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# DIELECTRIC PROPERTIES OF BLACK SANDY SOILS AT LOW FREQUENCY

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## ABSTRACT

**Dielectric properties of black sandy soil collected from different part of Manipur valley are measured for different temperature using LCR meter SM6019 at low frequencies 1000Hz, 5000Hz, 12500Hz and 25000Hz. The real (ε′) and imaginary (ε″) components of dielectric constant are plotted as a function of temperature. At lower frequencies the imaginary (ε″) dominate due to orientational polarization of water molecules and interfacial polarization at grain boundaries but at higher frequencies real (ε′) dominate due to the soil retains a reasonable capacity to store electrical energy through polarization mechanisms. The dominance of ε′ over ε″ at these higher frequencies implies that polarization processes prevail over loss mechanisms, highlighting efficient energy storage and stable dielectric performance of black sandy soil in low-temperature, high-frequency regimes. Such soils at low frequency are important for assessing soil moisture content, fertility, and texture**

**KEYWORDS:** Frequency, Dielectric constant, Black soil, Water molecule, Electric dipole, Polarization

Electrical properties of every material are different to each other which are dependent on its dielectric properties. The dielectric constant is a measure of the response of a system to an applied field. These properties provide the valuable information which helps researchers to utilize these data into their design or for the purpose of material characterization or for monitoring quality. Black sandy soils are prevalent in Manipur, contributing significantly to the region's agricultural landscape. Understanding the dielectric properties of soils, are essential for effective soil management, agriculture and environmental monitoring in Manipur. It also influences various phenomena such as soil moisture content, soil salinity, nutrient availability, soil structure and soil composition. Black sandy soils are characterized by its coarse texture and low water retention capacity, is widely distributed and has significant importance in agriculture and environmental studies. Understanding the frequency dependence of the dielectric constant of sandy soil is essential for interpreting electromagnetic measurements in fields such as geophysics, agriculture, and environmental monitoring (Pancholi, 1994). The dielectric properties of soil are function of its naturally available chemical constituents such as carbon, sodium, potassium, iron and physical properties such as sand, silt, clay (Chaudhary *et al.*, 2020). The dielectric constant is directly proportional to pore-space of soil (Wang and Schmugge, 1980). Also, dielectric constant increases with gravimetric moisture content and then rapidly after a fixed frequency (Rajeev and Sharma, 2016). In the low frequency band, the intensification mechanism causes the dielectric permittivity of rocks and soils to increase with decreasing frequency, and in the high frequency band (higher than 10 GHz), the dielectric permittivity values start to decrease as they start to approach the relaxation frequency of water molecules (Bittelli *et al.*, 2004).

This paper reports an experimental investigation importance of low frequency dependence of the dielectric constant of black sandy soils in Manipur to enhance our understanding of their electrical behavior.

## METHODOLOGY

### Theoretical

The dielectric properties of a material depend on the concentration, activity of the permanent electric dipole molecules, ionic conduction and degree of alignment with the applied time varying electric field. Therefore, when sample holder is field with material, the dielectric properties are affected by the composition of the material and temperature, which affects the molecular movement.

In an alternating electric field, the complex permittivity varies with applied frequency. This frequency dependence can be described by the complex permittivity.

$$\varepsilon^* = \varepsilon_r' - j\varepsilon_r''$$

Where, $j = -1$, $\varepsilon_r'$ is real part called dielectric constant or dielectric permittivity which represents the storage of electric field and $\varepsilon_r''$ is an imaginary part, called loss factor which represents how much energy

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dissipate is a measure i.e. how dissipative a material is to an external electric field. The dielectric constant is associated to material's capacitance which is ability to store energy (polarization) i.e. how much electrical energy store when an electric field is applied. The ratio between dielectric constant (real part) and loss factor (imaginary part) of permittivity correspond to another parameter, dissipation factor or loss tangent.

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'}$$

where tanδ represents ratio of energy lost to energy stored per cycle.

