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Dielectric Properties of Commercial non-Polar Polymers.

Hameed M. Ahmed , Shuja-Aldeen B. Aziz*
Department of Physics, College of Science-Sulaimani University, Kurdistan Region - Iraq

Abstract

Frequency and temperature dependence of dielectric constant (ε') and dielectric loss (ε''), in commercial non-polar polymers which were high density polyethylene (HDPE) and polystyrene (PS), of thicknesses 2.8 and 2.7mm respectively with diameter 5.6 cm, are studied in the temperature range (20-110°C) and in the frequency range (1KHz-1MHz).It was observed that the dielectric constant of non-polar polymers decrease with increasing temperature as well as with frequency. The dielectric constant of PS increases with temperatures above 70°C, which is due to the glass transition temperature. It has been found that the dielectric loss of HDPE and PS decrease with increasing frequency and some loss peaks are observed. The dielectric loss of HDPE was found to be slightly temperature dependent, while the dielectric loss of PS, were found to increase slightly with increasing temperature.

Keywords: commercial non-polar polymers, dielectric constant, dielectric loss, dielectric relaxation

Introduction

Non-polar polymers such as polyethylene, polytetrafluoroethylene, and polystyrene are especially significant because of their low loss values over the widest frequency range. Because of their partial use in the electrical industry and because of the partial relevance of dielectric studies to questions of molecular mobility and relaxation time, extensive studies of polymer behavior have been performed by dielectric method [1]. The dielectric dispersion and absorption are the crucial quantities required in the design of any device. The study of dielectric loss as a function of temperature and frequency is one of the most convenient and sensitive methods of investigating polymer materials [2]. The frequency dependence of dielectric constant and dielectric loss has considerable practical importance. For example, dielectric heating in lossy polymers may cause a thermal breakdown. For electrical insulation application, a large band gap, a low dielectric constant, and a low dielectric loss over a wide frequency range are desirable [3]

Experimental Method

The non-polar polymers used in the present study, as mentioned before, are HDPE and PS. Extrusion molding process was used for making the polymer samples.
The dielectric loss cell was locally designed. The heating coil was made from a resistive wire in the form of circular coil arranged symmetrically in the chamber. The resistance coil is connected to an A.C source variac transformer. The current through this heater could be adjusted to optimal, the temperature gradient in the hollow space enabling a sample temperature to be determined with 1°C or better. To eliminate temperature gradient we heated the system for several hours to attain thermal equilibrium (a pre experiment was performed in which two identical

***Email: dr_tayfoor@yahoo.com**

Cited from his M.Sc Thesis

thermocouples was attached to each disc it was found that at thermal equilibrium they record the same temperature). Also we switched off the power supply during the taking of the measurement, otherwise A.C current passed through the electrical heater around the sample cell; this would produce a magnetic field which could have a bad effect on the results.

The sample holder which was two identical discs of 1cm thickness made from aluminium was set at the centre of the circular coil and at the high of 7cm The lower plate is fixed, while the upper is movable by using a screw to as sure good electrical contacts between the electrodes and the sample; this enables us to avoid the parasite capacitance induced by the presence of air interstices at the interfaces between the sample and the electrodes. The thermocouples were not being attached to the capacitor plates because it changes the value of the capacitance, there for it was as close to the capacitor plate as thickness of one mica sheet.

The dielectric properties (Dielectric constant and Dielectric loss) were measured as functions of temperature and frequency. The capacitance and resistance of polymer samples were measured by using Programmable Automatic Precision RCL meter type PM6036. The sample temperature was measured by Alumel-Chromel constantan thermocouple, with digital thermometer TM-914C (40~1200°C). The thermocouple was not attached to capacitor plates because it produces some leakage which can change the values of the capacitances, therefore it was put as close to the capacitor plate as the thickness of one mica sheet.

Results and Discussion

The dielectric constant of a material can be expressed as a complex quantity, ε^*, consisting of real part (ε') and an imaginary part (ε''). The real part of the dielectric constant is the quantity that describes electrical energy converted to stored potential energy, generating a polarization of the dielectric material. This energy storage process is always accompanied by a loss current. This represents energy that is not stored, but is dissipated within the material in the form of heat. This dielectric loss phenomenon is represented by the imaginary part of the dielectric constant [4]

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Dielectric constant (ε') and dielectric loss(ε''), were measured in the frequency range, 1KHz to 1MHz and temperature range 20 to110°C in both two polymer samples.

