A STUDY OF D. C. RESISTIVITY OF CALCUTTA SOIL

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ABSTRACT. The paper reports the results of study of d.c. resistivity of soil in and around the city of Calcutta and of its variation with time, temperature and humidity The effect of endosmosis has also beeen ascertained.

INTRODUCTION

It is well known that for the protection and safety of electrical machines and equipment as well as of human and animal lives, all electrical power systems are earthed. Even to the earliest part of the present century, the resistivity of the earth was commonly believed to be so low as to make the potential at any point on the earth's surface practically zero. But recent researches have shown it otherwise. One may, therefore, apprehend that whenever a fault in a power system occurs, it may lead to dangerous consequences if the resistance of the path to the fault current through the earth is not sufficiently low. This resistance is considered to consist of three separate parts, *viz.*, (1) the resistance of the connecting link to the earth connection and of the material of the earth connection itself, (2) the contact resistance between the metal of the earth connection and the surrounding earth and (3) the resistance of the earth surrounding the earth connection. Of these the first is easily calculated from a knowledge of the dimensions and material of the link and the earth electrode but for evaluating the other two factors, a knowledge of resistivity of earth at the locality in question is essential. It may be noted that the resistivity of soil at any locality depends not only on its chemical composition and physical structure but also on its moisture content and temperature as well as on the nature of current, direct or alternating, passing through it and also on the frequency of current when alternating. Furthermore, endosmosis and polarisation may set in and influence the value of its resistivity when direct current flows through the soil.

Almost in all progressive countries elaborate investigations have been carried out for the determination of resistivities, both d.c. and a.c., and contact resistance between the earth and earth electrodes. The a.c. resistivity has been measured not only at power frequencies but also at audio and radio frequencies. Important contributions in this direction have been made by several scientists in U.K. Higgs (1930) made investigations on d.c. and a.c. resistivities of soil at power frequency and observed changes in their values due to polarisation and endosmosis. Ratcliff and White (1930), Strutt (1930) and Collard (1932) measured the conductivity of soil not only at power frequency but also at telephonic and radio frequencies. Smith-Rose (1934), however, made a comprehensive study of the electrical properties of soil with alternating current at various frequencies. He found the electrical conductivity of the soil to increase rapidly with moisture-content but slowly with frequency. Measurements of conductivity of soil at medium frequencies were also made by Dellinger (1933) in America and by Cheery (1930) in Australia. In India, the resistivity of soil has so far been measured at radio frequencies only, notably by Joshi (1938), Rahaman and Muhi (1944) and by Khastgir, Roy and Banerjee (1946). Joshi studied also the effect of temperature on the electrical constants of soil. He found the temperature co-efficient of its electrical conductivity to be positive having a value of 2.0 percent per degree centigrade at 20°C and to increase with frequency. But no attempt has yet been made to ascertain the value of resistivity, d.c. or a.c., of Indian soil which may throw further light on the system of earthing to be satisfactorily adopted in our country by the power engineers. It is, therefore, proposed to carry out a systematic investigation of resistivity of soil of different parts of India. In the present paper are reported the results of measurement of d. c. resistivity of soil in and around the city of Calcutta.

Samples of soil used in this investigation have been taken from Sinthee in the north, from Beliaghata in the east, from Tollygunge in the south and from Dockyard in the west of the city of Calcutta. Samples have also been taken from the compound of the University College of Science and Technology at 92, Upper Circular Road to respresent the nature of soil of the central part of the city. As Calcutta is situated on the bank of the Ganges, a sample from the river silt has also been included in the invetigation.

Experimental cylinder:

The experimental cylinder, as shown in figure 1, is a porcelain tube of length 25.4 cm., of thickness 1.6 cm. and of internal diameter 10 cm. The cylinder is fitted with adjustable brass electrodes. It may be mentioned

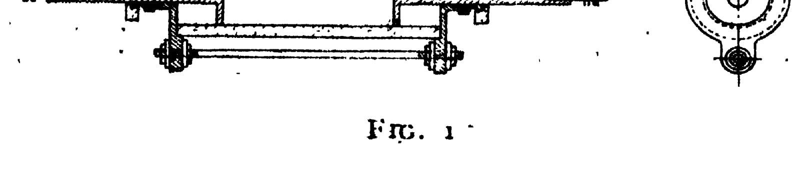

FIG. 1

here that attempts were first made to use a glass cylinder, but it proved futile as even the best quality of glass locally available was found unsitable to stand the effects of unequal heating during the experiment.

