Computation of Dielectric constant and loss factor of 1-ethyl-3-methylimidazolium chloride (emim)

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Abstract

Ionic liquid has special characteristics such as wide electrochemical windows electrochemical stability, tunable physiochemical properties etc. They potentially excellent candidate are for environmentally sound, green electrolytes in batteries. Because of its unique properties, it is essential to gain information about their dielectric properties. The Cole-Cole relaxation equation was derived and the values for the dielectric constant and loss factor of 1-ethyl-3-methylimidazolium chloride (emim) were determined. The computation was done within the frequency of 0.1GHz to 10GHz and temperature between 5°C to 55°C. The result obtained shows that the dielectric constant and loss factor of 1-ethyl-3-methylimidazolium chloride (emim) 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 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 it is advisable to use such IL in high frequency because the dielectric constant is low at high frequency.

Keywords — Dielectric Constant, Loss Factor, Frequency, Temperature, Cole-Cole Method

I. INTRODUCTION

Ionic liquids are one of the most promising classes of new materials investigated in the last decade. They 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 [1], [2], [3] that show a melting point lower than 100°C, that make them liquid under ambient conditions. Their negligible vapour 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 [4], [5], [3]. Among these applications we find catalysis, synthesis, sensoritics, medicine, electrochemistry and green chemistry in general [6],

[7], [8]. 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 [9] 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. The anion is generally inorganic as e.g. (PF₆)-, (BF₄)-, Br-, Cl-. The cation is an asymmetric organic cation such as alkylammonium, alkylphosphorium, N. Ndialkylimidazolium and N-alkylpyridinum. Due to the freedom in designing the organic cation and to the possible combination of cation and anion, one can generate a huge number of different ionic liquids. 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 [10], [1], [3].

II. LITERATURE REVIEW

A. Dielectric polarization Build up

In the classical approach to the dielectric model, a material is made up of atoms. Each atom consists 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 behaviour of the dielectric depends on the situation. The more complicated the situation, the richer the model must be to accurately describe the behaviour. 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:

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

$$\frac{dP(t)}{dt} = \frac{dP_{\infty}}{dt} \left(1 - e^{-t/\tau} \right)$$
We let $u = P_{\infty}$ and $\frac{du}{dt} = 0$

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

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

Substituting in equation (*), we have

$$\frac{dP(t)}{dt} = P_{\infty} \left(-\frac{1}{\tau} e^{-t/\tau} \right) + \left(1 - e^{-t/\tau} \right) (0)$$
$$\Rightarrow \frac{dP(t)}{dt} = -\frac{1}{\tau} P_{\infty} = \frac{P_{\infty} e^{-t/\tau}}{\tau}$$
(2)

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

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

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

$$e^{-t/\tau} = \frac{P_{00} - P(t)}{P_{00}}$$
 (4)

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

$$\frac{dP(t)}{dt} = \frac{P_{00} - P(t)}{\tau} \tag{5}$$

We can now express our total polarization as:

$$P_T(t) = P_a(t) + P_g \tag{6}$$

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:

$$P_T(t) = \varepsilon_o(\varepsilon_s - 1)E \tag{7}$$

$$P_{\varepsilon}(t) = \varepsilon_{o}(\varepsilon_{\infty} - 1)E \tag{8}$$

Where, ε_{o} and ε_{∞} are the dielectric constant under direct voltage and at infinity frequency respectively. The dielectric constant ε_{∞} is defined in Maxwell's relation as:

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

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

$$\begin{split} P_{a}(t) &= P_{T}(t) - P_{\infty} \\ P_{a}(t) &= \varepsilon_{o}(\varepsilon_{s} - 1)E - \varepsilon_{o}(\varepsilon_{\infty} - 1)E \quad (10) \\ P_{a}(t) &= (\varepsilon_{o}\varepsilon_{s} - \varepsilon_{o})E - (\varepsilon_{o}\varepsilon_{\infty} - \varepsilon_{o})E \\ P_{a}(t) &= \varepsilon_{o}\varepsilon_{s}E - \varepsilon_{o}E - \varepsilon_{o}\varepsilon_{\infty}E + \varepsilon_{o}E \\ P_{a}(t) &= \varepsilon_{o}\varepsilon_{s}E - \varepsilon_{o}\varepsilon_{\infty}E = \varepsilon_{o}(\varepsilon_{s} - \varepsilon_{\infty})E \\ (11) \end{split}$$

