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Computation of Dielectric Constant and Loss Factor of 1, 3-Diethoxymethyl Imidazolium Hexaflurophosphate [Dietmeim] [PF6]

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Abstract:
Ionic liquids are receiving more and more interest because of their unique properties. Based on these properties, a multitude of applications are being developed. Although ionic liquids are applied in many fields and considered to be very potential to meet the special need for different projects, the lack of systematic and mechanistic understanding of the properties is a bottle neck for its progress. However, this research on ionic liquids will determine the frequency level that the dielectric constant and loss factor will be more effective .The Cole-Cole relaxation equation was derived and the values for the dielectric constant and loss factor of 1,3-diethoxymethyl Imidazolium hexaflurophosphate [DiEtMeIm][PF$_6$*] were determined. The computation was done within the frequency of 0.1GHz to 10GHz and temperature between 5℃ to 65℃. The result obtained shows that the dielectric constant and loss factor of 1,3-diethoxymethyl Imidazolium hexaflurophosphate [DiEtMeIm][PF*$_6$*] were higher at low frequency (i.e. F = 0.1GHz) and decreases as the frequency increases. The dielectric constant also increases with increase in the temperature except at 0.1GHz. The increase in the dielectric constant of the ionic liquids may be due to all the phase change of the ionic liquid. The loss factor was small for all frequencies and temperatures. This may be due to the fact that the ionic liquids consumed less energy when subjected to an applied field. However, chemical industry and other industries that use IL for their production can do so at higher frequencies. This is because higher frequencies have the lowest value of the dielectric constant. Higher dielectric constants have the tendency to breakdown more easily when they are subjected to intense electric fields than lower dielectric constants.*

Keywords: *Dielectric constant, loss factor, frequency, temperature, Cole Cole method*

1. Introduction

So many years ago there has been an upsurge in research activities pointing on replacing the abundant used of volatile organic solvents (VOC) with a more environmental friendly one (Barrer, 1943; Gabriel & Weiner, 1888; Chum *et al.,* 1975; Wilkes *et al.,* 1982; Wilkes & Zaworotko, 1992). Several alternative methods have been developed and recently ionic liquid have emerged as 'green' and environmental friendly solvents (Onimisi & Ikyumbur, 2015a, Onimisi & Ikyumbur, 2015b; Ikyumbur*et al.,* 2017). Ionic liquids are a new class of purely ionic salt like materials that are liquid at ambient temperature which includes all the molten salts e.g. Nacl at temperature that is higher than 800°C (Onimisi *et al.,* 2016). Today however the term ionic liquid is used for the salt whose melting point is low (below 100°C) (Hagiwara, 2000). A typical ionic liquid (IL) has a bulky organic cation that is weakly coordinated to an organic and inorganic anions, such as Bf_4^-, Cl^-, I^-, $Cf_3SO_3^-$ and $AlCl_4^-$ Onimisi & Ikyumbur, 2015b). Because they properties of ionic liquids have attracted great attention in many fields including organic chemistry, electrochemistry, plasma physics, industrial physics and engineering generally. Today ionic liquids have been thought to be more safe electrolytes materials for electrochemical and energy storing devices such as lithium batteries for cellular phones, batteries for vehicles, fuel cells, super capacitors, solar cells etc. (Sakaebe, Matsumoto & Tatsumi, 2007; Sato, Masuda & Takagi, 2004).

Ionic liquids are well known as 'green solvents' because of their low vapor pressures. Instead of traditional organic solvent or extraction media, the use of ionic liquids largely reduces the loss of solvents caused by evaporation, so that the resulting environmental damages can be avoided.

