Physico-Chemical Studies on Molecular Interactions of Curcumin with Mono and Divalent Salts at Different Temperature

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Abstract

The ultrasonic velocity, density and refractive indices have been measured for systems at 303.15, 308.15, 313.15, 318.15 and 323.15 K. From the experimental data adiabatic compressibility (β_s), intermolecular free length (L_f), internal pressure (π), acoustic impedance (Z), molar refraction (R_m), Polarisability, (α_p), thermal expansion coefficient (α), Rao's molar sound function (R), solvation number (S_n) , Relative Association Parameter (R_A) have been computed. Excess properties are fitted to Redlich-kister polynomial equation to obtain binary coefficients and the standard errors with main thrust of the study is to correlate the excess properties and the relevant interactions parameters with the nature of molecular interactions between the mixing components at different temperatures. Lorentz–Lorenz equation and Eykman equations are used to estimate thermal expansion coefficient of the systems from their respective experimental densities and refractive indices. The knowledge of refractive index (n), molar refraction (R_m), thermal expansion coefficient (α) and polarizability (α_p) are useful for predicting many physico-chemical properties of solutions.

Keywords: *Molecular interactions; ultrasonic velocity; adiabatic compressibility; intermolecular free length.*

1. Introduction

Molecular interaction studies of the metal ions like (Na^+ , K^+, Ca^{++}, Zn^{++}, Cu^{++}, Fe^{+++}etc.) with antioxidants and their derivatives will be useful in understanding the mechanism of action of antioxidants in the living system. It will be interesting to study the molecular interaction of curcumin antioxidant with metal ions which are present in our body playing a important role viz., circulatory system (Fe^{+++}), nervous system (Na^+&K^+), digestive system (Zn^{++}), excretory system (Na^+&K^+), muscular system (Ca^{++},Mg^{++}) and respiratory system (Mg^{++},Mn^{++} K^+) . The interactions of ions and antioxidants provide important information about physiological systems and can be used to understand the mechanism of their metabolism in living system. In living organisms interactions of antioxidants with metal ions play a key role in the wide range of biochemical processes such as immunology, biosynthesis, pharmacology and medicine.

Curcumin is a natural polyphenolic component of turmeric, the powderd rhizome of the perennial herb Curcuma Longa Linn (family – Zingiberacae), which is widely used as a dietary spice, as a colourant in cooking as well as herbal medicine in Ayurveda for centuries. Chemically curcumin is (1,7-bis-4-hydroxy-3-methoxyphenyl-1,6-heptadiene-3,5-dione) known as diferyloylmethane [1] contains two parahydroxyl groups responsible for antioxidant activity, two keto groups and two double bonds responsible for anti-inflammatory, anticancer & antimutagenic activity , two methoxy groups and an active methylene group

established by analysis of chemical structure of curcumin via its biological activity [2]. Although curcumin is wonder drug but the main problem is associated due to its low solubility, poor adsorption and less bioavailability. An ideal drug has to act both as lipophilic (fat soluble) to pass through cell lining of the gut wall and also as water soluble in order to dissolve in the gut and blood serum. Due to its fat soluble nature and low molecular weight, it is difficult for the molecules to squeeze through small gaps between the cells of gut wall. It has to pass from the gastrointestinal tract into the blood supplied by travelling through the cell lining of gut wall. The phospholipids bilayer of the gut and blood cells must be preventing it from entering and leaving the cell because curcumin is a polar molecule. Extensive investigations over last five decades have indicated that curcumin is a potent antioxidant [3-4] which has important naturally occurring nutrients in maintaining health by slowing the destructive ageing process of cellular molecules. They are found naturally in body & in plants such as fruits and vegetables and are used in diabetes [5-6], leishmanisis [7], psoriasis [8], apoptosis [9] and many other chronic diseases. The characteristics of living organisms such as selective permeability across cell membrane, muscle contraction, hearing and memory process and nerve conduction etc. can be interpreted in terms of interactions of molecules.

