

## Study the Effect of Heat Treatment and Pressure on Some Electrical Properties of Nano Polycarbonate

May A.S. Mohammed and Mohamed Muthana Ghazi  
College of Education For Nano Science, University of Baghdad, Baghdad, Iraq

**Abstract:** In the present research, the electrical properties which included the ac-conductivity ( $\sigma_{ac}$ ), loss tangent of dielectric ( $\tan \delta$ ) and real dielectric constant ( $\epsilon'$ ) are studied for nano polycarbonate in different pressures and frequencies as a function of temperature these properties were studied at selective temperature gradients which are (RT-50-100-150-250) $^{\circ}$ C. The results of the study showed that the values of dielectric constant and dissipation factor increase with increasing pressure and temperature and decreases by increasing frequency. And the results of electrical conductivity showed that it increases with increasing temperature, pressure and frequency.

**Key words:** Polycarbonate, electrical properties, electrical conductivity, dissipation factor, dielectric constant, pressure

### INTRODUCTION

Polycarbonates are polyesters of carbonic acid and diols or diphenols that feature a carbonate group (-O-C(O)-O-) in their repeating unit and which are each of the aromatic and the aliphatic type (Goethals, 1988; Percec *et al.*, 1989; Jerome *et al.*, 1991) (Fig. 1).

Polycarbonates are a principal engineering plastics which find uses in a wide range of fields in particular in appliances and consumer goods, packaging and building materials and electrical, automotive, aircraft and electronic components. Certainly, they feature excellent physical properties a fair chemical resistance, very good heat resistance, flame retardancy, excellent toughness, electrical insulation, optical characteristics and fair processing (Goethals, 1988; Percec *et al.*, 1989; Jerome *et al.*, 1991).

The polycarbonates are for the time being most commonly synthesized by the ring-opening polymerization of cyclic carbonate monomers or the copolymerization of epoxides with carbon dioxide while the past approach allows in some status the preparation of telechelic polymers that oftentimes impeded by the formulation of the five-membered cyclic carbonate side product and by the concomitant decarboxylation reaction leading to poly(ether-carbonate)s instead of nano polycarbonates (Goethals, 1988; Percec *et al.*, 1989; Jerome *et al.*, 1991).

Through the 1980s, polycarbonate turned into the principle thing of business and research was done on its properties including optical qualities, electrical and mechanical properties. In view of its capacity to be changed and custom fitted to explicit applications, the polycarbonate business is very broad (Brunelle and Korn, 2005).

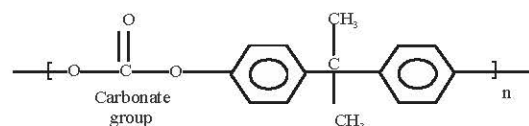


Fig. 1: The structure of polycarbonate

### MATERIALS AND METHODS

The dielectric constant of polymers is of great importance and has become increasingly important when polymers have been used as insulating materials because they are important for engineering applications. The insulation constant is measured from the capacitance of the electrolytic capacitor which includes the polymer material as an insulating medium to the capacitor capacitance when the air only includes an insulating medium (Kao, 2004; Allcock *et al.*, 2003).

Where electrical conductivity depends in general on the presence of free ions or electrons and their movement these ions or electrons in the insulating materials are constrained because of the strong correlation between the atoms which is formed by strong covalent bonds. In other words, electrons are highly localised in atoms and are not free to roam in the crystal (Callister and Rethwisch, 2013).

Because of the strong bonding of electrons in the case of insulation materials including polymers, due to a power gap which causes low electrical conductivity. This conductivity varies from polymer to polymer.

In branched polymers, the value of electrical conductivity is increased by a certain amount due to the interconnectivity that makes the electrons move more easily (Han and Fina, 2011).

Electrical conductivity is the measure of the materials susceptibility to transport electrical charges and its unit is Sm<sup>-1</sup> and its symbol is  $\sigma$  (Lowrie, 2007; Kumar, 2004).

