for correlation line graph

Volts:	Wt. of sand:	Weight of sand:	Vol. of sand:	Percent
:(wt. of sand):	moisture:	can	:(wt. of sand):	moisture
Volts:	Wt. of sand:	Weight of sand:	Vol. of sand:	Percent
2	32.55	8.47	12.8	33.23
3	31.55	8.90	13.1	19.60
4	24.57	11.90	13.0	3.55
12	23.05	15.95	13.3	6.00
15	25.05	17.05	13.1	4.90
21	25.75	16.45	13.0	2.52
30	25.30	15.82	13.3	1.83
33	25.05	15.45	13.1	1.67
35	25.32	15.90	13.1	1.49

Table 16. Calculations for correlation line graph
on size 40-60 sand.

Volts:	Weight of sample: plus can, grams	Wt. of moisture:	Weight of: can	Vol. of sand (wt. of sand)	Percent moisture
	wet	oven dry:	in grams:	S.G.	by vol.
2	64.66	55.60	9.06	13.0	42.6 1.69 35.88
5	62.60	57.80	4.80	12.8	45.0 1.69 18.02
8	69.16	66.30	2.86	13.1	53.2 1.69 9.08
12	67.08	65.20	1.88	12.8	52.2 1.69 6.10
16	68.47	67.10	1.37	13.0	54.1 1.69 4.17
21	67.39	66.60	0.79	13.1	53.5 1.69 2.49
25	68.38	67.75	0.63	12.8	54.95 1.69 1.95
36	67.54	67.00	0.54	13.0	54.0 1.69 1.70
55	66.36	65.91	0.45	13.1	52.8 1.69 1.43

Table 17. Calculations for correlation line graph
on size 60-80 sand.

Volts:	Weight of sample: plus can, grams	Wt. of moisture:	Weight of: can	Vol. of sand (wt. of sand)	Percent moisture
	wet	oven dry:	in grams:	S.G.	by vol.
2	62.32	52.85	9.47	12.8	40.05 1.64 38.23
5	62.10	56.90	5.20	13.1	43.8 1.64 19.50
9	64.37	61.80	2.57	13.0	48.8 1.64 8.65
12	65.93	64.05	1.88	12.8	51.25 1.64 6.00
15	64.98	63.60	1.38	13.1	50.5 1.64 4.50
21	64.79	64.00	0.79	13.0	51.0 1.64 2.53
30	65.50	64.92	0.58	12.8	52.12 1.64 1.82
35	65.98	65.45	0.53	13.1	52.35 1.64 1.67
55	65.36	64.90	0.46	13.1	51.8 1.64 1.45

Table 18. Data and calculations for specific gravity determination. Size 40-60 sand.

$$\text{Specific gravity} = \frac{\text{wt. of oven dry sand}}{\text{wt. of equal vol. of water}}$$

Wt. of oven dry sand plus can in grams	:	Wt. of equal vol. of water plus can in grams	:	Weight of can in g	:	Specific gravity
333.1	:	206.61	:	23.0	:	1.688
332.5	:	206.59	:	23.0	:	1.685
334.2	:	206.61	:	23.0	:	1.695

Table 19. Data and calculations for specific gravity determination. Size 60-80 sand.

$$\text{Specific gravity} = \frac{\text{wt. of oven dry sand}}{\text{wt. of equal vol. of water}}$$

Wt. of oven dry sand plus can in grams	:	Wt. of equal vol. of water plus can in grams	:	Weight of can in g	:	Specific gravity
324.9	:	206.60	:	23.0	:	1.644
324.3	:	206.60	:	23.0	:	1.641
325.0	:	206.60	:	23.0	:	1.644



PERCOLATION CHARACTERISTICS
OF VARIOUS SEDIMENTS

By

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of
Agriculture and Applied Science, 1950

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology and Geography

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1952

Two grain sizes of sand were used to determine a few of the hydrologic properties of an unconsolidated homogeneous sediment.

The principle involved included the use of an electrode box which contains seven electrodes spaced at 0.2 ft intervals from the bottom. A potential of 2 to 140 volts was applied across the electrodes. The potential varied inversely with the percentage of moisture in the sand and was such as to cause 20 MA of current to flow. A correlation table was made to represent the recorded voltages in percent moisture.

By knowing the time, voltage, and depth of percolation it was possible to determine the rate of percolation.

The two sand sizes made possible the comparison of the hydrologic characteristics of two sediments when grain size was the only variable.

Several hydrologic properties, porosity, permeability, specific gravity, and gradient were necessary for calculations and also to determine the percolation rate by the accepted method (i.e., Darcy's law) and to compare the results obtained by both methods.

The method used for the determination of percolation rate is based on the assumption that, after the initial wetting (1.4 to 1.6 percent moisture) of the sand has taken place, the time between this point of initial wetting and the point of near saturation (26 to 30 percent moisture) is equivalent to the same percolation rate as would be obtained from saturated sand that was allowed to drain freely with a continuous supply of water.

The calculated results obtained by using Darcy's law and those obtained from the electrode box compare very favorably for the coarser sediment (40-60 sand.) The results of percolation rate using the electrode-box data on the 60-80 sand are very irregular and do not compare closely with the calculated results by the accepted method.

The lack of agreement between the calculated percolation rates for the finer sediment is thought to be due to procedure of water application rather than the fault of the method. In all respects the data obtained from the electrode box appeared to be satisfactory. The procedure for obtaining these data was equally satisfactory except, possibly, for the manner of application of water and the use of the commercial variac as a device for determining potential within a limit of one volt.