Ionic liquids are one of the most promising classes of new materials investigated in the last decade. The do not easily fit the conventional description of molecular fluids therefore promoting a necessary exploration of their physical properties at a microscopic level. Conventionally, ionic liquids are chemicals entirely made by ions (Freemantle, 2009; Gaune-Escard & Seddon, 2010; Rogers & Seddon, 2005) that show a melting point lower than 100°C, which makes them liquid under ambient conditions. Their negligible vapor pressure, high thermal stability, properties tenability upon slight changes in the chemical architecture, has made these materials tailored for a constantly increasing range of applications (Plechkova & Seddon, 2008; Rogers, Plechkova & Seddon, 2009; Rogers & Seddon, 2005). Among these applications we find catalysis, synthesis, sensoritics, medicine, electrochemistry and green chemistry in general (Fisher *et al.*, 1999; Galinski *et al.,* 2006; Hough *et al.*, 2007). Ionic liquids are utilized as solvents; their specific composition where ions solely exist provides amazing functional properties such as dissolution of bio-related materials that never dissolve in conventional solvent. The dissolution of biopolymers as cellulose (Fujita *et al.,* 2009) is one of such examples. Chloride based ionic liquid dissolve cellulose better than other solvents because of hydrogen bonding between chloride anions with hydroxyl groups of the polymer. The use of ionic liquids allows a simple benign system for the processing of cellulose and has potential environmental and cost advantages over current processing methodologies. Ionic liquids are made entirely by ionic couples. Ionic liquids exist in at least a million of pure forms and a trillion ternary mixtures. This liberty allows one to design these materials to optimize a specific task such as a solvent for reaction. This is the reason why these liquids have been termed designer solvents (Fei *et al.,* 2006; Freemantle, 1998; Rogers & Seddon, 2003).

We attempt to study the dielectric properties of 1,3-diethoxymethyl Imidazolium hexaflurophosphate [DiEtMeIm][PF6] because of its high ionic conductivity and low viscosity. It is expected that it will be a good electrolyte candidate for lithium batteries when compare to organic solvent electrolytes.

2. Literature Review

2.1. Dielectric Polarization Build Up

In the classical approach to the dielectric model, a material is made up of atoms. Each atomconsists of a cloud of negative charge (electrons) bound to and surrounding a positive point charge at its center. In the presence of an electric field the charge cloud is distorted.

This can be reduced to a simple dipole using the superposition principle. Dipole is characterized by its dipole moment. When an electric field is removed the atom returns to its original state. The time required to do so is called relaxation time, an exponential decay.

This is the essence of the model in physics. The behavior of the dielectric depends on the situation. The more complicated the situation, the richer the model must be to accurately describe the behavior.

When a dc voltage is applied to a polar dielectric, then, the polarization builds from zero to the final value. Referring to the exponential law, we can write our polarization as function of time as:

$$P(t) = P_\infty(1 - e^{-t/\tau}) \qquad (1)$$

where $P(t)$ *is* the polarization at any time (t) is, τ is the relaxation time and it is the function of temperature and independent of the time.

If $\omega t = 2\pi f t$; then differentiating equation (1) with respect to time t using product rule. i.e.

$$\frac{dP(t)}{dt} = \frac{dP_\infty}{dt}\left(1 - e^{-t/\tau}\right)$$

We let $u = P_\infty and\ \frac{du}{dt} = 0$

$$v = \left(1 - e^{-t/\tau}\right) and\ \frac{dv}{dt} = -\frac{1}{\tau}e^{-t/\tau}$$

$$\frac{dP(t)}{dt} = u\frac{dv}{dt} + v\frac{du}{dt} \qquad (*)$$

Substituting in equation (*), we have

$$\frac{dP(t)}{dt} = P_\infty\left(-\frac{1}{\tau}e^{-t/\tau}\right) + \left(1 - e^{-t/\tau}\right)(0)$$

$$\Rightarrow \frac{dP(t)}{dt} = -\frac{1}{\tau}P_\infty = \frac{P_{\infty e^{-t/\tau}}}{\tau} \qquad (2)$$

