The effect of salinity on the apparent dielectric constant values of rock specimens

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Dielectric constant values of two rock specimens saturated with aqueous sodium chloride solution at various concentrations have been measured at various frequencies in the range 1 MHz to 24 MHz and a significant rise in the values has been noticed with the decrease of frequency and increase of concentration An attempt has been made to fit these data into an empirical relation and to explain the increase

Introduction

Determination of the dielectric properties of natural-state rocks is beset with many difficulties both in measurement and in interpretation of results The relative permittivity data obtained so far show a dispersion with change of frequency far in excess of theoretical predictions due probably to the existence of dispersing mechanisms not yet understood Among factors affecting the dielectric properties of such rocks may be mentioned composition, structure, porosity, water-content, salinity, temperature and pressure For an understanding of their dielectric behaviour it is therefore necessary to study the effects of these factors within wide limits

The pore-fluids in rocks are known to contain dissolved salts and organic matter Measurements of the dielectric constant, loss tangent and the electrical conductivity of natural-state rocks at various frequencies, temperatures and levels of water content have been reported by many workers (Keller & Licastro 1959 Howell & Licastro 1961, Scott *et al* 1967 and Singh & Jha 1965) At frequencies above about 10MHz, many mechanisms known to operate at low frequencies are rendered inoperative and the observed permittivity values decrease drastically. Only the large values at low and medium frequencies are of interest in the present study In the present work the frequencies between 1 MHz and 24 MHz have been chosen with a view to avoid large errors in measurement at lower frequencies due to polarization at the electrodes while retaining the dispersive mechanisms referred to above Metallic film electrodes and a Q-meter have been used in these measurements to study the effect of salinity on the dielectric constant of natural rock specimens.

Apparatus used

A Q-meter, by Messrs. Advance Ltd of England, was used for this purpose. The sample holder was a completely covered and earthed brass box with one insulated electrode of 2·54 cm diameter The two electrode surfaces to be in contact

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with the specimen were carefully polished plane and parallel to within 1/20 mm and arranged one above the other as viewed through a microscope. To reduce the edge effects, the specimens were made of diameters less than that of the insulated electrode by about twice the specimen thickness as recommended by Von Hippel (1956) and the edge of the insulated electrode was bevelled. The connection between the Q-meter and the sample holder was effected through a specially prepared coaxial line of low capacitance and loss, having a length of about 30 cm

PREPARATION OF THE SAMPLE AND METHOD OF MEASUREMENT

Specimens were prepared from core-samples of homogeneous rock (very fine-grained carbonaceous shale from Jharia near Dhanbad, India) with low porosity They were lathed down to the required diameter and flats were sliced out, having thicknesses slightly larger than the required value, using a copper disc saw imbedded with diamond bits. The flat faces were then polished to the required thickness and checked to be within 1/50 mm   Thin aluminium foil was used as the electrode material and pasted on the specimen in the manner recommended (Von Hippel 1956) and held tightly in the sample holder. This system was considered sufficient for the kind of measurement undertaken. At each chosen frequency the standard capacitor of the Q-meter, which is capable of an accuracy of 0.2 pF, was adjusted for resonance   This procedure was followed with and without the specimen in position. The relative permittivity was calculated as the ratio of the capacity of the condenser, with the specimen forming the medium, to the capacity of the same system with air as dielectric. Loss tangent values could not be measured as these were found somewhat larger than what might be measured accurately with the apparatus, especially below 6 MHz. The reliability of the instrument was first tested using discs of paraffin wax and polythene and the values obtained agreed very closely with those quoted in standard handbooks, which were well within the accuracy of 5 percent, claimed for the measurements.

With any given specimen, three kinds of measurements were made with the specimen (a) remaining completely dry, (b) saturated with pure distilled water and (c) saturated with pure aqueous solution of sodium chloride at concentrations of 2.5, 5.0, 7 5, and 10.0 percent by weight.

After the specimen was washed with pure benzene and dried, it was saturated with distilled water and dried several times to remove any dissolved salts. Finally the disc was dried thoroughly in a hot air oven   Measurements were made on the sample quickly after cooling it in anhydrous calcium chloride. Sides of the disc were not covered as readings obtained were found materially to be the same during dry summer days with or without cover   Next the specimen was saturated with distilled water by forcing water into its pores with a vacuum pump. Immediately

after placing the specimen in the holder, readings were obtained every 15 minutes for one hour, and every one hour for 6 hours thereafter and the change in the readings, if any, was observed as the specimen dried. It was found that initially the loss values were large and changing, though the capacity values remained almost steady. After a period of one to two hours depending on the atmospheric conditions, both the loss and the capacitance values were found to remain steady for several hours. The initial changes were attributed to the conductivity of the liquid adhering to the sides. The steady values were recorded. In the third stage, the specimen was dried as aforesaid and then saturated with 2.5 percent aqueous solution of sodium chloride in the same manner as with distilled water and data obtained. The specimen was then left in distilled water for several days with frequent renewal of water to ensure that all the salt was removed. The removal was assumed to be complete when the readings obtained agreed with those at the second step described above The same procedure was followed before using solutions of other concentrations. All the data were obtained between temperature limits of 30°C and 36°C. Lastly, readings were also obtained with the specimens saturated with 10 percent aqueous solution of cane sugar for the reason given in the discussion of results The data are presented in the table and graphs.

