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Effect of Temperature on the Electrical Properties of Poly (Ethylene Oxide) Doped with Carbon Black Nanoparticles Films

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Abstract: AC electrical properties were studied using the AC impedance technique. The electrical properties of thin films made of Poly (Ethylene Oxide) (PEO) dispersed with dopants fixed amount of carbon black (0.1 wt.%) were used in this study. The prepared films by casting method have been electrically. The present study has studying the variation of AC electrical conductivity with temperature in the range (30-55°C) at frequency 200 kHz for (PEO) with doped 0.1wt.% carbon black as compared to that case of the un doped (PEO) film and determined of some physical quantities and parameters as AC conductivity, impedance, dielectric constant, dielectric loss. The observed values of the impedance (Z), dielectric constant (ε'), dielectric loss (ε") and AC-conductivity (σ_{AC}) showed temperature. It was found that the dielectric constant and dielectric loss of the prepared thin films increase with doped (0.1 wt.%) Carbon Black (CB) complexes and that it increase with temperature according to polarization processes.

Key words: PEO, CB, impedance, dielectric constant, dielectric loss, AC-conductivity

INTRODUCTION

Generally, thermoplastic (polyethylene) (PEO) are good insulators. Conductive Polymer Composites (CPC), one usually refers to polymers containing conductive fillers. These fillers impart their conductive properties to the composite (Myers, 1990). There has been great interest in the study of CPC for various industrial applications. CPC means mixing conductive particles with insulating polymers to modify their electrical properties. The most common conductive filler used is Carbon Black (CB) (Ramos *et al.*, 2005). Polyethylene oxide has a property to form molecular complexes which enhance the electrical conductivity (Fanggao *et al.*, 1996).

A dopant is an impurity inserted into semiconductor lattice or a crystal in minimum quantity, so as to improve the optical and electrical properties. The majority of dopants used to affect conductivity of polymers are Br_2, I_2 and C. Since, a carbon black atom accepts an electron from a host atom, it 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 outcome of the drift motion of holes created by acceptors and holes and electrons produced by valence-band disruption (Ankrum, 1981).

Carbon black when doped in polymers, may reside at various sites. It may go substitutionally into the polymer chains and compose Charge Transfer Complexes (CTC) or may exist in the form of molecular aggregates between polymer chains (Mehendru and Chand, 1983).

Carbon black is a non-crystalline form of carbon which can only be obtained artificially by controlled burning of hydrocarbon fuels. Carbon black works as a pigment and can also help reduce photo-oxidation (Ou *et al.*, 2003). The most important CB use is as a filler in polymers to improve electrical conduction and is used in preparation of conductive polymer composites.

MATERIALS AND METHODS

Experimental work: In this study, the material examined is (poly ethylene oxide) thin films doped with carbon black as dopant and neat PEO sample for contrast the noticed consequences. The objective of the research is to investigate the AC electrical properties of casted poly (ethylene oxide) thin films doped with conducting carbon black as compared to that case of the un doped (PEO) film. The conduction mechanism in PEO doped with CB films was verified as function of temperature and is discussed in this study by acceptors and holes and electrons produced by valence-band disruption.

Preparation of thin films: PEO and CB powders were blended together in methanol as a convenient solvent. Then for 2 days, the mixture was mixed by using a rotary magnet to get a homogeneous mixture. On to a glass mould the mixture was directly casted to delicate films. At room temperature by waiting for 2 days the methanol was permitted to evaporate perfectly. All samples were dried in the oven at temperature 40°C for 2 days.

Measurements of electrical properties: Hewlett Packard (HP) 4192A impedance analyzer was used to measure impedance and phase angle values by varying the applied frequency (ranges from 5 Hz up to 13 MHz). The specimen was placed firmly between two copper electrodes in a sample holder shown in Fig. 1. These electrodes are connected through cables to the impedance analyzer. Impedance measurements were performed in a frequency range from about 30 kHz up to 5 MHz over a temperature range (30-55°C) with steps of 5°C. Since, the melting Temperature (T_m) for PEO is about 60°C, no higher temperature measurements were conducted. Temperature readings were taken in a steady state condition.

Dielectric materials are a special class of substances that, under almost all conditions are insulators. They have the 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 (Pollock, 1993).

