Indian Journal of Pure & Applied Physics
Vol. 58, June 2020, pp. 455-464

Dielectric properties of soil mixed with urea fertilizer over 20 Hz to 2 MHz frequency range

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Received 14 November 2019; accepted 7 April 2020

The dielectric properties of sandy soil for various moisture contents of distilled water and Urea-fluid solutions in soil are estimated in the lower frequency range from 20 Hz to 2 MHz using precision LCR meter. The spectra of complex permittivity $\varepsilon^*(\omega)$, loss tangent tan $\delta(\omega)$, electrical conductivity $\sigma^*(\omega)$, and complex impedance $Z^*(\omega)$ plane plots of these soil-fluid system have been investigated for various moisture contents of different concentrations of Urea solution in the soil samples. The dielectric constant and dielectric loss of the soil increase with increase in moisture content of different concentrations of Urea solution in the soil. The dielectric constant and dielectric loss of the soil increases significantly with the decrease in frequency over the given frequency range. The complex impedance plane (Z' versus Z'') plot separates electrode polarization and bulk material phenomena, which can also be observed in the dielectric loss tangent peaks.

Keywords: Complex permittivity, Conductivity, Impedance, Soil, LCR meter, Urea fertilizer

1 Introduction

The complex permittivity of a material is composed of real and imaginary parts. The real part represents the polarization of the material, while the imaginary part is due to ohmic and polarization losses[1]. Thus, the dielectric constant is a measure of the response of a system to an applied field. The measurement of dielectric properties of soil-fluid system provides very much useful information for the interpretation of data obtained by various sensors for agriculture, hydrology and meteorology. Soil is a multi component framework comprising of solid, fluid, and vaporous stages, and living organisms[2]. The solid phase of soil consists of both inorganic and natural parts. According to Mohamed and Paleologos[2] the organic components present in much smaller quantities than inorganic components, may significantly alter the properties of soil. The frequency of the electric field, soil texture, volumetric water content in the soil, and salinity influence both the real and imaginary components of the complex permittivity[3-4].The permittivity of soil-water mixtures in the megahertz range have been estimated by Campbell *et al.*[5], and Santamarina and Fam[6], and observed that the dielectric constant and dielectric loss of the soils under investigation increased with increase in moisture contents in the soil. Francisca and Rinaldi[7] suggested that monitoring of the dielectric properties of soil-contaminant mixtures might be a promising method for the detection of contaminants. They observed that the organic contaminants can be easily detected in dry sand from the dielectric properties, and difficult to detect in wet sand. The presence of contaminates also affects the electrical properties of soil-fluid mixtures, e.g., high ionic concentration increases the DC conductivity, alters the polarizability of ionic clouds, and affects interfacial polarization[6]. Santamarina and Fam observed that multiple phenomena affect the permittivity of clay-fluid mixtures, and also the ionic concentration and valance have no unique effect on the complex permittivity of electrolytes. The understanding of interaction between electromagnetic waves and soil mixtures with inorganic fluids is an important parameter in remote sensing applications. This study mainly focuses on the factors affecting the dielectric response of soil+ Urea fertilizer water solutions in the low frequency range, using LCR meter (20Hz to 2MHz). The effect of parameters like soil texture, Urea-water content, contaminant present in the soil and frequency of measurement on the permittivity were evaluated at low frequencies. The purpose of selecting Urea fertilizer was that it is very widely used in agriculture. Many researchers[8,10-12] have observed that the dielectric permittivity of soils increases with increase in fertilizer concentration in the soil.

2 Materials and Methods

The sample to be tested here was obtained from the field near Kapadwanj town, Gujarat, India (23° 08′ 64″ N, 79° 04′ 13″ E). First, the stones and gravels

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*Corresponding author (E-mail: dhgadani@yahoo.com) were removed from the soil and then the soil was oven dried for 24 hours, at 110 ºC temperature. Table 1 shows the physical and chemical properties of Kapadwanj soil. The physical and chemical analyses of the soil sample were carried out by Vishal Analytical Laboratory, Ahmedabad. Soil texture represents that it is a sandy soil.

To study the effect of Urea fertilizer on the dielectric properties of the soil, Urea was purchased from the market. Urea contains 46% Nitrogen in ammonic form (NH_4^+), zero Phosphorus and zero Potassium. Urea can be applied to the soil in the solid form as granules or can be dissolved in water and used as a soil drench. For the sample preparation, 45 g soil was taken in each vessel. Urea was dissolved in double distilled water with two concentrations of 10 g, and 30 g per litre. This Urea+ distilled water solution was mixed with each soil sample in different proportions of various moisture contents, and these soil-fluid samples were allowed to saturate for 24 h.

The wilting point (WP), transition moisture (Wt), gravimetric moisture (W_m), and volumetric moisture (W_v) content of the soil (cm^3/cm^3) have been calculated using Wang and Schmugge model[3] as:

$$WP = 0.06774 - 0.00064 \times Sand + 0.00478 \times Clay \quad \ldots (1)$$

$$Wt = 0.49\ WP + 0.165 \quad \ldots (2)$$

where sand and clay represent the sand and clay contents in percent of dry weight of the soil.

Table 1 – The physical and chemical properties of Kapadwanj soil.

Parameter	Content	Value	TDS (PPM)	Remark
Mechanical analysis	Sand	84.2%	-	High
	Silt	4.9%	-	Low
	Clay	10.9%	-	Low
Particle size	Coarse	0.0	-	
	Medium	35%	-	
	Fine	65%	-	
Texture Class	-	Sandy	-	
pH	-	8.09	-	Medium
TDS	-	0.065%	130 PPM	
Available Fertilizer	N App.	320 kg/ha.	-	Medium
	P App.	60 kg/ha.	-	Medium
	K App.	280 kg/ha.	-	Medium
Dry Density(g/cm^3)	-	1.369	-	
WP (cm^3/cm^3)	-	0.065	-	
Wt(cm^3/cm^3)	-	0.197	-	
Porosity	-	0.433	-	

$$W_m = (W_1 - W_2)/W_2 \quad \ldots (3)$$

where W_1 = weight of wet soil, and W_2 = weight of dry soil.

