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VARIATION OF ELECTRICAL PROPERTIES WITH TEMPERATURE FOR POLYETHYLENE OXIDE DOPED WITH 0.1 WT. % IODINE

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ABSTRACT

The electrical properties of thin films made of polyethylene oxide (PEO) dispersed with dopants fixed amount of iodine (0.1 wt. %) were studied using the AC impedance technique. The films were prepared by electrically casting method. In this present work, the variation of AC electrical conductivity with temperatures ranging from 30 ^oC to 55 ^oC at a frequency of 200 kHz for (PEO) film doped with 0.1wt. % iodine and undoped (PEO) film were studied. Physical quantities and parameters such as AC conductivity, impedance, dielectric constant, and dielectric loss, were determined. The observed values of the impedance *(Z)*, dielectric constant *(*ε'*)*, dielectric loss *(*ε''*)*, and AC-conductivity *(*σ_{AC}*)* showed temperature dependence. It was found that the dielectric constant and the dielectric loss of the prepared thin films increased with doped (0.1wt. %) iodine complexes and also increased with the increase of temperature according to the polarization processes.

Keywords: PEO, Iodine, impedance, dielectric constant, dielectric loss, AC-conductivity.

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1. INTRODUCTION

Polymer composites and polymer electrolytes are the most widely used materials in the past few decades. Understanding their properties is extremely important for scientific applications. Most polymeric materials are poor conductors of electricity because of the unavailability of a large number of free electrons or ions to participate in the conduction process, so great attention has been focused on enhancing their electrical conduction and improving their properties. To promote the optical and electrical properties of polymeric systems, many different materials have been developed such as conducting polymers electrolytes, and polymer composites [1].

Because of their desired qualities that made them preferable to other commercial materials, conductive polymer composites (CPC) have sparked a lot of interest in various industrial applications. The change from insulating to conductive behavior was achieved by adding various conducting elements such as metallic particles, carbon or steel fibers, aluminum flakes, and iodine. Thermoplastic (polyethylene) is a good insulator in general. Polymers containing conductive fillers are sometimes referred to as conductive polymer composites. These fillers provide the composite with its conducting quality [2]. The study of (CPC) for numerous industrial applications has sparked much interest. CPC refers to the process of combining conductive particles with insulating polymers to change their electrical characteristics [3].

A dopant is an impurity inserted into a semiconductor lattice or a crystal in minimum quantity to improve its optical and electrical properties. The majority of dopants that affect the conductivity of polymers are Br_2, I_2, and C. The Iodine atom accepts an electron from a host atom, and is called an acceptor; i.e., generates hole carriers. When this occurs, the acceptor atom becomes negatively charged when an electric field is applied, current flow occurs as the outcome of the drift motion of holes created by the acceptors and holes and electrons produced by valence-band disruption [4].

Iodine is known to form polymer-halogen complexes when doped into the polymers and to effect their electrical, and dielectric properties, conductivity, charge storage capacity, dielectric loss, dipole moment, and relaxation time [5]. When doped in the polymers, iodine may reside at various sites. It may go substitutionally into the polymer chains or may reside at the amorphous/crystalline and diffuse preferentially through the amorphous region forming a charge transfer complex (CTC), or may exist in the form of molecular aggregates between the polymer chains [6].

2. EXPERIMENTAL WORK

In this study, the examined material consisted of (polyethylene oxide) thin films doped with iodine as a dopant and a pure PEO sample for comparison. The objective of this research is to investigate the AC electrical properties of casted Poly ethylene oxide thin films doped with conducting iodine compared to the case of the undoped (PEO) film. The conduction mechanism in PEO doped with iodine was verified as a function of temperature.

2.1 Materials and Composites Films Preparation

PEO and iodine were blended in methanol as a convenient solvent. Then for two days, the mixture was mixed by using a rotary magnet to obtain a homogeneous mixture. On a glass mould, the mixture was directly cast into delicate films. The mixture was left at room temperature for two days to evaporate the methanol. All samples were left to dry in the oven at 40 °C for three days.