Representing the alternating electric field as:

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

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

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

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

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

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

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

Solving equation (14) using integration by part; we let the integrating factor be $e^{\int adt}$, 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:

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

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

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

Taken the integral both sides, we have:

$$e^{t/\tau} \int \frac{dP(t)}{dt} = \frac{1}{\tau} \int e^{1/\tau} \left[\varepsilon_o(\varepsilon_s - \varepsilon_\infty) E_{max} e^{j\omega t} \right]$$
$$e^{t/\tau} P(t) = \frac{1}{\tau} \varepsilon_o(\varepsilon_s - \varepsilon_\infty) E_{max} \int e^{t/\tau} e^{j\omega t} dt$$
(15)

Note:

$$\int e^{t/\tau} e^{j\omega t} dt = \int e^{\left(\frac{1}{\tau} + j\omega\right)t} dt$$
$$= \frac{e^{t/\tau} e^{j\omega t}}{\frac{1}{\tau} + j\omega} = \frac{e^{t/\tau} e^{j\omega t}}{(1 + j\omega\tau)}$$
(16)

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

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

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

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

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

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

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

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

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

$$P(t) = \varepsilon_o(\varepsilon_s - \varepsilon_\infty) E_m e^{j\omega t} + \frac{\varepsilon_o(\varepsilon_s - \varepsilon_\infty) E_m}{\varepsilon_o(\varepsilon_s - \varepsilon_\infty) E_m} e^{j\omega t}$$

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

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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:

$$\begin{split} \varepsilon_{o}\varepsilon^{*}E_{max}\varepsilon^{j\omega t} &= \varepsilon_{o}E_{max}e^{j\omega t} + \\ \left[\varepsilon_{\infty} - 1 + \frac{(\varepsilon_{s} - \varepsilon_{\infty})}{(1 + j\omega \tau)}\right]\varepsilon_{o}E_{max}e^{j\omega t} \end{split} \tag{24}$$

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

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

$$E *= \mathcal{E}' - j\mathcal{E}'' \tag{*b}$$

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:

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

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

This gives

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

Now setting

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

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

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

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 $\boldsymbol{\varepsilon}''$, 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:

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

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:

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

Simplifying the above expression yields:

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

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

B. 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.

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

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

The exponential parameter α which takes a value between 0 and 1 allows describing different spectral shapes. When $\alpha = 0$, the Cole-Cole model reduces to the Debye model and when $\alpha > 0$, the relaxation is stretched.

Separating the complex dielectric constant into the real and imaginary parts yield:

$$\begin{split} \mathcal{E}' &= \varepsilon_{\infty} + \frac{(\varepsilon_s - \varepsilon_{\infty}) [1 + (cwT_c - c)^n \cos\frac{n\pi}{2}]}{1 + 2(wT_c - c)^n \cos\frac{n\pi}{2} + (wT_c - c)^{2n}} \\ \mathcal{E}'' &= \frac{(\varepsilon_s - \varepsilon_{\infty}) [1 + (cwT_c - c)^n \sin\frac{n\pi}{2}]}{1 + 2(wT_c - c)^n \cos\frac{n\pi}{2} + (wT_c - c)^{2n}} \end{split}$$

III. METHOD

 \mathcal{E}' and \mathcal{E}'' are the real and imaginary part of Cole-Cole relaxation model. The real part (\mathcal{E}') represent the dielectric constant while the imaginary part (\mathcal{E}'') represent the loss factor. An algorithm was written using maple 13 and the value for the dielectric constant and loss factor of 1-ethyl-3methylimidazolium chloride (emim) was generated. The computation was done within the frequency range of 0.1GHz to 10GHz and temperature range between **5°C** and **55°C** for an interval of **10°C**.

IV. RESULTS

The results generated from the computation are interpreted based on the existing theories and are presented in Tables 1 and 2, whereas, the relationship between the dielectric constant and the frequencies for emim are as shown in Fig. 1.