Volumetric moisture content, $W_v = W_m \times \rho_b$, where ρ_b = dry bulk density of the soil.

2.1 Method of measurement

A precision LCR meter Agilent make E-4980A operating over the frequency range from 20 Hz to 2 MHz (at room temperature of 27 ºC) was used for the measurement of capacitance and resistance offered by a coaxial capacitor. The LCR meter can simultaneously measure the parallel capacitance (Cp) and parallel resistance (Rp) with single manual trigger over the frequency range from 20 Hz to 2 MHz. The co-axial capacitor was connected to the LCR meter through a Kelvin-clip probe (Agilent make- 16089 A). The coaxial capacitor was connected at the end of the probe and was fixed pointing downward, in a stand. The calibration of coaxial capacitor using LCR meter was done, for open circuit condition with air as dielectric, and for short circuit condition using mercury. The standardization of coaxial capacitor for liquid was done by using liquids of known dielectric constant. The coaxial capacitor was dipped into the test liquids like benzene, 1-propenol, chloro-benzene and methanol of AR grade, and the Cp and Rp were measured for the frequency range 20 Hz to 2 MHz. For the value of capacitance of each standard liquid, the difference of capacitance Cp-Co was calculated (Co = capacitance offered by coaxial capacitor with air as dielectric). A graph was drawn for dielectric constant against Cp-Co (in pF) for known standard liquid and linear fitting equation was obtained as shown in Fig. 1.

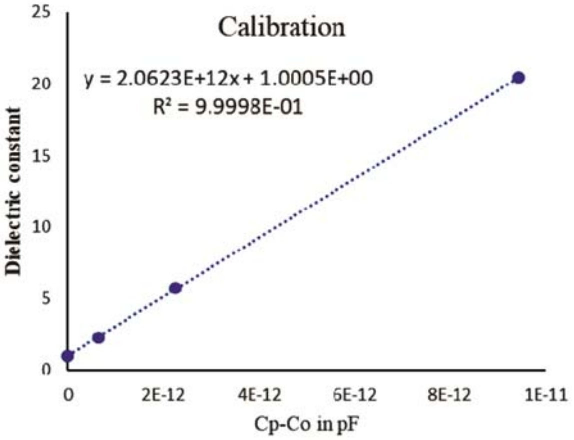

Fig. 1 – Calibration graph of the dielectric constant (ε′) plotted against Cp-Co in pF.

The dielectric constant was calculated for each soil sample using equation:

$$\varepsilon'_{\text{measured}} = 2.0623\times10^{-12}\times(\text{Cp-Co}) + 1.0005 \qquad \ldots(4)$$

For the coaxial capacitor, the conductivity and dielectric constant are given by[13]:

$$\sigma' = \frac{\ln(b/a)}{2\pi H}G = \frac{\ln(b/a)}{2\pi H}\frac{1}{R}, \qquad \ldots(5)$$

and $$\varepsilon' = \frac{\ln(b/a)}{2\pi H\varepsilon_0}C, \qquad \ldots(6)$$

where, a = inner radius of coaxial capacitor, b = outer radius of the coaxial capacitor,

H = length of the coaxial capacitor (in meter), G = Conductance, and R = Resistance = $1/G$

The tan δ in terms of ε' and σ' (parallel circuit) can be represented by[13,14]:

$$\tan\delta = \frac{\sigma'}{\omega\varepsilon'\varepsilon_0} = \frac{\varepsilon''}{\varepsilon'} \qquad \ldots(7)$$

$$\therefore \varepsilon'' = \frac{\sigma'}{\omega\varepsilon_0} = \frac{\ln(b/a)}{2\pi H\varepsilon_0}\frac{1}{R\omega}$$

But from Eq. (6), $\frac{\ln(b/a)}{2\pi H\varepsilon_0} = \frac{\varepsilon'}{C}$

$$\therefore \varepsilon'' = \frac{\varepsilon'}{\omega C R} \qquad \ldots(8)$$

where we used, $C = C_P - C_0$ and $R = R_P$ to calculate ε'' of soil samples[10].

The dielectric constant and dielectric loss of the soil samples were calculated using Eqs (4) and (8).

The conduction phenomena in materials are due to the movement of electric charges (e.g., ions and electrons) which get displaced from their original equilibrium position under an applied electric potential between two electrodes[15]. The frequency-dependent real (σ′) and imaginary (σ″) part of AC conductivity σ*(ω) were calculated using:

$$\sigma^*(\omega) = \sigma' + j\sigma'' = j\omega\varepsilon_0\varepsilon^*(\omega)$$
$$= \omega\,\varepsilon_0\varepsilon'' + j\omega\varepsilon_0\varepsilon' \qquad \ldots(9)$$

where $\varepsilon_0 = 8.854\times10^{-12}$ F/m is permittivity of free space.

From the graph of σ′ against *f*, the dc conductivity (see Table 2) of each sample was calculated.