2.2 Measurements of Electrical Properties

Hewlett Packard (HP) 4192A impedance analyzer was used to measure the impedance and the phase angle values by varying the applied frequency ranges (from 5 Hz up to 13 MHz). The specimen was firmly placed between two brass electrodes in a sample holder as shown in Figure-1. These electrodes are connected through cables to the impedance analyzer. Impedance measurements were performed at frequencies ranging from 30 kHz to 5 MHz over a temperature range (30 ºC - 55 ºC) with 5 ºC steps. Since the melting temperature *(Tm)* for PEO is about 60 ºC, no higher temperature measurements were conducted. The temperature readings were taken under a steady state condition.

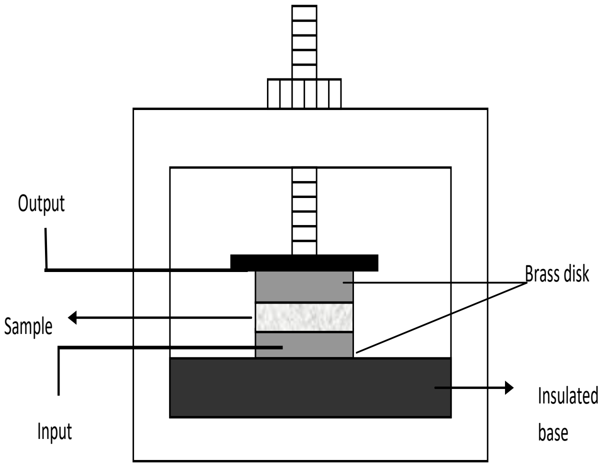

Figure-1. The sample holder diagram for Impedance analysis.

Dielectric materials represent a special class of substances that, under almost all conditions, are insulators. They have an interesting and useful property that their electrons, ions, or molecules may be polarized under the influence of an external electric field. When such materials are placed between charged plates as in capacitors, they increase the total capacity of these devices. This application constitutes one of the important applications of these materials [7].

Connecting a capacitor *(C)* to a resistor *(R)* in parallel, the impedance *(Z)*, the real component of the impedance *(Z')*, and the imaginary component of the impedance *(Z'')* of the circuit are calculated according to the following equations:

$$Z = \frac{R\ (1 - i\omega\ C\ R)}{1 + (\omega\ C\ R)^2} \tag{1}$$

$$Z' = \frac{R}{1 + (\omega\ C\ R)^2} \tag{2}$$

$$Z'' = \frac{\omega\ CR^{\ 2}}{1 + (\omega\ CR\ )^2} \tag{3}$$

The dielectric constant *(ε')* which is related to the stored energy within the medium, and the dielectric loss ***(ε'')*** which is related to the loss of energy within the medium in the form of heat generated by an electric field are determined according to the following equations [8]:

$$\varepsilon' = \frac{Z''}{2\pi f C_o Z^2} \tag{4}$$

$$\varepsilon'' = \frac{Z'}{2\pi f C_o Z^2} \tag{5}$$

where C_o is the capacitance without the thin film, and f is the frequency of the (AC) electric field.

The AC conductivity ***(σ_{AC})*** of the thin film is given by the relation:

$$\sigma_{AC} = 2\pi f \varepsilon_0 \varepsilon'' \tag{6}$$

3. RESULTS AND DISCUSSIONS

An iodine dopant to the matrix of polyethylene oxide to form solid electrolyte thin films is being used to evaluate the role of doping in the process of electrical conduction when the electric field is affected. The objective of studying electrical conduction in polymers is to realize the type and nature of the charge transmission in conducting materials [9].

In this study, the electrical conduction mechanism in doped polyethylene oxide with iodine was investigated and the results were reported and discussed. In continuation of these studies, the conduction mechanism in PEO doped with iodine films was verified as a function of temperature.

Figure-2 shows the effect of temperature on the impedance *(Z)* for (PEO) with doped 0.1 wt. % iodine compared to that of the undoped (PEO) film. The impedance decreases with the increase in temperature. This could be due to the increase in charge mobility, the generation of charge carriers, and reducing the energy gap. The charge carrier's transport is affected by these processes in the bulk thin film, and these processes could occur from the effects of conduction current and polarization superposition. The polarization currents are temperature dependent, where with increasing temperature the polarization decay time is reduced. This behavior illustrates that, as the temperature increases, the conductivity increases, such as the behavior of ionic and semiconducting materials [10]. While temperature increases, *(Z)* decreases due to the polarization effects, formation of connected iodine paths, and the increase of electronic mobility.

