# DIELECTRIC PROPERTIES AND THERMAL CONDUCTIVITY OF HDPE AND PS

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## Abstract

Dielectric constant ($\varepsilon'$) over the frequency range 1KHz-1MHz and thermal conductivity (*k*) have been measured for high-density polyethylene (HDPE) and polystyrene (PS) (with thicknesses 1.6 and 1.1 mm respectively and all with diameter 3.2 cm), in the temperature range 30-110°C, It has been found that the dielectric constant is almost frequency independent and slightly temperature dependent, this reveals the fact that these polymers are non-polar. However, there was a significant effect of temperature on the thermal conductivity of the samples, especially at $T_g$ of PS and $T_m$ of HDPE.
**Key words**: Dielectric constant, thermal conductivity, non-polar polymer.

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1KHz-1MHz                              ($\varepsilon'$)

1.6mm          ) (PS)                    (HDPE)

.(30-110ºC)                    3.2cm          ( .  mm

.

($T_m$)                              (PS)          ($T_g$)

.(HDPE)

## 1. Introduction

Polymers can be made that are electrically insulating, semiconducting, conducting, or magnetic [1].

The use of polymers as *insulators* is very common because of their high resistivity but now the researchers are engaged in converting insulating polymers to conducting materials due to their strength, toughness, frictional resistance, plasticity, elasticity, and corrosion resistance. The advantage of using polymers as *conductors* is that they are light weight, low cost materials and can easily be shaped into fibers and films through known procedures [2].

The purposes of the particular materials for definite uses are depended on their thermal conductivity, this is done by the two behaviors either they have low or high thermal conductivity. The study of thermal conductivity often requires a context of materials science in the widest sense. For example furs, skins, building materials (woods, bricks and polymers like PVC and HDPE) and others that are used as low thermal conductive to protect and isolate a system from its external [3].

## 2. Experimental Technique

The polymers used in the current study, are high-density polyethylene (HDPE), and polystyrene (PS) of thicknesses of 1.6 and 1.1mm respectively and diameter of 3.2cm, where they obtained from Aldrich Company in the form of grain. We have designed a system for molding grain and powder polymer to produce disc shaped solid polymer samples with mentioned diameter, as shown in (Figure 1).
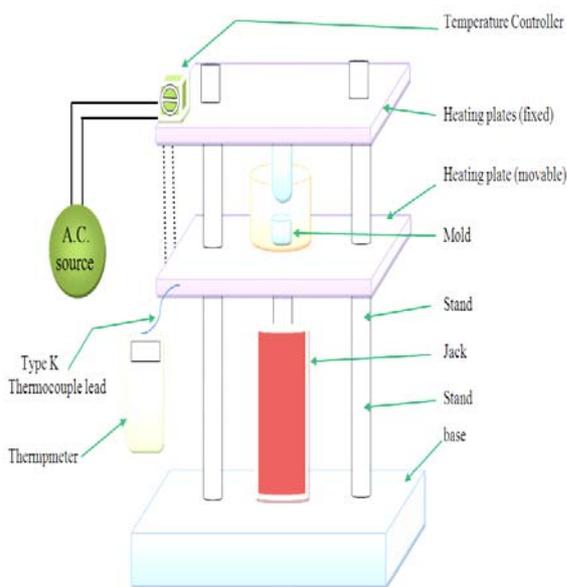


