CHARACTERIZATION OF POLYMERS BY THE ac ELECTRICAL PROPERTIES

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ABSTRACT

Characterizations of some commercially available and well-known polymers have been made by studying their ac electric properties. Samples of Polyethylene [-CH₂-CH₂-]ₙ, Polyvinyl Chloride [-CH₂-CH₂Cl]ₙ, and Ethyl Vinyl Acetate [CH₃-COOCH=CH₂] have been prepared in the laboratory using the injection molding system. The measurements of the ac conductivity, dielectric constant and dielectric loss tangent as a function of frequency and temperature were carried in the frequency range of 60 Hz to 3 MHz and at the temperature range of 25 to 185°C. A comparative study has been performed between these polymer samples. From our study, it reveals that the PVC and PE samples do not have better insulating property than that of EVA. Experimental observations of the ac electrical and dielectrical properties of polyvinyl chloride (PVC), ethyl vinyl acetate (EVA) and polyethylene (PE) also suggest that the interfacial polarization mechanism is dominant in these measurements.

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INTRODUCTION

Dielectrics are materials, which are electrical insulators, i.e. have direct current resistivity greater than about $10^8 \ \Omega \cdot \text{cm}$. Insulator have very useful ability to store electrical charge mainly in capacitors. The class of insulating polymers has manifold application for electrical insulation and industrial activities. Studies of dielectric behavior of polymers give valuable information about their use as insulators and for other mechanical and electrical properties [1]. The physical and chemical structure of the macromolecule, the molecular mobility of segments of such molecules and various other properties can be described from a study of the variation of dielectric constant with temperature and frequency and position of the loss peaks [2]. Gerald make co-polymer of ethylene and styrene and modify the ratio between them over a wide range. The E-series, with around 80% ethylene, are semi crystalline, elastomeric inter polymers. The S-series, with 25% ethylene, are amorphous semi-rigid inter polymers. These polymers can be blended with polypropylene, polyethylene, polystyrene, polyvinyl chloride and ethyl vinyl acetate. Amin and Kamal investigated the possibilities of developing a long life co-extruded polyethylene films [4]. The developed films containing up to 60% recycled materials. The investigations on plastic from agriculture refuse clearly show, that waste material could be used for the production of transparent multilayer films for agricultural purposes. Cagin et al. [5] found that canonical molecular dynamics reaches equilibrium thermal distributions in about 10 ps whereas micro canonical dynamics has not produced an equilibrium distribution in about 1ns simulation. The equilibrium distributions calculated by time-averaging canonical molecular dynamics over 10-30 ps agree with each other and with the results obtained from static molecular mechanics calculations (using the same classical interaction potential for polyethylene). Eisetsu [6] had a plan to utilize waste
plastics instead of fine coals charged into blast furnaces. However, even slight amounts of polyvinyl chloride (PVC) in waste plastic mixtures generate the hazardous hydrogen chloride gas. For this reason, PVC should be separated as much as possible. Therefore separation of PVC in plastic mixtures had been studied using an air table. The air table has a function to control the frequency of the shaking deck, the inclination angle, and air velocity. They described the separation condition of the air table to obtain plastic mixtures of which PVC content is less than one percent.

In view of recent work in which relatively simple organic molecules show high electronic conductivity, it appears that polymers showing essentially metallic conductivity will soon be developed. At the present time, however, the most important electrical applications of polymers of high resistivity are used as insulators. In a previous study, we reported a study of the ac electrical properties of pure polypropylene and polypropylene-talc composites [7]. The electrical properties of pure polypropylene and polypropylene-talc composites were compared and it has been established that the fabricated composites do not show any better insulating property than that of pure Polypropylene. In the present paper, we have reported the investigation of the ac conductivity and dielectric behavior of some insulating polymer samples. The experimental results of these materials obtained are compared with one another in order to find better insulating property by the understanding of the dielectric quality and ac electrical properties of these commercial polymers.

**EXPERIMENTAL**

**Sample preparation**

Two batches of individual polymer samples were prepared using injection-molding machine, set up at Department of Physics, Bangladesh University of
Engineering and Technology (BUET). The polymer beads were pressurized and pushed down from the cup to the heating zone through the jug. There the polymer was melted to the required temperature and the molten materials were then forced to inject through a nozzle into the mould cavity (die). After the mould was filled with the molten material under pressure then it was cooled by water circulation and then opened so as to eject the molded materials in the form of pellets. The surface of the pellets was then coated with Aluminum by vacuum evaporation technique and the connection was made by a fine Cu-wire with the help of silver paste.

