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Influence of temperature on breakdown voltage of 10 MeV electron beam irradiated LDPE and HDPE

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Abstract The paper presents measurements of the breakdown (dielectric strength) and dielectric constant of the low density polyethylene (LDPE) and high density polyethylene (HDPE) thin sheets, which were irradiated with a 10 MeV electron beam in the range of 0–470 kGy using a Rhodotron accelerator system. The tests were performed at temperatures ranging from 20°C to 110°C. Variation of the measured parameters vs. radiation absorbed dose and temperature were discussed.

Key words breakdown voltage • dielectric constant • temperature effect • electron beam • low density polyethylene (LDPE) • high density polyethylene (HDPE)

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Introduction

Polyethylene is widely used as insulating material for medium and high voltage wire and cable because of its excellent electrical properties. Compared to conventional oil-paper, PE insulated wire and cables are almost maintenance-free, have a lower weight and a lower thermal resistance for a given voltage and conductor cross section. Due to the advantages much work has recently been done to develop PE insulated high voltage cables [5, 8, 10]. PE has a simple chemical composition, but its electrical behavior is very complicated. It is a crystalline polymer which has both crystalline and amorphous regions. This morphological state of PE is considered to be one factor of its complicated electrical properties.

Some papers described the relationship between electrical tree and super molecular structure of PE and emphasized that initial tree or electrical trees, which leads to electric breakdown, grow along the trans-crystals, or lamella, or boundaries of spherulites of LDPE and HDPE [8].

In this paper, the authors emphasize the importance of temperature which influence the electrical breakdown of LDPE and HDPE that were irradiated by a 10 MeV electron beam. In fact, under service conditions insulating materials often work at higher temperatures. Therefore, the breakdown and dielectric behavior of PE cable insulation was investigated at different temperatures.

Materials and methods

Materials

Two sets of low density polyethylene (LDPE 0075) and high density polyethylene (HDPE 3840) with a density of 0.92 and 0.94 g/cm^3, respectively, were used in this investigation. Both were supplied by Bandar Imam Petrochemical Company.

Sample preparation and irradiation

The samples were prepared in a sheet form with 0.7 ± 0.1 mm thickness using the warm press system. The samples were irradiated with doses which varied from 70 to 470 kGy with a constant dose rate. The irradiation was performed using the Rhodotron type electron accelerator machine, TT200 model, using 10 MeV electron beam with a maximum of 8 mA beam current.

Electric breakdown

A dielectric rigidity system, P/N 6135.053, CEAST Company made in Italy was used for determining the breakdown voltage of the samples [1].

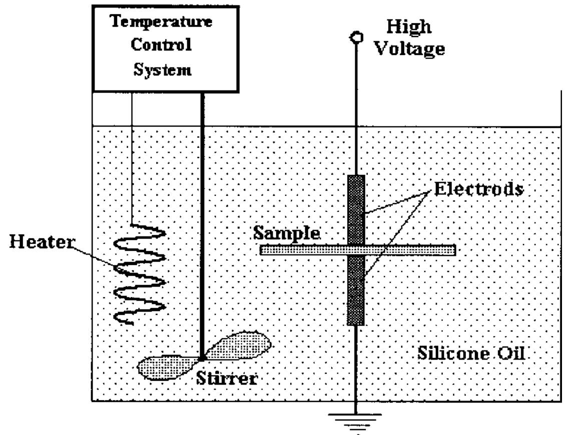

Fig. 1. Scheme of breakdown voltage measurement system including temperature control.

A temperature control system was also designed and installed as shown in Fig. 1. This system consists of a heater to increase the temperature of the silicone oil and the sample, a stirrer to make the temperature homogeneous along the oil and a control box.

Dielectric constant measurement

A dielectric loss measurement system, model TRS-10T, made by ANDO ELECTRIC Company in Japan, was used for determining the dielectric constant of the samples [2]. The system frequency was set at 1 MHz in our experiment.

Results and discussion

Influence of radiation dose

Figure 2 shows the variations of breakdown voltage as a function of radiation dose for LDPE and HDPE samples. In all cases, it was observed that the breakdown voltage does not vary a lot when increasing the absorbed dose. As mentioned before, one of the important factors which affect the electrical properties is the morphological state of polymers. Another study on PE describes the influence of molecular weight on morphological properties, and the consequences on electrical properties [6]. Irradiation changes the polymer network and, therefore, changes the morphological state of the polymer. An increase in the radiation dose leads to an increase in cross-linking degree in the amorphous area. This process may be used as a barrier to prevent the electric breakdown path and thus increase breakdown stress [8]. On the other hand, the increase of radiation dose and the increase of chain scission of PE lead to a decrease in the breakdown. In parallel, it increases the oxidation degree of PE which leads to increase the concentration of carbonyl groups and also trap centers. Therefore, it causes the mobilities of the charge carriers to increase and, finally, decreases the breakdown voltage [4]. Our assumption is that the above discussion shows an opposite behavior, so that it may be concluded that the irradiation dose does not affect the breakdown voltage variation so much.

