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Dielectric Behaviour of Soil with Texture of Nagaur Region in Rajasthan

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Abstract

Physical, chemical and dielectric properties of soils are attributed to surface phenomena that take place at the interface between the liquid (moisture) and the solid phases. These properties are correlated to the specific surface area of the solid phase surface area of soil particles affects its dielectric, physical and chemical properties and largely controlled by amount of clay present. So that, study of dielectric properties of soils with varying clay percentage is an important field of research.

Keywords: Dielectric, SMC, Sieving, Sedimentation.

Introduction

In general, soil medium can be treated as a volume consisting of variable fractions of soil solids, aqueous fluids and air. The solid phase of soils consists of discrete units, called primary soil particles. These particles vary widely in size, shape and composition. Thus, the soils can be classified according to the particle-size or texture of the mineral solids. The soil particles are divided into different ranges on the basis of their sizes called soil separates (sand, silt and clay).

The United States Department of Agriculture (USDA), has classified the mineral particles of soils usually ranging from 0.002 mm to 2.0 mm in diameter as shown in Table-1. The relative proportions of sand, silt and clay determines the soil texture. USDA classification system recognizes twelve textural classes from pure sand to clay which are arranged in a triangular form, known as the soil texture classification triangle given in figure-1. Sand mostly consist quartz, feldspar and mica (fragments), traces of heavy metals, having low surface area. The mineralogical composition of silt is similar to sand with intermediate surface area. The reactive fraction of soil is clay so that, it is important portion of soil. Clay is colloidal, having large surface area and high charge density. Since soil consists of particle size distribution having different proportion of constitutes and different mineralogical composition with varying amount of pore space (air) and aqua’s phase or soil moisture content (SMC). Texture has a large influence on water holding capacity, water conducting ability, physical, chemical and dielectric properties of soils.

Physical, chemical and dielectric properties of soils are attributed to surface phenomena that take place at the interface between the liquid (moisture) and the solid phases. These properties are correlated to the specific surface area of the solid phase. According to Hillel [1980] the specific surface of a soil material is a fundamental and intrinsic property which is correlated with important phenomena such as cation exchange, retention and release of various chemicals (including nutrients and certain potential pollutants of the environment), swelling, retention of water and mechanical properties such as plasticity, cohesion and strength. Hence, surface area of soil particles affects its dielectric, physical and chemical properties and largely controlled by amount of clay present. So that, study of dielectric properties of soils with varying clay percentage is an important field of research.

Objective of the Study

Study of dielectric Properties of Soil with varying clay percentage is an impotant field of research.

Dielectric Properties of Soil with Textural Consideration

The dielectric properties of soil at microwave frequencies are primarily controlled by SMC. Because, the large difference between the dielectric constant of water (ε = 80) and dry soil (ε = 3.0 to5.0) produces a strong dependence of the dielectric constant of soil on its moisture content. Several laboratory studies Wang and Schmugge (1980), Hallikainen *et al* (1985), Dobson *et al* (1985), Peplinski *et al* (1995) and Boyarskii Model (2002) have been conducted, to investigate the effects of soil moisture and soil texture on the dielectric behaviour of the soil medium using either guided-wave or free-space transmission techniques. In particular, these studies sought to quantify the role of dielectrically bound water (not necessarily chemically bound water), whose quantity is strongly dependent upon soil texture and mineralogy. The results of these studies and examination of soil textural effects on microwave emission and backscattering explain that the quantity of "bound water" is controlled by soil texture and mineralogy (being roughly proportional to the soil clay fraction), which results in profound differences among soil types with respect to the dielectric constant at a given moisture content.

While studying the effect of soil texture on dielectric behaviour of soils at microwave frequencies Hallikainen *et al* (1985) formulated the model that relates the real and imaginary parts of complex permittivity with the volumetric soil moisture content (SMC) and texture. According to this model ε' and ε'' of the soil can be determined with textural components (sand and clay) of soil in terms of percentage weight, volumetric moisture content and empirically determined coefficients. The model equation generated by curve fitting experimental data with second order polynomial expression was given by equation (1) as

$$\varepsilon' \; or \; \varepsilon'' = (a_0 + a_1 S + a_2 C) + (b_0 + b_1 S + b_2 C) m_v + (c_0 + c_1 S + c_2 C) m_v^2 \quad (1)$$

Where S is percentage of sand and C is percentage of clay, m_v is the volumetric soil moisture content (SMC) of the soil and $a_0 \; a_1 \; ...... c_2$ are the empirically determined coefficients for the best fit.