Preparation of the sample for test :

Each sample of soil is first dried as completely as possible in an electrically heated oven, the temperature of which never exceeds 105°C. It is found that if dried sample is stored in a dry place for several days it does not absorb more than one precent of moisture. It is then powdered and packed tightly into the experimental cylinder. To prepare a sample with a desired value of moisture content a given quantity of the dried sample was taken and a calculated amount of water was intimately mixed with it.

Experimental arrangement.

The experimental arrangement for measuring the resistance is shown in figure 2. The well known ammeter-voltmeter method was used. All the voltmeters and ammeters used in the measurement were calibrated with the help of a potentiometer in conjunction with a Weston standard cadmium cell and standard resistances. The d.c. voltage was taken directly from 220 volt d. c. supply mains and with the help of a potential divider, the voltage across the experimental cylinder was maintained at a nominal value of 120 volts (true value=124V) throughout the experiment.

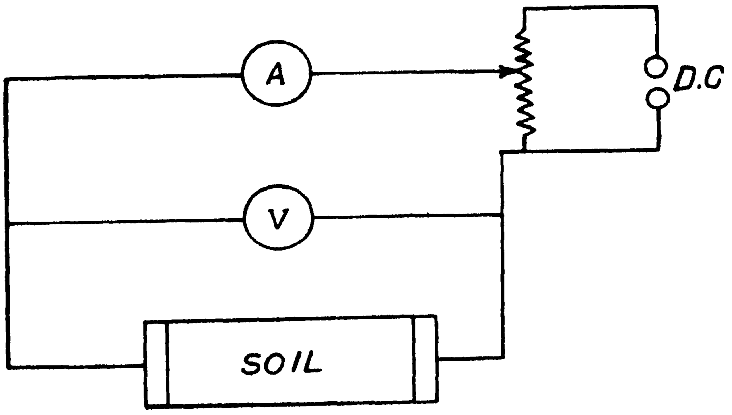

FIG. 2

Determination of the percentage of moisture content :

The moisture content of the soil was found out from the difference in weight of the moist soil and dried soil. A quantity of soil under test was taken in a weighing bottle and weighed. It was then dried in a muffle furnace maintained at a temperature between 100° – 105°C. and weighed again until its weight was found constant. The difference in weight gave the amount of moisture content in the sample and the percentage of moisture could then be easily calculated.

EXPERIMENTAL RESULTS

D. C. Resistivity :

The data of d.c. resistivity of different samples of soil are given in Table I. To obtain these data, measurements were made at a room temperature of 30°C, each sample having a moisture content of 15 per cent.

TABLE I

Soil taken from	D. C. Resistivities in ohm-cm.
North (Sinthee)	1450
East (Beliaghata)	3250
South (Tollygunge)	1400
West (Dockyard)	1415
Central (Science College)	2850
Silt (Ganges)	1365

It is seen from the table that the value of d. c. resistivity of each of the samples of soil taken from the northern, southern and western parts of Calcutta which are nearer to the Ganges is nearly equal to that of the sample taken from the Ganges silt, while it differs considerably in the case of the sample taken from the central and eastern parts of the city, which are away from the river. The sample of soil taken from Beliaghata, which is farthest from the river on the eastern part of the city has the highest value of resistivity.

TABLE II

Sample of soil taken from the central part of the city. Percentage of moisture content = 16.2

Time in minutes	Ammeter reading (m amp.)	Temp. °C	d. c. resistivity in ohm-cm	Time in minutes	Ammeter reading (m amp.)	Temp. °C.	d. c. resistivity in ohm-cm.
0	96.5	31.1	2469	180	56.2	41.7	4238
10	106.0	36.2	2248	360	26.8	34.5	8174
30	117.0	42.5	2079	540	20.8	33.4	11450
45	118.5	46.0	2012	720	16.8	32.7	14220
60	118.5	48.0	2012	1500	9.2	31.5	25890
90	110.5	49.5	2152	1620	9.2	31.5	25890
120	86.0	47.4	2771				