Expanding the right hand side of equation (1), we have

$$P(t) = P_\infty - P_\infty e^{-t/\tau}$$

$$\Rightarrow P_\infty e^{-t/\tau} = P_\infty - P(t) \qquad (3)$$

Dividing both sides of (3) by P_∞, we have

$$e^{-t/\tau} = \frac{P_\infty - P(t)}{P_\infty} \qquad (4)$$

Substituting equation (4) into equation (2), we obtain

$$\frac{dP(t)}{dt} = \frac{P_\infty - P(t)}{\tau} \qquad (5)$$

We can now express our total polarization as:

$$P_T(t) = P_a(t) + P_e \qquad (6)$$

Where $P_a(t)$ is the atomic polarization and P_e is electronic polarization. The final value attained by the total polarization is given by:

$$P_T(t) = \varepsilon_o(\varepsilon_s - 1)E \qquad (7)$$

$$P_e(t) = \varepsilon_o(\varepsilon_\infty - 1)E \qquad (8)$$

where ε_o and ε_∞ are the dielectric constant under direct voltage and at infinity frequency respectively. The ε_∞ is defined in Maxwell's relation as:

$$\varepsilon_\infty = n^2 \tag{9}$$

Substituting equations (7) and (8) into (6), we have

$$P_a(t) = P_T(t) - P_\infty$$

$$P_a(t) = \varepsilon_o(\varepsilon_s - 1)E - \varepsilon_o(\varepsilon_\infty - 1)E \tag{10}$$

$$P_a(t) = (\varepsilon_o\varepsilon_s - \varepsilon_o)E - (\varepsilon_o\varepsilon_\infty - \varepsilon_o)E$$

$$P_a(t) = \varepsilon_o\varepsilon_s E - \varepsilon_o E - \varepsilon_o\varepsilon_\infty E + \varepsilon_o E$$

$$P_a(t) = \varepsilon_o\varepsilon_s E - \varepsilon_o\varepsilon_\infty E = \varepsilon_o(\varepsilon_s - \varepsilon_\infty)E \tag{11}$$

Representing the alternating electric field as:

$$E = E_{max}e^{j\omega t} \tag{12}$$

Substituting equation (11) into equation (6), we have

$$\frac{dP(t)}{dt} = \frac{1}{\tau}[E(\varepsilon_s - \varepsilon_\infty)\varepsilon_o - P(t)] \tag{13}$$

Substituting equation (12) into equation (13), we have

$$\frac{dP(t)}{dt} = \frac{1}{\tau}[E_{max}e^{j\omega t}(\varepsilon_s - \varepsilon_\infty)\varepsilon_o - P(t)]$$

Adding on both sides of the expression $\frac{1}{\tau}P(t)$, we have

$$\frac{dP(t)}{dt} + \frac{1}{\tau}P(t) = \frac{1}{\tau}[E_{max}e^{j\omega t}(\varepsilon_s - \varepsilon_\infty)\varepsilon_o] \tag{14}$$

Solving equation (14) using integration by part; let the integrating factor be $e^{\int a dt}$, where $a = \frac{1}{\tau}$

$$Q(t) = \frac{1}{\tau}\varepsilon_o(\varepsilon_s - \varepsilon_\infty)E_{max}e^{j\omega t}$$

$$e^{\int\frac{1}{\tau}dt} = e^{t/\tau}$$

Multiplying equation (14) by $e^{t/\tau}$, we have

$$e^{t/\tau}.\frac{dP(t)}{dt} + e^{t/\tau}.\frac{1}{\tau}P(t) = e^{t/\tau}.\frac{1}{\tau}[\varepsilon_o(\varepsilon_s - \varepsilon_\infty)E_{max}e^{j\omega t}]$$

Note that the left hand side of the above expression is the derivative of $e^{t/\tau}P(t)$

$$\therefore \quad e^{t/\tau}\frac{dP(t)}{dt} = \frac{1}{\tau}[\varepsilon_o(\varepsilon_o - \varepsilon_\infty)E_{max}e^{j\omega t}]$$

Taken the integral both sides, we have

$$e^{t/\tau}\int\frac{dP(t)}{dt} = \frac{1}{\tau}\int e^{1/\tau}[\varepsilon_o(\varepsilon_s - \varepsilon_\infty)E_{max}e^{j\omega t}]$$

$$e^{t/\tau}P(t) = \frac{1}{\tau}\varepsilon_o(\varepsilon_s - \varepsilon_\infty)E_{max}\int e^{t/\tau}.e^{j\omega t}dt \tag{15}$$

