IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

DIELECTRIC STUDY OF SOIL CONTAMINATED BY CRUDE OIL AT MICROWAVE FREQUENCY

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Abstract

The real and imaginary parts of dielectric constant (ε' and ε'') of artificially contaminated dry and moist soil (contaminated with crude oil) are determined, percentage concentration of crude oil varying 0.0% to 10.0% gravimetrically. ε' and ε'' of soil are determined at 34.5^{0}C temperature and at a single microwave frequency 9.78 GHz by wave guide cell method. It was observed that ε' and ε'' increases as percentage concentration of crude oil in the soil increase but the effect of crude oil mixing on dielectric properties is more significant for moist soils. ε'' of moist soil is strongly correlated with contamination level of soil. The parameter "tangent loss" related to the microwave heating of soil is also measured regarding reclamation of soil.

1.Introduction

Soil contamination is the alteration in the natural soil environment. Many contaminants have been reported as sources of organic contamination of soil such as: petroleum product, mineral oils, fuels, aromatic hydrocarbons, automobile exhaust, industrial effluents, fertilizers and pesticides. Primary reason of soil contamination is associated with increased use of petroleum products. Crude oil is basic source of all petroleum products, comprise varying fractions of different hydrocarbons with different boiling points. Crude oils can vary greatly in composition, viscosity, density and flammability. The chemical composition of crude oil varies between regions and even within the same geological formation. The major fractions are defined as: Light ends (C_2-C_5), Light naphtha, Medium naphtha, Heavy naphtha, Kerosene, Light gas oil, PGO (pyrolysis gas oil) and Residual oil.

It is no longer a matter of argument that human activities regarding development (urbanization, industrialization, vehicular traffic) have increased the presence of the hydrocarbons in the soil, which has significant social and environmental impacts. Human exposition of these compounds can have serious health consequences like neurological diseases or cancer. Characterization of soil contaminated with crude oil and the determination of the level of contamination and reclamation of contaminated soil is important emerging field of study. Several geophysical methods have been developed which utilizes the contrast in the physical properties of the soil caused by the presence of organic contaminant. Dielectric studies show high potential for characterization of contaminated soil[1]. Detection of locations of contamination sites, determination of the level of contamination and reclamation of contaminated soils are possible by dielectric studies at microwave frequencies. The dielectric constant is an electrical property of matter and is a measure of the response of a medium to an applied electric field. This is a complex quantity include both real and imaginary parts. The real (in phase) component determines the propagation characteristics of the electromagnetic wave in the material (i.e. its velocity), imaginary component (out of phase) determines the energy losses or absorption as the electromagnetic wave travels through the material, and is often referred to as the dielectric loss factor and related to microwave heating of materials.

According to various dielectric mixing models[2-5] the dielectric permittivity of an inhomogeneous media like contaminated soil is function of permittivity of the constituent phases (soil solid, water, air and crude oil), the fractional volume of each phase and possibly some other parameters characterizing the microstructure of the mixture. When no contaminants are present, the pore space in dry soil is completely filled with air, wet soils pores are partially filled by air and water (vapor and liquid). In case of contaminated moist soil the relative volume fraction of the three phases in the pore structure of the soil (water, crude oil and air) describe the dielectric properties. The dielectric properties of soils at microwave frequencies greatly depend upon soil moisture content (SMC) in free state[6]. In case of contamination with hydrocarbons, the soil moisture profile in the sub surface changes due to presence of hydrophobic nature of contaminants. Thus, the water retention capacity, tenancy, hydraulic conductivity and nature of SMC may be controlled by the percentage of organic contaminants in the soil up to an extent. So we can say that the degree of freeness of water in the soil is directly related to the percentage of contaminants.

2. Experimental procedure and theory

For sample preparation, the soil of Alwar has been selected. Soil was grinded and sieved well. Textural composition of soil was determined (sand=67.6%, silt= 24.3% and clay= 8.1%) by the method of sieving and sedimentation. Soil was oven dried for twenty four hours at temperature 110^0C. The total twenty two soil samples are prepared and divided into two groups (dry and moist) such that each group consist eleven samples. One group of samples kept oven dried and other group of samples is artificially moistened by desired amount of conductivity water, in order to have volumetric SMC= 5.0%. Time of setting has taken twenty four hours for SMC mixing. The eleven samples of each group have been contaminated with crude oil obtained from Mathura refinery. Concentration of crude oil was kept at 0.0%, 1.0%, 2.0%, 3.0%, 4.0%, 5.0%, 6.0%, 7.0%, 8.0%, 9.0% and 10.0% by weight of dry soil. The mixture of soil samples are shake well for 30 minutes for even mixing of crude oil and then kept for twenty four hours in sealed plastic air tight container to avoid any evaporation. The aim of this operation is to ensure a uniform distribution of crude oil and moisture within the soil samples and a well adsorption of crude oil and water by the soil grains. Dielectric constant of soil determined at 34.5^0C temperature and at a single microwave frequency 9.78 GHz. Dielectric constant of soil has been measured by using the shift in minima of the standing wave pattern inside a rectangular wave-guide excited in TE_{10} mode. The experimental set-up theory and procedure for the present work is the same as used earlier by other workers[7-8] The dielectric constant (ε') and dielectric loss (ε″) for low level SMC and contamination present in the soil are determined using the following equations (1) and (2) respectively.

$$\varepsilon' = \left(\frac{\lambda_0}{\lambda_c}\right)^2 + \left(\frac{\lambda_0}{\lambda_d}\right)^2\left[1-\left(\frac{\alpha_d}{\beta_d}\right)^2\right] \tag{1}$$

$$\varepsilon'' = 2\left(\frac{\lambda_0}{\lambda_d}\right)^2\left(\frac{\alpha_d}{\beta_d}\right) \tag{2}$$

