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Measurement of Dielectric Properties of Moist and Fertilized Soil at Radio Frequencies

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ABSTRACT

The paper presents the experimental results which have been carried out for understanding the behaviour of soil-water mixer and soil-fertilized water mixture over radio frequency range from 20Hz to 2MHz.The samples were prepared by mixing different concentration of moisture and fertilized-water (Urea) content in the Surendra nagar district sandy loam soil. The dielectric constant and dielectric loss have been measured in frequency range from 20Hz to 2MHz using precision LCR meter (Agilent make E-4980A) at room temperature (25 ºC).It has been observed that the dielectric constant and dielectric loss of the soil increase with increase in moisture content in the soil over the frequency of measurement. The value of ac conductivity increases slowly with increases in moisture in the soil. The electric modulus values M’ and M” are found to increase with increase in frequency, moisture content in the soil and fertilized water content in the soil. The complex impedance plane plots (Z” against Z’)over the given frequency range, for various moisture and fertilized moisture content in the soil have been plotted and analysed.

KEYWORD: Dielectric Properties, Soil, Moisture content, Fertilizer content, Precision LCR meter

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INTRODUCTION

Knowledge of soil moisture is necessary for agriculture, geology and civil engineering. The study of variation of complex permittivity of the soils with moisture content and fertilizer content isvery muchuseful for the interpretation of the data obtained by remote sensors.Soil is a very complex material, with such a complicated structure of pore spaces and soil particles that its characterization can be problematic. Soils vary widely in salinity, soil particle size and shape, organic matter content, and porosity[1].Porosity of the soil is helpful to judge the moisture content in the soil[2]. Yadav*etal*[2] measured the dielectric properties of fertilized sand for various concentrations of urea, Shree Ram-33, Shree Ram-50P,DAP(di-ammonium phosphate), and mosaic at X-band microwave frequency using two-point method.

The objective of the present work is to study the effect of moisture content and fertilizer content on the dielectric properties of soils of Surendranagar(Gujarat) at radio frequencies.Dielectric constantε' and dielectric lossε" of the wet fertilized soil for various concentrations of fertilizer (Urea) overthe frequency range from 20Hz to 2MHz at room temperature(25 ºC) has been measured using the precision LCR meter. The values of loss tan δ, conductivity, complex impedance and electric modulus of the wet fertilized soil forvarious proportions of fertilized water in the frequency range from 20Hz to 2MHz have been calculated from the measured values of ε'and ε"[3,4].

Moist and fertilized soils exhibit different complex dielectric spectra from dry soils. Increase of the imaginary part of the dielectric constant with volumetric water content can be explained by the increase of conduction loss caused by the increase of continuous current path in soil samples. In addition, both real and imaginary parts of dielectric constant of soil sharply decrease with frequencies at higher volumetric water content[3-5].

MATERIALS AND PREPARATION

Sample preparation

The soil sample was collected from theSayala region ofSurendranagar district. Stones and gravels were removed from the soil sample and then soil sample was oven dried. Texture structure of Surendranagar soil is as follows[6]:

Sand: 69%, Silt: 29%, Clay: 2%, Welting point(wp): 0.03314 cm^3/cm^3, Transition moisture: 0.18124 cm^3/cm^3.

The welting point and transition moisture (Wt) have been calculated using the Wang and SchmuggeModel[7] as

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

$$Wt = 0.49 \times wp + 0.165 \quad ...(2)$$

Where, Sand and clay stand for the sand and clay contents in percent of dry weight of the soil.

Preparation of soil sample with moisture content

Distilled water was added to the soil and afterthat allowed to saturate for 24hrs. Gravimetric moisture and volumetric moisture content were calculated using given equation[6],

$$Wm = \frac{W1-W2}{W2} \quad (3)$$

Where w_1 = weight of wet soil, and w_2 = weight of dry soil,

The volumetric moisture content was determined as

$$Wv = Wm^* \rho_b \quad (4)$$

Where, ρ_b= dry bulk density of the soil.

Preparation of soil sample with fertilized-water content

The fertilized water solutionwas prepared by adding Urea of 20gm per litrein the distilled water. Fertilized water of different proportionswas added to the soil and then allowed to saturate for 24hrs.The gravimetric moisture and volumetric moisture content in the soil sample were calculated using Equations(3) and (4), respectively.

EXPERIMENTAL SET UP AND METHOD

A precision LCR meter (Agilent make E-4980A) was used for the measurements in the frequency range from 20 Hz to 2 MHz. A standard four terminal probe (Agilent 16089A) with Kelvin clip was connected to the LCR meter. A coaxial capacitor with four vertical cuts on the outer cylinder was designed which gives almost in-situ dielectric properties of the soil sample[3].

The open and short circuit compensation of the coaxial capacitor was carried out to eliminate the effect of stray capacitance during the evaluation of frequency dependant values of complex dielectric constant. For calibrating the coaxial capacitor, capacitance C_O and $C_P$without and with sample and parallel resistance R_P with sample were measured for liquid samples, like carbon tetrachloride(ccl4), benzene and 1-propanol (AR grad), of known dielectric constant. A graph was drawn for dielectric constant of liquid sample against C_P-C_O, to get linear curve fit equation(5), Gadani*et al*[3].