TABLE III

Sample of soil taken from the southern part of the city. Percentage of moisture content = 15.4

Time in minutes	Ammeter reading (m amp.)	Temp. °C.	d. c. resistivity in ohm-cm.	Time in minutes	Ammeter reading (m amp.)	Temp. °C.	d. c. resistivity in ohm-cm.
0	145.2	31.1	1811	255	54.7	44.7	4808
10	151.7	38.1	1737	315	36.9	38.7	7125
20	156.7	42.8	1678	375	29.2	36.0	9007
25	158.2	44.5	1663	435	19.3	34.5	13630
30	158.2	45.7	1663	495	18.3	33.8	14370
60	154.2	51.4	1705	1380	12.0	32.9	21920
135	126.8	55.1	2074	1500	12.0	32.5	21920
195	100.5	51.9	2617	1620	12.0	32.5	21920

TABLE IV

Sample of soil taken from the Ganges silt. Percentage of moisture content = 12.1

Time in minutes	Ammeter reading (m amp)	Temp. °C	d. c. resistivity in ohm-cm	Time in minutes	Ammeter reading (m amp.)	Temp. °C	d. c. resistivity in ohm-cm.
0	125.0	30.0	1905	120	68.6	42.6	3473
10	137.5	34.2	1733	180	52.7	37.6	4522
20	147.2	39.7	1617	240	41.8	35.0	5699
30	154.2	43.1	1545	390	31.2	32.7	7645
55	165.0	48.8	1443	510	26.5	32.4	8989
60	165.0	49.6	1443	1290	15.4	31.7	12280
70	148.7	50.9	1603	1470	15.4	31.7	12280
90	91.0	47.8	2619	1620	15.4	31.7	12280

Time-current characteristics:

A steady d.c. voltage was applied across a sample of soil and the readings of ammeter at suitable intervals noted until the current was found to attain a constant value. Along with each ammeter reading the temperature of the test sample was also recorded with the help of a sensitive thermometer introduced into it through a hole along the axis of the cylinder. Such observations were made on the samples of soil taken from the central and southern parts of the city as well as from the Ganges silt. These data are given in Tables II, III and IV which also include the corresponding values of d.c. resistivity of the sample. The results are also shown graphically in figures 3, 4 and 5.