**Figure 1: System of sample preparation**

We have also designed a system of dielectric constant measurement manually which is shown in (Figure 2), it is composed of two aluminum discs (as a capacitor plat), heating coil, thermometer, Variable power supply, Digital ammeter, Insulating wool on desecrater glass, and Wood stand. The heating coil was made from a resistive wire in the form of circular coil arranged symmetrically around the sample. The resistance coil is connected to an A.C source with variable power supply. The current (observed by ammeter) through this heater were adjusted to a desired possible value, and the temperature of the sample was taken at thermal equilibrium, in this way the temperature gradient was eliminated. Also to avoid the effect of the magnetic field produced by A.C current on the measurement; we disconnect the power supply while taking the measurements; this would affect the result.
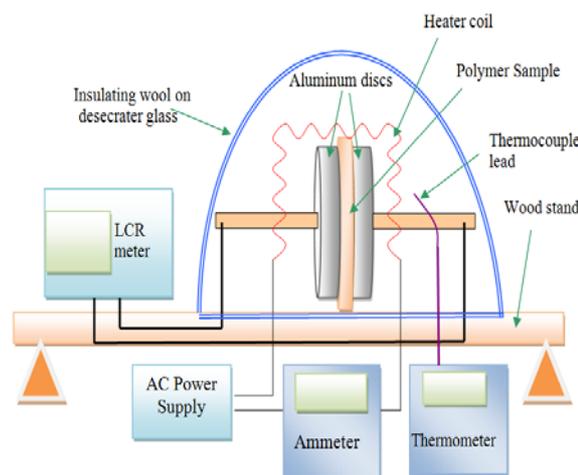


**Figure 2: System of electrical measurements**

The sample was sandwiched between two identical aluminium discs of 2.5cm diameter and they were set horizontally at the centre of the circular heating coil. One of the plates is fixed, while the other made movable by using a spiral spring to get a good electrical contact between the electrodes (plates) and the sample; this removes the capacitance induced by the presence of air at the interfaces between the sample and the electrodes. To measure the sample temperature, a thermocouple (Cu-constantan type K) inserted to the system, and connected to the digital thermometer TM-914C (40~1200°C).

The dielectric constant was measured as functions of temperature and frequency. The capacitance $(C_p)$ was measured by using Programmable Automatic Precision RCL meter type Agilent 4284A.

Finally, we have designed a Modified Lee's discs system made from copper to measure the thermal conductivity of these samples at different temperatures, this shown schematically in (Figure 3).
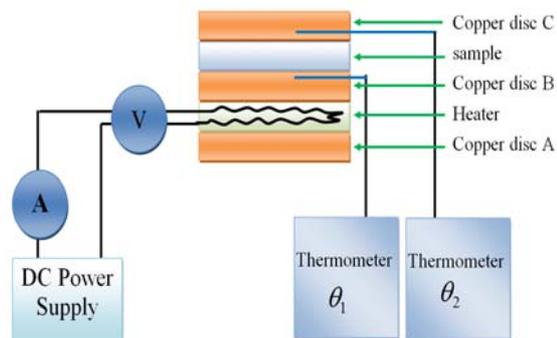


**Figure 3: Lee's Disc apparatus**

## 3. Dielectric constant and Thermal conductivity

The dielectric constant ε ' of the HDPE and PS is evaluated from the measured capacitance C from equation [4]

$$\varepsilon' = \frac{C_p}{C_\circ} \quad \text{...................} (1)$$

Where $C_p$ is the Capacitance of the polymer sample, and $C_\circ = \varepsilon_\circ A / d$ , $\varepsilon_\circ$ permittivity of air.

Using the well-known Fourier's law of heat conduction we have

$$\frac{dQ}{dt} = -k\, A\, \frac{\theta_1 - \theta_2}{dx} \quad \text{...............} (2)$$

Where $k$ is the thermal conductivity of the sample considered, A is the exposed sample area, $dx$ is thickness, $\theta_1 - \theta_2$ is the temperatures difference across the sample.

And also for the rate of heat flow we have

$$\frac{dQ}{dt} = m_c\, c\, \frac{d\theta}{dt} \quad \text{......................} (3)$$

Where $m_c$ is the mass of the copper disc C, and c its specific heat capacity. Since, dQ/dt is the same in each time since the rate of flow of heat through the polymer sample is the same as the rate of flow through the copper disc C at thermal equilibrium, and the rate of flow when cooling process is the same as the heat of flow when at steady state.