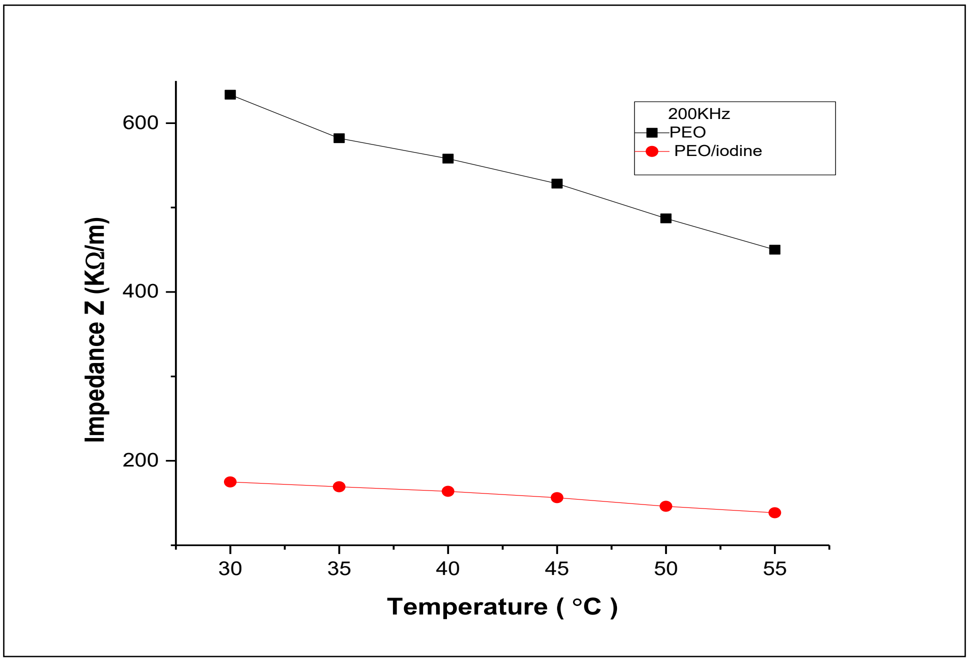

Figure-2. Impedance versus temperature for PEO composites.

Figures 3 and 4 display the dielectric constant for pure PEO thin film and PEO/iodine thin film versus the temperature for different frequencies. With increasing the temperature, the dielectric constant *(ε′)* increases. This is caused by a reduction in the polarization of space charge (interfacial) and the formation of electronic arrangements or clusters in the polymer by heating. It is noticed that at high temperatures ***(ε′)*** will quickly increase. This illustrates that the orientation of polyethylene oxide dipoles is simplified and relaxed when the temperature increases, so the dielectric constant increases [11].

The dielectric constant increases as the temperature is increased, and this is due to the greater freedom of the movement of dipole molecules chain of polymer at high temperatures. At lower temperatures, as the dipoles are rigidly fixed in the dielectric, the field cannot change the coordination of dipoles. As the temperature increases, the dipoles comparatively become free and they respond to the applied electric field. Thus polarization/orientation increases and hence dielectric constant is also increased with the increase of temperature [12].