The complex impedance plan plots (Z″ against Z′) are commonly used to separate the bulk material and electrode surface polarization phenomena[16]. The value of frequency dependent complex impedance Z*(ω) was calculated by using equation:

$$Z^*(\omega) = \frac{1}{Y^*(\omega)} = Z' - j\,Z'' = \frac{R_p}{1+(\omega C_p R_p)^2} - j\frac{\omega C_p R_p^2}{1+(\omega C_p R_p)^2} \qquad \ldots(10)$$

3 Results and Discussion

3.1 Complex permittivity

The frequency-dependent complex permittivity (ε*) is a measure of the amount of polarization in a material. There can be some different polarization mechanisms present, each having a characteristic relaxation frequency and associated dielectric dispersion centred around this relaxation frequency and the ratio of surface water to bulk water in the pore space of a sandstone that controls the dielectric response through a Maxwell-Wagner type of mechanism[9]. Typical dielectric properties of the soil for various moisture contents of distilled water and Urea-fluid solutions in soil are presented in Figs 2 and 3, over the frequency range from 20 Hz to 2 MHz. The dielectric constant and dielectric loss decrease with increase in frequency. It can be observed from Figs 2(a) and 3(a) that for the drier soil with Wv = 0.0168 cm^3/cm^3 volumetric moisture content the dielectric constant (ε′) and dielectric loss (ε″) remains nearly constant above 10 kHz and slowly increases with decrease in frequency below 10 kHz. As moisture content in soil increases the dielectric constant and dielectric loss of the soil increases. The rate of increase in dielectric constant of wet soil with decrease in frequency is found to increase with increase in moisture content in the soil. The logarithmic slope of frequency dependent dielectric constant values of wet soil near to -1 for frequency less than ~100 kHz represents the leakiness of EDL (electric double layer) capacitances to moving charges formed in EP (electrode polarization) region, and the slope near to 0 after 1 MHz frequency suggests a complete block of movement of charges through the layers[10,17]. The decrease in ε′ and ε″ with increase in frequency reveals the influence of interfacial polarization (i.e. Maxwell-Wagner polarization and electrode polarization) at low frequency[18]. The decrease in dielectric constant (ε′) of soil with increase in frequency; is commonly known as the relaxation behaviour[5,6]. The decrease in ε′ of wet soil with increase in frequency suggests a relaxation extending up to 2 MHz region. This can be interpreted as a result from the development of spatial

Table 2 – Values of $R_{dc} = Z'(\Omega)$ corresponding to Z''_{min}. relaxation frequency f_{EP}, and electrode polarization relaxation time τ_{EP}, for soil sample.

Volumetric moisture content in the Soil (Wv) cm^3/cm^3	$R_{dc} = Z'\Omega$ corresponding to Z''_{min}	f_{EP} (kHz)	τ_{EP}(μs)	σ_{dc}(S/m)
		Soil+ Distilled water		
0.0530	3966.6	42.269	3.76	3.20×10^{-3}
0.0805	2334.7	50.237	3.16	5.05×10^{-3}
0.1129	2149.9	70.962	2.24	5.55×10^{-3}
0.1738	902.10	79.621	1.99	1.06×10^{-2}
0.2002	911.69	70.962	2.24	1.15×10^{-2}
0.2473	724.56	75.167	2.11	1.04×10^{-2}
0.2833	528.87	89.336	1.78	1.45×10^{-2}
0.3144	533.65	70.962	2.24	2.47×10^{-2}
		Soil+ 10 g/L Urea Solution		
0.0385	7801.5	28.250	5.63	1.64×10^{-3}
0.0552	3812.6	56.367	2.82	3.25×10^{-3}
0.0823	2271.4	70.962	2.24	5.13×10^{-3}
0.1166	1911.9	75.167	2.11	6.83×10^{-3}
0.1488	1293.6	79.621	1.99	1.04×10^{-2}
0.2003	734.14	79.621	1.99	1.72×10^{-2}
0.2480	692.61	94.630	1.68	1.83×10^{-2}
0.2893	613.39	94.630	1.68	1.96×10^{-2}
0.3222	545.92	89.336	1.78	2.18×10^{-2}
		Soil+ 30 g/L Urea Solution		
0.0416	7143.6	17.825	8.93	1.85×10^{-3}
0.0637	2847.7	59.707	2.66	4.40×10^{-3}
0.0934	1820.7	70.692	2.24	7.24×10^{-3}
0.1229	1372.9	84.339	1.88	9.66×10^{-3}
0.1919	843.95	94.630	1.68	1.50×10^{-2}
0.2215	720.67	106.177	1.49	1.66×10^{-2}
0.2561	625.58	112.191	1.41	1.72×10^{-2}
0.2868	552.92	126.191	1.26	1.91×10^{-2}
0.3180	552.04	112.468	1.41	1.96×10^{-2}

polarization which manifests as a relaxation response at low frequency, even though the individual components of soil sample have a constant permittivity value within this frequency range. The polarization mechanism in the soils develops at the interface between the pore fluid and the soil particle or air due to ionic migration. The space charge and macroscopic field distortions are observed when the ionic charge carriers are impeded in their motion, because they become trapped at such surfaces. Such distortion appears as an increase in the capacitance of the sample[19]. Campbell reported the decrease in dielectric constant (ε′) with respect to frequency, dependent on water content in the soil. Soils with higher gravimetric water content at a constant porosity have greater areas of soil-fluid interfaces. Increasing the soil-fluid interface of soil could magnify the spatial polarization at low frequency. Although at lower frequency many researchers have found the presence of mainly two polarization mechanisms, Maxwell-Wagner polarization and electrode polarization or electric double layer[20]. However, as explained by Ishai et *al.*[21] the resultant capacitance of these layers can dominate the signal at the lower frequencies, masking the relaxation of bulk sample. This phenomenon is known as electrode

