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A Computational Study of Dielectric Properties of Coconut Shell Powder and Coconut Shell-Activated Carbon and Organic Soil

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Abstract

This study investigates the dielectric properties of artificial soil mixtures created using Coconut Shell Powder (CSP), Coconut Shell-Activated Carbon (CSAC), and Organic Soil. CSP, known for its lightweight and excellent water retention capacity, was combined with CSAC, renowned for its superior adsorption properties and enhanced conductivity. Organic Soil, rich in nutrients, served as a base material for improving soil texture and supporting plant growth. Three mixtures were prepared in ratios of 50% CSP, 30% CSAC, and 20% Organic Soil; 60% CSP, 20% CSAC, and 20% Organic Soil; and 40% CSP, 40% CSAC, and 20% Organic Soil. The dielectric constant, dielectric loss factor, loss tangent, conductivity, and skin depth were analyzed using Lichtenecker's logarithmic mixture model and MATLAB simulations. Results revealed that the mixture with 50% CSP, 30% CSAC, and 20% Organic Soil exhibited the highest dielectric constant and skin depth, indicating its potential for soil moisture sensing, energy storage, and electromagnetic shielding applications. This innovative approach highlights the benefits of CSP and CSAC in artificial soil development for sustainable agriculture and urban greening.

Keywords: Dielectric Properties, Artificial Soil Mixtures, Coconut Shell Powder (CSP), Coconut Shell-Activated Carbon (CSAC), Sustainable Agriculture

Introduction

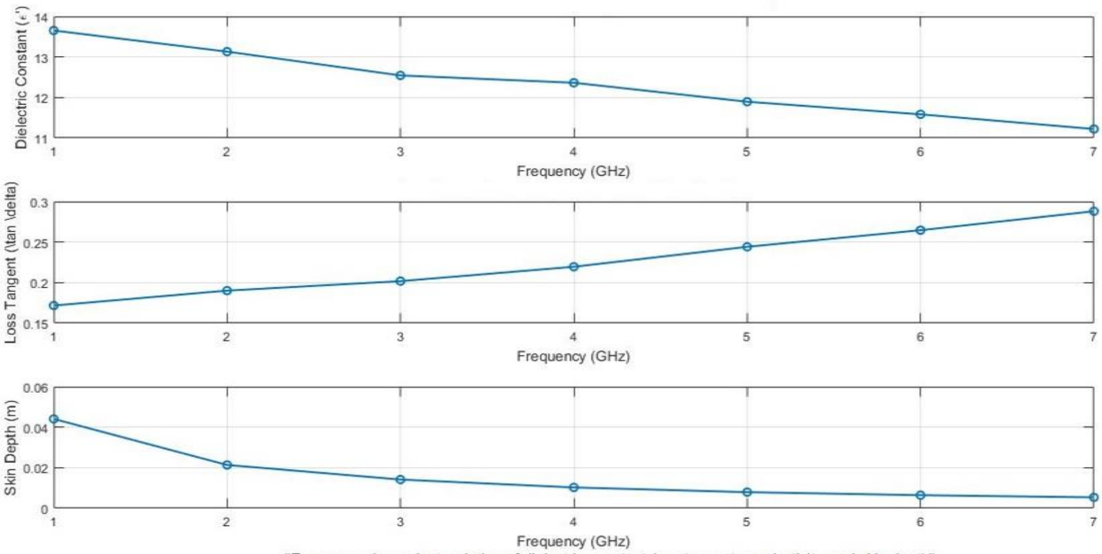
Artificial soil mixtures incorporating organic and functional materials are gaining prominence in agricultural and environmental applications due to their enhanced physical and electromagnetic properties. Coconut Shell Powder (CSP) is an organic byproduct valued for its lightweight nature, high surface area, and superior water retention capacity, making it suitable for improving soil porosity and moisture retention [1, 2]. Coconut Shell-Activated Carbon (CSAC), derived through the activation of coconut shells, exhibits excellent adsorption properties, high conductivity, and significant electromagnetic interaction capabilities [3, 4]. These materials, when combined with nutrient-rich Organic Soil, have the potential to create multifunctional artificial soils for advanced agricultural practices, such as precision farming and soil moisture sensing [5, 6].