The Dielectric Constant E' and Loss Factor E'' of emim within the Temperature Range of 5°C to 35°C								
F(Ghz)	E' at 5°C	€'' at 5°C	E' at 15°C	E'' at 15°C	E' at 25°C	E'' at 25⁰C	E' at 35°C	E'' at 35°C
0.1	11.5917	2.3161	11.3552	2.7237	11.1885	3.1599	10.9407	3.5679
0.2	11.1351	2.0949	11.1142	2.5726	11.0877	3.0755	10.8808	3.5124
0.3	10.7674	1.9282	10.9015	2.4461	10.9889	2.9961	10.8195	3.4573
0.4	10.4534	1.7927	10.7067	2.3350	10.8910	2.9200	10.7569	3.4025
0.5	10.1775	1.6783	10.5254	2.2351	10.7938	2.8468	10.6929	3.3480
0.6	9.9310	1.5795	10.3552	2.1442	10.6972	2.7760	10.6278	3.2938
0.7	9.7081	1.4929	10.1945	2.0607	10.6013	2.7074	10.5616	3.2401
0.8	9.5047	1.4929	10.0421	1.9834	10.5062	2.6420	10.4946	3.1867
0.9	9.3178	1.3470	9.8973	1.9116	10.4118	2.5765	10.4268	3.1337
1.0	9.1453	1.2847	9.7593	1.8445	10.3184	2.5140	10.3583	3.0812
1.2	8.8358	1.1763	9.5016	1.7228	10.1349	2.3943	10.2199	2.9778
1.5	8.4420	1.0443	9.1546	1.5656	9.8685	2.2277	10.0101	2.8271
1.8	8.119	0.9386	8.8472	1.4322	9.6143	2.0752	9.8001	2.6823
2.0	7.9194	0.8791	8.6609	1.3539	9.4520	1.9811	9.6609	2.5893
2.5	7.5112	0.7579	8.2494	1.0876	9.0715	1.7688	9.3195	2.3696
3.0	7.1814	0.6650	7.9011	1.0537	8.7270	1.5858	8.9917	2.1686
3.5	6.9082	0.5915	7.6023	0.9438	8.4161	1.4278	8.6811	1.9859
4.0	6.6774	05319	7.3433	0.8521	8.1362	1.2908	8.3893	1.8206
4.5	6.4794	0.4826	7.1165	0.7746	7.8841	1.1718	8.1171	1.6716
5.0	6.3072	0.4412	6.9164	0.7084	7.6568	1.0679	7.8643	1.5373
5.5	6.1559	0.4058	6.7384	0.6512	7.4515	0.9768	7.6300	1.4164
6.0	6.0219	0.3754	6.5791	0.6015	7.2657	0.8966	7.4134	1.3076
6.5	5.9018	0.3490	6.4357	0.5579	7.0971	0.8257	7.2133	1.2095
7.0	5.7938	0.3257	6.3059	0.5194	6.9436	0.7629	7.0284	1.1211
7.5	5.6960	0.3052	6.1879	0.4852	6.8036	0.7068	6.8575	1.0412
8.0	5.6070	0.2869	6.0800	0.4546	6.6756	0.6567	6.6996	0.9689
8.5	5.5254	0.2705	5.9811	0.4272	6.5581	0.6118	6.5534	0.9034
9.0	5.4505	0.2558	5.8900	0.4025	6.4501	0.5713	6.4179	0.8438
9.5	5.3813	0.2424	5.8059	0.3800	6.3506	0.5347	6.2924	0.7897
10.0	5.3172	0.2303	5.7280	0.3597	6.2586	0.5016	6.1757	0.7403
Average	7.7655	1.7820	8.2626	1.2864	8.8100	1.7417	8.8632	2.2065

TABLE 1



Fig. 1: Dielectric constant versus frequency for emim

The dielectric constant was high at lower frequency. At low frequencies, all types of polarization may be effective, however, as frequency increases some may not be effective and hence the dielectric constant at higher frequencies may be quite small as compared to the values at low frequencies. As frequency increases the dielectric constant reduces which may be due to the fact that the dipoles cannot follow up the rapid variation of the applied field. This is because the dielectric constant strongly dependent on the structure of materials.