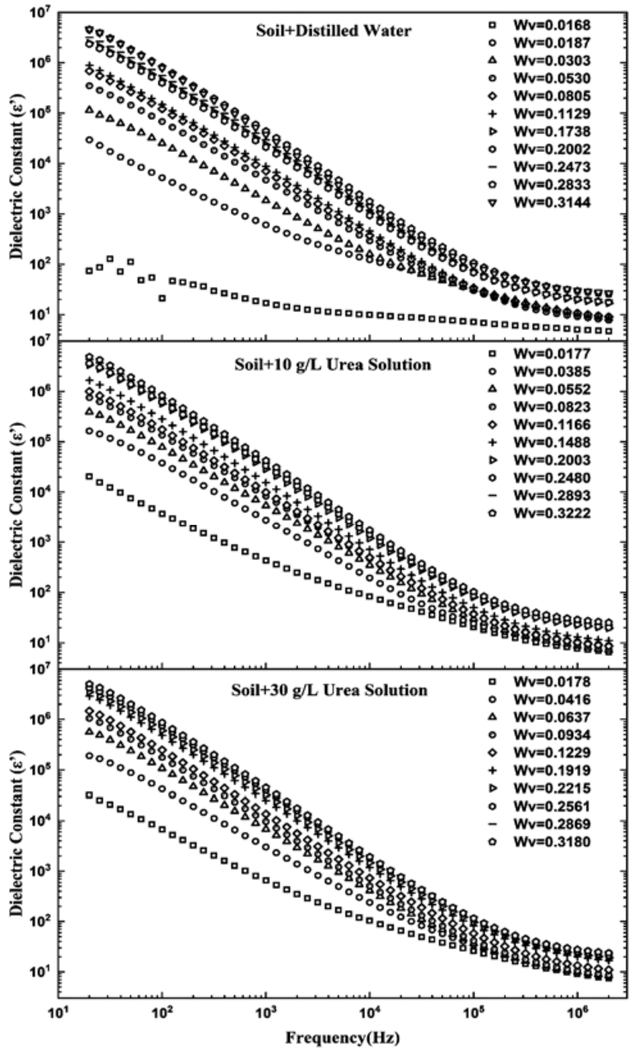

Fig. 2 – Variation of dielectric constant of soil with frequency, for various moisture contents of distilled water and water with different concentration of Urea.

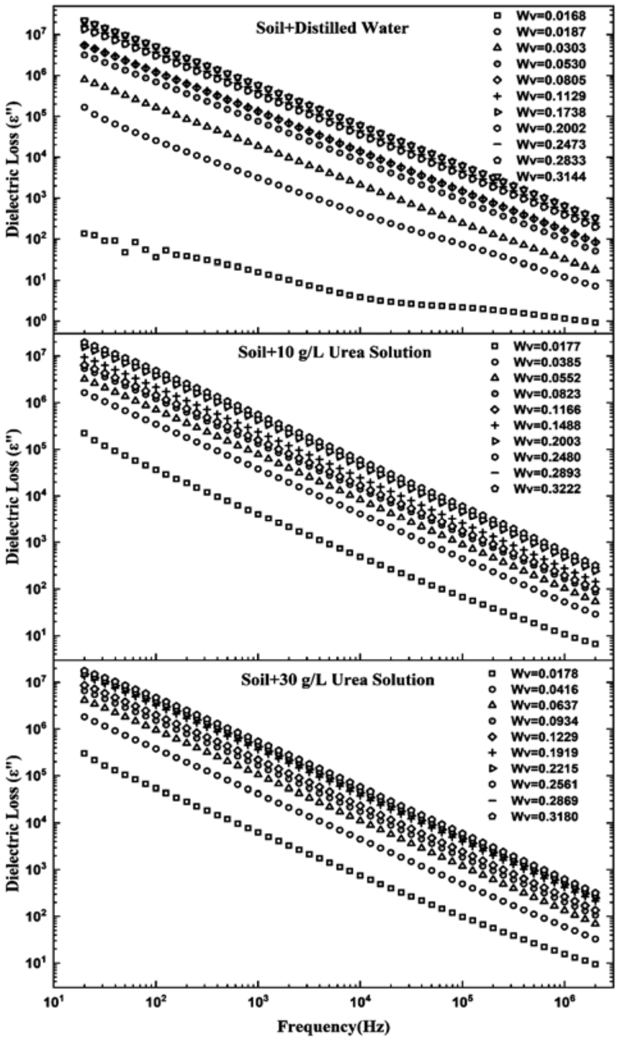

Fig 3 – Variation of dielectric loss of soil with frequency, for various moisture contents of distilled water and water with different concentration of Urea solution.

polarization (EP). EP can present a major obstruction to interpretation of dielectric spectra as a measure of conductivity of the sample, the sample temperature, the structure of electrodes, their composition and even the roughness of the electrode surface. There are systems like blemished charge transport, for example, Stern layer (the inner layer of the electrical double layer) polarization or diffused twofold layer and Maxwell−Wagner polarization are often assigned to relaxation processes at frequencies from 1 MHz down to less than 1 Hz. Stern layer polarization is caused by the movement of tightly bound ions on the particle surface while Maxwell−Wagner polarization occurs in cases of charge accumulation perpendicular to the electric field[18]. The volumetric water content (Wv) is the ratio of volume of pore to the total volume of soil. An increase in the volumetric water content means an increase in the number of permanent electric dipoles which are responsible for orientation polarization. Therefore, the dielectric constant of soil is significantly affected by the amount of water, which acts as a permanent dipole[19].

