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Brewster's Angle as a Diagnostic Tool for Soil Reclamation

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Abstract: *This study investigates the variation in Brewster's angle of contaminated and reclaimed soil samples with varying moisture content using the waveguide cell method. Ten samples of each soil type were analysed over a moisture content range from 0% to 30%. Results consistently indicate a positive correlation between moisture content and Brewster's angle in both soil types. However, contaminated soils showed a steeper increase and higher maximum Brewster's angle values compared to reclaimed soils. The study provides insight into the dielectric behaviour of soils, aiding remote sensing, microwave soil characterization, and environmental monitoring.*

Keywords: Brewster's angle, contaminated soil, reclaimed soil, waveguide cell, microwave characterization, moisture content, dielectric properties

I. INTRODUCTION

Brewster's angle is a critical optical parameter at which reflected electromagnetic wave intensity becomes minimized or null for p-polarized light at an interface between two media. In soil physics and remote sensing, it provides information about the dielectric properties of soils, which are directly affected by factors like moisture content, contamination, and soil texture (Ulaby et al., 1986; Verma and Roy, 2020).

Contaminated soils, due to industrial effluents and pollutants, often undergo reclamation for safe reuse. Monitoring the effectiveness of such reclamation involves evaluating their electromagnetic behaviour (Reddy and Kumar, 2023). The waveguide cell method offers a non-destructive and efficient approach to determining dielectric parameters at microwave frequencies (Patel and Mehta, 2021; Sharma and Singh, 2022).

This study aims to examine Brewster's angle variation in contaminated and reclaimed soil samples with moisture variation, using a waveguide cell setup at X-band frequencies.

II. MATERIALS AND METHODS

Soil Sampling:

The soil samples were collected from different contaminated sites from this area. The soil contaminated sites formed due to Oil factory, Chemical factory, Sugar factory and Textile mills are selected for this study. The most common chemicals involved causing soil pollution are petroleum hydrocarbons, heavy metals, pesticides, fertilizers, weedicides and other solvents. We collected contaminated soil samples from ten contaminated sites from North Maharashtra Region. Ten soil samples each were collected from contaminated and reclaimed sites. Contaminated soils were sourced from regions with known industrial activity, while reclaimed soils underwent biological and chemical treatment (Reddy and Kumar, 2023). Each soil sample was dried and rehydrated to specific moisture contents: 0%, 5%, 10%, 15%, 20%, 25%, and 30% (Topp and Davis, 1985).

These soil samples were first sieved by gyrator sieve shaker of size 425 μm to remove the coarser particles in the soil. The sieved out fine particles are then dried in the hot air oven shown in Fig.3.4 to a temperature around 110oC for about 24 hours in order to completely remove any trace of moisture. Such dry samples are then called as oven-dry or dry base samples as compared with wet samples. Soil samples of various volumetric moisture contents (up to 30%) are

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prepared by adding an exact amount of distilled water to the known mass of the oven dry soil. The single pan precision balance having digital readout accuracy of 0.1 mg. is used for weighing the sample. The soil-water mixtures are well mixed and are kept in a closed container for proper settling over several hours. These contaminated soil samples of desired volumetric moisture content are then inserted into the solid dielectric cell for measuring their dielectric properties.

Experimental Set-up:

We use the Waveguide Cell Method to measure dielectric measurement in X-band frequency range. This method is perhaps the best known and is most widely used. It is useful over wide range of frequencies (500 MHz - 110 GHz) and can measure both real and imaginary part of dielectric constant of solids, liquids and semi-liquids. Further, this method gives comparatively more accurate results. The details of dielectric constant measurement set up for X-Band can also be seen from the photographs given in Figure 1.

Fig.1 Photograph of automated X-band microwave bench setup for measurement of dielectric constant of contaminated and reclaimed soils.