**Experimental part:** Samples were prepared in the following steps: nano polycarbonate has been used in our current research in the form of powder and product from Japanese company (Teijin).

To measured proper weights, we used sensitive balance. About 30 samples were weighed, each sample weight was 3 g.

The powder was pressed for 1 min, into disc-shaped pellets 10 mm in thickness and 15 mm in diameter using hydraulic press on 30 samples, every 7 samples were compressed in one of the following ranges (388, 416, 443, 471, 499, 527 MPa).

Sintering each six of the different pressured samples at one of the ranges (RT, 50, 100, 150, 250°C) for 20 min by using a non-vacuum electric furnace (Carbolite) at the heating rate 5°C min<sup>-1</sup>.

Where all samples were measured at various frequencies with ranging from (50 Hz, 1 MHz, 3 MHz) and Capacitance (C) at room temperature using the (LCR METER) Model (8000 G series, GW instek company, Japan, frequency range (50 Hz-10 MHz).

The measurements involve ac-conductivity, real ( $\epsilon'$ ) and imaginary ( $\epsilon''$ ) dielectric constant and the loss tangent of dielectric ( $\tan \delta$ ) according to the following equations:

$$\epsilon' = Cd/A \epsilon_0 \quad (1)$$

$$\epsilon'' = \tan \delta * \epsilon' \quad (2)$$

$$\omega = 2\pi f \quad (3)$$

$$\sigma_{ac} = \epsilon_0 \epsilon' \omega \tan \delta \quad (4)$$

Where:

- ( $\omega$ ) : Angular frequency
- (A) : The area of the electrode
- (f) : The frequency of the applied field
- (d) : Sample thickness
- ( $\epsilon_0$ ) : Vacuum permittivity (Hermiz, 2014)

## RESULTS AND DISCUSSION

**AC-Conductivity ( $\sigma_{ac}$ ):** The alternating electrical conductivity of polycarbonate was calculated at different pressures, temperatures and frequencies by Eq. 1-4.

Table 1-3 and Fig. 2-4 show electrical conductivity at (50 Hz, 1 MHz, 3 MHz) it has been shown that the values of electrical conductivity increase with increasing temperature, pressure and frequency and for all samples.

From Fig. 2-4, we note the response of the  $\sigma_{ac}$  for PC at various temperatures. Generally, the noted improvement in  $\sigma_{ac}$  is attached to the electronic

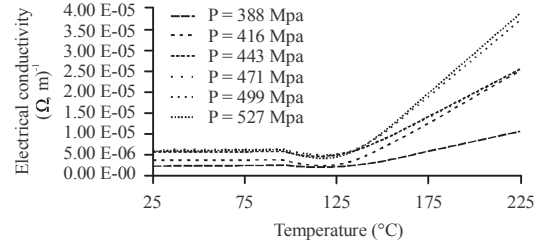


Fig. 2: Electrical conductivity as a function of pressure and temperature at 50 Hz frequency

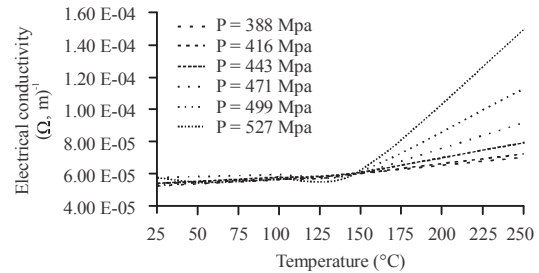


Fig. 3: Electrical conductivity as a function of pressure and temperature at 1 MHz

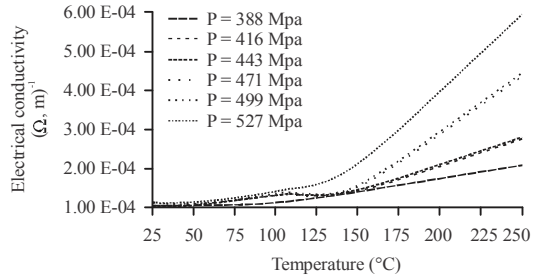


Fig. 4: Electrical conductivity as a function of pressure and temperature 3 MHz

interactions where the samples contain definite quantities of impurities and metallic ions which are activated at a special temperature, yet samples that have a poorer degree of conducting components must show a less reaction and in this way, giving weak electrical conductivities (Elimat, 2006).