Figure 3 shows the variation of dielectric loss (ε″) of soil-fluid system for various concentrations of Urea solution, with different volumetric water contents in the soil. The dielectric loss (ε″) of soil-fluid mixture decreases with the increase in frequency and increases with increase in volumetric moisture content in the soil. The dielectric loss (ε″) is a parameter which represents the losses due to both polarization and conduction, which is inherently a frequency-dependent parameter. An increase in the effective dielectric loss of the soil with increase in volumetric water content can be explained in terms of the increase in conduction loss, as demonstrated in the ac conductivity spectra which is explained in detail in section 3.3. According to Oh *et al.* [19] the higher volumetric water content enhances the conductivity of pore fluids which acts as electric current path ways in the soil, consequently leading to a greater amount of conduction losses. Rinaldi and Francisca[22] (1999) reported that loss from conduction has a greater effect than that from polarization on effective dielectric loss.

3.2 Loss tangent

Figure 4 shows the variation of loss tangent of the soil for various moisture contents of Urea solutions, over the frequency range from 20 Hz to 2 MHz. It can be observed from the figure that for drier soil, the relaxation frequency f_{EP} corresponding to tan δ peak, lies in the frequency range below 1 kHz. As moisture content in the soil increases, the value of tan δ increases. Further the peak value of tan δ and corresponding relaxation frequency f_{EP} increases with increase in moisture content in the soil. The peak in tanδ represents the electrode polarization (EP) relaxation frequency (f_{EP}) which separates the bulk material dielectric properties from the EP phenomenon[23,24]. In lower frequency range up to f_{EP}, EP polarization dominates over MW polarization. The values of EP relaxation time τ_{EP} of these soil-fluid systems were obtained directly from the value of f_{EP} by using equation[25,26], $\tau_{EP} = (2\pi f_{EP})^{-1}$ (see Table 2). The τ_{EP} involves charging and discharging time of EDL capacitance, and its values are associated with the overall dynamics of micro-aggregates[16,27-29]. It can be observed from Table 2, that τ_{EP} for drier soil-fluid systems is higher, and decreases rapidly with increase in moisture content in the wet soil, which becomes nearly constant after the transition moisture of Wt = 0.197 cm^3/cm^3 for the soil. It can also be observed from the table that at higher moisture contents above the transition moisture, the value of τ_{EP} decreases with the increase in concentration of Urea in the soil-fluid system.

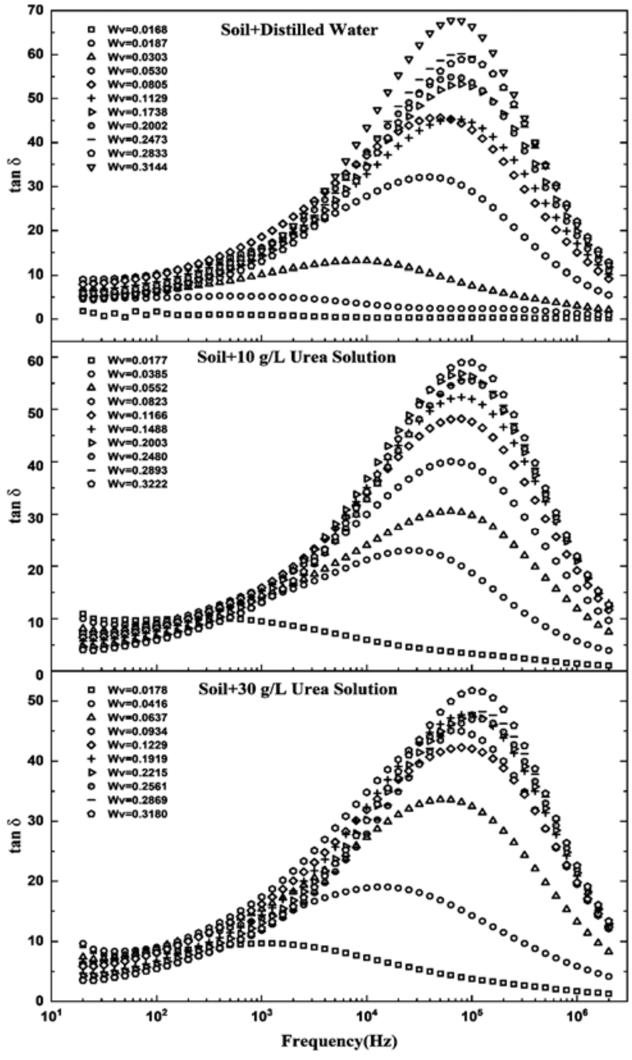

Fig 4 – Variation of loss tangent of soil with frequency, for various moisture contents of distilled water and water with different concentration of Urea solution.

3.3 Complex conductivity

The real conductivity (σ′) of soil-fluid system is illustrated in Fig. 5. For the drier soil, the real and imaginary parts of conductivity increase with increase in frequency. For pure water in soil, the electric conductivity of soil decreases with decrease in frequency at lower volumetric moisture contents, while at higher volumetric moisture content in soil the conductivity remains nearly constant over the given frequency range. The frequency independent plateau of σ′ spectra at higher moisture contents in the soil corresponds to the ionic or dc electrical conductivity (σ_{dc})[30]. This behaviour obeys the Jonscher power law $\sigma' = \sigma_{dc} + A\omega^n$, where A is the pre-exponential factor and n is the fractional exponent ranging between 0 and 1. The smaller deviation from plateau region on the lower frequency side of the conductivity spectra confirms the EP effect for the wet soil. At constant ionic concentration the electric conductivity of soil-fluid system essentially remains constant for a wide range of frequency[1]. According to Rinaldi and Cuestas[15], in the fine-grained soil, the electric double layers are developed around the particles of colloidal size with negative surface charge and the electric conductivity becomes more complex. At lower frequencies below few kHz, the ions in electric double layer (EDL) are able to follow the variation of the electric field and hence the conduction of particles can be considered as ohmic[15]. At higher frequencies the ions in the EDL cannot follow the variation of electric field, hence energy is dissipated, and conductivity as well as polar losses contribute to the electric conductivity of the soil. At intermediate frequencies between those corresponding to EP and EDL relaxation frequency, the conductivity of soils exhibits an almost constant behaviour[31], which depends on the water content in the soil. At higher moisture contents in the soil this region extends up to few MHz, while at very low moisture content almost no region of constant conductivity is developed. As volumetric moisture content in the soil increases, EDL hydrates, and hence free and bound ions acquire mobility, which increases the conductivity.