Note:

$$\int \quad / \quad {}^{j\omega t}dt = \int e^{\left(\frac{1}{\tau}+j\omega\right)t}dt$$

$$= \frac{e^{t/\tau}e^{j\omega t}}{\frac{1}{\tau}+j\omega} = \frac{e^{t/\tau}e^{j\omega t}}{(1+j\omega\tau)} \tag{16}$$

Substituting equation (16) in to equation (15), we have

$$\text{x}e^{t/\tau}P(t) = \frac{\varepsilon_o(\varepsilon_s-\varepsilon_\infty)E_{max}e^{t/\tau}.e^{j\omega t}}{(1+j\omega\tau)} + c$$

Dividing the above expression by the factor $e^{t/\tau}$, we have

$$P(t) = \frac{\varepsilon_o(\varepsilon_s - \varepsilon_\infty)E_{max}e^{t/\tau}.e^{j\omega t}}{(1 + j\omega\tau)e^{-t/\tau}} + ce^{-t/\tau}$$

$$P(t) = ce^{-t/\tau} + \frac{\varepsilon_o(\varepsilon_s-\varepsilon_\infty)E_{max}e^{j\omega t}}{(1+j\omega\tau)} \tag{17}$$

where c is a constant and if time$t$is sufficiently large when compared with τ, then the first term on the right-hand side of equation (16) becomes so small that it can be neglected and we get solution for $P(t)$ as:

$$P(t) = \frac{\varepsilon_o(\varepsilon_s-\varepsilon_\infty)E_{max}e^{j\omega t}}{(1+j\omega\tau)} \tag{18}$$

Substituting equation (18) into equation (16), we get

$$P_T(t) = P_a(t) + P_e$$

$$\Rightarrow P_a(t) = \varepsilon_o(\varepsilon_s - \varepsilon_\infty)E_{max}e^{j\omega t}$$

$$P(t) = \varepsilon_o(\varepsilon_\infty - 1)E_{max}e^{j\omega t} + \frac{\varepsilon_o(\varepsilon_s-\varepsilon_\infty)E_{max}e^{j\omega t}}{(1+j\omega\tau)} \tag{19}$$

Simplifying equation (19), we obtain

$$P(t) = \varepsilon_o\left[(\varepsilon_\infty - 1) + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1 + j\omega\tau)}\right]E_{max}e^{j\omega t}$$

$P(t) = \left[\varepsilon_\infty - 1 + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)}\right]\varepsilon_o E_{max} e^{j\omega t}$ (20)

Equation (20) shows that $P(t)$ is a sinusoidal function with the same frequency as the applied voltage. The instantaneous value of the flux density D is given by:

$D(t) = \varepsilon_o \varepsilon^* E_{max} \varepsilon^{j\omega t}$ (21)

The flux density is equal to

$D(t) = \varepsilon_o E_{max} e^{j\omega t} + P(t)$ (22)

Equating equation (21) with equation (22), we have

$\varepsilon_o \varepsilon^* E_{max} \varepsilon^{j\omega t} = \varepsilon_o E_{max} e^{j\omega t} + P(t)$ (23)

Substituting equation (22) into equation (23) and simplifying it, we get

$\varepsilon_o \varepsilon^* E_{max} \varepsilon^{j\omega t} = \varepsilon_o E_{max} e^{j\omega t} + \left[\varepsilon_\infty - 1 + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)}\right]\varepsilon_o E_{max} e^{j\omega t}$ (24)

Dividing equation (24) by the factor $\varepsilon_o E_{max} e^{j\omega t}$, we have

$\varepsilon^* = 1 + \left[\varepsilon_\infty - 1 + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)}\right]$ (25)

$E *= \varepsilon' - j\varepsilon'$ (*b)

