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Experimental Investigation on Surface Potential Kinetics in Polyethylene Terephtalate (PET)

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Abstract: In this study, the results of experimental investigation carried out on Surface Potential Decay (SPD) after corona charge deposition for Polyethylene-Terephthalate (PET) material are presented. This work shows that the classical interpretation of potential decay in terms of injection or polarization is not sufficient. The experimental results have revealed that there is a cohabitation of two processes namely, polarisation and charge injection with respective parts (shares) changing according to initial potential value and temperature. This investigation has showed that the surface potential decay is highly conditioned by temperature, relative humidity and charge density initially layed down on the material. More over, humidity and temperature influence on SPD is not the same.

Key words: Surface potential decay, corona discharge, polymer, charge injection, polarization, trapping kinetics

INTRODUCTION

Since several years, synthetic polymers have known a large application in electrical industry due to their excellent electrical, thermal and mechanical properties. At the same time, solid insulating polymers are used in hostile environments where they may be subjected to water attack, high static non-ionizing radiation and other corrosive materials or reactions. Therefore, the insulation properties are deteriored and involved a premature ageing of electrical insulation.

Electrostatic charges can play an undesired role in diverse industrial applications, particulary in plastic industry and in high-impedance circuitry. The main fields of industry source of numerous work on surface potential decay are: Electrooptics (photocopies and laser printers)[1-3], electrets materials[4-6] and electrical industry working on insulating polymer developments for high voltage insulation[7-11].

It is therefore important to have appropriate knowledge on generation and decay of surface charges. The optimization of their performance requires the elucidation of charge transport processes. One of the experimental techniques to investigate the charge carrier transport in solid insulating polymers is the surface potential decay method. Its main interest being to avoid any contact with the surface, provided that charge is deposited by means of a DC corona discharge and that potential is measured by a vibrating reed probe, or by an induction probe. The critical issue concerning potential decay measurements is the interpretation of the curves.

Many experimental works have been carried out with this powerful method[7,12,13]. The great diversity of parameters influencing these mechanisms makes difficult the study and the interpretation of the processes. Several physical processes can be held responsible for the potential decay after corona charge deposit which are: Surface conduction[4,14], polarization phenomena[15], charge injection[16,17] and atmospheric neutralization[18]. One can add also the possible effects of piezoelectric phenomena under the influence of electrostatic pressure at high field.

However, the recent literature on potential decay measurements is dominated by the hypothesis of injection and polarization phenomenon of the charge deposited on the surface. The "Cross-over" of the curves which reported initially by Ieda and co-Workers[7] on polyethylene and has also been observed by other research works[8,19,20] is widely admitted as an experimental evidence of a partial injection into the bulk of the charge deposited on the surface. The amount of charge injected depends on the initial potential value[12,21].

In this work, experimental measurements on 1 mm thick PET which were not taken into consideration by similar studies are presented. Other results on PET thin film (in order μm) are also discussed. The obtained results analysis leads to the conclusion that charge injection mechanism can explain surface potential decay[19,22-24].

This experimental investigation is particularly interested on potential decay dependence on temperature, Relative Humidity (RH) and charge density.

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MATERIALS AND METHODS

Samples: The polyethylene terephtalate is a material of a thermoplastic family. It is largely known under the commercial names mylar, melinex or hostaplan. The PET is often used as a dielectric in high performance foil capacitors[22], electric cables and insulation of electric motors coils. On the other hand, PET is one of the major electret material which has been studied and widely used in charge storage application for a long time[23].

The usual arrangement for studying potential decay using corona charged samples is shown in Fig. 1.

The samples with one surface held firmly on to an earthed metal plate electrode and the other free surface have been used. They may be charged on their free surface by exposure to a corona point discharge situated above the surface and behind a grid electrode. The grid is a fine metal mesh situated above the sample surface so that a reasonably uniform field may be generated in the gap between the grid and the PET surface.