The dielectric constant of each sample was calculated using Eq. 5 as

$$\varepsilon' = 2.1337\,(C_P - C_O) + 1.0554 \qquad (5)$$

The dielectric loss of each sample was calculated using equation

$$\varepsilon' = \left(\frac{\varepsilon'}{CR\omega}\right) \qquad (6)$$

The real and imaginary conductivity (σ',σ") of the soil samples was calculated using equation

$\sigma' = \omega\, \varepsilon'' \varepsilon_0$ and $\sigma'' = \omega\, \varepsilon' \varepsilon_0$ (7) where angular frequency, $\omega = 2\pi f$, and the permittivity of free space, $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m. A graph of σ' against frequency was drawn for each soil sample. Extending the linear fitting line towards lower frequency end, the value of dc conductivity σ'_{dc} was obtained. ε''_{actual} was calculated using equation[8,9]

$$\varepsilon''_{actual} = \varepsilon'' - \frac{\sigma'_{dc}}{\omega\varepsilon_o} \qquad (8)$$

To check validity of the results, static dielectric constant of methanol was measured and was compared with the literature values. It has been observed that for methanol ε' = 31.34 (literature value = 32.63[10]). The complex permittivity of the soil samples of varying moisture and fertilized-water contents was measured over the radio frequency range (20 Hz to 2 MHz) at room temperature(25ºC) using the LCR meter. The loss tangent is calculated as $\tan\delta = \varepsilon''/\varepsilon'$.

The complex impedance calculated by following relation[11]

$$Z^*(\omega) = \frac{1}{Y^*(\omega)} = Z' - jZ'' = \frac{Rp}{1+(\omega CpRp)^2} - j\,\frac{\omega CpRp^2}{1+(\omega CpRp)^2} \qquad (9)$$

The complex impedance plane plots (Z" against Z') are commonly used to separate the bulk material and electrode surface polarization phenomena[12-14].

Considering the charges as the independent variable conductivity relaxation effects can be suitably analysed within the modulus formalism in terms of a dimensionless quantity called electric modulus M*(ω). Analogous to mechanical relaxation, the frequency-dependent values of electric modulus M*(ω) is obtained from the relation[15,16]

$$M^*(\omega) = \frac{1}{\varepsilon^*(\omega)} = M' + jM'' = \frac{\varepsilon'}{\varepsilon'^2+\varepsilon''^2} + j\,\frac{\varepsilon''^2}{\varepsilon'^2+\varepsilon''^2} \qquad (10)$$

RESULTS AND DISCUSSION

Moist soil of Surendranagar district

Figure (1) shows the variation of dielectric constant and dielectric loss of Surendranagar district sandy loam soil with frequency for various moisture contents in the soil. It has been observed that

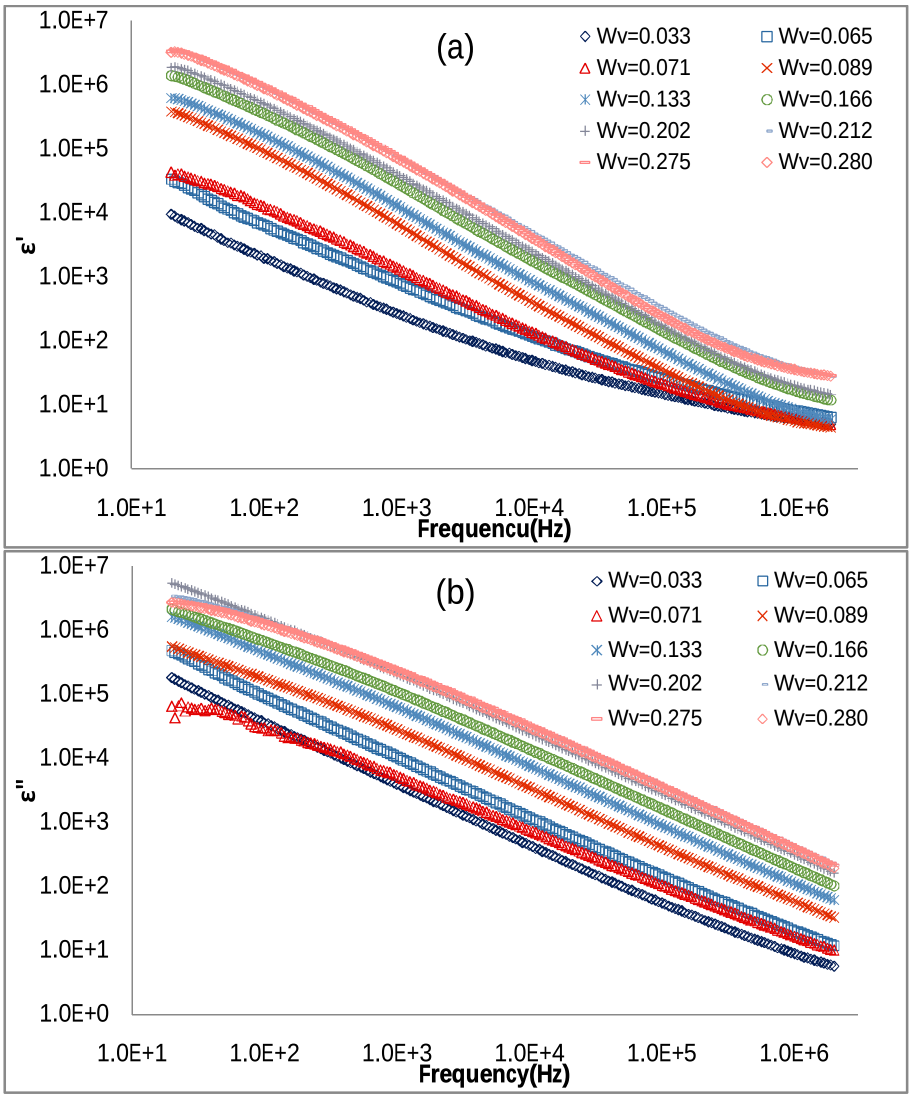


Figure-1: Measured values of (a) dielectric constantε' and (b)dielectric lossε" of soil for various moisture content with frequency

the dielectric constant ε' and the dilectric lossε" decrease with increase in frequency over the frequency region 20Hz to 2 MHz. The dielectric constant ε' and dielectric loss ε" of the soil increases with increase in moisture content in the soil. Very large enhancement in the value of ε' and ε" is observed with decrease in frequency from 2MHz to 20Hz for wet soil.This very large enhancement in the permittivity value of moist soil is due to electro chemical polarization[5] which arises due to increase in surface charge carrier density in the presence of water molecules in the pore spaces of the soil. Analogous behavior has been reported in literature[2-4]. This result shows that dielectric properties can be used to determine the moisture content of soil.

