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# Influence of Methyl Orange Dye Doping on Structural and Dielectric Behavior of Polystyrene

This study examines how the structural and electrical characteristics of polystyrene (PS) are affected by varying methyl orange dye concentrations. The heat-press technique was used to create samples with different dye ratios (0%, 5%, 10%, and 15%). X-ray diffraction (XRD) was used for structural research, and an LCR meter was used to look at electrical characteristics. According to the findings, PS kept its polycrystalline structure, and when the dye ratio rose, so did the crystallinity. More dye concentration also resulted in higher electrical conductivity at high frequencies, indicating improved charge transfer. Furthermore, at low frequencies, the real and imaginary dielectric constants rose, whereas at higher frequencies, they decreased. These results suggest that PS is a potential material for electronic and dielectric applications as doping it with methyl orange enhances its structural ordering and electrical performance.

***Keywords***: Polystyrene; Methyl orange; Structural properties; Heat press method
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## 1. Introduction

The monomer styrene is the starting point for the synthetic aromatic hydrocarbon polymer known as polystyrene (PS). It comes in both solid and foamed forms, and because of its accessibility, affordability, and simplicity of processing, it is widely employed in many different sectors, especially in the production of plastics and thermoplastics [1,2]. PS has had a steady rise in demand worldwide since its industrial manufacture started in the late 1930s. The polymer is highly resistant to water, acids, and alkalis, and its molecular weight ranges from $7\times10^4$ to $2\times10^5$ [3,4]. Notwithstanding these benefits, its employment in electronic and energy-related applications is severely constrained by its intrinsic electrical insulation and poor dielectric performance [5,6].

Researchers have used techniques like doping or combining PS with functional additives to improve its electrical and structural characteristics in order to overcome these constraints. Among them, organic dyes have drawn interest because of their conjugated molecular architectures, which affect dipolar polarization processes and enhance charge transfer [7,8]. The capacity of the anionic azo dye methyl orange (MO) to interact with polymer matrices and perhaps change their electrical and morphological properties has been investigated. With a molar mass of 327.33 g/mol, MO has the chemical formula $C_{14}H_{14}N_3NaO_3S$. It comes in the form of an orange powder that dissolves in water but not in alcohol, is frequently used as a pH indicator in acid-base titrations, and must be handled carefully since it can cause mutations [9-11].

Even though a lot of work has been done to improve the electrical and dielectric properties of polymers, little is known about how different MO concentrations affect PS's structural and electrical performance. Thus, the purpose of this work is to use X-ray diffraction (XRD) and electrical measurements to systematically examine the impact of MO doping at various concentrations (0%, 5%, 10%, 15%, and 20%) on the conductivity, crystallinity, and dielectric constant of PS films [12,13].

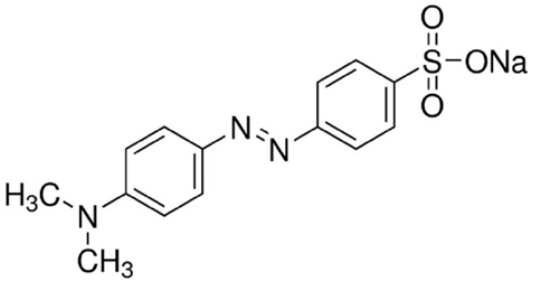


**Fig. (1) The chemical formula for methyl orange [13]**

The goal of this work is to provide important information on the creation of PS-based composites with improved functional qualities, which might facilitate their use in flexible electronics, sensors, and capacitors.

## 2. Experimental Part

The basis material for this investigation was 98% pure polystyrene (PS) powder that was obtained from China. Methyl orange (MO) dye in weight percentages of 0%, 5%, 10%, 15%, and 20% was combined with 2.5 g of PS. To guarantee uniformity, the granules were well mixed. After that, a hot-press machine was used to compress the homogenous mixtures. A temperature of 145°C, a pressure of 100 bar, and a pressing duration of 10 minutes were the precise and regulated parameters under which the molding process was carried out. The circular mold, which had a

  

diameter of 3 cm, produced disc-shaped samples that were uniformly thick (around 0.145 cm). The purpose of these samples was electrical and structural characterization.