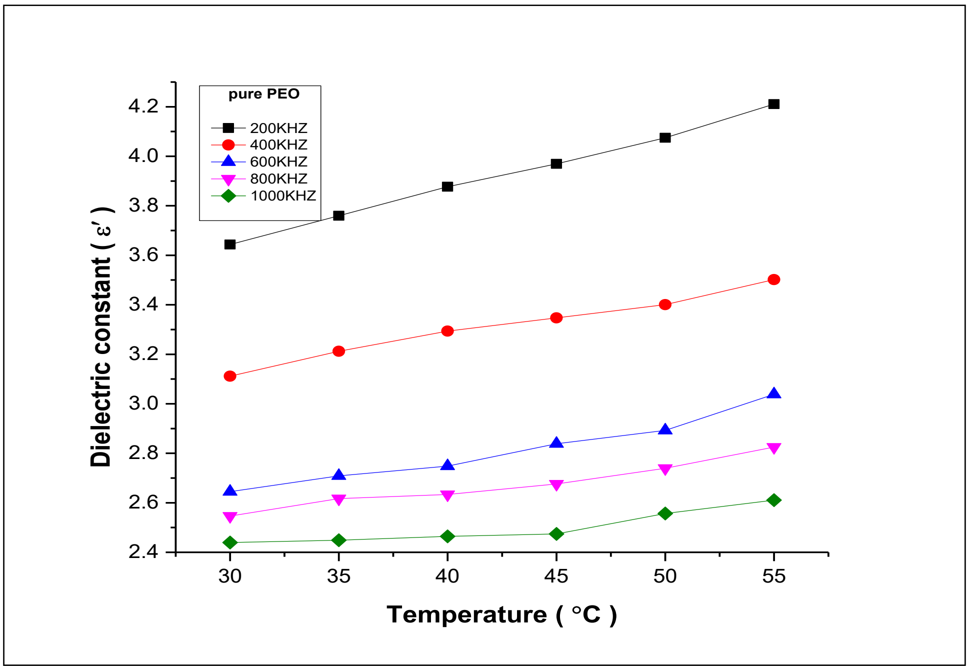

Figure-3. Variation of dielectric constant with temperature for pure PEO.

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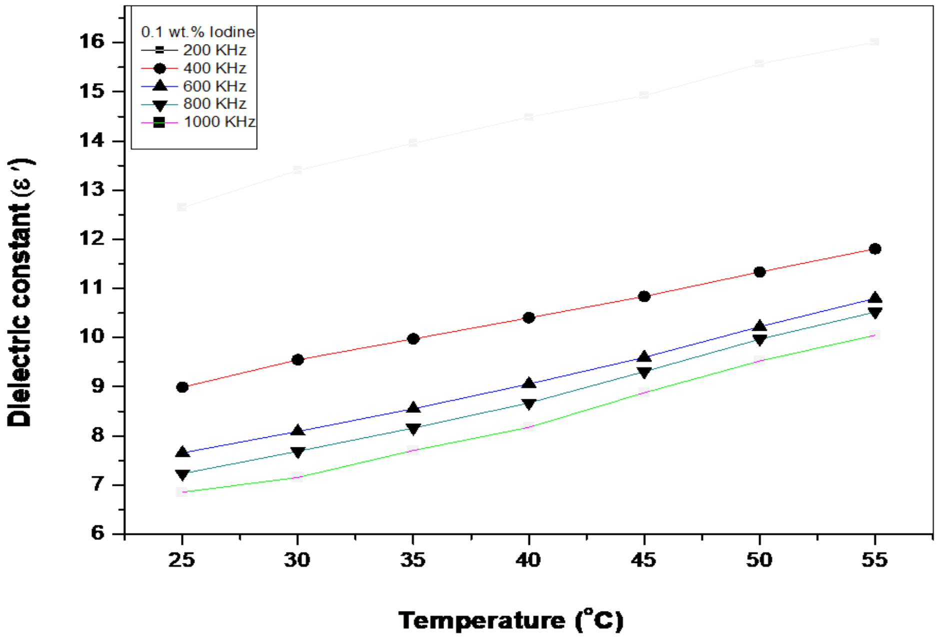

Figure-4. Variation of dielectric constant with temperature for PEO/iodine.

Figures 5 and 6 show the dielectric loss for pure PEO thin film and PEO/iodine thin film versus the temperature for different frequencies. With increasing the temperature the dielectric loss *(ε'')* increases. This is caused by a reduction in the polarization of space charge (interfacial) and the formation of electronic arrangements or clusters in the polymer by heating. This shows that the orientation of polyethylene oxide dipoles is simplified and relaxed when the temperature increases, so the dielectric loss increases. It can be seen from these figures that the dielectric loss, in general, shows an increase with the increase in temperature. The increase in the dielectric loss is attributed to a relaxation process connected with the motion of large parts of the polymer molecules, and it is characterized by the relaxation process [13].