DISCUSSION

As may be found from the table and curves, the dielectric constant data show three kinds of change. (a) At any frequency, d.e.c increases with increasing concentration and tends to a steady value. (b) At any given concentration of the salt in the pore fluid d e c. decreases with increasing frequency and rapidly so from 6 to 1 MHz. (c) In the case of the specimen saturated with distilled water and 2 5 percent solution, it is found that there is a slight fall and then a rise in d e.c. values as the frequency decreases from 24 MHz. This change is barely noticeable in the case of 5 percent and hardly so in 10 percent solution.

The change (a) closely resembles the change in electrical conductivity of aqueous sodium chloride solution as its concentration increases and is as to be expected The change (b) is also known to take place but the significance in this case is that it is more than if the pore fluid were distilled water. Though the permittivity values may be increased by the presence of ions in a solid, this increase is expected to appear only at much higher frequencies. Interfacial effects are stated to contribute to the large d.e c. values at the frequencies of observation (Smyth 1955). Thus the presence of ions at interfaces in rock specimens seems to accentuate the effect very considerably. This seems to be particularly noticeable below 3 MHz whereas, above 6 MHz there is only a nominal increase. That the ions do play an important part becomes apparent if one compares the permittivity values of the specimens with those obtained when they are saturated with solutions in water containing non-ionizing solutes, *e.g.*, sugar. Data for a

Table 1. Dielectric constants of two rock samples, dry and saturated with various pore fluids, and of two materials used for standardization.

	Specimen 1	Specimen 2	Polythene disc	Paraffin wax disc
Diameter (cm)	1.69	1.80	2.04	1.66
Thickness (cm)	0.423	0.352	0.085	0.416
Porosity (% by vol.)	3.2	3.2		

The specimens obtained from core samples of hard, fine-grained carbonaceous shale from Jharia near Dhanbad

Freq. in MHz	Specimen 1 (Observed)						Specimen 2 (Observed)						Calculated from empirical relation						Poly-thene disc	Para-ffin disc	Spec 2 saturated with 10% sugar soln.
	Dry	Dist. water	2.5%	5.0%	7.5%	10.0%	Dry	Dist. water	2.5%	5.0%	7.5%	10.0%	Dry	Dist. water	2.5%	5.0%	7.5%	10.0%			
24	7.9	15 0	17 0	14.6	15 0	17 0	7 2	16 2	17 7	16 2	17 7	17 7	5 6	12 5	15.7	18 2	20 0	21 3	2.33	2.1	18.7
21	7.2	14.4	17.4	17 5	18 5	17 2	7.1	18.7	18.5	18 2	19 2	16 2	5 6	13 1	16 4	19 1	21 1	22 5	2 36	2 2	18 7
18	6.4	13.5	16.7	15.7	18 5	19 0	6 8	18.7	17 7	19.0	17 7	20 7	5 6	13 8	17.4	20.3	22 4	23 8	2.33	2 2	16 2
15	6 2	12 6	15.0	17 0	17 5	19 0	6 2	15.4	16 2	19 2	18 7	22 3	5 6	14 7	18 6	21.5	23 9	25 5	2 26	2 1	15 4
12	6 2	13.5	17.5	21 0	19.5	20.8	5.9	18.7	19 2	19.8	23 8	23 8	5.6	15 9	20.2	23 5	26.0	27.8	2.23	2 1	16 2
9	5 6	14 4	18.0	20.0	20 0	24 0	5 7	18.7	19 8	20 2	21 9	23 8	5.6	17 6	22 4	26.3	29 1	31 1	2.26	2.2	18 7
6	5.7	16 1	20.5	20 0	24.0	35.5	5 7	19 5	20 2	25 3	27.6	31 4	5 6	20.3	26 0	30.6	34 0	36 4	2.36	2 2	18.7
3	5.8	20 4	27.0	34.0	40.0	45 5	5.4	22.3	26 8	30.6	29 8	34 4	5 6	25.8	33 4	39 6	44.4	47.5	2.33	2.1	23.8
1	5 8	30.1	50.0	72 0	76.0	80.0	5.7	35 8	51 2	55 5	63.2	68 3	5 6	37 9	50.2	60 3	67.9	73.4	2.33	2.2	38 8