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:

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

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

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

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 form of heat generated by an electric field are determined from these relations (Elimat, 2006):

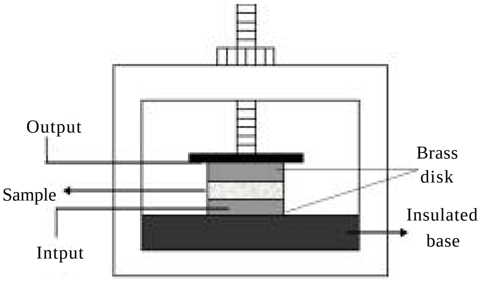

Fig. 1: The sample holder diagram impedance analyze

$$\varepsilon' = \frac{Z''}{2\pi f C_0 Z^2} \tag{4}$$

$$\varepsilon'' = \frac{Z'}{2\pi f C_0 Z^2} \tag{5}$$

where, C_0 is the capacitance without the thin film and f is the frequency (AC) of electric field. The AC conductivity (σ_{AC}) of the thin film is given by the relation:

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

RESULTS AND DISCUSSION

A dopant carbon black appended to the matrix of polyethylene oxide to compose solid electrolyte thin films is being searched to evaluate the role of the doping in the process of the 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 (Agrawal and Pandey, 2008).

In this study, the electrical conduction mechanism in doped poly (ethylene oxide) with CB was investigated and the results were reported and discussed. In continuation of these studies, the conduction mechanism in PEO doped with CB films was verified as function of temperature.

Figure 2 displays the variation of impedance (Z) with temperature for (PEO) with doped 0.1 wt.% carbon black as compared to that case of the un doped (PEO) film at frequency 200 kHz. It is obvious that increasing temperature decreases the impedance. This could be illustrated in specific cases like increasing charge mobility, generation of charge carriers and reducing the energy gap. The charge carriers transport is affected by these processes in the thin film bulk and these processes could occur from effects of conduction current and polarization superposition. The polarization currents are temperature

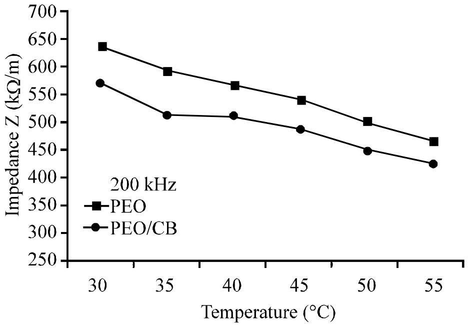

Fig. 2: Impedance versus temperature for PEO composites

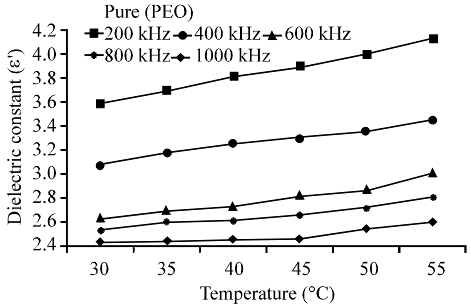

Fig. 3: Variation of dielectric constant with temperature for pure PEO

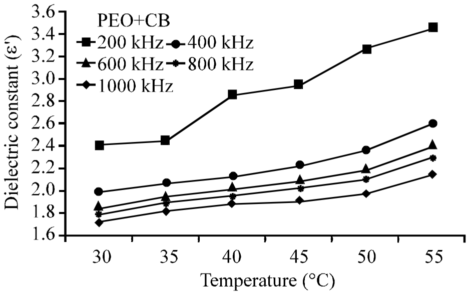

Fig. 4: Variation of dielectric constant with temperature for PEO/CB

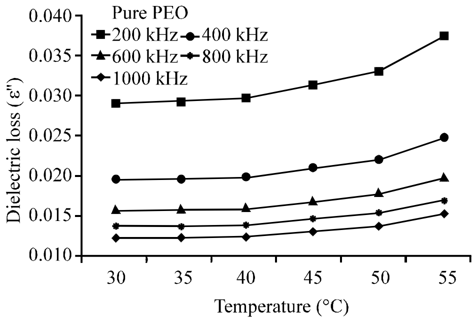

Fig. 5: Variation of dielectric loss with temperature at different frequencies for pure PEO