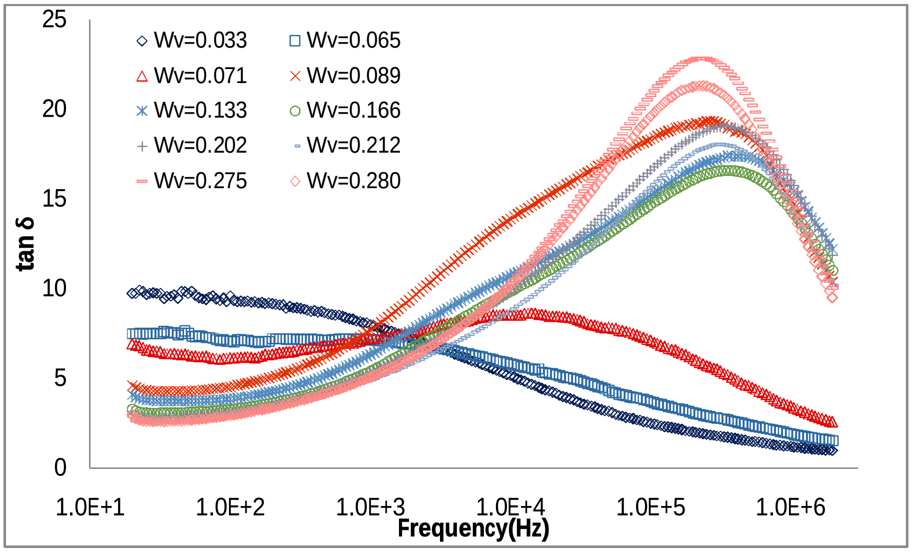


Figure-2: Calculated values of loss tan δ of soil for various moisture-content with frequency

The variation of loss tangent tan δ of the Surendranagar district sandy loam soil for various moisture contents in the frequency range from 20Hz to 2 MHz is shown in Fig. (2). It is observed that at low moisture content,no peak isobserved in this frequency range. As moisture content in the soil increases the value of tan δdecreases at lower frequency below about 1KHz, above which these values are higher, peak in tanδ values is observed to occur moisture content in the soil increases. Further it is observed that peak value of tan δ increase with increase in moisture content. The peak in the frequency dependent tanδ values of soil for various moisture contents correspond to the electrode polarization (EP) relaxation frequency. The bulk material and the electrode surface polarization phenomena are separated by the relaxation frequency. When water is mixed with soil, the initially absorbed cations with the soil particles defuse into soil water mixture adjacent to the soil particle surfaces and form electric double layers (EDL)[3]. Analogous behaviour have been reported in literature[4,17].

Figure (3) shows the variation of real and imaginary value of conductivity with variation in frequency for various moisture contents in soil. It is observed from Fig.(3) that the frequency

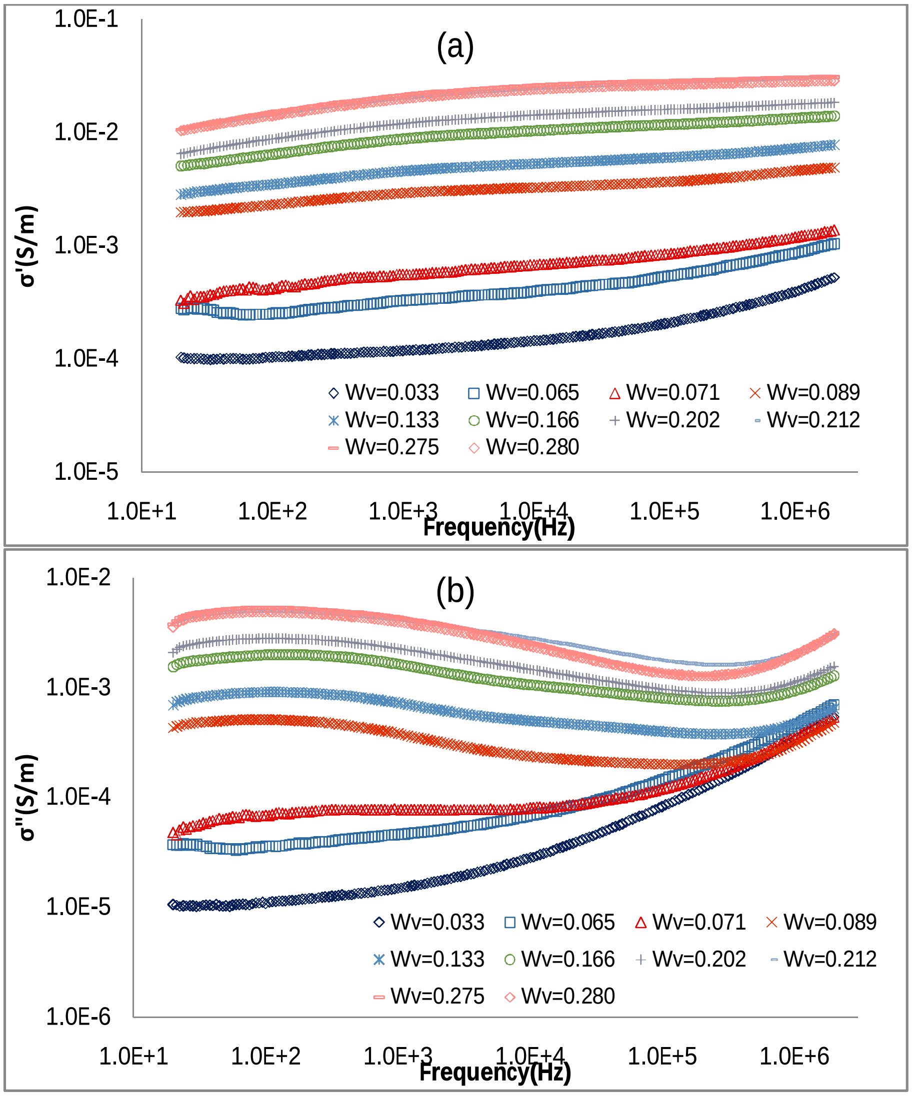


Figure-3: Calculated values of Real (a) and Imaginary (b) conductivity of soil for various moisture-content with frequency