From the equations 2 and 3, we can obtain the thermal conductivity (k) of the sample, as:

$$k = \frac{-\, m_c\, c\, \dfrac{d\theta}{dt}}{A\, \dfrac{\theta_1 - \theta_2}{dx}} \quad \text{...............} (4)$$

### 3.1 Dielectric constant as a function of frequency

(Figures 4 and 5) shows the variation of the dielectric constant $\varepsilon'$ as a function of frequency at different temperatures for polymers (HDPE and PS) respectively.
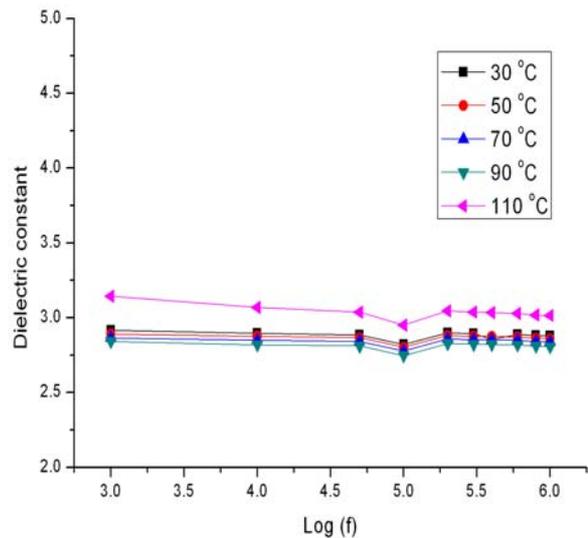


**Figure 4: The Relation between** *Frequency and dielectric constant (* $\varepsilon'$ *) at different temperatures of HDPE*
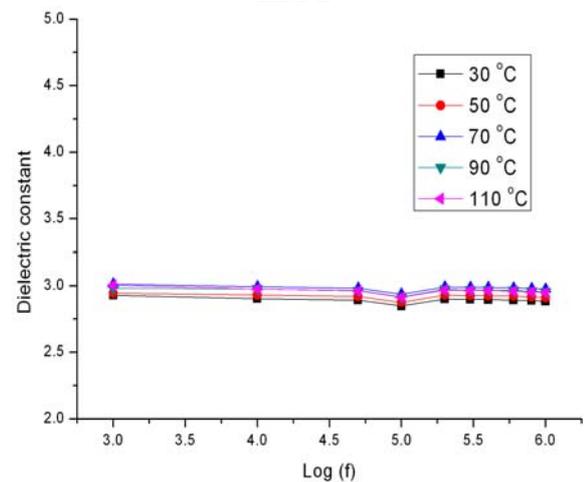


**Figure 5: The Relation between** *Frequency and dielectric constant (* $\varepsilon'$ *) at different temperatures of PS*

It is evident from the figures that for a HDPE and PS, $\varepsilon'$ is approximately frequency independent. These indicate that these polymers are non-polar. Dipole polarization requires a relatively long time compared with that of practically almost inertialess phenomena of deformational polarization therefore the dielectric constant of nonpolar polymers remains invariable with frequency[5].

If a polymer consisted entirely of non-polar groups, or contained polar groups arranged in such a way that their dipoles cancelled out, it would have a low dielectric constant at all frequencies, determined only by the deformational polarizations, and it would not undergo dielectric relaxation[6].

## 3.2 Dielectric constant as a function of temperature

(Figures 6 and 7) shows the variation of dielectric constant $\varepsilon'$ as a function of temperatures at different frequency for polymers (HDPE and PS) samples respectively.
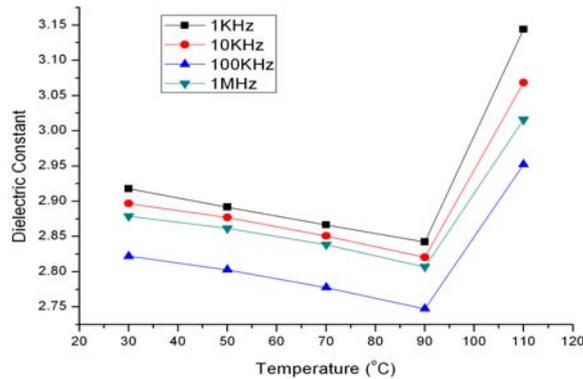