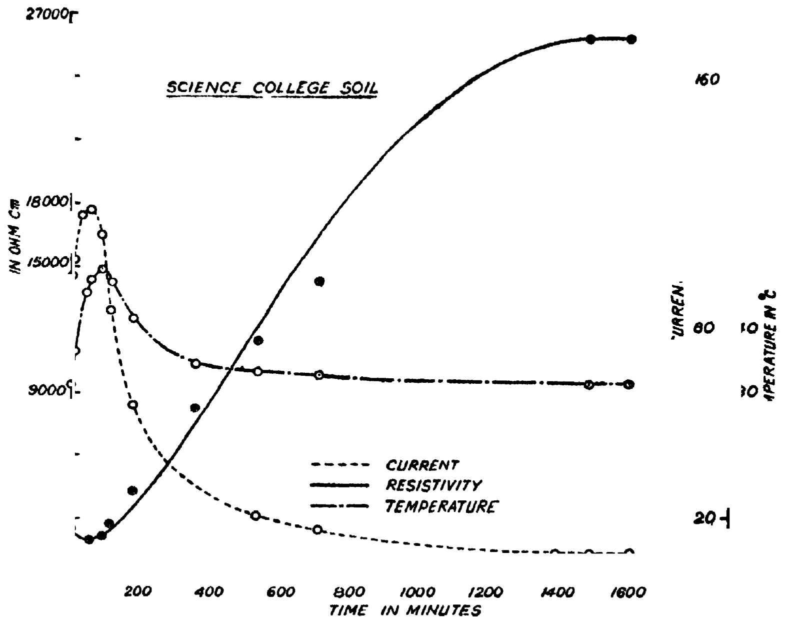

FIG. 3

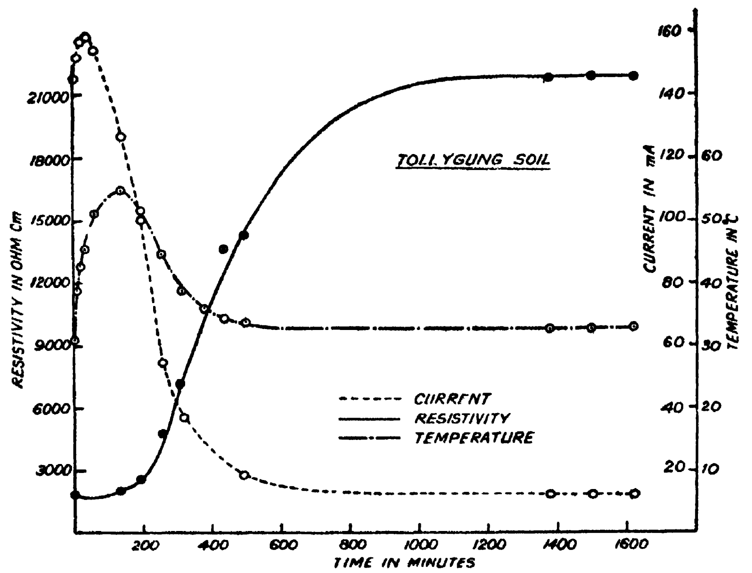

FIG. 4

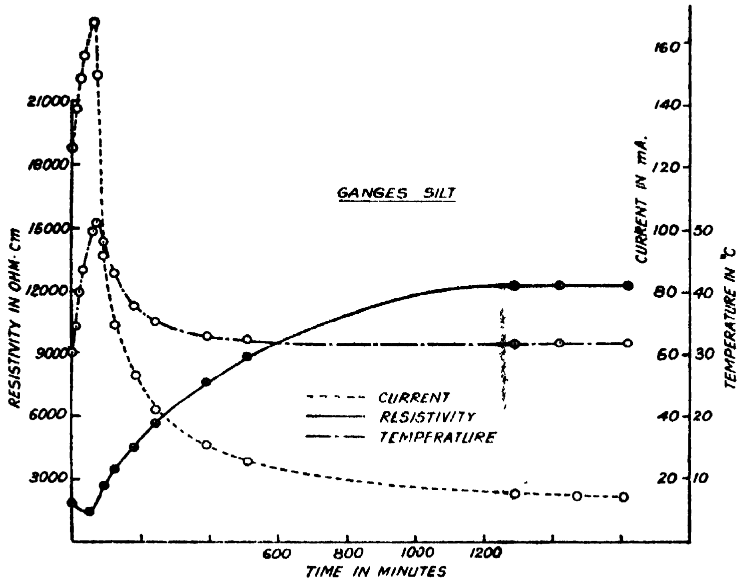

FIG. 5

It may be noted that as one would expect the time-temperature curves are similar in nature to the time-current characteristic curves. It will be seen further that for each sample of soil, the current at first increases, reaches a maximum and then decreases to a minimum value. Such a behaviour may be explained by assuming the soil to consist of many electrolytic salts in its composition.

The current passing through the sample increases its temperature. This increase of temperature decreases the resistance of the soil thereby increasing the magnitude of the current flowing through it. This increase of current further increases the temperature. Thus the current increases with time. This state of affair would have continued for a long time had there been no polarisation and endosmosis effects in the soil. The last two effects tend, however, to decrease the current. Thus the value of the resultant current depends on the relative magnitude of these effects. One may, therefore, be led to infer that at first the heating effect but finally the effect of endosmosis becomes predominant.

Effect of endosmosis :

It is well known that the process of preferential movement of moisture contained in a body from one part to another is called endosmosis. It is, therefore, of interest to study how endosmosis affects the resistivity and hence the current distribution and the voltage drop in the body of the soil when subjected to a constant d.c. voltage.