dependent real part of conductivity σ' of soil is very small at lower frequency and increases very slowly with increase in frequency. With increase in moisture content in soil the conductivity σ' increases. The imaginary conductivity σ" of moist soil is very small at lower frequency and low moisture which increases with increase in frequency. At given higher moisture content in the soil, the conductivity σ" decreases with increases in frequency up to certain minimum value after which it increases. Further, it has been observed that the value of σ" increases with increase in moisture content in the soil. The effective conductivity in the wet soil is due to the presence of salts composed primarily of calcium[19] in the wet soil medium. The increase in ionic conductivity of wet soil medium represents the increase in number of mobile charge carriers introduced/produced with increase in moisture content in the soil. The adsorbed cations are tightly held with negatively charged dry soil particle, mainly clay[20]. The excess amount of cationsabove the required value to satisfy the surface charge density σ of the soil particles is present in the dry soil as the salt precipitates. When water is mixed with soil, the salt precipitates dissolve in the water and increase the conductivity of the soil[3].

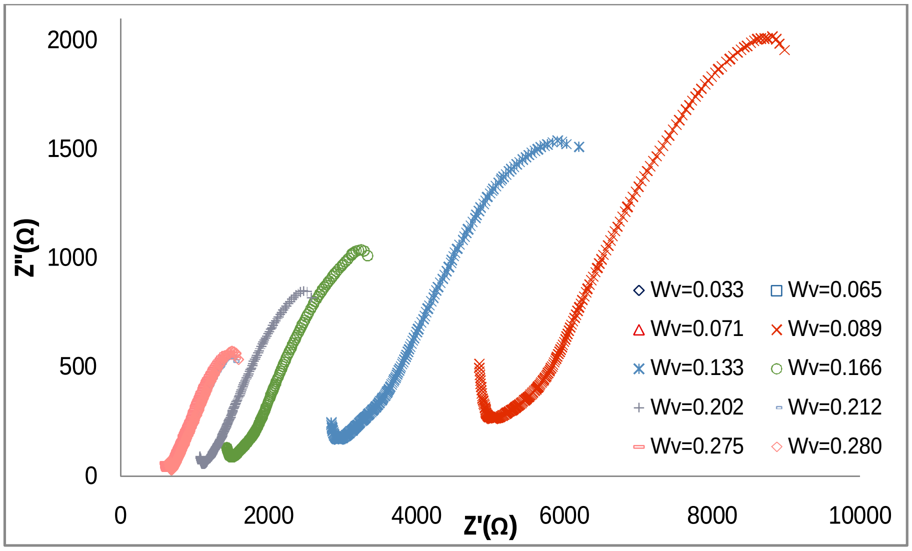


Figure-4: Plot of Z" against Z' for various moisture-content in soil

Figure (4) shows the complex impedance plane plot (Z" against Z') for various moisture contents in the soil. The value of Z" is found to decrease while looking from right to left side decrease Z' on the arcs of complex impedance plane plot. It is shows that with the increase in moisture content, the value of Z''_{min} shift from right to left side along Z' axis. The complex impedance plane plot has two arcs, separated by some minimum value of Z", one part is very small(left side) and second is very large(right side). The arc on the right side of Z''_{min} for each soil sample correspond to the electrode surface polarization effect and arc on the left side of Z''_{min} for each soil sample corresponds to the bulk material effect[3,4,11].

Figure (5) shows the frequency dependentvariation of electric modulus, real part M' and imaginary part M", of moist soil. It has been observed that the real part M'and imaginary part M" of electric modulus increase with increase in frequency. With increase in moisture content in the soil, the value of electric modulus real M' and imaginary M" part are decreases.