Figure 6 shows the variation of imaginary part of conductivity (σ'') with frequency for the soil-fluid system. It can be observed that for higher moisture content of pure water and Urea solutions in the soil, σ'' decreases with increase in frequency, reaches a deep at the EP relaxation frequency (f_{EP}) and then increases with increase in frequency. The frequency f_{EP} corresponding to minimum value of σ'' separates the EP process from the bulk material properties. The frequency f_{EP} corresponding to deep in the σ'' increases with increase in moisture content in the soil.

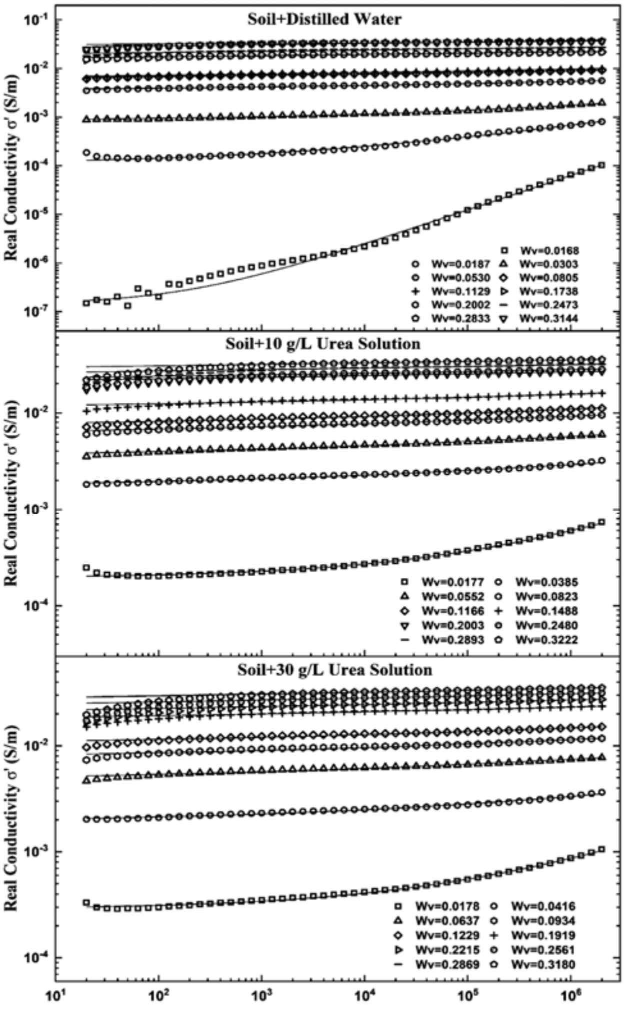

Fig 5 – Variation of real conductivity of soil with frequency, for various moisture contents of distilled water and water with different concentration of Urea solution.

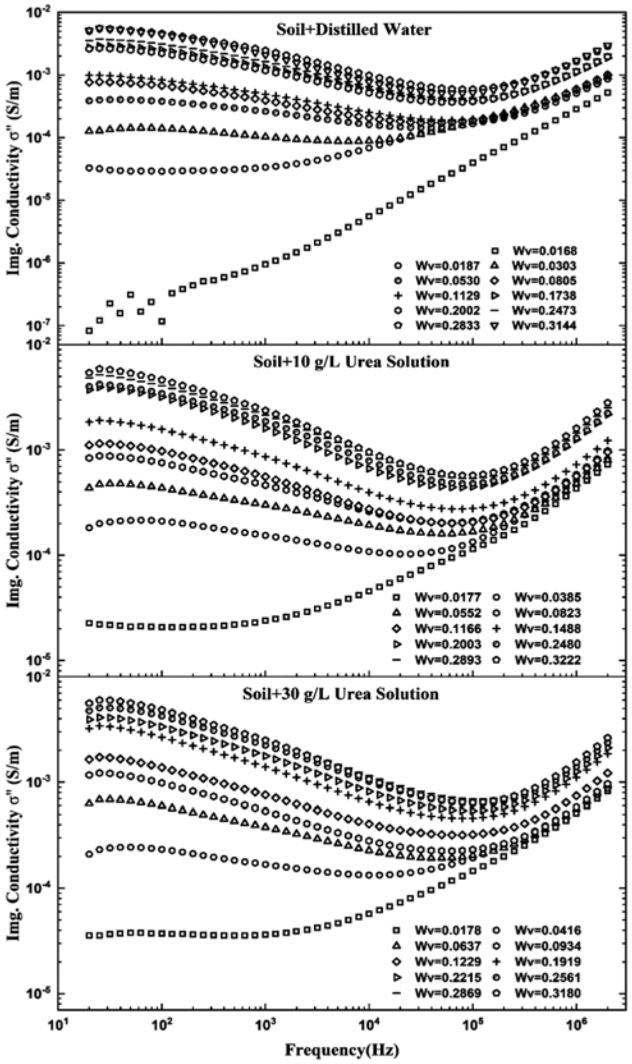

Fig 6 – Variation of imaginary conductivity of soil with frequency, for various moisture contents of distilled water and water with different concentration of Urea solution.