Equating equation (*b) with equation (25), we have

$(\varepsilon' - j\varepsilon'') = 1 + \left[\varepsilon_\infty - 1 + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)}\right]$ (26)

Solving for real and imaginary parts of equation (26), we have

$$\varepsilon' - j\varepsilon'' = 1 + \varepsilon_\infty - 1 + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)}$$

$$\varepsilon' - j\varepsilon'' = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)}$$

This gives

$\varepsilon' = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)} + j\varepsilon''$ (27)

Now setting

$\varepsilon'' = \frac{(\varepsilon_s - \varepsilon_\infty)\omega\tau}{(1+\omega^2\tau^2)}$ (28)

Substituting equation (28) into equation (27), we have

$$\varepsilon' = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)} + j\frac{(\varepsilon_s - \varepsilon_\infty)\omega\tau}{(1+\omega^2\tau^2)}$$

$$\varepsilon' = \varepsilon_\infty + (\varepsilon_s - \varepsilon_\infty)\left[\frac{1}{(1+j\omega\tau)} + \frac{j\omega\tau}{(1+\omega^2\tau^2)}\right]$$

Taking the LCM of the above expression and cancelling out common terms gives

$\varepsilon' = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+\omega^2\tau^2)}$ (29)

To obtain ε'', we again consider the imaginary part of equation (27), i.e.

$j\varepsilon'' = \varepsilon' - \varepsilon_\infty - \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)}$ (30)

Substituting equation (29) into equation (30), we have

$$j\varepsilon'' = \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+\omega^2\tau^2)} - \frac{(\varepsilon_s - \varepsilon_\infty)}{(1+j\omega\tau)}$$

$$j\varepsilon'' = (\varepsilon_s - \varepsilon_\infty)\left[\frac{1}{(1+\omega^2\tau^2)} - \frac{1}{(1+j\omega\tau)}\right]$$

Dividing the above expression by j, we have

$$\varepsilon'' = (\varepsilon_s - \varepsilon_\infty)\left[\frac{1}{(1+\omega^2\tau^2)} - \frac{1}{(1+j\omega\tau)}\right](-j)$$

Taking the LCM of the above expression, we obtain

$$\varepsilon'' = (\varepsilon_s - \varepsilon_\infty)\left[\frac{1(1+j\omega\tau) - 1(1+\omega^2\tau^2)}{(1+\omega^2\tau^2)(1+j\omega\tau)}\right](-j)$$

Simplifying the above expression yields

$\varepsilon'' = \frac{(\varepsilon_s - \varepsilon_\infty)\omega\tau}{(1+\omega^2\tau^2)}$ (31)

Equations (29) and (31) are called the real and imaginary parts of Debye equation.

Cole-Cole Equation

The Cole-Cole equation is a relaxation model that is often used to describe dielectric relaxation in polymers. It is given by the equation

$\varepsilon^* = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1+(jwT_{c-}c)1-a}; 0 \leq \alpha \leq 1$

Where ε^* is the constant dielectric constant, ε_s and ε_∞ are the static and infinite frequency, w is the angular frequency and T is the time constant.

The exponential parameter α, which takes a value between 0 and 1 allows to describe different spectral shapes. When α = 0, the Cole Cole model reduces to the Debye model when> 0, the relaxation is stretched.
Separating the complex dielectric constant into the real and imaginary parts yield.

$$\mathcal{E}' = \varepsilon_\infty + \frac{(\varepsilon_S - \varepsilon_\infty)[1+(cwT_C - c)^n \cos\frac{n\pi}{2}}{1+2(wT_C - c)^n \cos\frac{n\pi}{2} + (wT_C - c)^{2n}}$$

$$\mathcal{E}' = \frac{(\varepsilon_S - \varepsilon_\infty)[1+(cwT_C - c)^n \sin\frac{n\pi}{2}]}{1+2(wT_C - c)^n \cos\frac{n\pi}{2} + (wT_C - c)^{2n}}$$

3. Methods

$\mathcal{E}'$ $and\mathcal{E}'$ are the real and imaginary part of Cole Cole relaxation model. The real part (Ɛ′) represent the dielectric constant while the imaginary part (Ɛ’) represent the loss factor. An algorithm was written using maple 13 and the value for the dielectric constant and loss factor of 1,3-diethoxymethyl Imidazolium hexaflurophosphate [DiEtMeIm][PF_6]was generated. The computation was done within the frequency range of 0.1GHz to 10GHz and temperature range between 5℃ and 65℃ for an interval of 10℃.