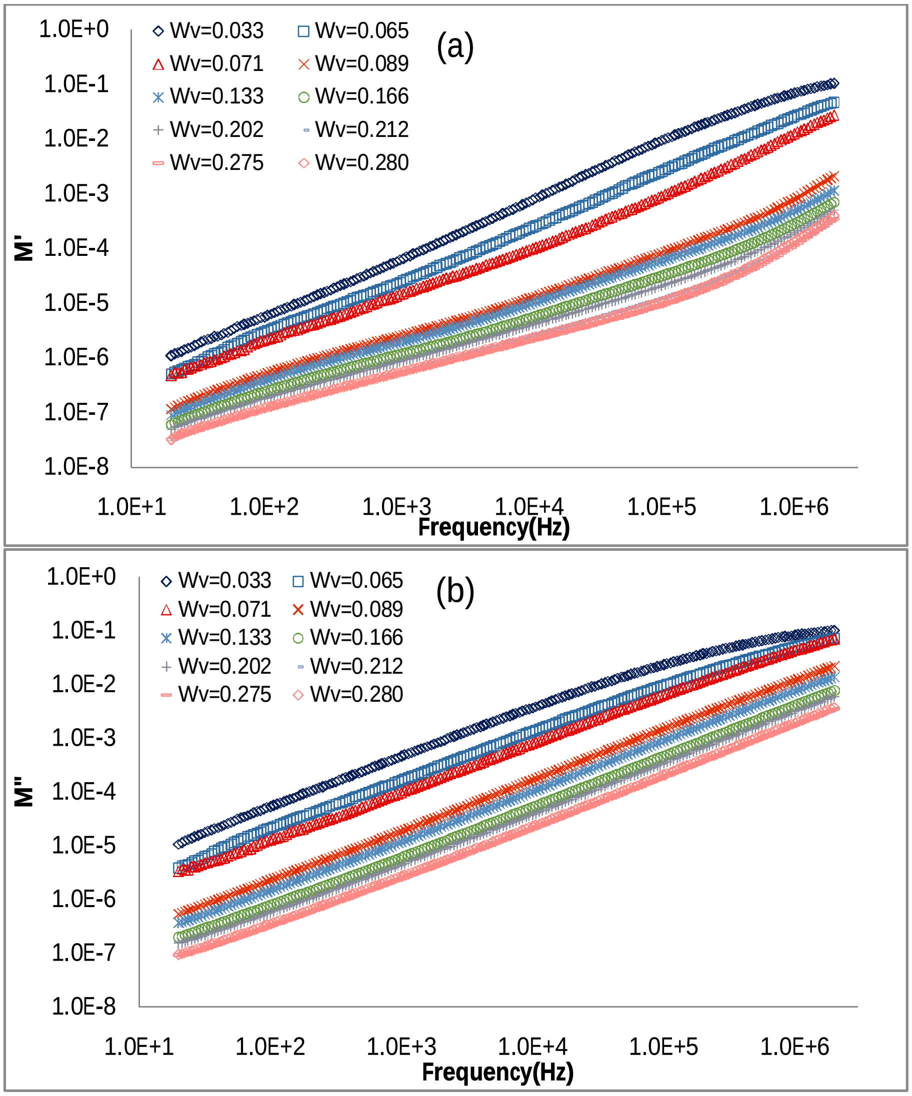


Figure-5: Calculated value of Real (a) and imaginary (b) electric modulus of soil for various moisture-content with frequency

Fertilized soils of Surendranagar district

The variation of dielectric constant ε' and dielectric loss ε" of fertilized soils(sandy loam soil of Surendranagar district) is shown in figure (6) for various concentration of fertilized-water (Urea) in the frequency range 20Hz to 2MHz at room temperature(25ºC). It has been observed that the dielectric constant ε' and dielectric loss ε" of fertilized soil decreases with increase in frequency.The dielectric constant ε' and dielectric loss ε" increase with increase in the fertilized-water content in the soil. Gadani*etal*[3] measured the dielectric permittivity of fertilized soils of Palanpur district and Gandhinagar district at radio frequencies.

The fertilizer increases the porosity of the soil[2]. Due to more pore space, water holding capacity of soil increases, and hence the dielectric constant ε' increases.

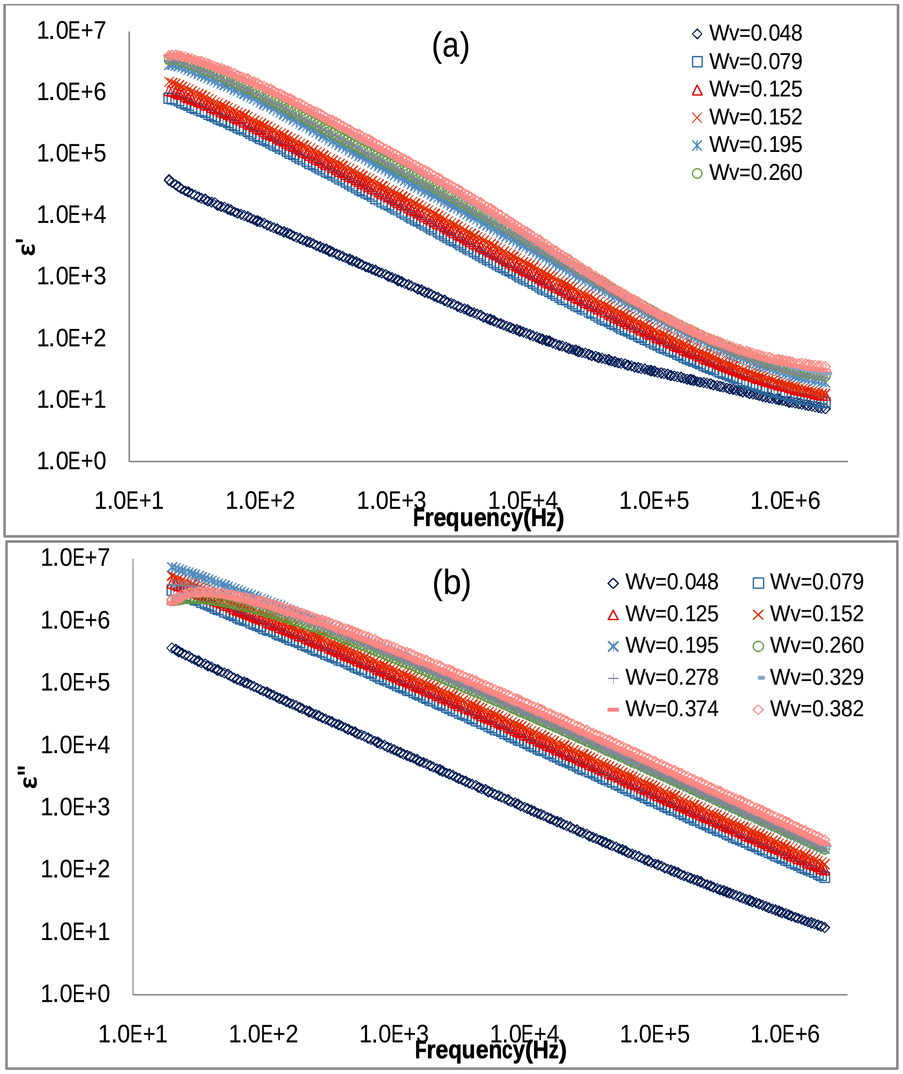


Figure-6: Measured values of (a) dielectric constant ε' and (b)dielectric loss ε" of soil for various fertilized-content with frequency