A sample of soil taken from the Ganges slit, having a moisture content of 18 per. cent. was taken in the experimental cylinder. The soil was divided approximately into three equal parts by two perforated zinc

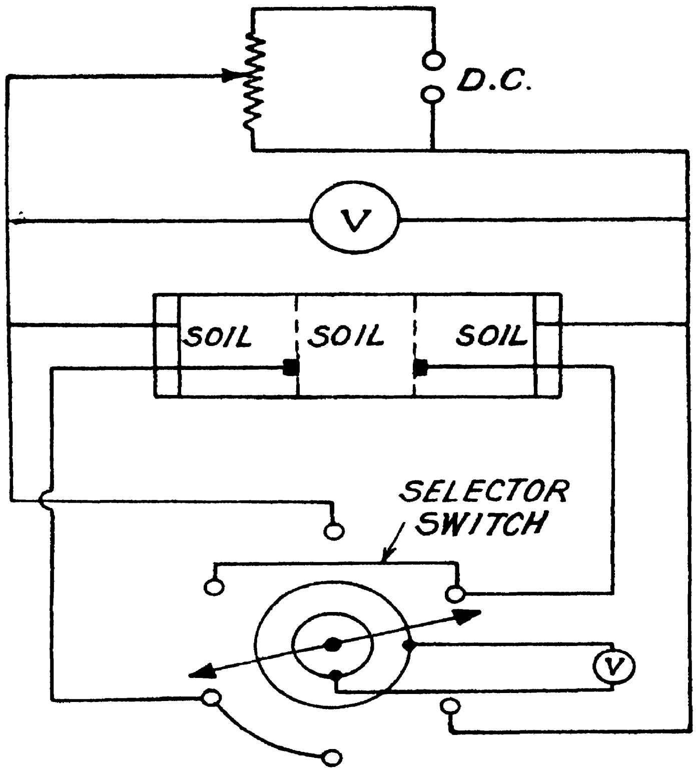
D.C.
V
SOIL
SOIL
SOIL
SELECTOR
SWITCH
V

FIG. 6

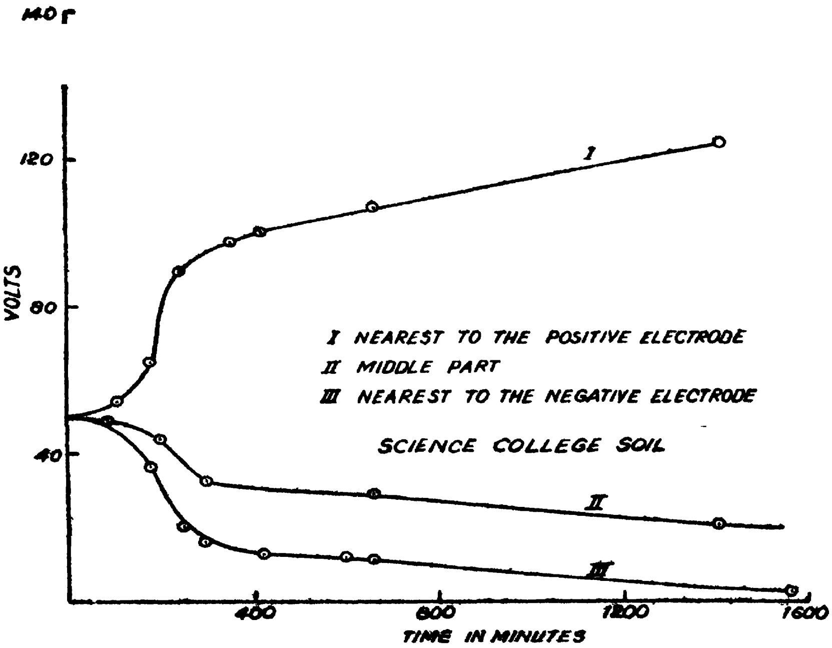
140
120
80
40
VOLTS
I
II
III
I NEAREST TO THE POSITIVE ELECTRODE
II MIDDLE PART
III NEAREST TO THE NEGATIVE ELECTRODE
SCIENCE COLLEGE SOIL
400
800
1200
1600
TIME IN MINUTES

FIG. 7

electrodes. A constant d. c. voltage was applied across the outer electrodes and the current allowed to flow continuously. The voltage drop across each section was noted. For this purpose it was necessary to introduce one low range voltmeter (0–75V) and a selector switch into the previous arrangement. The experimental arrangement is given in figure 6. At the end of the experiment the percentage of moisture content of each section was found out in the usual way.

The percentage of moisture content of the section adjacent to the negative electrode was the highest and that to the positive electrode the lowest, being 22 and 9.5 respectively. The middle section showed a moisture content of 17.5%. Curves showing the variations of voltage drop across each section with time are given in figure 7.