The loss factor on the other hand has high value at lower frequency and as frequency increases, loss factor reduces, and as temperature increases the loss factor increases especially at frequency 0.1GHz. This behaviour exhibited by the IL studied in this work is the same to the statement made by Guan *et al.* [11] which said: "Generally, 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".

The Dielectric Constant \mathcal{E}' and Loss Factor \mathcal{E}'' of emim within the Temperature Range of 45°C to 55°C								
F(Ghz)	Е'45°С	€''45 <mark>°C</mark>	€'55 <mark>°C</mark>	€''55°C				
0.1	10.7641	3.6844	10.9499	3.4484				
0.2	10.7267	3.6482	10.9037	3.4078				
0.3	10.6882	3.6116	10.8584	3.3687				
0.4	10.6487	3.5749	10.8133	3.3306				
0.5	10.6082	3.5379	10.7683	3.2934				
0.6	10.5667	3.5009	10.7233	3.2567				
0.7	10.5245	3.4638	10.6783	3.2206				
0.8	10.4414	3.4266	10.6332	3.1850				
0.9	10.4376	3.3894	10.5881	3.1499				
1.0	10.3932	3.3522	10.5428	3.1152				
1.2	10.3025	3.2780	10.4522	3.0471				
1.5	10.1626	3.1674	10.3162	2.9478				
1.8	10.0194	3.0581	10.1803	2.8518				
2.0	9.9225	2.9863	10.0901	2.7897				
2.5	9.6778	2.8101	9.8666	2.6404				
3.0	9.4326	2.6429	9.6474	2.4998				
3.5	9.1900	2.4830	9.4337	2.3675				
4.0	8.9527	2.3318	9.2265	2.2432				
4.5	8.7222	2.1895	9.0264	2.1266				
5.0	8.5000	2.0563	8.8337	2.0173				
5.5	8.2868	1.9317	8.6487	1.9149				
6.0	8.0830	1.8156	8.4715	1.8189				
6.5	7.8890	1.7075	8.3020	1.7291				
7.0	7.7046	1.6071	8.1400	1.6451				
7.5	7.5298	1.5137	7.9853	1.5663				
8.0	7.3642	1.4271	7.8377	1.4925				
8.5	7.2076	1.3466	7.6970	1.4234				
9.0	7.0595	1.2719	7.5629	1.3585				
9.5	6.9197	1.2024	7.4349	1.2977				
10.0	6.7873	1.1379	7.3130	1.2405				
Average	9.1838	2.5718	9.4642	2.4598				

TABLE 2

V. DISCUSSION

Findings have reveal that the mean dielectric constant at 5°C, 15°C, 25°C, 35°C, 45°C and 55°C, are 7.7655, 8.2626, 8.8100, 8.8632, 9.1838 and 9.4624 respectively, which is in line with the findings of [12], [13], [14]. But not in line with the findings of [15], [16], [17] 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. From above result, as temperature increases the dielectric constant increases to. This increase in the dielectric constant as a result of increase in temperature may be due to the relaxation time which has been found to be fast at high temperature and increases dramatically at low temperatures, suggesting a freezing of electric dipoles at low temperatures.

The loss factor on the other hand at the frequencies from **5°C** to **65°C** was 1.7820, 1.2864, 1.7417, 2.2065, 2.5718 and 2.4598 respectively which is in line with

[12], [15], [16], [17] who has a higher values of loss factor but not in line with [14], [11] who found the value of the loss factor to be smaller. From the above result, as temperature is increasing, loss factor 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).

VI. CONCLUSIONS

The Cole-Cole equation and its derivatives have been used to compute the dielectric constant and loss factor of emim. The computations was done within the frequency range of $0.1 \leq f \leq 10 \; GHz$ and temperature 5°C to 55°C. 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.

The Cole-Cole equation was able to generate good results for the Ionic liquid. The researcher suggests that other methods order than dielectric constant should be used to study the properties of other Ionic liquids.

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