By selecting appropriate corona point and grid potential Vp and Vg, respectively, it is possible to charge polymer surface with ions of either sign and to a potential value limited by grid potential Vg[25].

After charging, the turnable was rotated under a non-contacting probe. The probe is connected to an electrostatic voltmeter (monroe type), which transmits data to the computer. The surface potential was then measured and continuously recorded. All operations are controlled by a computer.

All measurements of surface potential decay were carried out in situ, in a commercial climatic chamber, in which humidity and temperature are controlled. The charging duration was 1s. The experiment was carried in a range of relative humidities from 20 to 80% and for temperature ranging between 20 °C to 60°C and charging voltage from-700V to-1800V. In order to evacuate superficial charges, all the samples are conditionned on the first time at 60°C during one hour and then, they are subjected to climatic conditions chosen before to begin the experiment. For each test, a new sample is used.

RESULTS AND DISCUSSION

Temperature influence: Potential decay measurement is carried out on a temperature ranging from 20°C to 60°C at a fixed relative humidity of 50%. The charge deposit an initial potential (Vo) of-1800 V. These measurement results are shown on Fig. 2.

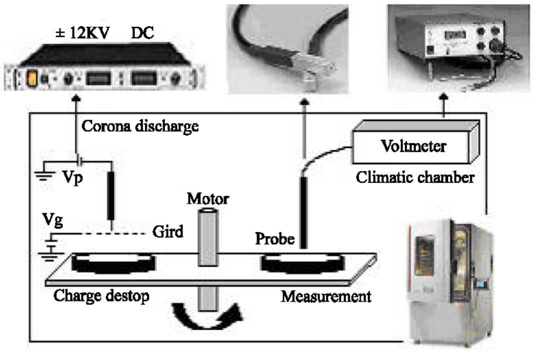

Fig. 1: Experimental setup

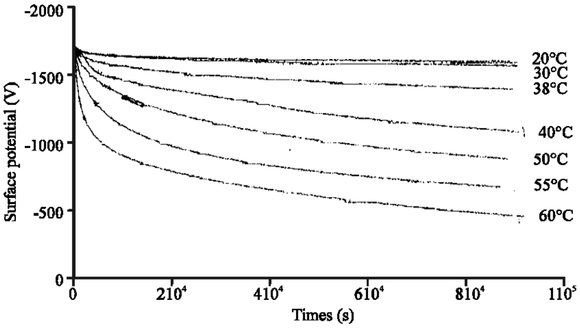

Fig. 2: Surface potential decay for different temperature values with RH = 50% and Vo =-1800V

From Fig.2, it can be noticed that surface potential decay is low at ambiant temperature and remains moderate at temperatures going up to 38°C. This decay is accentuated and becomes significant from 40°C. It can also be seen a fast initial decay and becomes more important with temperature increasing.

The difference in this decay curve supposes that a new process is taking place for temperature higher than 38°C. It is interesting to indicate for PET that at elevated temperature, a partial charge moving from the surface into bulk state and that charge can moves readly in the bulk[26]. Perhaps, this influence is based on a great thermal activation, which plays a very important role on the kinetics of potential decay.

As it can be seen, curves of potential do not reach zero value, but converge after a long time to a constant value. The residual potential is attributed to charges which have been trapped on their way through the sample. As it was shown[27] in dielectrics without traps or with shallow traps, the decay of surface potential is a linear function of time till the transit time. After this point it varies with the inverse of time.

Humidity influence: Figure 3 shows the relative humidity effect on temporal evolution of potential decay at a fixed temperature of 55°C. The initial potential for charge deposit is equal to-1800V.