From the curves it is seen that the potential drop across the soil section adjacent to the positive electrode increases while that in each of the other two sections decreases with time. It will be further seen that the section adjacent to the negative electrode has the lowest voltage drop. Such a variation of voltage drop across the different sections with time may be attributed to the fact that since a constant valtage is applied across the body of the soil, it is the movement of moisture from one section to the other with time in the direction of the current flow that produces this variation. Similar observations have previously been made by Higgs (1930). The nature of the curves also reveals the direction of the movement of moisture amongst different sections of the soil when carrying current.

Effect of moisture :

Samples of soil from a particular locality and having different values of moisture content were taken in the experimental cylinder and their d.c. resistivity calculated from the readings of the voltmeter and the ammeter. The data of d. c. resistivity and conductivity of a soil with different values of moisture content are given in Tables V, VI and VII and shown graphically in figure 8.

It will be seen from the graphs that with the increasing value of moisture content of a soil, its d.c. resistivity decreases or its coductivity increases. This may be explained by assuming the dry soil to contain many air packets, so that with increasing moisture content, more and more air packets are reduced thereby diminishing the resistivity of the soil. On the other hand, if the soil contains electrolytic salts, one would expect its resistivity to increase with increasing moisture content. The observed decrease of resistivity with moisture content may, therefore, be attributed to the superposition of these two effects.

It will be further seen that the rate of decrease of resistivity (or increase of conductivity) at first increases and then decreases with increasing value of moisture content. This shows that the conductivity of a soil approaches a saturation value after a certain value of its moisture content. This pheno-

TABLE V

Sample of soil taken from the central part of the city. Temp. = 30°C

Percent. moist. content	D. C.	
	Resistivity in ohm-cm.	Conductivity mho-cm $\times 10^{-6}$
4.7	28540	35.0
6.5	10010	99.9
8.9	5442	183.8
13.4	3070	325.8
16.2	2580	387.6
20.7	1481	675.0

TABLE VI

Sample of soil taken from the southern part of the city. Temp. = 30°C.

Percent. moist. content	D. C	
	Resistivity in ohm-cm.	Conductivity mho-cm $\times 10^{-6}$
1.6	139700	7.2
5.2	7725	129.4
9.0	3485	286.9
13.0	1811	552.1
15.7	1334	749.8
21.0	1287	776.9

TABLE VII

Sample of soil taken from the Ganges silt. Temp. = 30°C

Percent. moist. content	D. C.	
	Resistivity in ohm-cm.	Conductivity mho-cm $\times 10^{-6}$
3.7	28990	34.5
7.7	4919	203.2
12.1	1905	524.7
16.8	1153	883.9
19.5	914	1094.0