We conclude from Fig. 1-3 above that the  $\sigma_{ac}$  improved by increasing of the frequency where at the high-frequencies the contributions of the polarization effects reduce (Hussain and Zihlif, 1993; Jonscher, 1983; Atta, 2003).

When we study tables and Fig. 1-3, we noted that the utilization of pressure caused an increasing conductivity where pressure caused movement of the polymer chains which affect the arrangement structure of the polycarbonate. The variance in pressure with  $\sigma_{ac}$  can be explained by looking at two phenomena that occur in the structure of the material under study, namely the

**Table 1: Electrical conductivity as a function of pressure and temperature at 50 Hz**

T/P (MPa)	RT°C	50°C	100°C	150°C	250°C
P = 388	2.4*10 <sup>-6</sup>	2.49*10 <sup>-6</sup>	2.55*10 <sup>-6</sup>	2.61*10 <sup>-6</sup>	1.05*10 <sup>-5</sup>
P = 416	3.61*10 <sup>-6</sup>	3.80*10 <sup>-6</sup>	3.82*10 <sup>-6</sup>	3.94*10 <sup>-6</sup>	2.50*10 <sup>-5</sup>
P = 443	5.44*10 <sup>-6</sup>	5.61*10 <sup>-6</sup>	5.68*10 <sup>-6</sup>	6.38*10 <sup>-6</sup>	2.50*10 <sup>-5</sup>
P = 471	5.72*10 <sup>-6</sup>	5.85*10 <sup>-6</sup>	6.22*10 <sup>-6</sup>	6.23*10 <sup>-6</sup>	2.50*10 <sup>-5</sup>
P = 499	5.82*10 <sup>-6</sup>	5.86*10 <sup>-6</sup>	6.46*10 <sup>-6</sup>	6.29*10 <sup>-6</sup>	3.71*10 <sup>-5</sup>
P = 527	5.84*10 <sup>-6</sup>	5.86*10 <sup>-6</sup>	6.33*10 <sup>-6</sup>	6.30*10 <sup>-6</sup>	3.86*10 <sup>-5</sup>

**Table 2: Electrical conductivity as a function of pressure and temperature at 1 MHz**

T/P (MPa)	RT°C	50°C	100°C	150°C	250°C
P = 388	5.20*10 <sup>-5</sup>	5.36*10 <sup>-5</sup>	5.58*10 <sup>-5</sup>	6.02*10 <sup>-5</sup>	7.02*10 <sup>-5</sup>
P = 416	5.25*10 <sup>-5</sup>	5.37*10 <sup>-5</sup>	5.69*10 <sup>-5</sup>	6.05*10 <sup>-5</sup>	7.21*10 <sup>-5</sup>
P = 443	5.33*10 <sup>-5</sup>	5.47*10 <sup>-5</sup>	5.79*10 <sup>-5</sup>	6.09*10 <sup>-5</sup>	7.92*10 <sup>-5</sup>
P = 471	5.76*10 <sup>-5</sup>	5.83*10 <sup>-5</sup>	5.92*10 <sup>-5</sup>	6.09*10 <sup>-5</sup>	9.14*10 <sup>-5</sup>
P = 499	5.79*10 <sup>-5</sup>	5.46*10 <sup>-5</sup>	5.76*10 <sup>-5</sup>	6.17*10 <sup>-5</sup>	0.00011
P = 527	5.78*10 <sup>-5</sup>	5.44*10 <sup>-5</sup>	5.64*10 <sup>-5</sup>	6.21*10 <sup>-5</sup>	0.00015