4. Results

The results generated from the computation are interpreted based on the existing theories. The results obtained from this work are shown in Tables 1 and 2

F(Ghz)	Ɛ'5℃	Ɛ’5℃	Ɛ' 15℃	Ɛ’15℃	Ɛ' 25℃	Ɛ’ 25℃	Ɛ' 35℃	Ɛ’35℃
0.1	10.5535	0.0217	10.7783	0.0347	10.5173	0.0347	10.3059	0.0464
0.2	10.2544	0.0197	10.5565	0.0323	10.3107	0.0325	10.1866	0.0442
0.3	10.0539	0.0184	10.3912	0.0306	10.1562	0.0309	10.0874	0.0427
0.4	9.9000	0.0174	10.2558	0.0293	10.0295	0.0296	10.0002	0.0414
0.5	9.7740	0.0166	10.13997	0.0281	9.9201	0.0285	9.9212	0.0403
0.6	9.6669	0.0160	10.0374	0.0271	9.8237	0.0276	9.8486	0.0392
0.7	9.5736	0.0160	9.9455	0.0263	9.7370	0.0275	9.7811	0.0383
0.8	9.4907	0.0149	9.8618	0.0255	9.6580	0.0267	9.7177	0.0374
0.9	9.4161	0.0145	9.7850	0.0248	9.5852	0.0253	9.6579	0.0366
1.0	9.3481	0.0141	9.7137	0.0241	9.5177	0.0246	9.6012	0.0358
1.2	9.2281	0.0135	9.5850	0.0230	9.3954	0.0235	9.4956	0.0358
1.5	9.0770	0.0127	9.4181	0.0215	9.2365	0.0221	9.3531	0.0344
1.8	8.9508	0.0120	9.2745	0.0203	9.0993	0.0209	9.2255	0.0309
2.0	8.8767	0.0116	9.1886	0.0196	9.0171	0.0202	9.1470	0.0299
2.5	8.7173	0.0108	9.0001	0.0181	8.8363	0.0188	8.9697	0.0277
3.0	8.5849	0.0102	8.8401	0.0169	8.6823	0.0175	8.8137	0.0259
3.5	8.4718	0.0096	8.7011	0.0159	8.5480	0.0165	8.6743	0.0243
4.0	8.3731	0.0092	8.5781	0.0150	8.4289	0.0156	8.5484	0.0229
4.5	8.2855	0.0088	8.4680	0.0142	8.3221	0.0148	8.4335	0.0217
5.0	8.2069	0.0085	8.3683	0.0135	8.2253	0.0142	8.3279	0.0206
5.5	8.1357	0.0082	8.2774	0.0129	8.1367	0.0135	8.2304	0.0196
6.0	8.0705	0.0079	8.1939	0.0124	8.0552	0.0130	8.1399	0.0187
6.5	8.0106	0.0076	8.1166	0.0119	7.9797	0.0125	8.0552	0.0179
7.0	7.9550	0.0074	8.0448	0.0114	7.9095	0.0120	7.9761	0.0171
7.5	7.9033	0.0072	7.9779	0.0110	7.8439	0.0116	7.9016	0.0164
8.0	7.8550	0.0070	7.9151	0.0106	7.7823	0.0112	7.8315	0.0158
8.5	7.8097	0.0068	7.8561	0.0103	7.7244	0.0109	7.7652	0.0152
9.0	7.7670	0.0067	7.8005	0.0100	7.6697	0.0105	7.7024	0.0147
9.5	7.7267	0.0065	7.7479	0.0096	7.6179	0.0102	7.6428	0.0141
10.0	7.6885	0.0064	7.6980	0.0093	7.5688	0.0090	7.5867	0.0137
Average	8.7908	0.01160	9.0172	0.0190	9.8445	0.01955	9.8976	0.0280