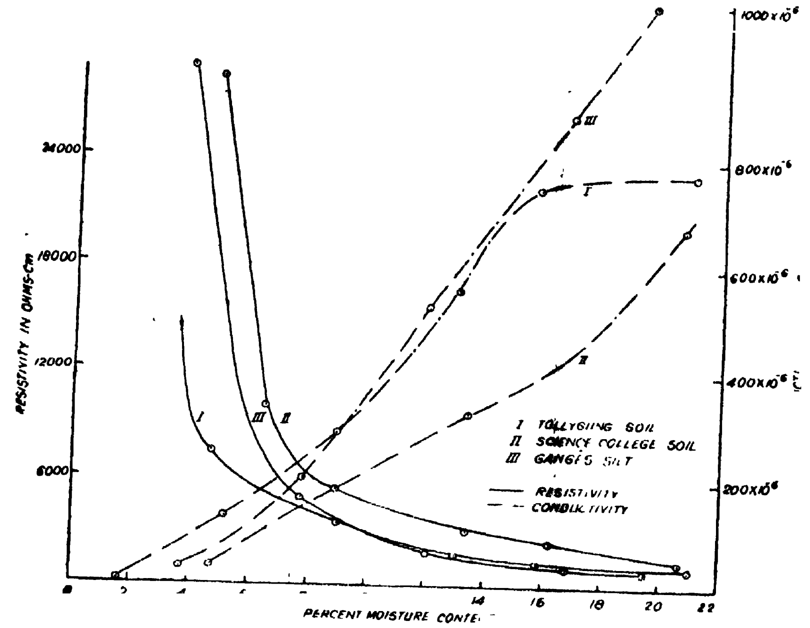

FIG. 8

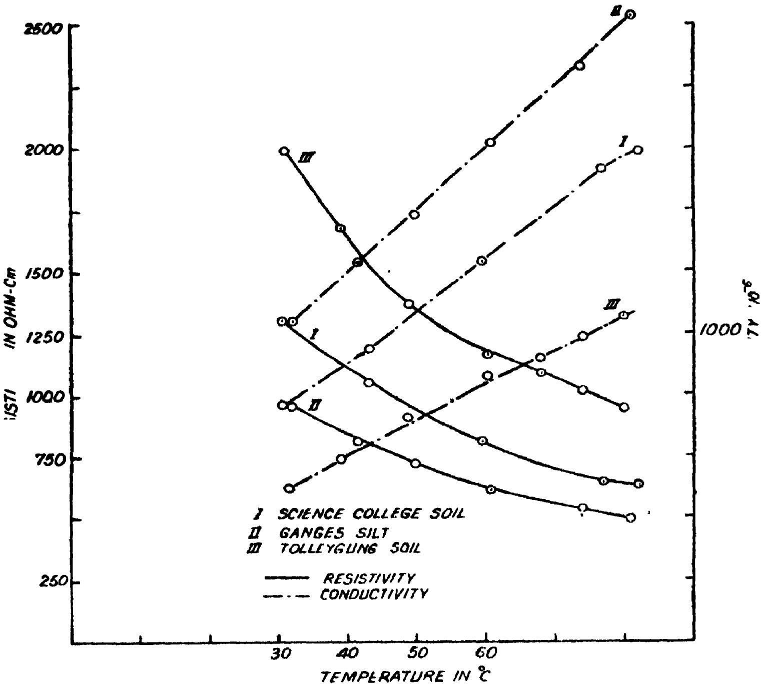

FIG. 9

menon was observed for the samples of soil taken from the Ganges silt and the sourthern part of the city but not from the central part for even a moisture content of 20 per. cent., the maximum limit used in the present work. This shows that the saturation point is not the same for all kinds of soil but it is dependent on the compo^ition on the soil.

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Effect of temperature :

The experimental cylinder was wound with insulated nichrome wire and covered with an asbestos sheet to minimise heat losses. By regulating the heating cnrrent the temperature of the test soil in the cylinder was kept at desired values and could be maintained constant for at least half an hour. From the readings of the ammeter and voltmeter, the d.c. resistivity was determined at each temperature. Tables VIII, IX and X give the data of d.c. resistivities and conductivities for three different soils.

TABLE VIII

Sample of soil taken from the central part of the city.
Moisture content = 20.7%

Temperature in °C.	Resistivity in ohm-cm.	Conductivity mho-cm $\times 10^{-6}$
30.4	1305	766.5
43.0	1049	953.0
59.5	811	1233.0
76.7	653	1531.0
82.1	631	1585.0

TABLE IX

Smple of soil taken from the southern part of the city.
Moisture content = 12.8%

Temperature in °C	Resistivity in ohm-cm.	Conductivity mho-cm $\times 10^{-6}$
31.4	1988	502.9
39.0	1677	596.4
48.2	1368	731.1
60.2	1165	858.2
68.0	1085	921.7
74.0	1015	985.4
80.0	939	1055.0

TABLE X

Ganges silt. Moisture content = 16.9%

Temperature in °C.	Resistivity in ohm-cm.	Conductivity mho-cm × 10^{-6}
31.8	959	1042
41.5	811	1233
49.8	721	1387
60.7	619	1615
73.7	536	1865
81.0	493	2029

Figure 9 shows the variation of d.c. resistivity with temperature. It will be seen that for each sample of soil the resistivity decreases with increase of temperaiure. This leads one to infer that the conduction in moist soil is predominatly electrolytic in nature as it is well known that the resistivity of an electrolyte decreases with increase of temperature. Conducttivity-temperature curves are drawn to find out the value of temperature co-efficient of conductivity. From these curves it is seen that the increase of conductivity with temperature follows a linear law and that within the observed range of temperature, the co-efficient of conductivity varies from 2 to 2.4 per-cent per degree centigrade.

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