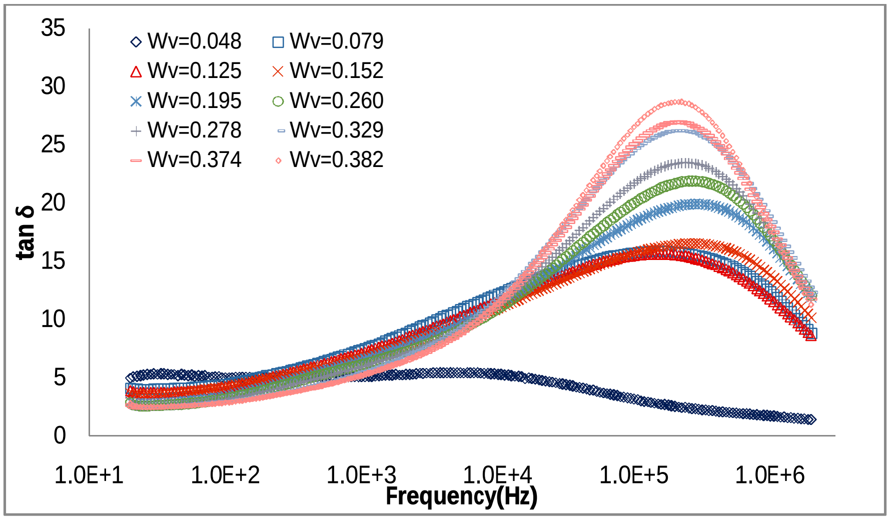


Figure-7: Calculated values of loss tan δ of soil for various fertilized-content with frequency

Figure (7) shows the variation of tan δ of the fertilized soils for various proportions of fertilized-water in the frequency range 20Hz to 2MHz. It has been observed that a loss peak increases with increase in proportionof fertilized-water.

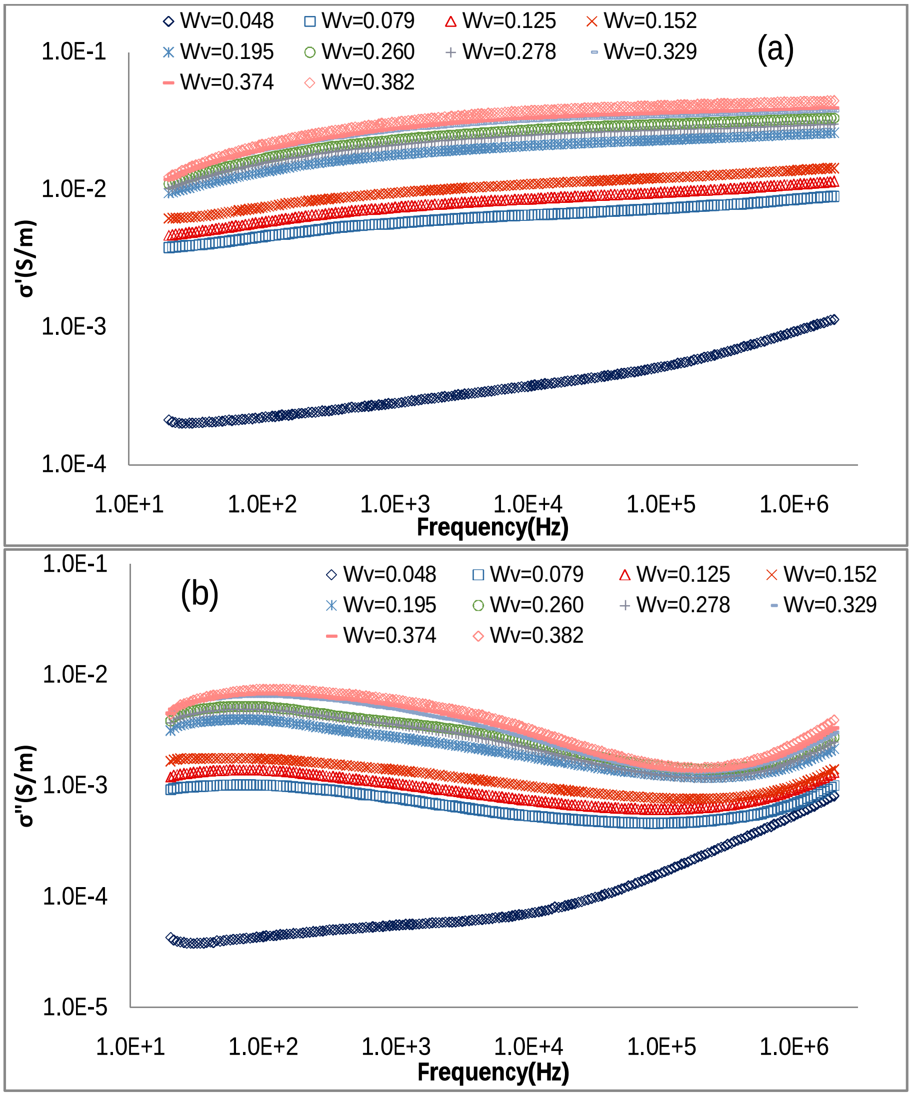


Figure-8: Calculated values of Real (a) and Imaginary (b) conductivity of soil for various fertilized-content with frequency

Figure (8) shows the variation of realσ' and imaginaryσ" conductivity of the fertilized (Urea) water at radio frequency. It has been observed that the real conductivityσ' increases very slowly with increase in frequency,and as given fixed frequency it increases with increase in concentration of fertilized-water content in the soil. The imaginary conductivity σ" of dryer soil at low fertilized-water content increase with increase in frequency, and for higher fertilized-water content imaginary conductivity σ" of soil increase with increase in frequency up to certain value of σ''_{max} and after which it decrease with increase in frequency up to certain value of σ''_{min} and again it increases with increase in frequency. Imaginary conductivity σ" of fertilized soil increases with increase in concentration of fertilized-water content in the soil at given frequency.