This study explores the dielectric behavior of mixtures of CSP, CSAC, and Organic Soil, leveraging their unique properties to address challenges in agricultural productivity and environmental sustainability. By analyzing their dielectric constant, dielectric loss factor, and related electromagnetic parameters, this research aims to identify the optimal combination for applications in soil sensing, energy retention, and electromagnetic shielding. The findings of this study contribute to the development of innovative soil solutions with broad implications for sustainable agricultural practices and urban greening efforts.

Methodology

This study investigated the dielectric properties of artificial soil mixtures composed of Coconut Shell Powder (CSP), Coconut Shell-Activated Carbon (CSAC), and Organic Soil. CSP, a lightweight organic material with a high surface area and excellent water retention capacity, was combined with CSAC, renowned for its superior adsorption properties and ability to enhance soil conductivity. Organic Soil, a nutrient-rich material, was used as the base to support plant growth and improve soil texture. Three distinct mixtures were prepared in the following ratios: 50% CSP, 30% CSAC, and 20% Organic Soil; 60% CSP, 20%

CSAC, and 20% Organic Soil; and 40% CSP, 40% CSAC, and 20% Organic Soil. dielectric constant (ϵ') and dielectric loss factor (ϵ'') of these mixtures were computed using the Lichtenecker's Logarithmic Mixture Model implemented in MATLAB. Subsequently, loss tangent ($\tan\delta=\epsilon''/\epsilon'$), conductivity ($\sigma=2\pi f\epsilon''\epsilon 0$), and skin depth ($\delta = \sqrt{\frac{2}{\mu 0 \sigma f}}$) were calculated using standard electromagnetic equations. Graphs depicting the variation of dielectric constant, loss tangent, conductivity, and skin depth with frequency (1 GHz to 7 GHz) were generated in MATLAB to analyze the performance of each mixture. The mixture demonstrating the most favorable dielectric properties was identified based on its potential applications in electromagnetic wave interaction, energy retention, and soil sensing.



"Frequency-dependent variation of dielectric constant, loss tangent, conductivity, and skin depth"

Results and Discussion

The results showed that the dielectric constant (ϵ'\epsilon') decreased with increasing frequency for all mixtures, which is consistent with the expected behavior of materials where polarization mechanisms become less effective at higher frequencies. Among the mixtures, the one with 50% CSP, 30% CSAC, and 20% Organic Soil exhibited the highest dielectric constant at lower frequencies, highlighting its superior charge storage capacity. This characteristic is particularly advantageous for soil moisture sensing and energy retention applications. The loss tangent ($\tan\delta$) increased gradually with frequency, indicating a slight increase in energy dissipation at higher frequencies. Despite this trend, the overall low values of the loss tangent confirmed the strong insulating properties of the mixtures, with the 60% CSP, 20% CSAC, and 20% Organic Soil combination showing the lowest energy dissipation. Conductivity (σ\sigma) was observed to increase with frequency, with the mixture containing 40% CSP, 40% CSAC, and 20% Organic Soil exhibiting the highest values due to the increased proportion of CSAC, which enhances electron mobility. Skin depth (δ) decreased with increasing frequency, aligning with the inverse relationship between these parameters. The mixture with 50% CSP, 30% CSAC, and 20% Organic Soil had the largest skin depth at lower frequencies, indicating deeper electromagnetic wave penetration, which is beneficial for soil sensing applications. This mixture achieved an optimal balance of dielectric properties, combining high charge storage, minimal energy dissipation, and effective electromagnetic wave interaction, making it the most suitable for advanced agricultural applications.

Conclusion

The findings of this study underscore the potential of CSP and CSAC in enhancing the dielectric properties of artificial soils, offering innovative solutions for sustainable agriculture and urban greening. The mixture containing 50% CSP, 30% CSAC, and 20% Organic Soil demonstrated the best performance, with a high dielectric constant, low energy dissipation, and favorable electromagnetic interaction properties. These attributes make it ideal for applications such as soil moisture sensing, energy retention, and electromagnetic shielding. Furthermore, the reduced skin depth at higher frequencies suggests its suitability for advanced soil sensing technologies. By leveraging the unique properties of CSP and CSAC, this study provides a pathway for the development of functional artificial soils that can enhance agricultural productivity, support sustainable practices, and contribute to the greening of urban environments.