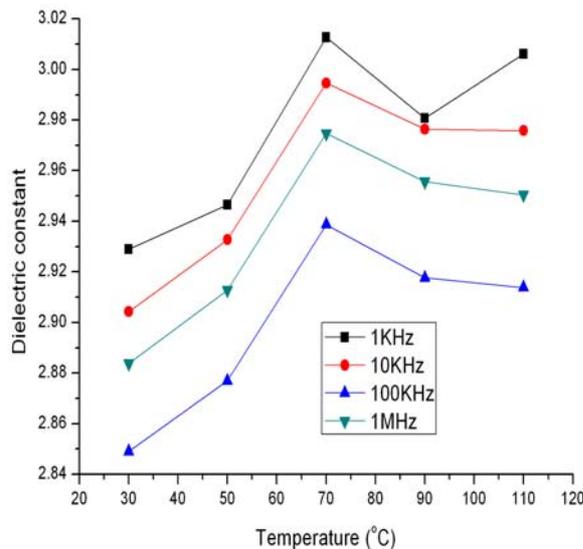**Figure 6:** *Temperature dependence of dielectric constant ( $\varepsilon'$ ) at different frequencies for HDPE*



**Figure 7** *Temperature dependence of dielectric constant ( $\varepsilon'$ ) at different frequencies for PS*

In the case of HDPE (Figure 6), $\varepsilon'$ decreases with temperature because we passing its glass transition temperature $T_g$ =-125 $^o$C, and as we approach $T_m$ (where $T_m$ =130$^o$C for HDPE), $\varepsilon'$ starts to increases rapidly with increasing the temperature, this may be related with the specific volume. 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 the increase of temperature [7]. But in PS, as we can see from (Figure 7), there is an increase in $\varepsilon'$ from 30-70$^o$C and then remain constant as

we go near its $T_g$=100$^o$C, which is due to some what increase of the freedom of movement of the charges, and reaching a maximum at their $T_g$.

## 3.4 Thermal conductivity as a function of temperature

(Figure 8) shows the temperature dependence of thermal conductivity for polymers (HDPE and PS) samples.
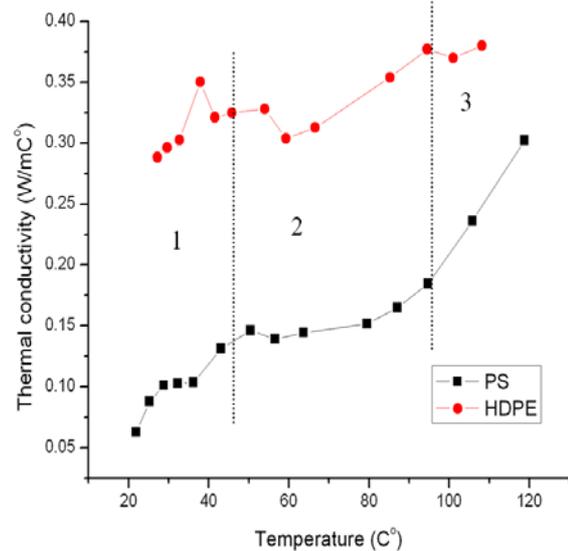


**Figure 8:** *Thermal conductivity as a function of temperature for polymer sample.*

It is obvious that there are three trends in the graph, in the first trend $k$ increases with temperature, while in the second $k$ stays almost constant, and finally another increase in $k$ is observed.

Since the polyethylene is a semi-crystalline polymer, the value of the thermal conductivity in the solid state depends mainly on its degree of crystallinity [8], based on this fact HDPE may have higher degree of crystalline than PS. Owing to the absence of electronic effects in most polymers, heat conduction occurs as a result of lattice vibrations (phonon), similar to dielectrics[9]. For example, HDPE having higher thermal conductivity and lower electrical conductivity, this indicates that the mechanism of heat conduction differs from that of electric conduction (or both thermal and electrical conductivity do not involve the same carriers). This is because the thermal conductivity in polymers is mostly due to so-called phonon transport.

## 4. Conclusions

The dielectric constant $\varepsilon'$ in non-polar polymers HDPE and PS have been studied at

different frequencies and temperatures. The experimental results indicate that the dielectric constant approximately remain constant with increasing frequency at any temperature, which can be due to the non-polarity structure.

There was a significant effect of temperature on the thermal conductivity of the samples.

HDPE and PS materials have excellent thermal and electrical properties, which make them useful as low cost insulating materials.

## Acknowledgement

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