3.4 Complex impedance

Figure 7 shows variation of impedance Z″ against Z′ of soil, for various moisture contents of distilled water and water with different concentrations of Urea solution in the soil over the given frequency range. The frequency of the experimental points increases (except some results) while going from right to left side on the arcs of complex impedance plan plot (Z″ against Z′) of soil-fluid system. All these plots have two separate arcs, the arc on right side of Z''_{minimum} corresponds to electrode surface polarization (EP) effect, the lower frequency arc (towards 20 Hz); and the arc on left side of $Z''_{\min}$ corresponds to bulk material effect, the higher frequency arc[32] (towards 2MHz). As the volumetric moisture content in soil-fluid system increases, the bulk material effect decreases, which means the right side arc length increases and left side arc length decreases. The response of impedance spectra of composite material provides information on the nature of conduction, whether the conduction is due to the presence of ions or electrons[24]. The presence of low frequency arc confirms the ionic conduction in these soil-fluid systems, which gives rise to EDL on the surface of each electrode of the sample holder[16,24]. The frequency values corresponding to $Z''_{\min}$ in the complex impedance plane plots are marked in Fig. 7. These frequency values are equal (e.g., see master curve Fig. 8) to the value of tan δ peak frequency f_{EP} for all samples of soil-fluid system. In complex impedance plan plots the extrapolated intercept corresponding to $Z''_{\min}$ of common part of two arcs, on

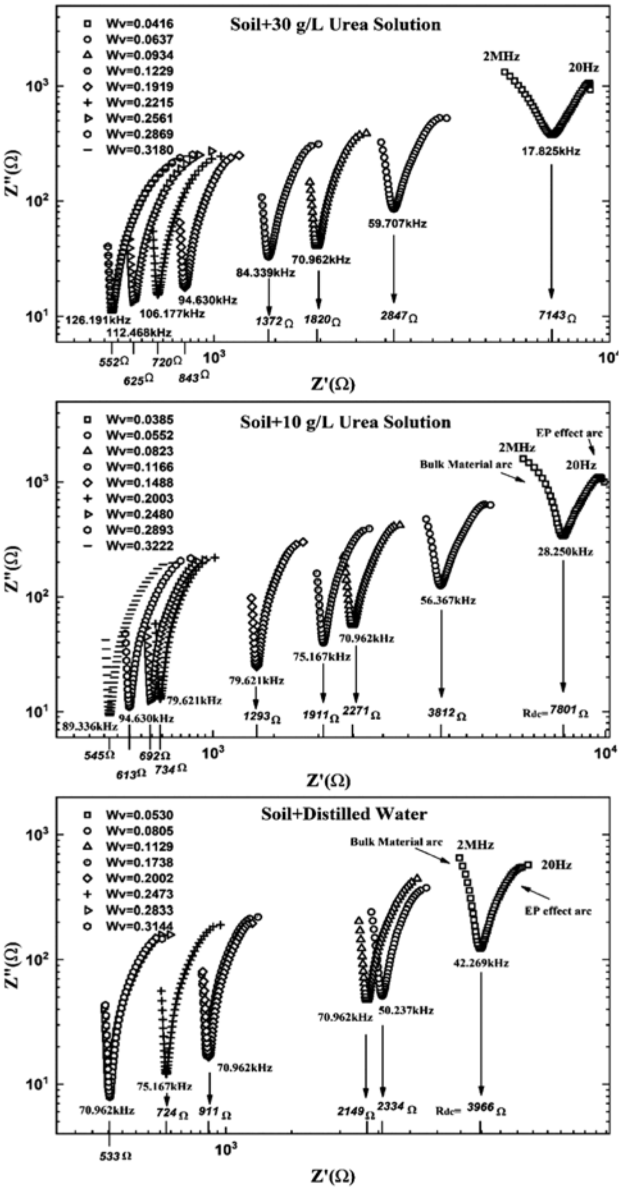

Fig 7 – Variation of complex impedance of soil with frequency, for various moisture contents of distilled water and water with different concentration of Urea solution.

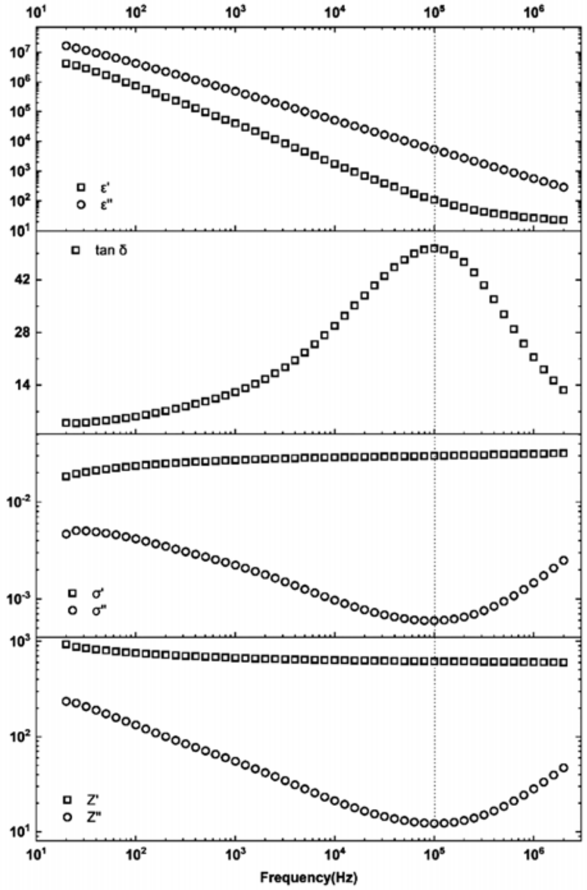

Fig 8 – Simultaneous superposition of the real and imaginary parts of the complex permittivity ε*, the loss tangent, the complex conductivity σ* and complex impedance z* for soil+ 10 g/L Urea Solution of volumetric content Wv=0.2480.