Table 1: The Dielectric Constant Ɛ′ And Loss Factor Ɛ’ Of PF_6 within the Temperature Range of 5℃ to 35℃

F(Ghz)	Ɛ' 45℃	Ɛ’ 45℃	Ɛ' 55℃	Ɛ’ 55℃	Ɛ' 65℃	Ɛ’ 65℃
0.1	9.8675	0.0461	10.0346	0.0563	9.9454	0.0570
0.2	9.7815	0.0447	9.9815	0.0553	9.8992	0.0561
0.3	9.7085	0.0435	9.9327	0.0543	9.8560	0.0552
0.4	9.6433	0.0425	9.8869	0.0534	9.8200	0.0544
0.5	9.5835	0.0415	9.8431	0.0525	9.7756	0.0536
0.6	9.5287	0.0406	9.8012	0.0518	9.7376	0.0528
0.7	9.4759	0.0398	9.7608	0.0511	9.7007	0.0521
0.8	9.4267	0.0391	9.7217	0.0503	9.6649	0.0514
0.9	9.3799	0.0384	9.6838	0.0496	9.6300	0.0507
1.0	9.3352	0.0377	9.6469	0.0489	9.5959	0.0500
1.2	9.2513	0.0364	9.5759	0.0476	9.5301	0.0488
1.5	9.1366	0.0348	9.4756	0.0458	9.4364	0.0470
1.8	9.0325	0.0333	9.3815	0.0442	9.3479	0.0454
2.0	8.9679	0.0324	9.3217	0.0432	9.2914	0.0443
2.5	8.8201	0.0304	9.1813	0.0408	9.1579	0.0419
3.0	8.6881	0.0286	9.0518	0.0386	9.0341	0.0398
3.5	8.5688	0.0271	8.9316	0.0367	8.9185	0.0378
4.0	8.4597	0.0257	8.8193	0.0349	8.8101	0.0360
4.5	8.3593	0.0245	8.7141	0.0333	8.7081	0.0343
5.0	8.2662	0.0234	8.6151	0.0318	8.6118	0.0328
5.5	8.1795	0.0224	8.5216	0.0305	8.5207	0.0314
6.0	8.0984	0.0214	8.4332	0.0292	8.4342	0.0301
6.5	8.0223	0.0206	8.3493	0.0280	8.3520	0.0301
7.0	8.9505	0.0199	8.2695	0.0269	8.2737	0.0277
7.5	7.8827	0.0191	8.1935	0.0259	8.1990	0.0267
8.0	7.8185	0.0184	8.1210	0.0249	8.1276	0.0257
8.5	7.7575	0.0177	8.0517	0.0240	8.0592	0.0247
9.0	7.6994	0.0172	8.9853	0.0232	8.9938	0.0239
9.5	7.6441	0.0166	7.9218	0.0224	7.9310	0.0230
10.0	7.5912	0.0161	7.8608	0.0216	7.8707	0.0222
Average	10.1308	0.0300	10.0356	0.0392	10.0078	0.0402

Table 2: The Dielectric Constant Ɛ′ and Loss Factor Ɛ’ Of PF_6 *within the Temperature Range of 45℃ To 65℃*