In some recent publications, efforts have been made to correlate biological activity with calculated physical parameters with the help of densities, ultrasonic velocity [10-13] and refractive indices [14-15] for mixtures at different temperatures. Refractive index [16-19] is an important physical property of liquid and solutions, which can be used to study the molecular interactions, and to evaluate other important parameters such as molar refraction, polarizability and thermal expansion coefficient. Lorentz–Lorenz [20] and Eykman [21] used to estimate thermal expansion coefficient of the systems from their respective experimental densities and refractive indices. The knowledge of refractive index (n), molar refraction (R_m), thermal expansion coefficient (α) and polarizability (α_p) [22] are useful for predicting many physico-chemical properties of solutions. The measurement of density, ultrasonic speed and refractive indices enables the accurate determination of some useful acoustical parameters and their excess functions, which are highly sensitive to molecular interactions in liquid mixtures, are fitted to Redlick-Kister equation [23], where X_1 is the mole fraction of salt electrolyte in mixture and A_i are the estimated coefficient.

Ionic association and electrostatic interactions are the prime factors that must be considered in these electrolytes. Various types of interactions exist between the ions in the solutions and of these, ion-ion, ion-solvent interactions are of current interest. The interaction help in better understanding of the types of solute and solvent, i.e. whether the added solute modifies or distorts the structure of the solvent. The addition of organic solvent to an aqueous solution of electrolyte brings about the change in ion salvation that often results in a large change in the reactivity of dissolved electrolyte.

When curcumin is taken orally, 75% of it excreted in the feces while only traces appear in urine [24]. Invitro studies carried out to access degradation kinetics of curcumin under various pH conditions and the stability of curcumin in physiological matrices was investigated [25] suggests that curcumin has very low bioavailability. Curcumin shows lots of pharmacological activities but it is a very good antioxidant. It helps in maintaining health by scavenging the free radicals, although free radicals helps in the proper functioning of immune system but when the free radicals increase to an abnormal value, the danger begins. Curcumin having antioxidant property breaks the free radicals chain reaction. Antioxidants are chosen for the molecular interaction studies because they have great potential and are gaining popularity. This type of work with therapeutic active antioxidant, curcumin has not been reported so far.

2. Experimental techniques

Curcumin (Merck) (2009) of high grade purity of batch number S543754 and product number 8.20354.0010 was purchased from Central Drug House (P). Methanol, Sodium chloride and Magnesium Chloride of high grade purity (> 99%) were purchased from BDH (India) in 2009. Very dilute solution of curcumin is prepared in methanol because of its low solubility [17-18]. The weighing was done by using an electronic balance (model GR-202R, Japan) with a precision of (0.01 mg).

A double stem calibrated [26] pyknometer purchased from M/S Science Corporation, Allahabad, has been used to determine the density of solvent and solutions. The capillary with graduated marks had a uniform bore and could be closed by a well-fitting glass cap. The marks on the capillary were calibrated using triple distilled water. The temperature of the test liquids during the measurements was maintained by circulating water from an electronically controlled thermostatic water bath (JULABO, model ME-3).

A crystal controlled ultrasonic interferometer supplied by M/s Mittal Enterprises, New Delhi, operating at a frequency of 2 MHz has been used to measure the sound velocity. The temperature of the test liquids during the measurements was maintained by circulating water through the jacket from an electronically controlled thermostatic water bath (JULABO, model ME-3). The refractive indices of pure liquids and their mixtures were measured by using a thermostatted Abbe refractometer purchased from M/S Science Corporation, Allahabad, which is calibrated by measuring the refractive indices of triple distilled water at various temperatures. The values of refractive index were obtained using sodium D line. The temperature of the test liquids between the prisms of the refractometer during the measurements was maintained by circulating water through the jacket around the prisms from an electronically controlled thermostatic water bath (JULABO, model ME-3), and the temperature was measured with a digital thermometer connected to the prism jacket. Fresh solutions in methanol have been prepared by the variation of stock solution of curcumin and methanol keeping the total volume constant in air tight stopper volumetric flasks.