Applications

The findings from this study reveal several potential applications for the artificial soil mixtures developed using CSP, CSAC, and Organic Soil. The mixture with the optimal ratio of 50% CSP, 30% CSAC, and 20% Organic Soil can be utilized in **precision agriculture**, particularly in soil moisture sensing systems, due to its high dielectric constant and excellent charge storage capacity. This enables accurate monitoring of soil moisture levels, which is critical for efficient irrigation and crop management. The low energy dissipation and strong insulating properties make it suitable for **energy storage applications**, such as in soil-based capacitors or energy retention systems in agricultural setups.

Additionally, the enhanced conductivity and reduced skin depth at higher frequencies suggest its potential use in **electromagnetic shielding**, where it can protect sensitive agricultural sensors and equipment from electromagnetic interference. Its ability to interact effectively with electromagnetic waves also makes it an excellent candidate for **soil health monitoring technologies**, enabling real-time analysis of soil conditions for optimized crop growth.

Beyond agriculture, the material's lightweight, water retention, and nutrient-rich properties make it ideal for **urban greening projects**, such as rooftop gardens, vertical farming, and potted plants. These applications support sustainable urban development by promoting greenery in limited spaces while improving soil quality and plant health.

Furthermore, the adsorption capabilities of CSAC within the mixture make it useful for **pollutant remediation**, where it can aid in filtering harmful substances from water or soil in contaminated areas.

By combining CSP, CSAC, and Organic Soil, this study presents an innovative approach to creating functional artificial soils with wide-ranging applications in agriculture, environmental management, and urban sustainability.

References

1. Jabal SNA, Seok YB, Hoon WF. The potential of coconut shell powder (CSP) and coconut shell activated carbon (CSAC) composites as electromagnetic interference (EMI) absorbing material. Malaysian Journal of Analytical Sciences. 2016; 20(2). Doi: 10.17576/mjas-2016-2002-29.
2. Nadzri SNIHA, *et al.* A comprehensive review of coconut shell powder composites: Preparation, processing, and characterization. Journal of Thermoplastic Composite Materials. 2022; 35(12):2641-2664. Doi: 10.1177/0892705720930808.
3. Kawalerczyk J, Dukarska D, Antov P, Stuper-Szablewska K, Dziurka D, Mirski R. Activated Carbon from Coconut Shells as a Modifier of Urea–Formaldehyde Resin in Particleboard Production. Applied Sciences (Switzerland). 2024; 14(13). Doi: 10.3390/app14135627.
4. Been Y Seok, *et al.* The Investigation on the Potential of Coconut Shell Powder Composite in Term of Carbon Composition, Surface Porosity and Dielectric Properties as a Microwave Absorbing Material. Doi: 10.14456/ea.2016.1.
5. Banaseka FK, Franklin H, Katsriku FA, Abdulai J-D, Ekpezu A, Wiafe I. Soil Medium Electromagnetic Scattering Model for the Study of Wireless Underground Sensor Networks. Wirel Commun Mob Comput. 2021; 2021(1). Doi: 10.1155/2021/8842508.
6. Abdulraheem MI, *et al.* Recent Advances in Dielectric Properties-Based Soil Water Content Measurements. Remote Sens (Basel). 2024; 16(8):1328. Doi: 10.3390/rs16081328.
7. An N, *et al.* Study on the impact of physical characteristics of soil-rock composite medium on its relative permittivity based on laboratory experiments. Front Earth Sci (Lausanne). 2024; 12. Doi: 10.3389/feart.2024.1342003.
8. Zainol N, Mustafa N, Aziz NH, Azman AN, Abdul Karim MS. Dielectric materials development using bio-waste: A review. Journal of Electrical Systems and Information Technology. 2023; 10(1). Doi: 10.1186/s43067-023-00117-x.