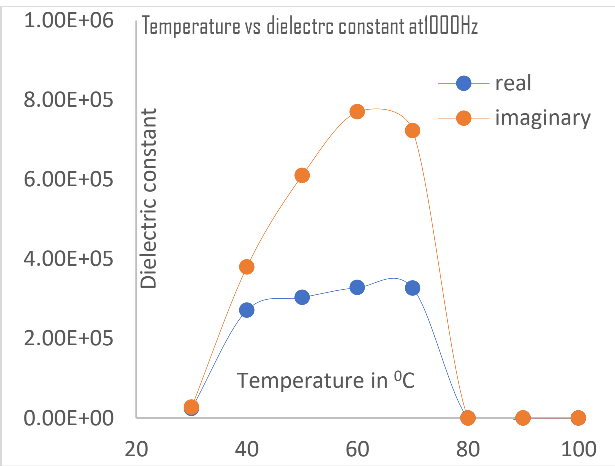
**Experimental**

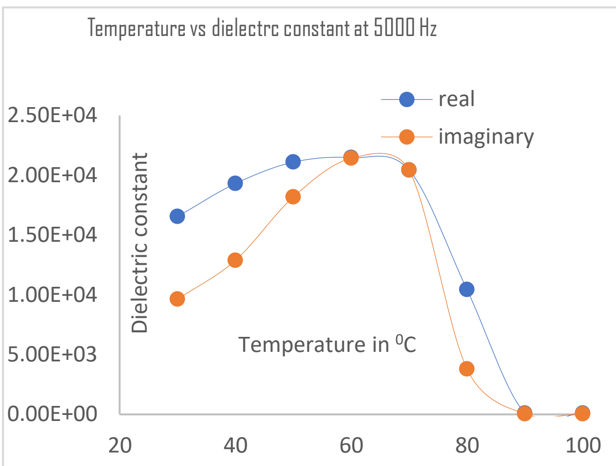
A thin sheet sample of thickness 1.8 mm is sandwiching between two copper electrodes having diameter 2.2cm to form a capacitor. Measurements can be taken using LCR meter SM6019 model for a certain frequency for different range of temperature. The sample preparation and measurement are same as that reported earlier (Shantibala *et al.*, 2024)

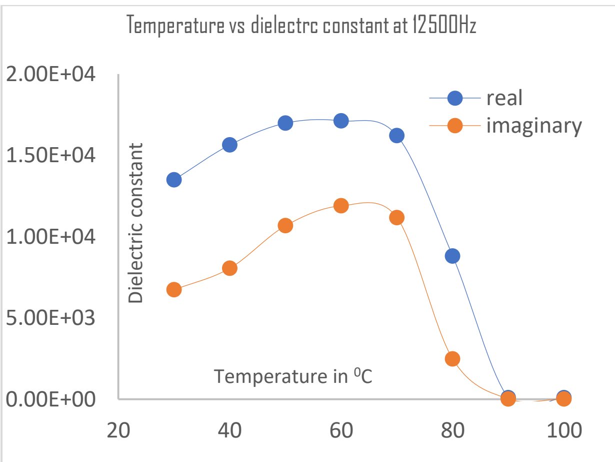
To measure dielectric constant, placing a dielectric sample into a sample holder, then sample holder was placed in the temperature-controlled bath (i-therm) and measured capacitance to calculate the permittivity. It has high measurement accuracy and involves very simple sample preparation and setup, typically frequency range from 1000Hz to 25000Hz use for this purpose.

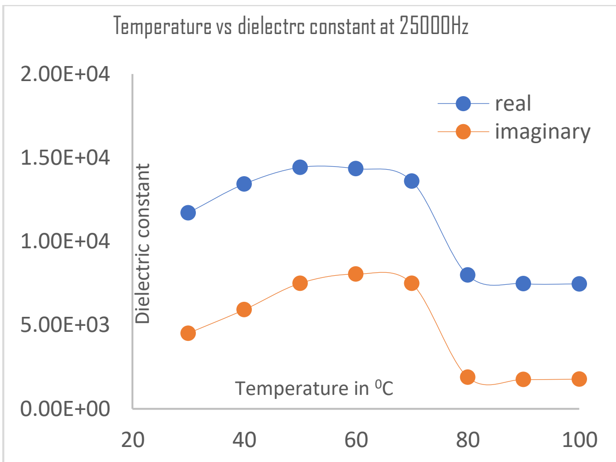
## RESULTS AND DISCUSSION

The temperature dependence of the dielectric constant of black sandy soil measured at 1000 Hz, 5000 Hz, 125000 Hz and 250000 Hz reveals a pronounced influence of thermal activation on both the real (ε′) and imaginary (ε″) components. At low temperature, the dielectric constant shows relatively small values, indicating limited polarization and low dielectric loss. In black sandy soil, polarization at such low frequency is mainly governed by space-charge polarization arising from soil particles, adsorbed water layers, dissolved ions, and the electrode–soil interface (Dhiware, 2018). At lower temperatures, the mobility of ions and bound water molecules is restricted, resulting in a reduced dielectric response.