Theoretical Aspects

Using the measured data, the acoustic parameters [27], such as Classical absorption coefficient $(\alpha/f^2)_{Cl}$, Viscous relaxation time (τ), Polarizability (α_p), Thermal expansion coefficient (α), adiabatic compressibility (β_s), free length (L_f), free volume (V_f), internal pressure (π) and their excess parameters [28] have been calculated using the following expressions where the notations have their usual meaning.

Molar refraction, R_m

$$R_m = \frac{n^2 - 1}{n^2 + 2} V_m \tag{1}$$

Polarisability

$$\alpha_p = \frac{3}{4} \frac{R_m}{\pi N} \tag{2}$$

Thermal expansion coefficient

$$\alpha = \rho \left(\frac{\partial \rho^{-1}}{\partial T} \right)_p \tag{3}$$

$$\alpha_{L-L} = \frac{-6n}{\left(n^2-1\right)\left(n^2+2\right)}\left(\frac{dn}{dT}\right) \quad (4)$$

$$\alpha_{Eyk} = -\frac{\left(n^2+0.8n+1\right)}{\left(n^2-1\right)\left(n+0.4\right)}\left(\frac{dn}{dT}\right) \quad (5)$$

Rao's Molar sound Function $R = M*(u^{1/3})/\rho$ (6)

Iso entropic Compressibility $\beta_s = 1/(u^2\rho)$ (7)

Specific Acoustic impedance $Z=\rho u$ (8)

Internal Pressure $\pi = b\,RT\,(K\eta/u)^{1/2}\rho^{2/3*}M^{-7/6}$ (9)

Inter molecular free path length $L_f = K_T\,\beta_s^{1/2}$ (10)

Salvation No. $S_n = M_2/(M_1(1-(\beta_s/\beta_0)(100-X)/X))$ (11)

Molal hydration no. $n_H = (n_1/n_2)(1-\eta/\eta_0)$ (12)

$Y^E = A_{exp} - Aid$ (13)

$A_{id} = \Sigma^n A_i X_i$, Ai is any acoustical parameters and X_i the mole fraction of the liquid

Redlich kister Eqn. $Y^{E} = X_1(1-X_1)\sum A_i\,(2X_1-1)^i$ (16)

n_1 = no. of moles of Solvent, n_2 = no. of moles of Solute, $M = M_1W_1+M_2W_2$, Where M is apparent molecular weight, b stands for cubic packing which is assumed to be 2 for liquids and K is a dimensionless constant independent of temperature and nature of liquids and its value is $4.281\text{x}10^{9}$, T is the absolute temperature and M_{eff} is the effective molecular weight. The non-ideality of the liquid mixtures i.e. excess parameters (Y^E) were computed by Redlich kister equation.

3. Results and discussion

The values of density (ρ), ultrasonic velocity (u) and refractive index (n) for all systems are measured at different temperatures 303.15, 308.15, 313.15, 318.15 and 323.15 K. It is seen that density (ρ) , Rao's molar sound function (R) , relative association parameter (R_A) , molal hydration number (n_H), intermolecular free length (L_f), internal pressure (π), adiabatic compressibility (β_s) increases with increase in temperature whereas, velocity (u), refractive index (n), molar refraction (R_m), apparent molal compressibility (ϕ_k), solvation number (S_n) , specific acoustic impendence (Z), polarizability (α_p) , thermal expansion coefficient (α), Lorentz-Lorentz (α_{L-L}) and Eykman (α_{Eyk}) values are given in Table (1-3) decreases with increase in temperature. The increasing value of density, velocity, refractive index, and solvation number, thermal expansion coefficients of solution, Rao's molar sound function and specific acoustic impendence with increase in concentration shows that there is moderate attraction between molecules. The decreasing values of molar refraction, polarizability, molal hydration number, intermolecular free length, internal pressure (π) and adiabatic compressibility (β_s) with concentration shows a decrease in intermolecular forces. An attempt has been made to calculate (α) from temperature dependent refractive index data calculated by Lorentz-Lorentz (α_{L-L}) and Eykman (α_{Eyk}) expressions. There is decrease in inter ionic interactions with increase in temperatures may be due to more solvation of solute ions with rise in temperatures.