The empirical model of Hallikainen *et al* (1985) accounts for frequency and soil texture. The equation (1) is applicable to dielectric data collected at frequencies 1.4, 6, 8, 10, 12, 14, 16 and 18 GHz, depending on the values of the parameters used. The values of empirical coefficients a_0, a_1, a_2, b_0, b_1, b_2, c_0, c_1, and c_2 for determination of ε' and ε'' at frequencies 1.4, 2.5, 4.0, 6.01, 8.0 and 10.0, GHz are given in Table 2.

The important Model proposed by Peplinski *et al* (1995), is a variant of the earlier model of Dobson *et al* (1985). This is commonly used dielectric mixing model of soil which includes the lower range of frequency (0.3GHz-1.4 GHz) and accounted for the important parameters of soil, including bulk density, soil texture and soil temperature. Both models (Peplinski and Dobson) are identical except the expressions of conductivity and the real part of the complex permittivity of soil.

Further, the dielectric constant of wet soil is strongly related to texture as is explained in Boyarskii Model (2002). The sand, silt and clay (with dielectric constants ε_{sa}, ε_{si} and ε_{cl}) are considered as spherical inclusions of particles in aerial medium. The bound water is present only in the shape of films around the clay particles and when water films covers entire soil particles it is considered as free water.

Recently, Calla *et al* (2004) generated CVCG model for the estimation of dielectric constant at X band microwave frequencies using only the percentage values of sand, silt and clay in the soil. They have experimentally determined the dielectric constant of different samples of soils of Rajasthan at X band microwave frequencies by wave guide cell method. Using experimental results, Calla *et al* (2004) have generated CVCG model given by the following equation (2).

$$\varepsilon = a^* (\% \; sand) + b^* (\% \; silt) + c^* (\% \; clay) \quad (2)$$

Here the constants a, b and c are function of frequency of microwaves.

Separation of Soil into Textural Constituents

Separate textural constituents (sand, silt and clay) are obtained using the two well known methods described below:

Sieving

Soil for the experimentation has been separated into their textural constituent: sand, silt and clay by the methods of sieving and sedimentation. The sizes of sand particles are larger than 0.05 mm can be separated easily by sieving with fifty micron sieve. The silt (.05 mm to .002 mm) and clay particles (< .002mm) can not be separated with high degree of accuracy by sieving because of the sieving of particles < 2.0 micron is not a easy process. So that, silt and clay particles are separated by sedimentation technique.

Sedimentation

The method of sedimentation involves dispersing a soil sample in water and determining the sedimentation rate of the sand, silt, and clay particles. The dispersed soil particles in water are like a suspended mixture. Sedimentation rates of suspended soil particles depend primarily on particle size. Large particles will settle out of suspension more rapidly than small particles because small particles present more specific area and therefore will experience greater frictional resistance.

Large sand particles settle faster than smaller clay particles. This relationship can be quantitatively expressed by Stoke's Law:

$$v = \left(\frac{D^2 g}{18\eta}\right)(\rho_s - \rho_w) \qquad (3)$$

Where, v = settling velocity (m/s), D = diameter of the particle (m), g = acceleration of gravity (9.81 N/kg), ρ_s = density of the particle (2.65x10^3 kg/m^3), ρ_w = density of the water (1.00 x10^3 kg/m^3), η = viscosity of the water.

Viscosity of water (η) strongly depends on temperature. Its value changes from 1.0 x 10^{-3} Ns/m^2 to 6.5x10^{-4} Ns/m^2 as temperature of water rises from 20 ^{0}C to 40 ^{0}C. We have used the value η =1.0 x 10^{-3} Ns/m^2 in present research work because sedimentation of soil in water is performed at 20.5^0 C.