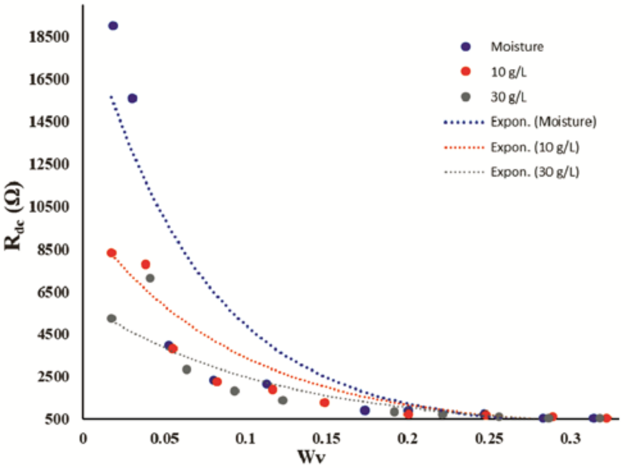

Fig 9 – The exponential fit graph of R_{dc} of soil with moisture content, for moisture contents of distilled water and water with two different concentration of Urea solution.

the real axis Z′, gives the value of dc bulk resistance R_{dc} of the material[26]. As illustrated in Fig. 7, the value of R_{dc} decreases with increase in volumetric moisture content in the soil, and hence the σ_{dc} value increases. It can also be observed from the figure that as the concentration of Urea fertilizer in the soil-fluid system increases the EP frequency increases for given moisture content in the soil.

As illustrated in Fig. 8, master curve for Wv=0.2480 cm^3/cm^3 sample shows simultaneous representation of $\varepsilon^*(\omega)$, tan $\delta(\omega)$, $\sigma^*(\omega)$, and $Z^*(\omega)$ spectra with frequency. This type of representation is important in the analysis of relaxation process occurring in the materials[32].Also this figure confirms that the position of tan δ peak, the minimum of σ″ and Z″ appears at the same frequency f_{EP}, and therefore, all these loss part spectra have exactly equal importance in regards to determination of soil-fluid systems[24].

Figure 9 shows the variation of dc bulk resistance (R_{dc} = Z′) corresponding to the minimum value of impedance (Z''_{min}) of soil with moisture content for the soil-fluid systems. It can be observed from the figure that the value of R_{dc} for the soils increase with decrease in moisture content in these soil-fluid systems below volumetric moisture content of Wv = 0.1 cm^3/cm^3, and for higher moisture contents R_{dc} remains nearly constant around550 ohm for all of the soil-fluid systems. Further, for pure water in soil the value of R_{dc} increases rapidly with decrease in moisture content below Wv = 0.1 cm^3/cm^3, as compared to that for Urea concentration in the soil. The higher R_{dc} value represent lager time taken by EDL for its charging and discharging.

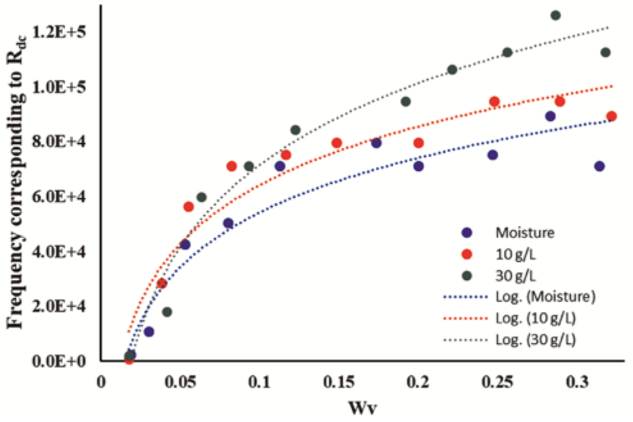

Fig 10 – The logarithmic fit graph of frequency corresponding to $R_{dc}$of soil with moisture content, for moisture contents of distilled water and water with two different concentration of Urea solution.

Figure 10 shows the variation of frequency corresponding to the dc bulk resistance R_{dc} for the soil-fluid systems. It can be observed from the figure that as moisture content in the soil increases, the frequency corresponding to R_{dc} increases, and at higher moisture contents above Wv = 0.1 cm^3/cm^3 in the soil, it increases slowly. Further the frequency corresponding to R_{dc} increases with increase in concentration of Urea in distilled water for these soil-fluid systems. Thus from Figs 9 and 10 it becomes clear that from the real impedance Z′= R_{dc} the presence of Urea in the soil can be distinguished at lower moisture contents in the soil.

4 Conclusions

From the investigation it is observed that the values of dielectric constant (ε′) and dielectric loss (ε″) of the soil increase with increase in moisture content of pure water as well as Urea solution in the soil over the frequency range from 20 Hz to 2 MHz. Further the values of ε′ and ε″ of wet soil decreases with increase in frequency of measurement. The peak value of tan δ decreases with increase in concentration of Urea fertilizer in the soil. The EP frequency of the soil increases with increase in moisture content in the soil as well as with increase in Urea fertilizer concentration in the soil. The value of σ_{dc} for the soil increases with increase in moisture content but at given moisture content in the soil, it decreases with increase in concentration of Urea fertilizer in the soil.

Acknowledgement

Authors are thankful to the funding agencies DST, New Delhi and UGC, New Delhi for providing financial assistance through DST - FIST (LEVEL - 1) project (SR/FST/PSI-001/2006) and DRS - SAP program grant [No.F.530/10/DRS/2010(SAP-1)] respectively, to develop experimental facilities which was utilized to carry out this work.

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