**Table 3: Electrical conductivity as a function of pressure and temperature at 3 MHz**

T/P (MPa)	RT°C	50°C	100°C	150°C	250°C
P = 388	1.02*10 <sup>-4</sup>	1.04*10 <sup>-4</sup>	1.12*10 <sup>-4</sup>	1.40*10 <sup>-4</sup>	2.08*10 <sup>-4</sup>
P = 416	1.03*10 <sup>-4</sup>	1.04*10 <sup>-4</sup>	1.31*10 <sup>-4</sup>	1.42*10 <sup>-4</sup>	2.77*10 <sup>-4</sup>
P = 443	1.04*10 <sup>-4</sup>	1.07*10 <sup>-4</sup>	1.33*10 <sup>-4</sup>	1.46*10 <sup>-4</sup>	2.79*10 <sup>-4</sup>
P = 471	1.08*10 <sup>-4</sup>	1.10*10 <sup>-4</sup>	1.34*10 <sup>-4</sup>	1.52*10 <sup>-4</sup>	4.36*10 <sup>-4</sup>
P = 499	1.1*10 <sup>-4</sup>	1.11*10 <sup>-4</sup>	1.39*10 <sup>-4</sup>	1.58*10 <sup>-4</sup>	4.45*10 <sup>-4</sup>
P = 527	1.12*10 <sup>-4</sup>	1.13*10 <sup>-4</sup>	1.40*10 <sup>-4</sup>	2.12*10 <sup>-4</sup>	5.94*10 <sup>-4</sup>

**Table 4: Dissipation factor as a function of pressure and temperature at 50 Hz**

T/P (MPa)	RT°C	50°C	100°C	150°C	250°C
P = 388	4.42*10 <sup>-1</sup>	4.58*10 <sup>-1</sup>	4.65*10 <sup>-1</sup>	6.93*10 <sup>-1</sup>	1.62
P = 416	4.57*10 <sup>-1</sup>	4.56*10 <sup>-1</sup>	4.67*10 <sup>-1</sup>	7.01*10 <sup>-1</sup>	1.79
P = 443	5.02*10 <sup>-1</sup>	4.79*10 <sup>-1</sup>	5.29*10 <sup>-1</sup>	6.92*10 <sup>-1</sup>	2.34
P = 471	4.89*10 <sup>-1</sup>	4.90*10 <sup>-1</sup>	5.46*10 <sup>-1</sup>	6.75*10 <sup>-1</sup>	2.67
P = 499	5.20*10 <sup>-1</sup>	5.36*10 <sup>-1</sup>	5.97*10 <sup>-1</sup>	7.29*10 <sup>-1</sup>	3.24
P = 527	5.52*10 <sup>-1</sup>	5.75*10 <sup>-1</sup>	6.24*10 <sup>-1</sup>	6.97*10 <sup>-1</sup>	3.17

**Table 5: Dissipation factor as a function of pressure and temperature at 1 MHz**

T/P (MPa)	RT°C	50°C	100°C	150°C	250°C
P = 388	2.05*10 <sup>-1</sup>	2.42*10 <sup>-1</sup>	2.73*10 <sup>-1</sup>	3.28*10 <sup>-1</sup>	3.69*10 <sup>-1</sup>
P = 416	2.22*10 <sup>-1</sup>	2.24*10 <sup>-1</sup>	2.82*10 <sup>-1</sup>	3.01*10 <sup>-1</sup>	3.71*10 <sup>-1</sup>
P = 443	2.39*10 <sup>-1</sup>	2.44*10 <sup>-1</sup>	2.78*10 <sup>-1</sup>	3.13*10 <sup>-1</sup>	3.90*10 <sup>-1</sup>
P = 471	2.50*10 <sup>-1</sup>	2.85*10 <sup>-1</sup>	3.01*10 <sup>-1</sup>	2.97*10 <sup>-1</sup>	4*10 <sup>-1</sup>
P = 499	2.49*10 <sup>-1</sup>	2.57*10 <sup>-1</sup>	3.10*10 <sup>-1</sup>	3.28*10 <sup>-1</sup>	4.80*10 <sup>-1</sup>
P = 527	2.48*10 <sup>-1</sup>	2.46*10 <sup>-1</sup>	2.70*10 <sup>-1</sup>	3.29*10 <sup>-1</sup>	5.80*10 <sup>-1</sup>