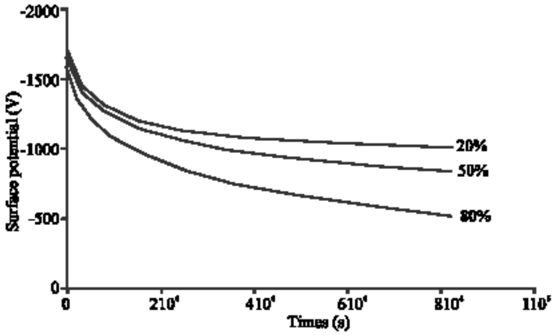

Fig. 3: Surface potential decay for different values of relative humidity with T° = 55°C and Vo =-1800V

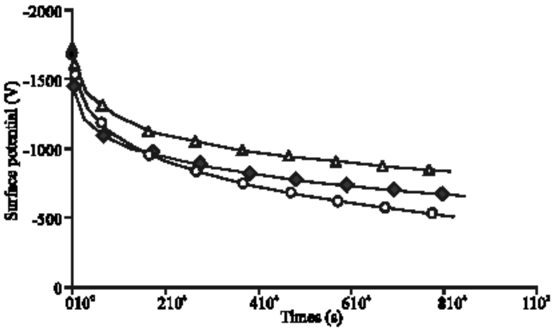

Fig. 4: Surface potential decay for: r: RH = 50% and T = 55°C ; ○: RH= 80% and T = 55°C; ♦: RH = 50%and T = 60°C;With Vo =-1800 V

In most research works carried out on SPD, humidity effect was not taken into consideration and was often neglected. In contrast to this interpretation, it is noted that the humidity acts strongly on the kinetics of the potential decay during all measurement time. It becomes more important as humidity increases.

It is shown that relative humidity forms an important parameter in the charge flow process of PET surface. Humidity and temperature act differently on surface potential decay especially during the first phase of the decay Fig. 4.

Increasing humidity at moderate temperatures seems intensify the potential decay, while increasing temperature at midding humidities accelerate the decay.

Deposit initial potential effect Vo: Figure 5. shows the results of potential decay for different values of initial potential, fixing temperature and relative humidity at 55°C and 50%, respectively.

It can notice a fast initial decay at high potentials and an intersting cross-over phenomenon in which material surface initally charged to high potential show more faster decay than those charged to a lower decay. Baum and al[26,28] were able to demonstrate that cross-over

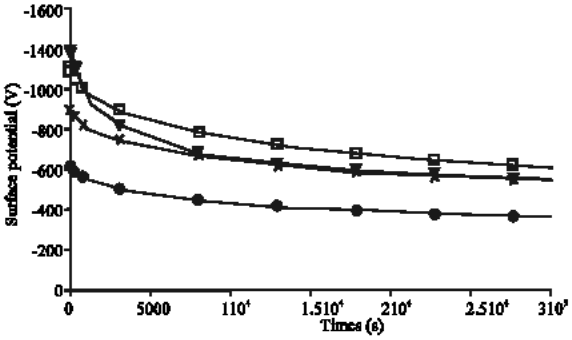

Fig. 5: Surface potential decay for various initial potential with RH = 50% and T° =55°C, •:-700 V, ×:-1100V, □:-1300 V,◆:1400V

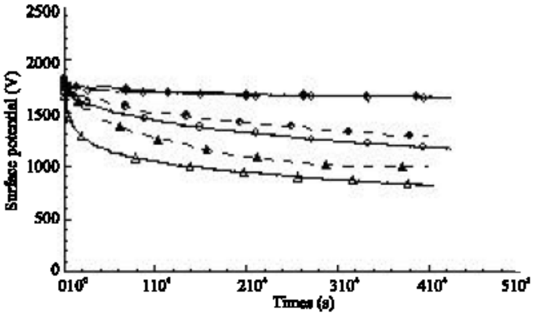

Fig. 6: Surface potential decay in positive and negative polarities (at absolute value): (◆: +1800 V,¯:-1800V and T =30°C), (○:-1800 V,:+1800 V and T=50°) (▲: +1800 V,△ :-1800 V and T = 60°C), withRH =50%

phenomenon depends on the sign of charge and duration of corona charging process. They proposed that excited molecules and photons generated in corona discharge were effective in encouraging charge originally deposited in deep surface state to become injected into bulk states where it becomes mobile. This would lead to a more rapid decay of surface potential, especially for high initial values when the field of charges themselves would help to lower the barrier to injection. They also demonstrate that cross-over did not occur if charging was completed in short times (~ 25 ms).