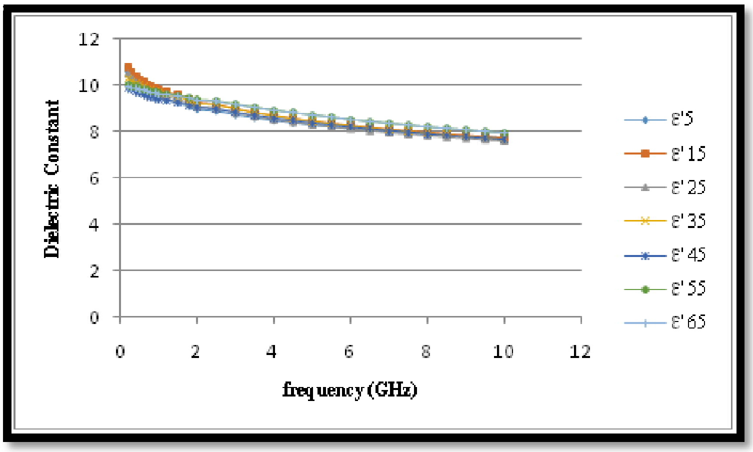

Figure 1: Dielectric Constant Vs Frequency for PF_6

In Figure 1, the dielectric constant of PF_6 decreases as frequency increases making the lower frequency to record higher value of the dielectric constant (i.e. 10.5535, 10.7783, 10.5173, 10.3059, 9.8675, 10.0346, and 9.9454 for 5°C, 15°C, 25°C, 35°C, 45°C, 55°C and 65°C, respectively).

The dielectric constant $\varepsilon'$was high at low frequencies as shown in Figure1, this may be due to the overall conductivity which consists of different conduction mechanisms. The most prevalent one in moist materials is the ionic conductivity which varies inversely proportional to the frequency. The decrease in the dielectric constant as frequency increases for all the temperatures may be due to the fact that the dipoles cannot follow up the rapid variation of the applied field.

The loss factor on the other hand has a small value for all frequency. The loss factor was higher at lower frequency and reduces as frequency increases. This behavior exhibited by the loss factor may be due to the contribution from all the four types of polarization (i.e. space charge, dipole, ionic and electronic). But as temperature increases the loss factor increases too.

5. Discussion

Findings have reveal that the mean dielectric constant for [DiEtMeIm][PF$_6$] at 5°C ,15°C25°C, 35°C, 45°C, 55°C, and 65°Cis 8.7908, 9.01729.8445, 9.8976, 10.1308, 10.0356 and 10.0078 which is in line with the findings of Cserjesi *et al*, 2016, Hermann (2009) and Ikyumbur *et al*, 2017a. But not in line with the findings of Ikyumbur *et al.*(2017b), Onimisi and Ikyumbur (2015a), and Onimisi and Ikyumbur (2015b) who found the mean dielectric constant of methanol, butan-1-ol and water to be 15.28, 28.18 and 20.13 using Debye relaxation method. This is because Debye relaxation model is a poor relaxation model one can use to study the dielectric properties of alcoholic solvents.

The loss factor on the other hand has the value of 0.01160, 0.0190, 0.01955, 0.0280, 0.0300, 0.0392 and 0.0402 at the frequency of 5°C to 65°C this is in line with Ikyumbur *et al.*(2017a) and Guan *et al.* (2004). But not in line with Cserjesi *et al.*(2016), Ikyumbur *et al.*(2017b), Onimisi and Ikyumbur (2015a), and Onimisi and Ikyumbur (2015b) who has higher values of loss factor. The behavior exhibited by the IL studied in this work is similar to the statement made by Guan *et al.* (2004) that'in general, the loss factor increases with increasing temperature at low frequencies due to ionic conductance and decreases with increasing temperature at high frequencies due to free water dispersion'.

6. Conclusion

The Cole-Cole equation and its derivatives have been used to compute the dielectric constant and loss factor of PF$_6$ The computations was done within the frequency range of $0.1 \leq f \leq 10\ GHz$, The results from our computation revealed that higher values of dielectric where observed at lower temperature, and the loss factor was small for all temperature. The result of this work has shown that as the dielectric constant increases, the electric flux density increases, this enables objects of a given size such as sets of metal plates to hold their electric charge for long periods of time, and to hold large quantities of charge. However chemical industry and other industries that use IL for their production can do so at higher frequencies. This is because higher frequencies have the lowest value of the dielectric constant. Higher dielectric constants have the tendency to breakdown more easily when they are subjected to intense electric fields than lower dielectric constants. However, since our computation was done in gigahertz we suggest that further work should try lower frequency such as kilohertz and megahertz.

7. References

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