**Table 6: Dissipation factor as a function of pressure and temperature at 3 MHz**

T/P (MPa)	RT°C	50°C	100°C	150°C	250°C
P = 388	9.10*10 <sup>-2</sup>	9.80*10 <sup>-2</sup>	1.02*10 <sup>-1</sup>	1.15*10 <sup>-1</sup>	1.93*10 <sup>-1</sup>
P = 416	9.34*10 <sup>-2</sup>	9.62*10 <sup>-2</sup>	1.16*10 <sup>-1</sup>	1.42*10 <sup>-1</sup>	2.10*10 <sup>-1</sup>
P = 443	9.65*10 <sup>-2</sup>	1.02*10 <sup>-1</sup>	1.14*10 <sup>-1</sup>	1.45*10 <sup>-1</sup>	2.19*10 <sup>-1</sup>
P = 471	9.92*10 <sup>-2</sup>	1.03*10 <sup>-1</sup>	1.23*10 <sup>-1</sup>	1.65*10 <sup>-1</sup>	2.34*10 <sup>-1</sup>
P = 499	1.02*10 <sup>-1</sup>	1.05*10 <sup>-1</sup>	1.29*10 <sup>-1</sup>	1.80*10 <sup>-1</sup>	2.47*10 <sup>-1</sup>
P = 527	1.05*10 <sup>-1</sup>	1.07*10 <sup>-1</sup>	1.34*10 <sup>-1</sup>	1.95*10 <sup>-1</sup>	2.60*10 <sup>-1</sup>

formation of additional conductive networks and the disruption of existing connection networks. The formation of this continuous pathway occurs not only through direct contact between the electrically conductive molecules that distributed in the polycarbonates but also when the distance between the molecules is very small, so, the electrons can easily jump across the gap. Thus, there is a threshold value for the molecular gap which is electrically equivalent to the molecular contact. The formation of a continuous pathway is facilitated by high pressure by decreasing the molecular gap in the non-continuous zone.

**Dissipation factor:** The dissipation factor or so-called the loss tangent of dielectric ( $\tan \delta$ ) of polycarbonate was calculated at different pressures and temperatures by Eq. 1 and 2.

It can be define as the ratio of the loss of power in the electrically insulating materials to the total moving capacity during the dielectric.

Table 4-6 and Fig. 5-7 show dissipation factor at (50 Hz, 1 MHz, 3 MHz), it has been shown that the values of dissipation factor increase with increasing temperature, pressure but decreasing with frequency and for all samples.