At low frequencies such as 1000 Hz, as the temperature increases from 30 °C to nearly 60–65 °C, both $\varepsilon_r'$ and $\varepsilon_r''$ increase rapidly, with $\varepsilon_r''$ showing a much steeper rise. The enhancement of $\varepsilon'$ suggests increased orientational polarization of water molecules and interfacial polarization at grain boundaries. Simultaneously, the sharp rise in $\varepsilon_r''$ indicates significant dielectric loss due to thermally activated ionic conduction and hopping of charge carriers between localized states within the soil matrix (Al-Hafid *et al.*, 2018). The large magnitude of $\varepsilon_r''$ compared to $\varepsilon_r'$ in this temperature range reflects the dominance of loss mechanisms, which is typical for soil systems rich in moisture and ionic species at low frequencies. The broad maxima observed around 60–70 °C may be associated with a relaxation process involving bound water and space-charge accumulation at interfaces. At 5000 Hz, as the temperature increases to about 60°C, both $\varepsilon_r'$ and $\varepsilon_r''$ increase gradually and reach broad maxima. It shows that the energy dissipated in the form of heat is proportional to the dielectric loss due to thermally activated hopping of ions and charge carriers within the soil (Hu *et al.*, 2022).

For higher frequencies (12500Hz & 25000Hz) at low temperature, the real part of the dielectric constant ($\varepsilon_r'$) shows a moderate value, while the imaginary part ($\varepsilon_r''$) is comparatively smaller, indicating that energy storage through polarization dominates over dielectric loss at this frequency and low temperature. At higher these frequencies, the dielectric behavior of black sandy soil at low temperatures reflects a balanced and stable response to an applied alternating electric field. Under these conditions, the real part of the dielectric constant ($\varepsilon_r'$) exhibits a moderate magnitude, signifying that the soil retains a reasonable capacity to store electrical energy through polarization mechanisms. At low temperatures, the thermal motion of charge carriers and dipolar species is reduced, which limits excessive polarization but still allows bound charges to respond effectively to the external field. In contrast, the imaginary part of the dielectric constant ($\varepsilon_r''$) remains relatively small, indicating minimal dielectric loss and reduced energy dissipation within the soil matrix (Navarkhele *et al.*, 2015). This lower loss component suggests restricted charge hopping and suppressed conduction processes at low temperatures. Overall, the dominance of $\varepsilon_r'$ over $\varepsilon''$ at these higher frequencies implies that polarization processes prevail over loss mechanisms, highlighting efficient energy storage and stable dielectric performance of black sandy soil in low-temperature, high-frequency regimes.

For all present frequency range, beyond approximately 65–70 °C, a sharp decline in both $\varepsilon'$ and $\varepsilon''$ is observed. This decrease is primarily associated with moisture loss and dehydration of the soil at elevated temperatures, which significantly reduces dipolar polarization. Increased thermal disorder further disrupts the alignment of dipoles, while the reduction in available mobile ions leads to diminished dielectric loss (Von Hippel and Morgan, 1955). At temperatures above 85–90 °C, both dielectric components approach very low or nearly zero values, indicating that the soil becomes effectively non-polarizable at this frequency once it is largely dried (Yadav *et al.*, 2009).

The dielectric constant at low frequency has important practical applications, particularly in soil and environmental studies. Low-frequency dielectric measurements are highly sensitive to soil moisture content because space-charge and interfacial polarization contribute strongly in this regime. This property is widely used in agriculture for real-time monitoring of soil water status, optimizing irrigation scheduling, and improving crop productivity (Nelson, 2015). In geotechnical engineering, low-frequency dielectric data help assess soil structure, porosity, and compaction. Additionally, low-frequency dielectric properties are crucial in ground-penetrating radar, subsurface imaging, and environmental monitoring, where accurate interpretation of soil composition and moisture distribution is required. Thus, understanding dielectric behaviour across temperature at higher frequencies complements low-frequency studies and provides a comprehensive picture of black sandy soil characteristics.

## CONCLUSION

The study demonstrates that the dielectric behaviour of black sandy soil is strongly governed by both temperature and frequency. At low frequencies, increasing temperature enhances space-charge and interfacial polarization, leading to significant rises in both dielectric constant and loss, with loss mechanisms dominating due to thermally activated ionic conduction. At higher frequencies and low temperatures, polarization processes prevail over dielectric losses, indicating stable and efficient energy storage. Beyond 65–70 °C, moisture loss causes a sharp decline in dielectric response across all frequencies, rendering the soil nearly non-polarizable at high temperatures. These findings highlight the sensitivity of dielectric properties to soil moisture and thermal conditions, underscoring their relevance in agricultural, geotechnical, and environmental applications.

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