Excess properties [27] for mixtures have been plotted against mole fractions of salt and given in Fig. (1-5) respectively and presented in Table (4) as a function of composition and temperature. These values are fitted to Redlich-kister polynomial equation and coefficients, Ai, were evaluated by using Redlich-kister polynomial equation by the method of least-squares .The coefficients A_0, A_1, A_2, A_3, and standard deviation are listed in Table (5). The observed trend indicates the presence of specific interaction [28] between the components is due to intermolecular hydrogen bonding is a specific dipolar interaction in proton atoms and non bonding electrons. Thus structural arrangement of molecule results in decreasing adiabatic compressibility by showing intermolecular interactions also reported by Bhatti and Singh [29].

Intermolecular free length is found to be a predominating factor on the basis of sound propagation in liquid increases with decrease in the velocity [30] suggested the presence of strong molecular interactions in solutions, whereas decrease of solvation number with concentration confirms powerful solute-solute interactions over solvent-solute interaction. Polar solvent methanol forms intermolecular hydrogen bonding with phenolic OH of curcumin whereas keto-enol tautomerism of curcumin shows intramolecular hydrogen bonding. Polar- polar interaction exists between polar phenolic OH of curcumin (solute) and polar methanol (solvent) and non polar- polar interaction exists between non polar carbon chains having double bond with polar methanol. Possible types of solute-solvent interaction exists in this system is ion-ion interaction in between ions (Na^+, Mg^{++}) and water, ion-polar site interaction in between ions and polar sites of curcumin (phenolic hydroxyls and diketo groups), ion-non polar interaction in between ions with CH_3OH, non polar-polar interaction or hydrophobic- hydrophilic interaction exists in between curcumin, water and metal ions with pi e- cloud of two benzene rings (aromatic nucleus) produces significant change in the physical properties of curcumin.

4. Conclusion

This paper reports that derived acoustical parameters and excess functions from the measured properties suggests the presence of strong molecular interactions [31-33] in the solution are fitted to Redlich-kister polynomial equation to obtain binary coefficients and the standard errors at different temperatures 303.15, 308.15, 313.15, 318.15 and 323.15K as a function of composition of mixtures. Water molecules are attached to the ions strongly by the electrostatic forces introduces a greater cohesion in the solution increases with the increase of water concentration in the solution. Intermolecular free length is found to be a predominant factor, depends upon the adiabatic compressibility. Ultrasonic investigation [34] in aqueous solutions of electrolytes with metal chlorides provides useful information in understanding the behavior of liquid systems, due to intermolecular and intra molecular association, complex formation and related structural changes affect the compressibility of the system which in turn produces corresponding variation in the ultrasonic velocity.

Study of antioxidants is a burning field of science nowadays as it is related to ageing process and several other diseases such as cancer, diabetes, neurodegenerative diseases, allergy and ophthalmologic problems. Curcumin is chosen for the molecular interaction studies because it has great potential as drug. Bio chemists now firmly believe that the characteristic of living organism such as selective permeability across cell- membranes, muscle contractions, hearing and memory processes and nerve conduction etc. can be interpreted in terms of co-coordinative interactions of small and large molecules. Therefore we have calculated different physico-chemical data to study the molecular interaction between curcumin and metal ions. Metal ions play several different roles in biological processes. Such types of studies will be useful in understanding the mechanism of action of antioxidants in the living systems. The interactions of ions and antioxidant provide important information about physiological system

and can be used to understand the mechanism of their metabolism in living system. Na^{+} ions play major role in nervous system and Mg^{++} ion in muscular system and respiratory system. Therefore these two ions are selected to study the interaction with curcumin as an antioxidant.