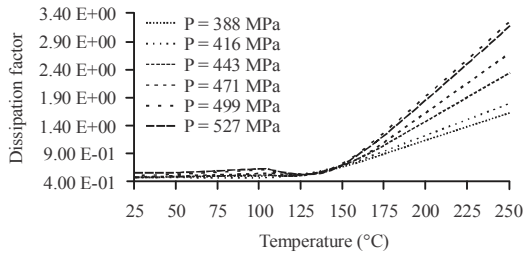


Fig. 5: Dissipation factor as a function of pressure and temperature at 50 Hz

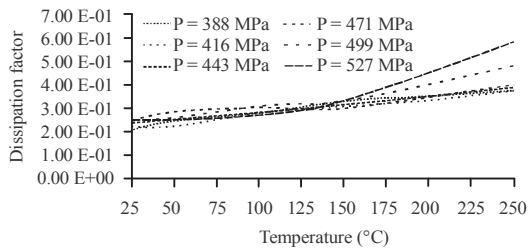


Fig. 6: Dissipation factor as a function of pressure and temperature at 1 MHz

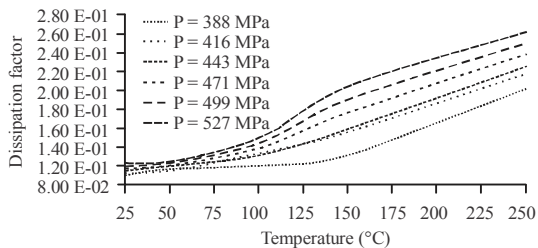


Fig. 7: Dissipation factor as a function of pressure and temperature at 3 MHz

We note from Fig. 4-6 that the value of the dissipation factor is high in the low frequencies due to the mobility of dipoles and therefore not to keep up with the poles of the electrode field and the dissipation factor stays fairly stable at high frequencies (Rabee and Hashim, 2011).

The relationship between dissipation factor and temperature was studied in the last three forms. This relationship is typical of polar insulators, thereby the increasing the temperature lead to facilitated of the direction of the dipole electrodes. The increase in the dissipation factor may also result from an increase in crystallization (Tareev,1979) but not in non-crystalline polycarbonates.

The dissipation factor increases with increasing pressure. Where the effect of pressure is rearranging the conductive molecules and create a three-dimensional 'cluster network' of conductive molecules (Nasr, 1996). As a result, the compactness of molecules in the polymer increases with an increase in pressure and hence, the dissipation factor of the PC decrease.

**Dielectric constant ( $\epsilon'$ ):** The real dielectric constant of polycarbonate was measured at different pressures and temperatures by Eq. 1 and 2. Table 7-9 and Fig. 8-10 show real dielectric constant at 50 Hz, 1 MHz, 3 MHz, it has been shown that the values of real dielectric constant increase with increasing temperature and pressure but decreasing with frequency and for all samples.

It can be observed that the  $\epsilon'$  increases as the temperature increases and thus, increased polymer movement facilitates the routing of the dipoles. Thus, we conclude that the segmental movement is the dominant mechanism (Rao and Shridhar, 2002; Berger and McCullough, 1985).

Table 7: Real dielectric constant as a function of pressure and temperature at 1 MHz (50 Hz)

T/P (MPa)	RT°C	50°C	100°C	150°C	250°C
P = 388	6.56*10	4.56*10 <sup>2</sup>	1.03*10 <sup>3</sup>	4.42*10 <sup>3</sup>	4.52*10 <sup>4</sup>
P = 416	9.08*10	7.72*10 <sup>2</sup>	1.08*10 <sup>3</sup>	5.09*10 <sup>3</sup>	4.98*10 <sup>4</sup>
P = 443	1.16*10	1.09*10 <sup>3</sup>	1.12*10 <sup>3</sup>	5.75*10 <sup>3</sup>	9.47*10 <sup>4</sup>
P = 471	1.41*10 <sup>2</sup>	1.40*10 <sup>3</sup>	1.17*10 <sup>3</sup>	6.42*10 <sup>3</sup>	1.50*10 <sup>5</sup>
P = 499	1.67*10 <sup>2</sup>	1.72*10 <sup>3</sup>	1.21*10 <sup>3</sup>	7.09*10 <sup>3</sup>	1.85*10 <sup>5</sup>
P = 527	1.92*10 <sup>2</sup>	2.04*10 <sup>3</sup>	1.26*10 <sup>3</sup>	7.76*10 <sup>3</sup>	2.29*10 <sup>5</sup>

Table 8: Real dielectric constant as a function of pressure and temperature at 1 MHz