Stoke's Law can be simplified for our use as gravity remains constant, the particle density and the density of water remain constant and the viscosity of water remains constant at a particular temperature. In the present experimentation, Stoke's Law is approximated by assuming that particles are smooth and rigid spheres having the same density, they do not interact with each other or with the walls of the container. Further, Brownian motion and turbulence are also neglected.

Using the above values in equation (3) we obtain equation (4).

$$v = 9\text{x}10^5 \text{ x } D^2 \quad \text{or} \quad v = kD^2 \qquad (4)$$

The time t, for a soil particle of velocity v to settle at a depth L can be given by

$$t = L / v \qquad (5)$$

Thus, the time t for a particle of diameter D to settle at depth L can be given by equation (6) as

$$t = L / kD^2 \qquad (6)$$

Where t is particle settling time (sec), L is particle settling distance (meter), D is particle diameter (meter) and k = 9x10^5 meter^{-1} sec^{-1}.

The time required for a sand particle with a diameter D = 0.05 mm or 0.00005 m to fall the distance L = 0.30 meter is calculated t = 133.33 seconds. The time required for a silt particle with a diameter of 0.002 mm or 0.000002 m to fall the distance of 0.30 m is calculated t = 83333.33 seconds or 23.148 hours.

Hence time of sedimentation of sand, silt and clay particles strongly depends on temperature. For sand particles (>0.05 mm), the sedimentation time may be between seconds to few minutes and for silt particles (size 0.05 mm to .002 mm) it may be of the order of many hours. After sedimentation of silt particles, the remaining part suspend in water is clay, which sediments up to a few days. An ample amount of soil mass more than 5.0 Kg was used for repeated separation of sand, silt and clay for each sample. Percentage yield obtained for eight different samples separates: Sand, Silt and Clay are given in table:3 respectively.

Sample Preparation

The different percentages of sand, silt and clay in the samples are collected from various sites of Nagaur. In the present investigations, we emphasised on the percentage of clay presents in the soil. Because surface area of soil particles affects it's physical, chemical and electrical properties, which are largely controlled by the amount of clay present in the soil.

Further, the values of ε' and ε'' for all samples at the state of SMC (0 .0276) are calculated using the semi empirical models of Hallikainen *et al* (1985) at a single temperature 37.0 ^{0}C at 10 GHz.

Results and Discussion

The texture effect on the dielectric constant (ε') of soil can be explained as: The dielectric constant (ε') of soil is primarily dependent on the SMC. The water in the soil medium can be classified as bound and free water. At low moisture contents the strong bonds has developed between the surfaces of the soil particles and the thin films of water which surrounding the particles. Smaller particles such as clay have a higher surface area-to-volume ratio and therefore are able to hold more water molecules at higher potentials. The unique plate-like structure of clay provides an additional source of high energy bonds and increases the soil's affinity to water. As more clay is added to the soil volume, surface area of soil increases and more water becomes bound subsequently decreases the dielectric constant of soil. Therefore, in the soils with relatively higher concentration of clay, the water is tightly bound and contributes little to the dielectric constant of the soil water mixture. Hence, in clayey soils which have greater particle surface areas and greater affinities for binding water molecules hold greater percentages of bound water. Bound water is less freely able to exhibit molecular rotation at microwave frequencies and hence, has a smaller dielectric effect than that of the free water in the pore spaces.

The present investigation the dielectric studies of soil of Nagaur region with textual consideration very important because, this parameter decide the very important properties of soil like, water holding capacity, mutual adhesion between soil particles, hydraulic conductivity, infiltration, surface run-off etc. Texture of a soil is a stable parameter does not change with respect to time. Since Nagaur region is situated at the Thar desert and soil erosion due to air and water, expansion of desert and dust-storms are burgeoning problems related to texture of soil of this area. Soil of this region is mostly sandy loam having low water holding capacity, so that monitoring of soil regarding textural composition through dielectric and remote sensing studies are important for the conservation of soil of this region.

Further, important moist states of soil from agricultural view point hygroscopic coefficient, wilting point, transition moisture and field capacity are strongly related to texture of soil. Availability of water for a particular plant from soil is controlled by texture of soil during distress time. So that continues monitoring of spatial and temporal variations of SMC through ground based dielectric studies and microwave remote sensing studies are very important for soil- water management studies of this area.