Measured quantities were the capacitance and resistance of the samples, from which the dielectric constant and dielectric loss were calculated [5]:

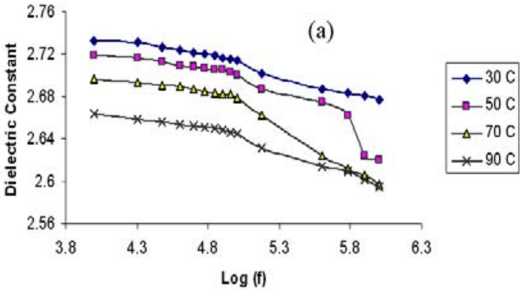
$$\varepsilon' = \frac{C_p}{C_\circ} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

$$\varepsilon'' = \frac{1}{R_p C_\circ \omega} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

C_p is capacitance of the polymer sample and $C_\circ = \varepsilon_\circ A/d$, $\varepsilon_\circ$ permittivity of air, A and d are respectively the active area of the sample and its thickness, and R_p is the resistance of the polymer sample. ω is the angular frequency and is given by $\omega = 2\pi f$.

Dielectric constant as a function of frequency

The fig. 1. (a-b) shows the variation of dielectric constant as a function of frequency at different temperatures for non-polar polymers.



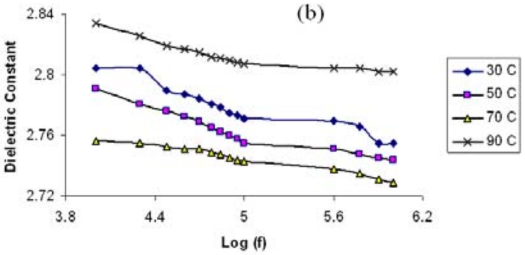


Fig1. Frequency dependence of dielectric constant at different temperatures for (a) HDPE (b)PS

The dielectric constant ε' curves of HDPE and PS (non-polar polymers) versus frequency at different temperature are presented in figures 1(a-b). It can be observed that for these non-polar polymers, the dielectric constant ε' is a slight function of frequency with a slight decrease as frequency increases; the total variation of dielectric constant against frequency at different temperature is small as clear from the graphs.

Dielectric constant is independent of temperature for non-polar polymers whereas for strong polar polymers dielectric constant increases with increasing temperature. However since the specific volume of the polymer is temperature-dependent, i.e. it increases as the temperature increases, so that in the case of weakly polar polymers the dielectric constant decreases with increase of temperature [6], it can be seen from the Figures 1(a-b) for HDPE and PS. The increase of ε' at 90°C for PS relative to its value at 30°C is indicative of the fact the glass transition temperature of PS sample is about (70 □ 80°C). The decrease of T_g of PS may due to the effect of plasticizers. The plasticizers modifies the reheological properties of high polymeric materials by lowering the melt viscosity, T_g or the elastic modulus of the plastic, thus plasticizers reduce T_g and increase the free volume, and the polymer chain moves more readily at a given temperature [7].

Dielectric loss as a function of frequency

The fig. 2.(a-b) shows the frequency dependence of dielectric loss at **different** temperatures for non-polar polymers.

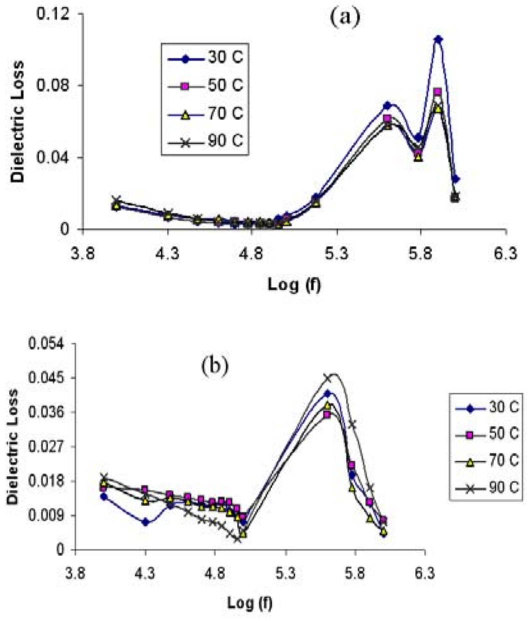


Fig. 2. Frequency dependence of dielectric loss at different temperatures for (a) HDPE (b) PS

Figures 2(a-b) illustrate the variation of dielectric loss ε'' with frequency at different temperatures for non-polar polymers (HDPE and PS). In HDPE and PS, polarization effects due to the dipole reorientations are minimal, as it is clear from the figures. This is due to a lack of structural components in the repeat unit that can couple to the electric field at radio frequencies [8]. Theoretically a non-polar polymer with linear should show only the α-dispersion since the only motion that can occur is due to the main chain at the glass transition temperature [9]. But two loss regions are observed in HDPE and one loss region observed in PS, the exact temperature and frequency dependence of dielectric loss depends upon the morphology and impurity in HDPE and PS samples.