The waveguide cell method was employed using an X-band (8.2–12.4 GHz) waveguide. The setup comprised:

- A waveguide sample holder (WR-90)
- A network analyser for reflection measurement
- A rotating mechanism to vary incidence angle (Patel and Mehta, 2021; Sharma and Singh, 2022)

The angle at which the reflected signal minimum occurred (Brewster's angle) was recorded for both contaminated and reclaimed samples at each moisture level.

The Waveguide Cell Method is a practical and accurate approach to measure the Brewster's angle in dielectric or soil samples, especially at microwave frequencies. Brewster's angle (θ_B) is the angle of incidence at which the reflected power of a polarized electromagnetic wave is minimized (ideally zero) when it encounters a dielectric surface.

At Brewster's angle $\tan \theta_B = n_2/n_1$, where n_1 is the refractive index of the incident medium (usually air) and n_2 is that of the dielectric or soil sample. The angle of incidence of the microwave is varied gradually by rotating the waveguide or adjusting the position of the sample inside the waveguide. Microwave detector is used to measure the reflected power at different angles. At the Brewster angle, the reflected power drops to a minimum or null.

III. RESULT AND DISCUSSION

Result:

The following trends were observed:

- Consistent Increase: Brewster's angle increased with increasing moisture in both soil types, due to the rise in dielectric constant with water content (Robinson et al., 2008).
- Contaminated vs. Reclaimed: Contaminated soils exhibited higher Brewster's angles than reclaimed ones at each moisture level.

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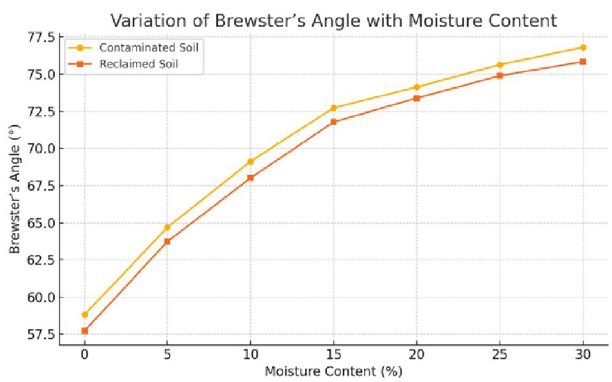
- Plateau Behaviour: Beyond 20% moisture content, the rate of increase in Brewster's angle diminished, consistent with saturation behaviour in dielectric response (Njoku and Kong, 1977).

The average values across 10 samples at different moisture levels are summarized below:

Sr. No.	Moisture Content (%)	Avg. Brewster Angle (°) for Contaminated Soil Samples	Avg. Brewster Angle (°) for Reclaimed Soil Samples
01	0	58.82	57.73
02	5	64.69	63.74
03	10	69.13	68.01
04	15	72.73	71.78
05	20	74.13	73.39
06	25	75.64	74.89
07	30	76.80	75.84



Discussion:

The increase in Brewster's angle with moisture content is attributed to the enhanced dielectric constant of wet soils. The dielectric constant, which determines the phase shift and wave impedance, increases with water content due to water's high permittivity (~80 at room temperature) (Von Hippel, 1954; Ulaby et al., 1986).

Contaminated soils showed consistently higher Brewster's angles, possibly due to increased ionic content and presence of heavy metals, which elevate the effective permittivity (Reddy and Kumar, 2023). Reclaimed soils, despite remediation, did not fully match the dielectric behaviour of natural soils.

This discrepancy suggests that reclamation may restore structural or chemical properties but dielectric differences can remain making Brewster's angle a sensitive parameter for assessing reclamation efficacy (Sharma and Singh, 2022).

IV. CONCLUSION

The waveguide cell method effectively measured Brewster's angle variation in soils. Moisture content significantly affects Brewster's angle, and contaminated soils exhibit higher values due to elevated dielectric properties. These findings support the use of microwave techniques in environmental diagnostics and remote soil sensing (Verma and Roy, 2020; Robinson et al., 2008).

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