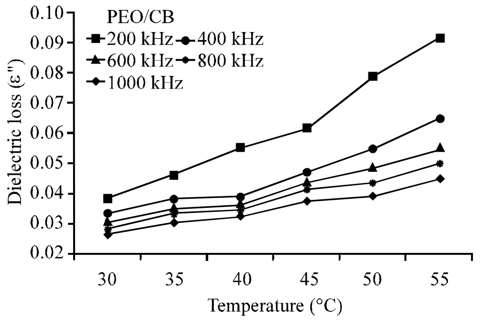

Fig. 6: Variation of dielectric loss with temperature at different frequencies for PEO/CB

dependent where with increasing temperature the polarization decay time is reduced. This behavior illustrates that as temperature increases the conductivity is increasing such as the behavior of ionic and semiconducting materials (Elliot, 2000). While increasing the temperature (Z) decreases due to the polarization effects, formation of connected carbon black paths and the increasing of electronic mobility.

Figure 3 and 4 display the dielectric constant for pure PEO thin film and PEO/CB thin film versus temperature for different frequencies. With increasing temperature the dielectric constant (ε') increases. This is caused by a reduction in the polarization of space charge (interfacial) and formation of electronic arrangements or clusters in the polymer by heating. It is noticed that at high values of temperature (ε') will increase quicker. This illustrates that, the orientation of polyethylene oxide dipoles is simplified and relaxed when the temperature increases, so, the dielectric constant increases (Ahmad *et al*., 2006).

The dielectric constant increases as the temperature is increased, this is due to 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 increase and hence, dielectric constant is also increased with the increase of temperature (Renukappa and Samuel, 2007).

Figure 5 and 6 display the dielectric loss for pure PEO thin film and PEO/CB thin film versus temperature for different frequencies. With increasing temperature the dielectric loss (ε") increases. This is caused by a reduction in the polarization of space charge (interfacial) and formation of electronic arrangements or clusters in the polymer by heating. This illustrates 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 attributed to a relaxation process connected with the motion of large parts of the polymer molecules and it is characterized by the α-relaxation process (Tsangaris *et al*., 1996) at frequency 200 kHz.

Figure 7 shows that at frequencies 200 kHz when the temperature increases the values of AC-conductivity will

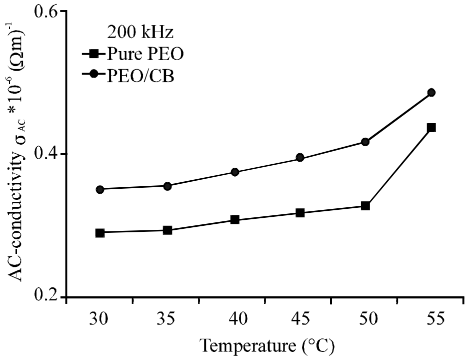

Fig. 7: AC-conductivity versus temperature for PEO/CB composites

increase. This is because of the activation of electron and impurity which increases with increasing temperature and because of molecular mobility of PEO stimulated when the temperatures increases, i.e., charged the electrons flow instituted among the electrodes surface 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 increasing 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. In order to the temperature conductivity behavior obey Arrhenius relationship, transport of cation is nearly like to that happening in ionic crystals where ions jump into nearby vacant positions, so that, the ionic conductivity increase (Mohan *et al.*, 2006).

Increasing temperature can increase the movement of carbon black particles that are trying to form percolation network (Psarras, 2007). Also, at high temperature (PEO) matrix has sufficient mobility, thus, carbon black particles could take place in the matrix which makes the conductivity of the sample increase (Zhao *et al.*, 2003). As a function of temperature and frequency, the electrical conduction process can be assembled as following:

- AC-charge conduction refers to free electrons charge complexes and impurities in carbon black dopant, 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

CONCLUSION

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

- Impedance was found to decrease with doped 0.1 wt.% carbon black, temperature and frequency
- The dielectric constant (ε') and the dielectric loss (ε") of the composites increase with temperature
- The AC conductivity (σ_{AC}) increases with doped 0.1 wt.% carbon black, temperature and frequency

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