Dielectric constant as a function of temperature

The fig. 3(a-b) shows the temperature dependence of dielectric constant at different frequencies for non-polar polymers.

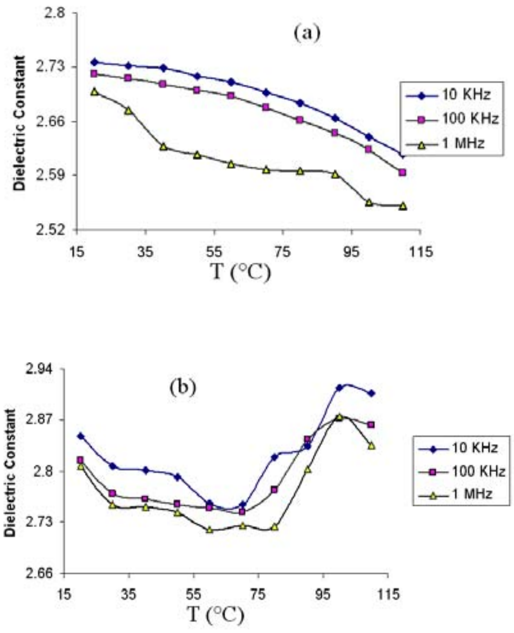


Fig. 3. Temperature dependence of dielectric constant at different frequencies for (a)HDPE, (b) PS

Figure 3(a-b) shows the variation of dielectric constant ε' with temperature at different frequencies for HDPE and PS (non-polar polymers). From the figures it's clear that the dielectric constant ε' is higher at low frequencies compared to its value at 1 MHz. The decrease in dielectric constant ε' with temperature is due to the temperature-dependent of the specific volume of HDPE and PS, i.e. it increases with temperature, and hence the dielectric constant decreases with temperature [10].

From Figure 3(b) of PS it's clear that the dielectric constant ε' is increasing with temperature, beyond 70 °C, which is the indication of the T_g of the sample, we approach to rubbery state; some segments of a long chain molecule may have freedom of movement while the molecule itself is not free to move. In this case the space between molecules or free volume increase to allow molecular chain motion [9]. This increase of molecular chain motion by increasing temperature, increase the polarization because they respond to the applied electric field and hence the dielectric constant ε' is also increased. The dielectric constant (ε') of PS decrease at higher temperatures, this may due to thermal agitation which will not allow the dipoles (by dipoles we mean some fillers and additives which contain in the sample) to orient, as clear in Figure 3(b) for PS [11].

Dielectric Loss as a function of temperature

The figure 4(a-b) shows the temperature dependence of dielectric loss at different frequencies for non-polapolymers. Figure 4 (a-b) shows the variation of dielectric loss with temperature at different frequencies for non-polar polymers.

From Figure 4(a) it’s clear that the dielectric loss ε'' of HDPE as a function of temperature is almost constant, that is slightly depend on the temperature, because HDPE is thermally more stable than other polymers.

This is relating to the number of constitution in the backbone, increasing the number of constituents in the backbone also decreases stability [9].

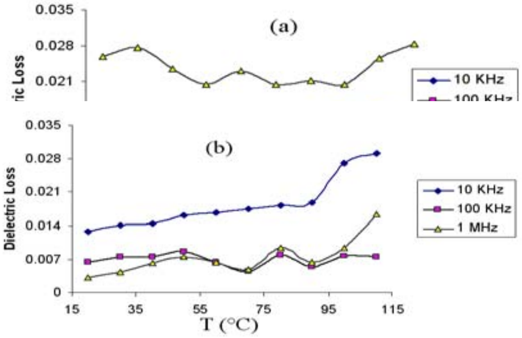


Fig. 4. Temperature dependence of dielectric loss at different frequencies for (a) HDPE (b) PS.

From Figure 4(a) for HDPE sample, it seen that some loss peaks are observed which may be due to the presence of polar additives or other impurity dipoles. The loss peak around 80°C, it could be α-relaxation for PS which is due to the movement of main chain segments. The loss peak below 70°C may be due to β_r -relaxation which is mainly due to the movement of side groups or small units of main chain. It is clear that the α_r -relaxation peak is much narrow than the β_r -relaxation peak. The temperature dependence of the process is much steeper than that of the β_r process, indicating that greater thermal activation energy is required for the motion. The α-relaxation process near T_g is largely dependent on free volume. Molecular structure affects the glass transition temperature and hence the dielectric relaxation times. Thus, a bulky side group would cause the T_g to decrease, and preventing the chains from packing together tightly. The presence of any impurities in the polymer can affect the relaxation processes and hence the value of dielectric constant ε' and dielectric loss ε''. The plasticizer can lower the glass transition temperature and polar impurities can increase the dielectric relaxation for non-polar polymers [12].