**Instrument used for the measurement of ac conductivity and dielectric constant and dielectric loss tangent**

For the experimental measurement, dielectric loss measuring system was used, having with three-transformer ratio Arm Bridges for using three different frequency ranges. One was used for the measurement range from 30 Hz-2 KHz, another was for the range from 2 KHz-100 KHz and the rest one was for the range from 100 KHz - 3 MHz. An initial balance known as zero balance was obtained at each frequency without the specimen connected and from the conductance ratio arm the value of $R_0$ was obtained. The specimen was then connected to the bridge terminals and conductance $G_r$ and capacitance $C_x$ was obtained. The final balance $R'$ was thus obtained and conductance $G$ was obtained by the relation $(R'-R_0)\times G_r$. Simultaneously the value of the capacitance was obtained by the capacitance scale. From these $C_x$ and $G_x$ values the calculation for dielectric constant, loss tangent and ac conductivity were obtained at different frequencies and temperatures by using the following formulae:

Dielectric constant, $\varepsilon' = (d/A) C_x/\varepsilon_0$

Dielectric loss tangent, $\tan\delta = G_x/\omega C_x = G_x/2\pi f C_x$
ac conductivity, $\sigma_{ac} = (d/A)G_x$

where $d$ is the thickness, $A$ is the area of the sample, $\omega$ is the angular frequency, $f$ is the frequency and $\varepsilon_0$ is permittivity of free space. During the experiment of frequency variation measurement of conductance and capacitance at different temperatures a thermostatic oven was used as a heating system.

RESULTS AND DISCUSSION

The measurements of ac conductivity, dielectric constant and dielectric loss tangent as a function of frequency and at the temperature range from room temperature to near softening temperature of these polymers were performed. The graphs for ac conductivity, dielectric constant and loss tangent against frequency at different temperatures were plotted and are presented bellow.

The ac conductivity was measured to understand the electrical conduction mechanism in the polymer. It was found that the ac conductivity for polyethylene, polyvinyl chloride and ethyl vinyl acetate and are in the range of $6.17 \times 10^{-10}$ to $1.36 \times 10^{-4}$ mho; $2.44 \times 10^{-9}$ to $1.38 \times 10^{-4}$ mho and $3.16 \times 10^{-10}$ to $7.08 \times 10^{-5}$ mho, respectively. The plots of $\log \sigma_{ac}$ (isothermal ac conductivity) versus $\log_{10} f$ (frequency) for all the samples are depicted in Figs.1a to 1c. It is observed that for all samples ac conductivity increases steadily with the increase of frequency at all working temperatures. It is also seen that ac conductivity decreases with the increase of temperature in Figs.2a to 2c. The present studies of ac conductivity points out that electrical conduction in these polymers are probably due to both ions and electrons. The charge motion might take place by the process of hopping [8]. The frequency and temperature dependent ac conductivity may be attributed to the increase of relaxation times dominated by interfacial type of mechanism.
Log frequency versus dielectric constant curves in Figs. 3a to 3c show that the dielectric constant decreases with the increase of frequency at all temperatures. It seems from the graphs of PE that at a particular high frequency the dielectric constant tends to be same i.e. the dielectric constant becomes independent of frequency and temperature at very high frequency. From temperature versus dielectric constant curves at different temperature for EVA and PE in Fig.4b and Fig.4c it is observed that the dielectric constant decreases with the increase of temperature at all frequency but for PVC in Fig.4a it seems the dielectric constant is independent of temperatures. These variations are in good agreement with the behavior reported in the literature [9-11]. The dielectric constant decreases with frequency and temperature. This behavior may be due to thermal agitation, which does not allow polarization. The dielectric constant is independent of frequency and temperature at high frequency for PE, which may be understood from the pining of dielectric [12]. The dielectric constant decreases with temperatures, which may be due to domination of interfacial polarization over dipole polarization. Therefore, it may be concluded that, the interfacial polarization mechanism is responsible for the dielectric relaxation in the specimen.

Log frequency versus loss tangent curves at different temperature in Figs. 5a to 5c show that the loss tangent decreases with the increase of frequency at all temperatures. The variation of loss tangent with log frequency and temperature shows a normal loss without having any $\alpha$, $\beta$, $\gamma$ peak.

Experimental observations suggest that EVA have lowest ac conductivity and highest dielectric constant compared with PVC and PE. From the comparison of the ac electrical properties of the EVA with the ac electrical properties of the PVC and PE it has been observed that the PVC and PE do not have better insulating property than that of EVA.
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REFERENCES


FIGURE CAPTIONS

Fig.1a: Log frequency versus log ac conductivity curve for Polyvinyl Chloride.
Fig.1b: Log frequency versus log ac conductivity curve for Ethyl Vinyl Acetate.
Fig.1c: Log frequency versus log ac conductivity curve for Polyethylene.
Fig.2a: Temperature versus log ac conductivity curve for Polyvinyl Chloride.
Fig.2b: Temperature versus log ac conductivity curve for Ethyl Vinyl Acetate.
Fig.2c: Temperature versus log ac conductivity curve for Polyethylene.
Fig.3a: Log frequency versus dielectric constant curve for Polyvinyl Chloride.
Fig.3b: Log frequency versus dielectric constant curve for Ethyl Vinyl Acetate.
Fig.3c: Log frequency versus dielectric constant curve for pure polyethylene.
Fig.4a: Temperature versus dielectric constant curve at different frequency for Polyvinyl Chloride.
Fig.4b: Temperature versus dielectric constant curve at different frequency for Ethyl Vinyl Acetate.
Fig.4c: Temperature versus dielectric constant curve at different frequency for Polyethylene.
Fig.5a: Log frequency versus loss tangent curve for Polyvinyl Chloride.
Fig.5b: Log frequency versus loss tangent curve for Ethyl Vinyl Acetate.
Fig.5c: Log frequency versus loss tangent curve for pure Polyethylene.