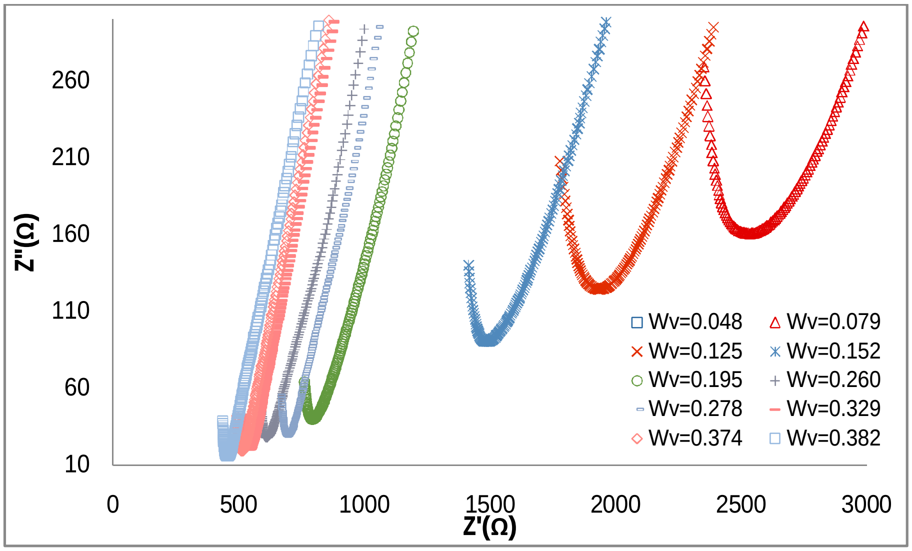
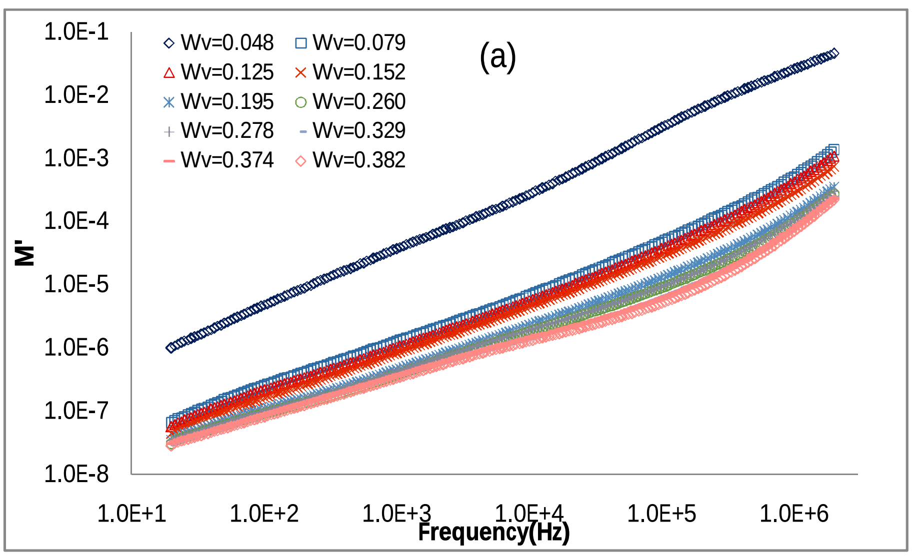


Figure-9: Plot of Z” against Z’ for various fertilized-content in soil

Figure (9) shows the complex impedance plane plot (Z” against Z’) for various fertilized-water in the soil. The experimental points of Z”$_{min}$ value are observed to shift from right to left side on the arcs of the complex impedance plane plot along Z’ axis, and increases with increase in fertilized-water content in the soil.



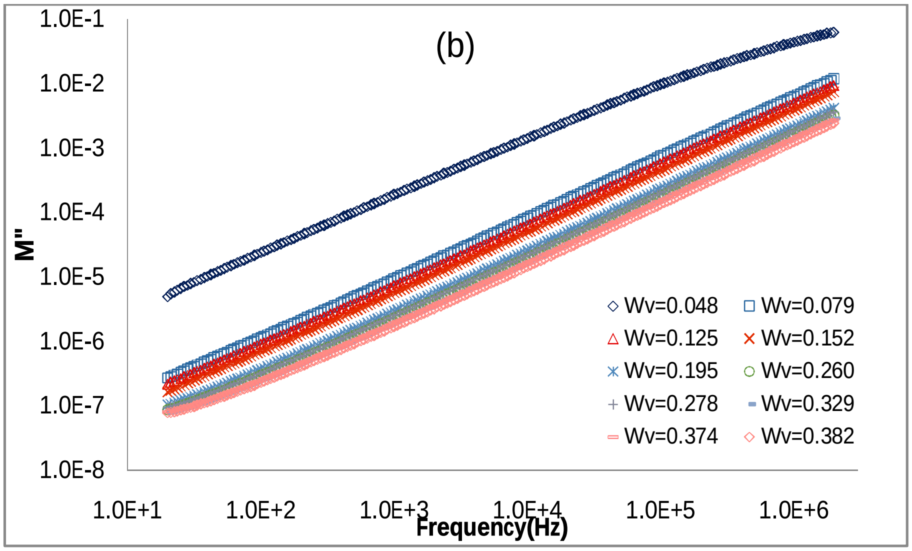


Figure-10: Calculated value of Real (a) and imaginary (b) electric modulus of soil for various fertilized-content with frequency

Figure (10) shows the variation of frequency dependent electric modulus (M', M") of fertilized soil. It has been observed that the real and imaginary part (M',M") of electric modulus increases with increase in frequency.Further (M',M") decrease with increase in fertilized-water content in the soil.

The variation of the measured values of the ε' and ε" of the sandy loam soil for various moisture and fertilizer content at 2 MHz is shown in Fig.(11). It can be observed that the dielectric constant and dielectric loss of soil with fertilized water is higher than that of soil with distilled water content.