4. Conclusions

The experimental results indicate that the decrease in dielectric constant with frequency as well as temperature for non-polar polymers (HDPE and PS), is ascribed to the weak polar nature of these polymers. The non-polar polymers (HDPE and PS), are low dielectric constant materials. The increase of ε' for PS above 70°C is appropriate to glass transition temperature. The dielectric loss of HDPE and PS, was found to decrease with increasing frequency and some loss peaks are observed owing to the presence of additives and other impurities. The dielectric loss of HDPE is almost constant; this is due to the thermal stability of HDPE which is related to the small number of constitutions. The loss peak of PS above 70°C is due to α_r-relaxation. It was observed that the dielectric loss of PS increase slightly with increasing temperature. From the dielectric loss measurements it can be concluded that the non-polar polymers (HDPE, PS) are low loss materials.

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ليكۆ ڵينەوە لەسەر سيفاتى نەگەياندنى كارەبايى بۆ پۆليمەرە بازرگانيە بێ جە مسەرەكان

حميد مجيد أحمد، شجاع الدين بكر عزيز، زانكۆى سلێمانى،كۆلێژى زانست، بەشى فيزيا، هەريمى كوردستان-عيراق

پوختە

ليكۆ ڵينەوە لەسەر نەگۆڕى نەگەياندنى كارەبايى(ε') وە گومبوى نە گاياندنى كارەبايى (ε'') بۆ پۆليمەرە ناجەمسەرەكان كە بريتى بوون لە بولى ا پيلين (HDPE) وبولى ستايرين (PS) لە نێوان پلەى گەرمى (20-110 C°) و لە نێوان لەرەلەرى(1MHz-10KH) وە دۆزرايەوە كەوا نەگۆڕى نە گەياندنى كارەبايى بۆ ئەم پۆليمەرانە كەم دەكا بەزيادبونى پلەى گەرمى وەهەروەهاش بۆ لەرەر. وە دەركەوت نەگۆڕى نەگەياندنى كارەبايى (PS) زياد دەكات بەزياد بونى پلەى گەرمى لەسەروى پلەى گەرمى 70C° وە ئەمەش دە گەرێتەوە بۆ پلەى گەرمى گۆڕانى شوشە. لەكاتێكدا نەگۆڕى نەگەياندنى كارەبايى بۆ هەردوو پۆليمەرەكان(HDPE) و (PS) دەركەوت كەوا كەم دەكا بە زيادبونى لەرەر وە هەروەها چەند بەرزيەك بەديكرا لەم پۆليمەرەدا. وە بۆمان دەركەوت نەگۆڕى نەگەياندنى كارەبايى(HDPE) ناگۆڕێت لەگەڵ پلەى گەرميدا بەلاّم بۆ (PS) نەگۆڕى نەگەياندنى كارەبايى كەمێك ئەگۆڕێت لەگەڵ زيدبونى پلەى گەرميدا.

دراسة خواص العزل الكهربائى للبوليمرات التجاريةغير القطبية

حميد مجيد أحمد ، شجاع الدين بكر عزيز، جامعة السليمانية، كلية العلوم، قسم الفيزياء، اقليم كوردستان- العراق

الخلاصة

تمت دراسة ثابت العزل الكهربائى (ε') و فقدان العزل الكهربائى (ε'') للبوليمرات غير القطبية التى شملت بولي اثيلين (HDPE) وبولي ستايرين (PS)فى مدى درجات حرارة (20-110 C°) ولمدى ترددات(1MHz-10KHz) لقد لوحظ أن ثابت العزل الكهربائى لهذه البوليمرات تقل مع زيادة الدرجة الحرارة كذلك الحال بالنسبة الى الترددات. ان ثابت العزل الكهربائى لـ (PS) تزداد مع زيادة درجة الحرارة فوق 70C° وهذا يعود الى درجة حرارة انتقال الزجاجى . أما فقدان العزل الكهربائى لكل من HDPE وPS وجد انما تقل مع زيادة التردد، كما وجد أيضاً عدد من القمم فى هذه العينات . أما فقدان العزل الكهربائى لـ (HDPE) فقد وجد انما يكاد لايعتمد على درجة حرارة اما بالنسبة الى (PS) فقد وجد ان فقدان العزل الكهربائى تزداد قليلاً مع زيادة درجة الحرارة.

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