A Bruker D8 Advance X-ray diffractometer with Cu Kα radiation (λ = 1.5406 Å) was used to perform XRD measurements for structural analysis. This revealed details on the materials' phase identification and crystallinity. The real and imaginary components of the dielectric constant and the dissipation factor were measured electrically using an LCR meter (Hioki 3532-50) across a frequency range of 50 Hz to 5 MHz. Using a typical dielectric equation, electrical conductivity was also computed based on these characteristics.

A HMS-3000 Hall Effect device, which consists of a digital voltmeter and a controlled electromagnet with a field strength of 0.55 Tesla, was also used to conduct Hall Effect measurements. The PS-MB composite samples' conductivity, mobility, and carrier concentration could all be measured thanks to this technique.

### 3. Results and Discussion

Pure polystyrene (PS) and samples doped with MO dye at concentrations of 5%, 10%, and 15% were characterized by XRD, which revealed that all of the samples were polycrystalline. The pure PS had poor initial crystallinity, according to the diffraction patterns, and when the MO concentration rose, there were discernible increases in peak strength, especially at the (−221) plane. In line with other research that found that adding dye to polymer matrices increased crystallinity, this behavior points to improved molecular ordering brought on by MO intercalation.

These structural alterations are depicted in Fig. (2), which clearly links increasing dye content to enhanced crystallinity. Because of better alignment and lower defect concentrations, these structural changes can affect electrical characteristics. To compute electrical conductivity (σ), the following formula was used:

$$\sigma = 2\pi f D f \varepsilon_0 \varepsilon^- \quad (1)$$

Where $\varepsilon_0$ is the vacuum permittivity, $\varepsilon^-$ is the dielectric constant, and *Df* is the dissipation coefficient [14,15]

For every sample, conductivity values were plotted versus frequency (Fig. 3). Because of interfacial polarization and restricted charge carrier mobility, the conductivity was almost constant at low frequencies. Due to improved hopping conduction and greater charge carrier availability, conductivity increased with frequency and increased more dramatically with increasing MO concentration. Doped polymers have shown similar frequency-dependent activity, suggesting that polarizable groups in MO promote electron mobility at high frequency fields.

The electrical dielectric constant is calculated from the equation below [16]:

$$\varepsilon = \frac{Cd}{\varepsilon_0 A} \quad (2)$$

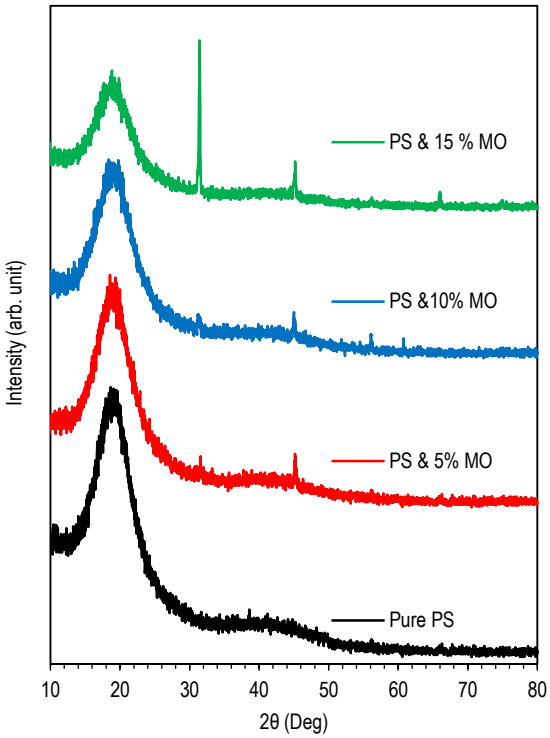


**Fig. (2) XRD patterns of pure and doped PS with different amounts of MO dye (0, 5, 10, and 15%)**

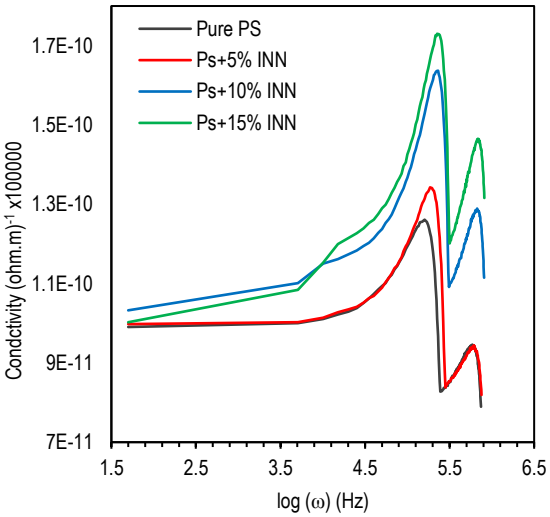


**Fig. (3) Variation of electrical conductivity with log(ω) for pure and doped PS with different amounts of MO dye (0, 5, 10, and 15%)**