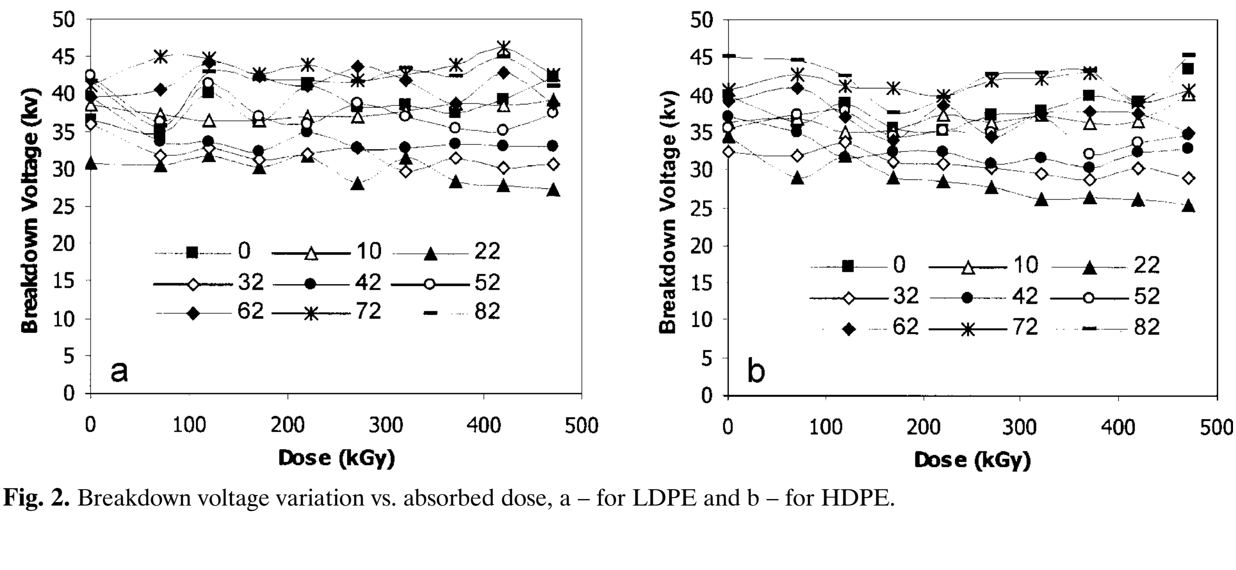

Fig. 2. Breakdown voltage variation vs. absorbed dose, a – for LDPE and b – for HDPE.

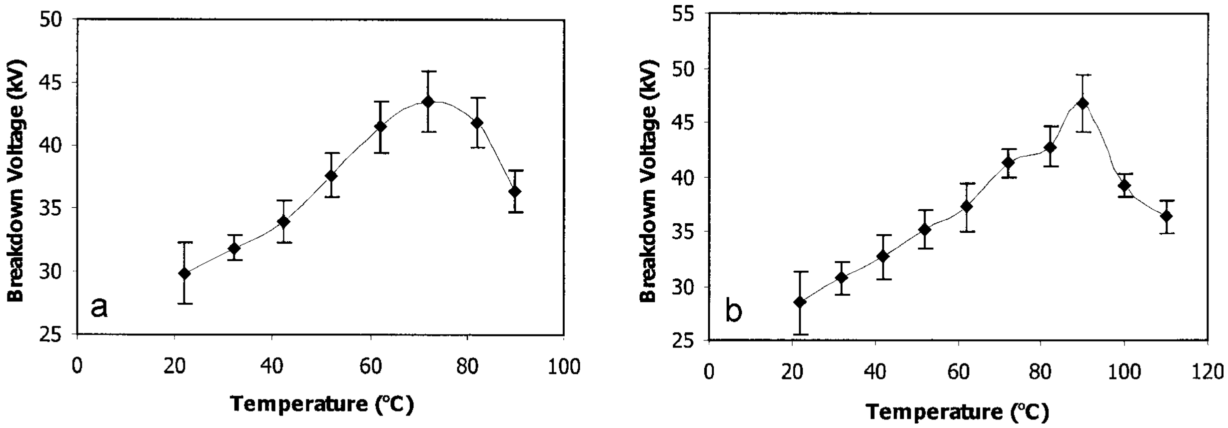

Fig. 3. Breakdown voltage (averaged) variation vs. temperature, a – for LDPE and b – for HDPE.