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References

[1] Jayaprakasha, G.K.; Rao, J. M.; J. Agric. Food Chem. ,50(13), 3668-72. (2002).
[2] Priyadarsini, K.I.; Maity, D.K.; Naik, G.H.; Kumar, M.S.; Unnikrishnan, M.K.; Satav, J.G.; Mohan, H., Free Radic. Biol. Med. 35(5), 475-484. (2003).
[3] Khopde, M. S.; Priyadarsini, K.I.; Venkatesan, P.; Rao, M.N.A. Biophys. Chem., 80(2), 83-89. (1999).
[4] Aggarwal, B. B.; Kumar, A., Bharti , A. C., Anticancer Res., 231A, 363-98. (2003).
[5] Arun, N.; Nalini, N., Plant Foods Hum Nutr, 57(1), 41-52. (2002).
[6] Fusheng,Y.; Giselle, P.; Lim, A. N.; Begum, O. J. U.; Mychica, R. S., J. Biol. Chem., 280, 5892-5900. (2005).
[7] Koide, T.; Nose, M.; Ogihara, Y.; Yabu, Y.; Ohta, N., Biol. Pharm. Bull., 25(1), 131-3. (2002).
[8] Heng, M. C.; Song, M. K.; Harker. J.; Heng, M. K., Br. J. Dermatology, 143(5), 937-49. (2000).
[9] Elena, T. P.; Gooz, J. C.; Oates, A.; Richard, L. B.; Stanley, M. S., Am. J. Respir. Cell Mol. Biol. 31, 28-35. (2004).
[10] Banipal, T. S.; Kaur, J.; Banipal, P. K.; Singh, K.; J. Chem. Eng. Data, 53 (8) 1803–1816. (2008).
[11] Santosh, M. S.; Bhat, D. K.; Bhat, A. S. , J. Chem. Eng. Data, 54 (10), 2813–2818. (2009).
[12] Pandey, J. D.; Dubey, G. P.; Shukla, B. P.; Dubey, S. N., Pramana, 37(6), 497-503. (2007).
[13] Nomoto, O. , J. Phys. Soc. Jpn., 12 739-739, (1957). DOI: 10.1143/JPSJ.12.739.
[14] Kannappan, V.; Shanthi, J. R., Ind. J. Pure & Appl. Phys., 43, 750-754. (2005).
[15] Ali, A.; Kumar, A.; Abida, J. Chine. Chem. Soc., 51, 477-485.(2004).
[16] Arul, G.; Palaniappan, L., Ind. J. Pure & Appl. Phys., (43), 755-758.(2005).
[17] Sarkar, L., Roy, M. N., J. Chem. Eng. Data, 54,(12), 3307–3312. (2009).
[18] Giner, B.; Lafuente, C.; Villares, A.; Haro, M.; Lopez, M.C. J. Chem. Thermodyn., 39(1), 148-157. (2007).
[19] Nain, A. K.; J. Chem. Eng. Data, 53 , 1208–1210. (2008).
[20] Lorentz,H.A., Wield Ann Physics, 9, 641. (1880)
[21] Eykman, P. ; Recherches Refractometriques, Haarlem, 23(9), 160. (1919)
[22] Bottcher,C. J. F.; Bordewijk, P.; "Theory of Electrical Polarization" Vol. II Elsevier Amsterdam, (1978) p.143.
[23] Redlich,O.; Kister,A.T., Ind. Eng. Chem., 40, 345–348. (1948).
[24] Ravindranath, V.; Chandrashekhera, N.,Toxicology, 20, 251–257. (1981).
[25] Wang, Y.J.; Pan, M.H.; Cheng, A.L.; Hsieh, Y.S.; Lin, C.Y.; J. Pharmaceu. And Biomedi Ana, 15(12), 1867-72. (1997).
[26] Srivastava, R.; Saksena, A.R.; Gupta, A. Asian J. Appl. Sci., 3(1), 13-24. (2010).
[27] Pandey, J. D.; Soni, N. K.; Dey, R.; Verma, R. Fluid Phase Equilib, 215(1), 17-22. (2004).
[28] Pal,A.;Kumar,S. J. Mol. Liqs., 121(2-3), 148-155. (2005).
[29] Bhatti, S. S.; Singh, D. P.; Ind. J. Pure & Appl. Phys., 21, 506-509. (1983).
[30] Nithya, R.; Nithiyanantham, S.; Mullainathan, S. Rajasekaran, M. E-J. Chem., 6(1) 138-140. (2009).
[31] Sivaprasad, V. E.; Rajogopal, Moorthy, N. M.; J. Mol. Liqs., 124(1-3),1-6 (2006)
[32] Kumari, P.G.; Sekhar, C.; Rajmohan, K.; Rao, M.V.P; Phys. Chem. Liq. 10, 701-710. (2006).
[33] Priya, C.S.,Nithya,S.Velraj,G.Kanappan,A.N, International Journal of Advanced Science and Technology, 18,59-72.(2010).
[34] Sharma, D.; Yadav, J. S. ; Singh, K. C.; Sharma, V. K. ; J. Solution Chem., 37(8), 1099-1112. (2008).
[35] Nath, G.; Sahu, S.; Paikaray, R. Ind. J. Phys., 83(4), 429-436. (2009).