T/P (MPa)	RT°C	50°C	100°C	150°C	250°C
P = 388	3.44	4.39	4.67	6.24	7.01
P = 416	3.92	4.50	4.99	6.27	7.08
P = 443	4.41	4.62	5.30	6.30	7.16
P = 471	4.54	4.70	5.86	6.79	7.23
P = 499	4.67	4.79	6.41	7.28	7.31
P = 527	4.81E	4.88	6.97	7.30	7.38

Table 9: Real dielectric constant as a function of pressure and temperature at 3 MHz

T/P (MPa)	T = RT°C	T = 50°C	T = 100°C	T = 150°C	T = 250°C
P = 388	1.55	1.92	2.62	2.92	3.29
P = 416	1.64	2.03	2.64	2.99	3.37
P = 443	1.67	2.36	2.83	3.28	3.38
P = 471	1.74	2.54	2.90	3.42	3.44
P = 499	1.80	2.76	3.00	3.60	3.49
P = 527	1.86	2.98	3.11	3.78	3.53



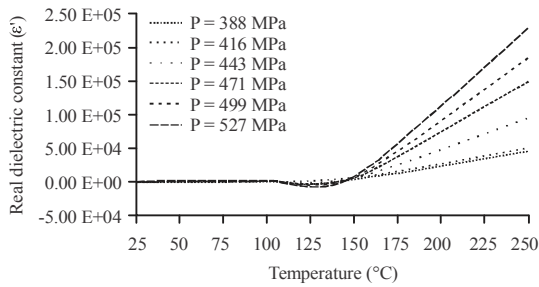


Fig. 8: Real dielectric constant as a function of pressure and temperature at 50 Hz

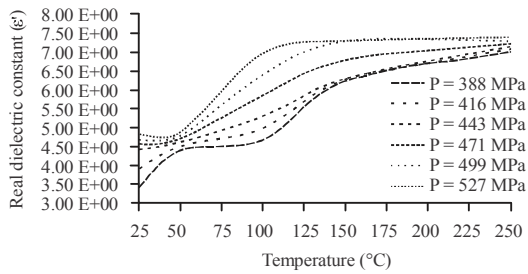


Fig. 9: Real dielectric constant as a function of pressure and temperature at 1 MHz

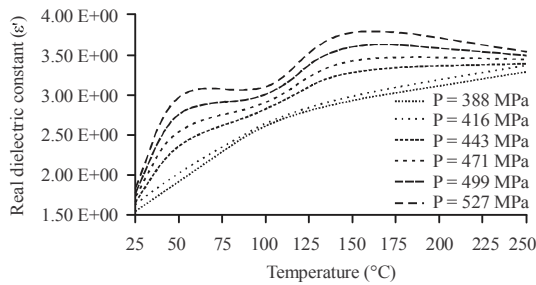


Fig. 10: Real dielectric constant as a function of pressure and temperature at 3 MHz

The inverse relationship between the  $\epsilon'$  and frequency can be explained by the fact that at low frequencies the time period is sufficient for the dipoles to arrange the molecules and align them to the current between the poles. At high frequencies, however, the time period is short and less than the time required by the molecules, so that, they can align themselves with the direction of the electric field external (Rabee, and Hashim, 2011).

### CONCLUSION

All the electrical properties that are included loss tangent of dielectric, real dielectric constant and ac-conductivity were found to increase with increasing temperature and pressure.

The ac-conductivity of PC as a function of frequency was calculated and it was observed to increase as frequency increased.

The real dielectric constant and loss tangent of dielectric of PC as a function of frequency was calculated and it was observed to decrease as frequency increased.