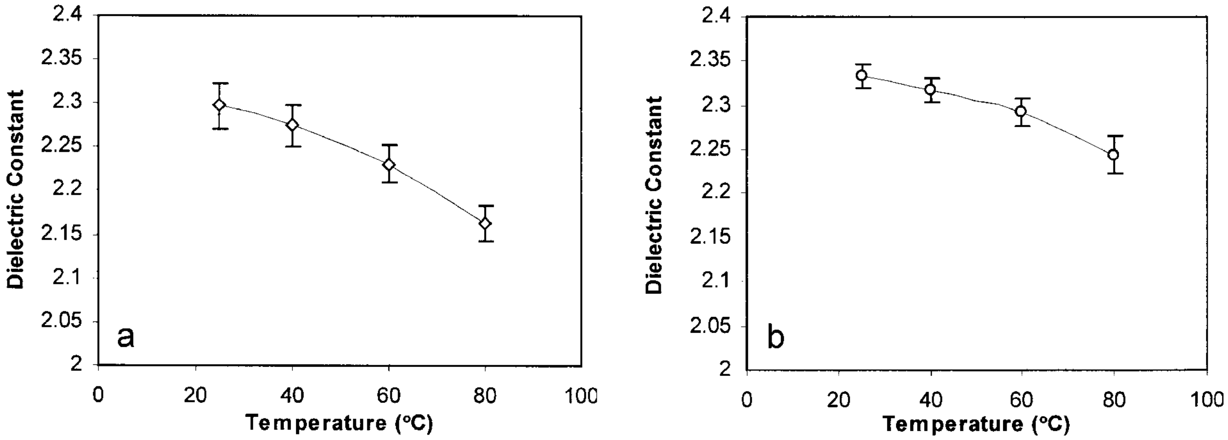

Fig. 4. Dielectric constant variation vs. temperature, a – for LDPE and b – for HDPE.

Influence of temperature

Figures 3 and 4 show the variations of breakdown voltage and dielectric constant, respectively, as a function of temperature for the LDPE and HDPE samples. It was observed that the breakdown voltage increases when increasing the temperature and then decreases again. Also, the dielectric constant slightly decreases when the temperature increases (Fig. 4). In fact, during the irradiation, electrons are injected into the insulating material and generate additional electron-hole pairs. The electrons may be either transported to the electrodes by the applied field or may be trapped in the material. Trapped electrons are subject to release by thermal stimulation and, hence, may be transported later to the electrodes. These processes can be described by charge-storage rate. The charge-storage rate is dependent on the charge-capture rate and the release rate. When the temperature of a sample is changed, the charge-buildup rate is significantly affected. The release term is strongly dependent on the temperature. Consequently, the charge storage is greater at lower temperatures than at higher temperatures [9]. Therefore, at higher temperatures the breakdown will be higher. Another approach, in turn, can be to increase the chain mobilities of the PE due to temperature rise which leads to increasing the probability of electron collisions to the polymer chain and, consequently, to decreasing the mean-free-path of the electrons in the material. Therefore, the electron energy cannot be sufficient to make a breakdown. On the other hand, further increment of temperature causes the breakdown to decrease. It could probably be due to a decrease in the degree of crystallinity in PE with increasing temperature, which leads to a reduction of the intrinsic strength of the material [3]. According to Fig. 3, this temperature is the threshold of melting temperature of the LDPE and HDPE samples which are 75°C and 95°C, respectively. Influence of radiation dose did not show any considerable variations in the dielectric constant of the samples. In fact, the variations were due to the uncertainty of the measurement. However, these variations were investigated at different temperatures and the results are shown in Fig. 4, which is in agreement with the previous works [7].

Conclusion

Measurements of the breakdown voltage and dielectric constant at different temperatures and different electron beam radiation doses were carried out for the LDPE and HDPE materials and lead to the following conclusions:

1. Increasing the radiation dose does not change the breakdown voltage considerably.
2. The breakdown voltage increases with increasing

temperature, but decreases after reaching a specific temperature.

3. The dielectric constant decreases slightly when the temperature increases.

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