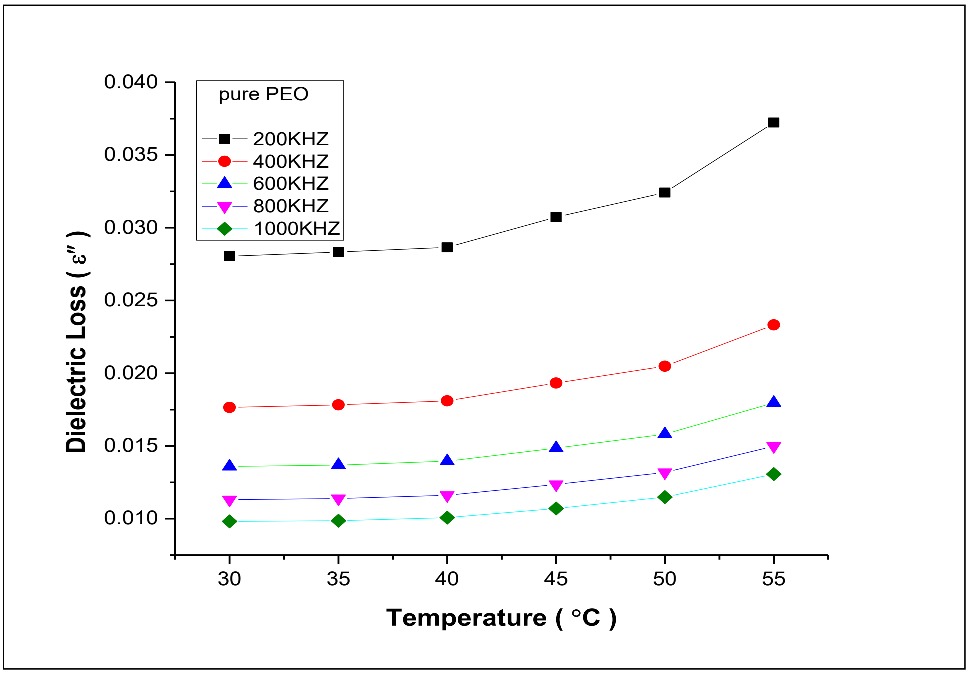

Figure-5. Variation of dielectric loss with temperature at different frequencies for pure PEO.

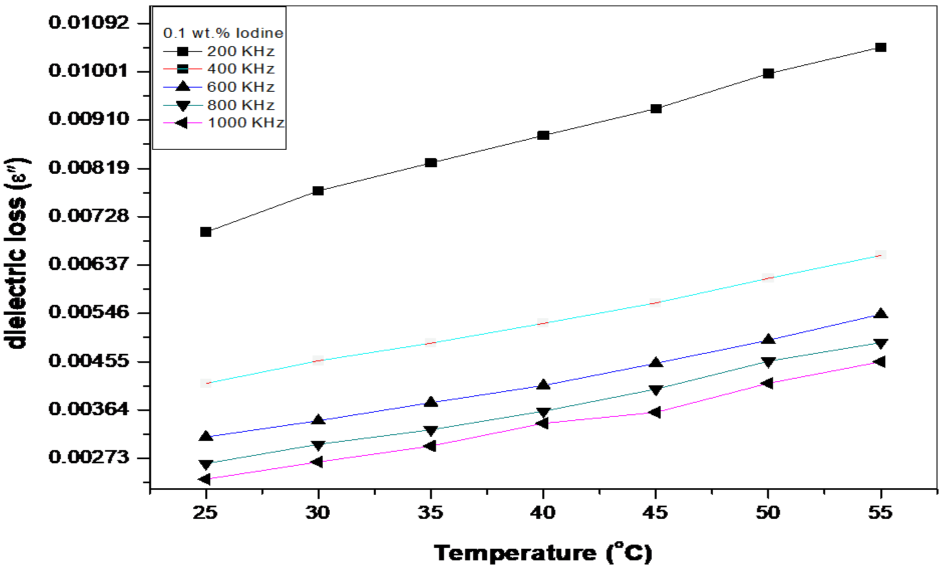

Figure-6. Variation of dielectric loss with temperature at different frequencies for PEO/iodine.