The measured capacitance of the LCR device, electrical dielectric constant ε, vacuum permittivity $\varepsilon_0$ ($8.85\times10^{-12}$ F/m), a cross-sectional zone, where d is the model's thickness. According to Fig. (4), both ε and $\varepsilon_0$ were large at low frequencies because of interfacial polarization (Maxwell-Wagner-Sillars effect), but they declined as the frequency increased

  

because dipole relaxation was unable to keep up with the alternating field. This effect was enhanced by increasing the MO ratio, which is consistent with earlier research on dye-doped polymers [17].

The imaginary dielectric constant is calculated by calculating the dissipation coefficient (*Df*) by the LCR device from the equation below:

$$\varepsilon^{-} = \varepsilon \times Df \quad (3)$$

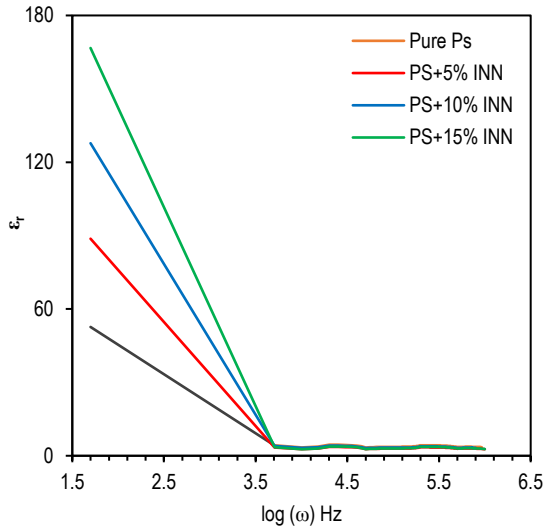


**Fig. (4) Variation of the real dielectric constant with log(ω) for pure and doped PS with different amounts of MO dye (0, 5, 10, and 15%)**

The dielectric constant of pure PS, to which 15% methyl orange was added, is shown in Fig. (5) and increasing at low frequencies. This means that as the frequency increases, more energy is lost due to the increased rotation of the polar aggregates. However, as the frequency increases, the dielectric constant starts to decrease, and this is because it is unable to follow the change in direction with the frequency increase. These findings support the theory that methyl orange improves polystyrene's electrical and structural characteristics, which makes PS-MO composites a potential material for dielectric and electronic applications.

## 4. Conclusion

This work showed that doping PS with methyl orange dye reasonably improves both its electrical performance and structural crystallinity. Higher conductivity and dielectric responsiveness were shown at higher frequencies, whereas better molecular ordering was verified with increased dye concentration. These results imply that PS-MO composites have encouraging potential for use in electronic components and dielectric devices. It is advised that future research examine these composites' long-term dependability and thermal stability under actual environmental circumstances.

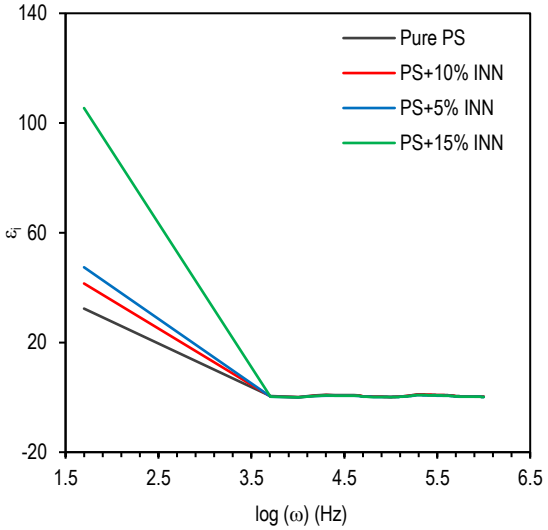


**Fig. (5) Variation of the imaginary dielectric constant with log(ω) for pure and doped PS with different amounts of MO dye (0, 5, 10, and 15%)**

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