### REFERENCES

- Allcock, H.R., F.W. Lampe and J.E. Mark, 2003. Contemporary Polymer Chemistry. 3rd Edn., Pearson Education, Hoboken, New Jersey, USA., ISBN:9780130650566, Pages: 814.
- Atta, A., 2003. Alternating current conductivity and dielectric properties of newly prepared poly (bis thiourea sulphoxide). Intl. J. Polym. Mater., 52: 361-372.
- Berger, M.A. and R.L. McCullough, 1985. Characterization and analysis of the electrical properties of a metal-filled polymer. Compos. Sci. Technol., 22: 81-106.
- Brunelle, D.J. and M.R. Korn, 2005. Advances in Polycarbonates. American Chemical Society, Washington, USA., ISBN:9780841238879, Pages: 304.
- Callister, W.D. and D.G. Rethwisch, 2013. Materials Science and Engineering: An Introduction. 9th Edn., John Wiley and Sons Inc., Hoboken, New Jersey, USA., ISBN:9781118476543, Pages: 992.
- Elimat, Z.M., 2006. AC electrical conductivity of poly (methyl methacrylate)/carbon black composite. J. Phys. D. Appl. Phys., 39: 2824-2828.
- Goethals, E.J., 1988. Telechelic Polymers. CRC Press, Boca Raton, Florida, USA., ISBN:9780849367649, Pages: 416.
- Han, Z. and A. Fina, 2011. Thermal conductivity of carbon nanotubes and their polymer nanocomposites: A review. Prog. Polymer Sci., 36: 914-944.
- Hermiz, G.Y., 2014. Dielectric properties of  $\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_2\text{Ca}_{2-x}\text{Mg}_x\text{Cu}_3\text{O}_{10+\delta}$  ( $0 \leq x \leq 0.5$ ) superconducting system. Intl. J. Innovative Res. Sci. Eng. Technol., 3: 8564-8572.
- Hussain, F.A. and A.M. Zihlif, 1993. Electrical properties of nickel-coated carbon-fiber/nylon 66 composite. J. Thermoplast. Compos. Mater., 6: 120-129.
- Jerome, R., M. Henriouille-Granville, B. Boutevin and J.J. Robin, 1991. Telechelic polymers: Synthesis, characterization and applications. Prog. Polym. Sci., 16: 837-906.
- Jonscher, A.K., 1983. Dielectric Relaxation in Solids. Chelsea Dielectrics Press, London, England, UK., ISBN:9780950871103, Pages: 380.

- Kao, K.C., 2004. Dielectric Phenomena in Solids. Elsevier, Amsterdam, Netherlands, ISBN:9780080470160, Pages: 579.
- Kumar, N., 2004. Comprehensive Physics XII. In: Signal Integrity: Simplified, Bogatin, E. (Ed.). Prentice Hall, Upper Saddle River, New Jersey, USA., ISBN:9780130669469, pp: 1-39.
- Lowrie, W., 2007. Fundamentals of Geophysics. 2nd Edn., Cambridge University Press, Cambridge, USA., ISBN:9781139465953,.
- Nasr, G.M., 1996. Vulcanization conditions: How they affect the electrical conductivity of SBR loaded with the percolation concentration of FEF-black. Polym. Test., 15: 585-591.
- Percec, V., C. Pugh, O. Nuyken and S.D. Pask, 1989. Macromonomers, Oligomers and Telechelic Polymers. In: Comprehensive Polymer Science: The Synthesis, Characterization, Reactions & Applications of Polymers, Allen, G., J.C. Bevington and G.C. Eastmond (Eds.). Elsevier, Amsterdam, Netherlands, ISBN:9780080362076, pp: 281-357.
- Rabee, B.H. and A. Hashim, 2011. Synthesis and characterization of carbon nanotubes-polystyrene composites. Eur. J. Sci. Res., 60: 229-236.
- Rao, R.V. and M.H. Shridhar, 2002. Effect of P-toluene sulphonic acid on the dielectric properties of poly (4-vinylpyridine). Mater. Sci. Eng. A., 325: 73-78.
- Tareev, B., 1979. Physics of Dielectric Materials. 2nd Edn., Mir Publisher, Moscow, Russia, Pages: 270.