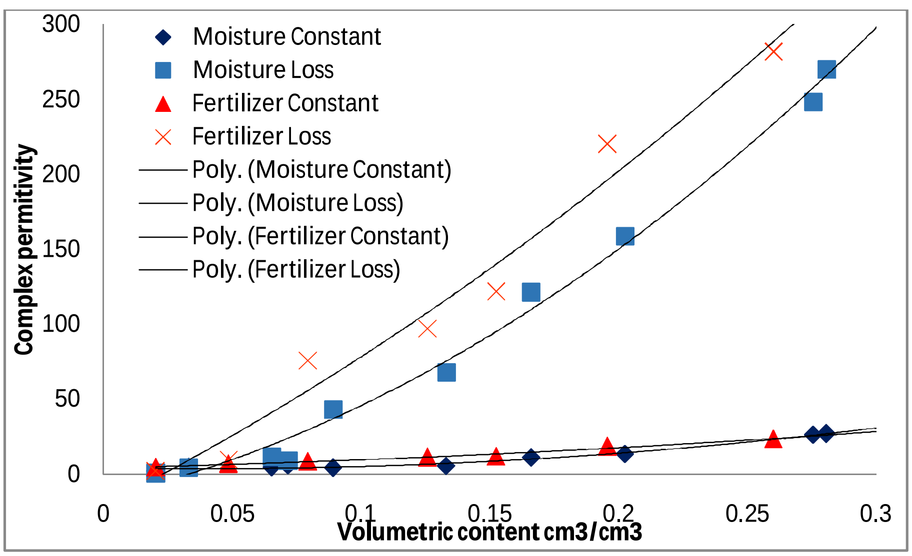


Figure-(11): Variation of dielectric constant and dielectric loss of the moisture and fertilized soil for various concentrations at spot frequency of 2 MHz

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REFERENCES

1. Jeffrey E. Compbell. Dielectric Properties and Influence of Conductivity in Soils at One to Fifty Megahertz. Soil Sci. Soc. Am. J. 1990; 54: 332-341.
2. Yadav V., Anil Kumar., Sharan S., Sinha A K., Yadav M., Gupta V K &Jangid R A. Measurement of dielectric behaviour of fertilized soil at microwave frequency, Journal of agriculture science. 2009;1(2): 42-49.
3. Gadani D H, Vyas A D, &Rana V A. Dielectric properties of wet and fertilized soils at radio frequencies. Indian journal of pure & applied physics, 2014; 52: 399-410.
4. Sengwa R J, Choudhary S, Sankhla S. Low frequency dielectric relaxation processes and ionic conductivity of montmorillonite clay nanoparticles colloidal suspension in poly(vinyl pyrrolidone)-ethylene glycol blends. eXPRESS polymer letters. 2008; 2(11): 800-809.
5. Sengnwa R J, and Soni A. Low-frequency dielectric dispersion and microwave dielectric properties of limestone. Geophysics. 2006; 71(5): 269-277.
6. Gadani D H, &Vyas A D. Measurement of complex dielectric constant of soils of Gujarat at X-and C-band microwave frequencies. Indian Journal of Radio & Space Physics. 2008; 37: 221-229.
7. Wang J R, and Schmugge T J. An empirical model for the complex dielectric permitivity of soils as a function of water content,IEEETransactions on Geoscience and Remote sensing, 1980;18(4): 288.
8. Sengwa R J, Soni A. Dielectric properties of some minerals of western Rajasthan.Indian Journal of Radio & Space Physics. 2008; 37: 57.
9. Sternberg Ben K, LevitskayaTsylya M. Electrical parameters of soils in the frequency range from 1 kHz to 1 GHz, using lumped-circuit methods.RadioScience. 2001; 36(4): 709.
10. Hill N E, Vaughan W E, Price A H & Davies M. Dielectric Properties and molecular behavior, Van Nostrand-Reinhold, London; 1969:290.

11. Sengwa R J, Choudhary S, Sankhla S. Dielectric spectroscopy of hydrophilic polymers-montmorillonite clay nanocomposite aqueous colloidal suspension. colloidal and surfaces A;Physicochem. Eng.Aspect. 2009; 336: 79-87.
12. Pissis P. Kyritsis A.Electrical conductivity studies in hydrogels. Solid state ionic. 1995; 97: 105.
13. Sengwa R J. Sankhla S. Dielectric dispersion study of coexisting phases of aqueous polymeric solution: Poly(vinyl alcohol) + poly(vinyl pyrrolidone) two-phase systems.Polymer. 2007; 48: 2737.
14. Sengwa R J. Sankhla S. Solvent effects on the dielectric dispersion of poly(vinyl pyrrolidone)-poly(ethylene glycol) blends. Colloids Polym.Science. 2007; 285: 1237.
15. Macedo P B. Moynihan C T. R. Bose. Role of ionic diffusion in polarization in vitreous ionic conductors. Phys. Chem. Glasses. 1972; 13: 172.
16. Zhang S. Dou S. Colby R H. J.Glass transition and ionic conduction in plasticized and doped ionomers. Non-Cryst. Solids. 2005; 351: 2825-2830.
17. Sengwa R J. Soni A. & Ram B. Dielectric behavior of shale and calcareous sandstone of jodhpur region.Indian journal of pure & applied physics. 2004; 33: 329-335.
18. Sternberg Ben K, LevitskayaTsylya M. Laboratory measurement of material electrical properties: Extending the application of lumped circuit equivalent models to 1 GHz. Radio science. 2000; 35: 371.
19. Hallikanen M T, Ulaby F T, Dobson M C et al., Microwave Dielectric Behaviour of wet Soil-part 1: Empirical Models and Experimental Observations. IEEE trans Geo Sci Remote Sensing , 1985;23(1): 25.
20. Dobson M C, Ulaby F T, Hallikanen M T, and EL-Rays M A, MicrowaveDielectric Behaviour of wet Soil-part II: Dielectric Mixing Models. IEEE Trans. Geo Sci. Remote sensing, 1985;23(1): 35.