Figure-7 shows that at all frequencies when the temperature increases the values of AC conductivity will increase. This is because of the activation of electrons and impurity, which increases with the increase of temperature, and due to the molecular mobility of PEO stimulated when the temperature increases, i.e., charged the electrons flow instituted among the surface of the electrode with high relative motion of polymer chains and thus leading to higher conduction, which is relatively similar to semiconducting materials.

The fast increase in AC conductivity refers to the increase of the charge carrier's concentration as a consequence of increasing structure defects. Accordingly, new energy levels inside the forbidden energy gap can be generated; also, at high temperatures, there is a stimulation of electronic mobility in impurities. For the temperature-conductivity behavior to obey the Arrhenius relationship, the transport of cation is nearly like that which is happening in ionic crystals, where ions jump into nearby vacant positions so that the ionic conductivity increases [14].

Increasing the temperature can increase the movement of the iodine particles that are trying to form a percolation network [15]. Also at high temperatures, (PEO) matrix has sufficient mobility, thus iodine particles could take place in the matrix which increases the conductivity of the sample [16].

As a function of temperature and frequency, the electrical conduction process can be summarized as follows:

- AC-charge conduction refers to free electrons charge complexes and impurities in the iodine dopant of the polymeric matrix.
- Maxwell-Wagner buildup polarization of interfacial charges at the composite interfaces.
- Hopping of the free electrons over smaller barrier heights and energy levels.

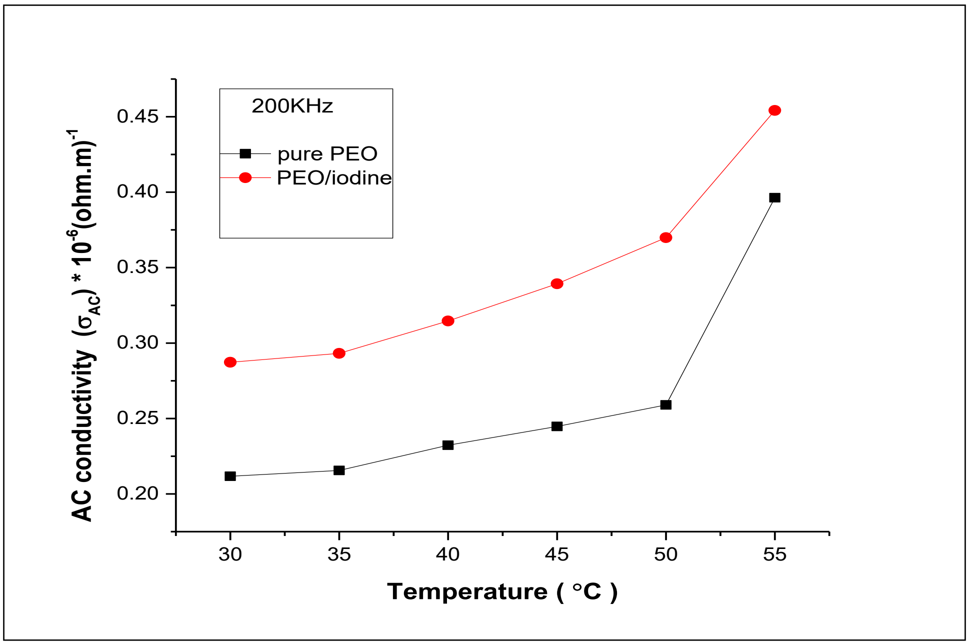

Figure-7. AC-conductivity versus temperature for PEO/iodine composites.

4. CONCLUSIONS

The electrical properties of PEO thin films doped with iodine were studied. By studying the results, we deduced that:

- The impedance was found to decrease with doped 0.1wt. % iodine, as a function of temperature and frequency.
- The dielectric constant (ε') and the dielectric loss (ε'') of the composites increases with the increase of temperature.
- The AC conductivity (σ_{AC}) increases with doped 0.1wt. % iodine, as the temperature and frequency increase.

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