The initial fast decay may be attributed to a partial injection of deposited charges into the polymer bulk under the electrical field generated by charges themselves[20]. Once injected into polymer bulk, the charges may be expected to drift towards the back electrode under the influence of this field. For low initial potential values, the decay was very slow, this behavior may be attributed to the possibility that charges deposited on the surface do not have sufficient energy to be injected into the polymer bulk. In accordance with seggern[29], the traps in PET are charaterized by higher energetic depth at the surface and become shallower with increasing depth in the material. So, under the influence of deposit charge, it can be assumed a slow polarisation processes occupied within the bulk volume.

Figure 6. shows the surface potential decay in both polarities (±1800 V at absolute value). At high temperature, no symmetry between the two polarities is noted. This can not be explained by dipolar relaxation phenomenon[11] and at low temperature, a symmetry tendency of both polarities is noticed, this can be explained by the existence of dipolar relaxation.

DV/dt transformation: Investigating decay characteristics of surface potential of corona charged polymers[17,30,15], it was showed that dV/dt = f(t) presentation in bilogarithmic coordanates is proportional to a current and is an appropriate mean to explain the most probable mechanism taking place in the charge flow process insulating surface.

To establish the link between potential decay and absorption current which are linked principally to a low polarization mechanism of material, Moliniė[15] has shown in his work on epoxy resine that the material polarization mechanism gives an absorption current according to Curie-von Schweidler law. According to the same author, the curve linearity of potential decay which follows the power law of dV/dt α At^{-n} type was assimilated to absorption current. This assumes therefore, polarization phenomenon predominance of surface potential decay in this material.

On the other hand, Von berlepch[17] and bigarré[30] have observed in their study on the polyethylhene from this representation two straight lines with different slopes on either sides of mean transit time value τ.

The authors have explained that this behaviour is a representation of charge partial injection mode into the material bulk.

Figure 7 presents a characteristic family of log (dV/dt) versus logt, curves obtained after negative charging with different temperature (Fig. 2.). At a temperature of 20°C and 38°C, the time dependance of the first derivatives is straight lines with a slope equal to-0.67 and-0.61, respectively, it is noted a good analogy with absorption current according to Curie von Schweidler law. This could justify the hypothesis of the analogy between this behaviour and that of Curie-Von Schweidler law and the material polarization phenomenon predominance of surface potential decay.

For temperatures higher than 38°C, the charateristic appears approximatively as an intersection of two straight lines. This behaviour corresponds to a power law[17-30] with a slope change of the decay rate evolution charateristic by a trasient time value τ.

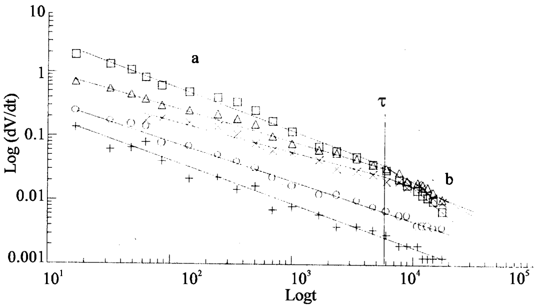

Fig. 7: Log (dV/dt)-vs-Log(t)for differenttemperature values with RH = 50%and Vo =-1800V (□ : 60°C; Δ: 55°C; × : 50°C ;o: 38°C; +: 20°C)