Where λ_0, λ_c, and λ_d are the free space wavelength, cut off wavelength (λ_c=2a) and wave length in the dielectric medium respectively, for the wave-guide excited in TE_{10} mode. α_d is the attenuation introduced per unit length of the material (in napers per meter) . β_d is the phase shift introduced per unit length of material in radian per meter. Magnitude of the complex permittivity of the soil is given by the following equation (3).

$$\varepsilon^* = |\varepsilon' - j\varepsilon''| \tag{3}$$

3. Results and Discussion

The variations of ε′ and ε″ of contaminated soil (dry and wet) with percentage concentration of crude oil (0.0% to 10.0 %) are shown in figure 1. It was observed that ε' increases with increasing percentage of concentration of crude oil in dry and moist soils. The ε″ for contaminated dry soil hardly increases with increasing crude oil concentration. But the ε″ of moist contaminated soil fairly increases with increasing crude oil content.

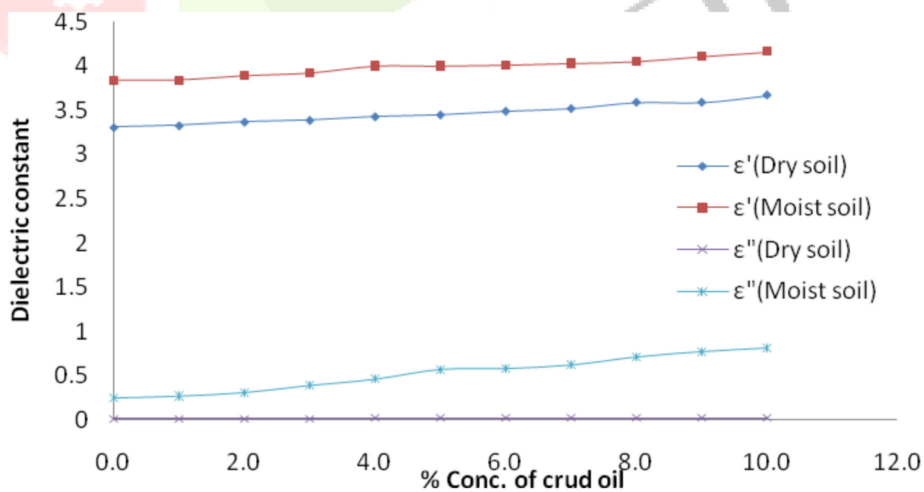

Figure 1: Variations of (ε') and (ε″) w.r.t percentage conc. of crude oil for dry and moist soil

The variations of tangent loss factor (tan δ) of contaminated soil (dry and wet) with percentage concentration of crude oil (0.0% to 10.0 %) are shown in figure 2. It is evident from figure that tangent loss is quietly higher for moist soil and slightly increases as percentage concentration of contamination increases.

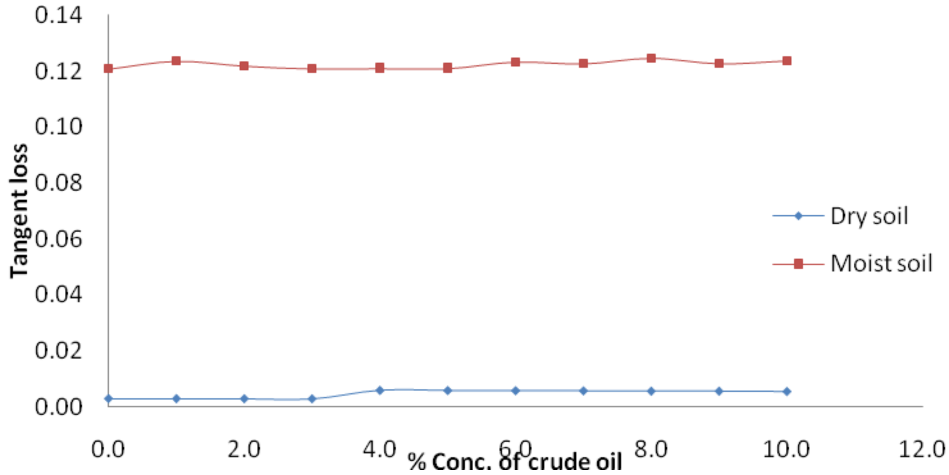

Figure-2: Variations of tangent loss w.r.t percentage conc. of crude oil for dry and moist soil

The dielectric mixing models[2-5] predicted that dielectric constant of soil will increase if the volumetric percentage of any constituent phase of soil corresponds to higher value of dielectric constant increases. The dielectric constant (ε' and ε") of crude oil measured at X band microwave frequency (4.26 and 0.61) are higher than ε' and ε" of soil mineral and air. Further the electromagnetic properties of soils are dependent on the interaction of the various phases (water, crude oil and air) in the voids of unsaturated moist soil. Due to phase interactions, the conducting channels of water forms in the pore space of soil[9]. Large number of the conducting channels means more free water is available inside the soil. At low moisture contents the unsaturated soil tends to form few conducting channels through the pore structure of soil and several other channels were terminated by air voids. Adding crude oil to this soil will fill some of the air voids and some of crude oil will displace water and give more chance for the water to form more conducting channels. This can attribute to the increase of ε' with increase in the conductance channel (free water content) formed by water. The loss factor ε" increases with contamination because, crude oil has the complex compositions consisting various compound as resins having the polar molecules, often containing hetero-atoms such as nitrogen, oxygen or sulphur. Further, certain amount of moisture is always present in contaminant. Due to these reasons loss factor may increase with contamination.

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