Table-1: Classification of Soil Particles as a Function of Diameter (Millimeters)

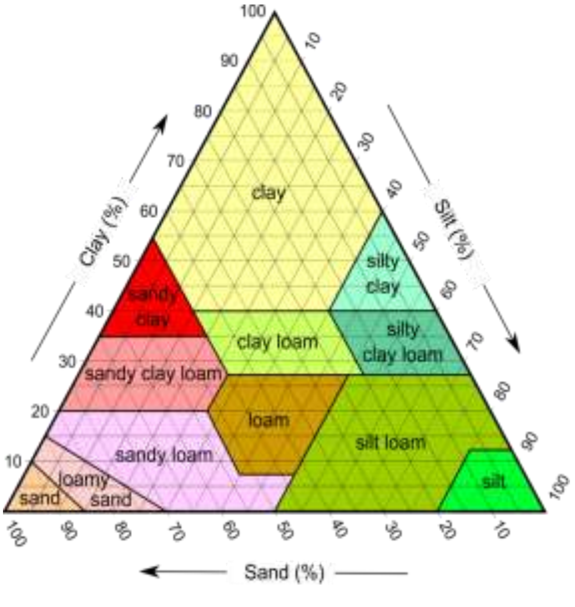
S. No.	Soil Separates	Size range (mm)
1	Clay	< 0.002
2	Silt	0.05 - 0.002
3	Very Fine Sand	0.10-0.05
4	Fine Sand	0.25-0.10
5	Medium Sand	0.50-0.25
6	Coarse Sand	1.00-0.50
7	Very Coarse Sand	2.00-1.00

Table -2: Hallikainen Model Coefficients at Different Microwave Frequencies for ε' and ε'' of soil

	Frequency (GHz)	a_0	a_1	a_2	b_0	b_1	b_2	c_0	c_1	c_2
Coefficients for Real Part of complex permittivity (ε')	1.4	2.862	-0.012	0.001	3.803	0.462	-0.341	119.006	-0.5	0.633
	2.45	3.009	-0.013	-0.002	0.773	0.48	-0.046	129.347	-0.64	-235
	4.0	2.927	-0.012	-0.001	5.505	0.371	0.062	114.826	-0.389	-547
	6.0	1.993	-0.002	0.015	38.086	-0.167	-0.633	10.72	1.256	1.522
	8.0	1.997	-0.003	0.018	25.579	-0.017	-0.412	39.793	0.723	0.941
	10.0	2.502	-0.001	-0.003	10.001	0.221	-0.004	77.482	-0.061	-0.135
Coefficients for Imaginary Part of complex permittivity (ε")	1.4	0.356	-0.003	-0.008	5.507	0.044	-0.002	17.753	-0.313	0.206
	2.45	0.187	-0.001	-0.003	2.33	0.031	0.007	18.895	-0.08	0.22
	4.0	0.004	0.001	0.002	0.951	0.005	-0.01	16.759	0.192	290
	6.0	-0.123	0.002	0.003	7.502	-0.058	-0.116	2.942	0.452	0.543
	8.0	-0.201	0.003	0.003	11.226	-0.085	-0.155	0.194	0.584	0.581
	10.0	-0.07	0	0.001	6.62	0.015	-0.081	21.578	0.293	0.332

Table -3: Soil Samples of Different Texture and Calculated Values of Real and Imaginary Part of Dielectric Constant by Hallikainen Model at 10 GHz at 0 .0276 volumetric SMC

S. No.	Sample	% of Clay	% of Silt	% of Sand	ε'	ε"
1	A	1.7	30.06	68.24	3.179	0.171
2	B	3.4	15.4	81.2	3.239	0.178
3	C	6.6	15	78.4	3.215	0.173
4	D	7.14	18.4	74.46	3.193	0.170
5	E	8.5	22.6	68.9	3.161	0.165
6	F	9.11	17.3	73.59	3.182	0.167
7	G	10.24	9.7	80.06	3.211	0.170
8	H	12	14.6	73.4	3.172	0.164



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