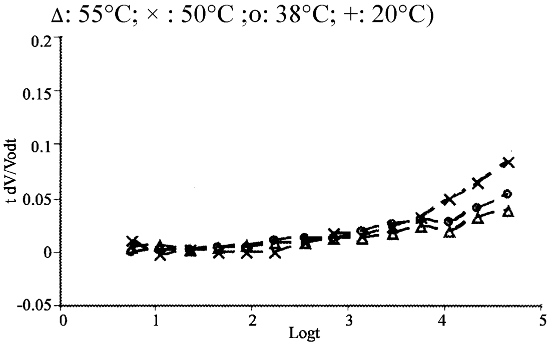

Fig. 8: t dV/Vodt curves for T: Δ : 20°C, o: 30°C, × : 35°C with RH = 50% and Vo =-1800V

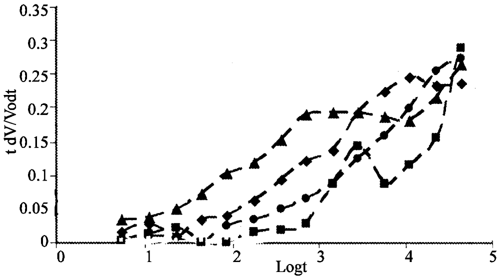

Fig. 9: tdV/Vodt curves for T: ■ : 40°C, : 50°C, • : 55°C, ◆: 60°C with RH = 50% and Vo =-1800V

Moreover, taking into account, the cross-over phenomenon, it can favour the charge injection mechanism to explain the surface potential decay in this case.

TdV/Vodt Transformation: To obtain more information about dielectric response an other mathematical treatment tdV/Vodt transformation is used.

The tdV/Vodt vs logt diagrams, which can be used for data analysis without considering any previous physical interpretation of potential decay curves. The tdV/Vodt transformation is well adapted to potential decay curves because it allows seeing fast phenomena and as the potential decay curves tend to slow down for long time and the derivative becomes smaller, the product of the derivative and the time permits the representation of the slow phenomena in an appropriate way. It has been used with some particular interpretations of potential decay measurement in polystyrene[31], epoxy resine and polypropylene material[32].

In the tdV/Vodt diagrams and for low temperature range (T < 38°C) Fig. 8, it is noted a potential decay obedient for Curie-von Schweidler law that is an evidence of polarization phenomenon into the material.

Whereas, for high temperature (T > 38°C) range, this behavior is absent Fig. 9. It is noted, a few reproducible behavior and a difference between a curves. Thus, most probably hypothesis is the charge injection phenomenon besides, the curves profile show some irregularities. This confirms our results in dV/dt characteristics

CONCLUSIONS

The combination of surface potential measurements after deposition, dV/dt transformation and tdV/Vodt diagrams can provide an operational tool for the investigation of insulators electrical properties. Charge injection dynamics, polarization processes and other components of dielectric response can be identified with a combination of this mathematical treatment and an experimental procedure.

This work allowed us to show the importance and the role of temperature and humidity in charge flow process evolution at PET surface. These two parameters do not contribute by the same maner in deposed charge neutralization mechanism surface. It is assumed, that the temperature as an accelerator of the process where as the humidity is accentuator. Furthermore, this study allows us to assume slow polarization phenomena attributed to the dipolar relaxation in the material at low temperature (till 40°C). Beyond this temperature, charge injection mechanism in material bulk seems to be the more probable hypothesis to explain charge flow in PET. The experiment results confirm the influence and the role of thermal activation and electrical field on the potential decay.

It is most probable that two physical causes can be held responsible for decay mechanism, charge injection and slow dielectric polarisation coexist in most cases, where the dominance of one with regard of the other depend on the initial potential and temperature.

It should be noticed that these results are in good agreement with those of a recent study[33] carried out on similar materials by a characterisation, through different techniques of space charge measurement. This shows the complementrity of a surface potential decay technique for conduction mechanism analysis in insulating materials bulk.

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