These values are calculated on the assumption that the frequency-dependent term in the empirical relation remains inoperative. The relation itself is taken to be valid only for specimens containing some pore fluid

specimen saturated with 10 percent aqueous solution of cane sugar have been obtained and presented in the table. It may be seen that these values differ insignificantly from those for distilled water.
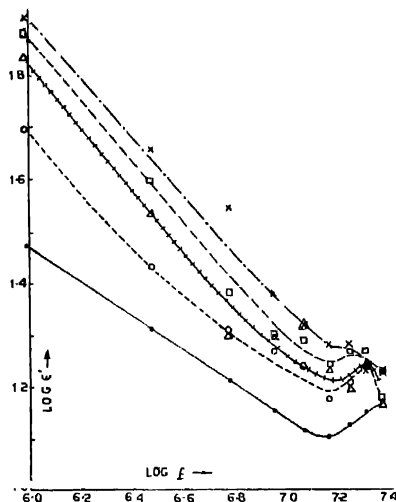

Figure 1.   Curves are indicated as : —●— distilled wate , - –o– – 2 5%
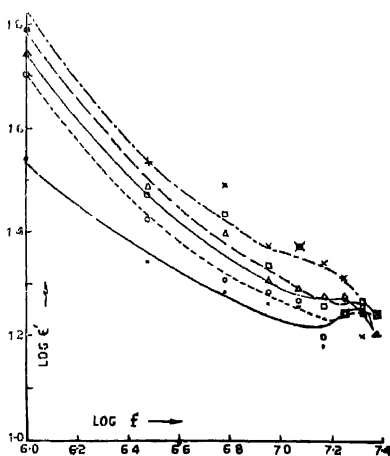++Δ++ 5% : - –□– – 7.5% :   × - 10%

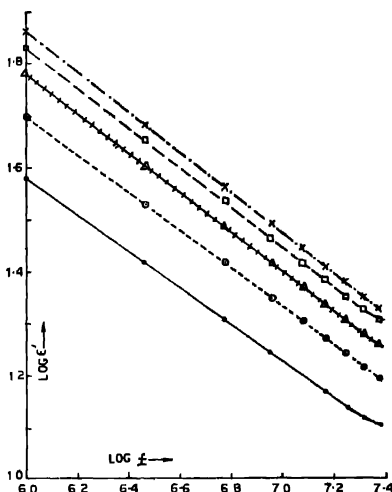
Figure 2.   Curves are similarly indicated as in figure 1

Figure 3.   Curves are indicated as in figure 1

No comprehensive theory for the dielectric behaviour of moist rocks seems to be available wherefrom one can calculate even approximately the d e.c. and other properties if the physical conditions of the rock specimen are known. However, Scott *et al* (1967) have given empirical relations for rough calculations of these values. Briefly, they have taken a very large number of specimens and obtained data with varying water-contents and frequencies. The graphical presentation of the data has to be a log-log plot, a trial relation with unknown constants is chosen, the data are fed into a computer to obtain a good fit and the constants are obtained from the computer. This has been done for a first and a second order fit. In this work under report, the coefficients of the first order equation have been suitably changed and a term has been added to take salinity into account through n, the normality of the solution. The effort appears to have been successful to the extent that the relation gives the trend of the changes. The values calculated from the empirical relation given below are also presented in the table and graphs.

The empirical relation used is,

$$\log k = 0.75 + 4.7 \log(1+w) - 0.35 \log f + \frac{2.1}{\log f}(1 - 1/\exp n).$$

where, k is the dielectric constant of the specimen, w, the water content by volume, f the frequency and n is the normality of the solution used.

The dispersion due to ions at the interfaces seems to vanish at frequencies above 9 MHz or so, and other complicating effects are also in evidence at the higher frequencies. The empirical relation assumes dispersion at all frequencies and so the curves representing the calculated values are spread out even at 24 MHz. Below about 6 MHz, the empirical relation gives nearly the same trend as curves depicting the observed values. However, it is recognised that more data with more specimens at lower frequencies are needed to make the equation more meaningful. Such measurements are in progress and will be reported shortly.

CONCLUSION

The salinity of the pore fluid in natural-state rocks does have a pronounced effect on the d.c.c. values, especially below a certain frequency which may depend on the specimen. The very large values of the observed d.c c. are likely to be due to the presence of ions in the interfaces. Any theory on the dielectric properties of natural-state rocks may not be complete without including the effect of salinity of the pore fluids explicitly or implicitly.

ACKNOWLEDGEMENT

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