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Table 1

Density(ρ),Adiabatic compressibility(β_s),Acoustic impedance (Z) of systems at different temperature (K)

C ($mol.m^{-3}$) / T (K)	303.15	308.15	313.15	318.15	323.15
			ρ x10^{-2}($kg\ m^{-3}$)		
System [i]					
0.050	7.996	7.961	7.948	7.899	7.822
0.100	8.209	8.154	8.143	8.114	8.089
0.150	8.356	8.354	8.326	8.285	8.281
0.200	8.816	8.556	8.509	8.457	8.443
0.250	8.892	8.771	8.718	8.672	8.602
0.300	9.114	9.004	8.924	8.899	8.779
System [ii]					
0.050	8.059	8.013	8.021	7.908	7.874
0.100	8.304	8.214	8.173	8.115	8.104
0.150	8.562	8.404	8.387	8.351	8.315
0.200	8.911	8.602	8.572	8.521	8.424
0.250	9.410	8.930	8.818	8.744	8.711
0.300	9.951	9.887	9.861	9.846	9.834
			βs x10^{9} ($kg^{-1}ms^{2}$)		
System [i]					
0.050	0.795	0.820	0.869	0.937	0.976
0.100	0.744	0.775	0.812	0.844	0.857
0.150	0.703	0.752	0.777	0.820	0.828
0.200	0.617	0.663	0.685	0.694	0.746
0.250	0.589	0.632	0.637	0.654	0.678
0.300	0.571	0.604	0.611	0.626	0.645
System [ii]					
0.050	0.899	0.929	0.943	0.970	0.988
0.100	0.836	0.901	0.915	0.945	0.958
0.150	0.769	0.803	0.821	0.847	0.887
0.200	0.708	0.773	0.788	0.830	0.869
0.250	0.654	0.732	0.745	0.772	0.834
0.300	0.568	0.585	0.608	0.653	0.695
			Z x 10^{-5} $kg\ m^{-2}s^{-1}$		

System [i]						
	0.050	10.026	9.854	9.562	9.181	8.954
	0.100	10.503	10.258	10.016	9.806	9.713
	0.150	10.905	10.543	10.351	10.050	10.000
	0.200	11.957	11.358	11.142	11.043	10.636
	0.250	12.287	11.780	11.695	11.514	11.260
	0.300	12.632	12.214	12.087	11.923	11.665
System [ii]						
	0.050	9.469	9.285	9.224	9.027	8.928
	0.100	9.965	9.550	9.450	9.265	9.196
	0.150	10.551	10.229	10.104	9.929	9.681
	0.200	11.222	10.547	10.432	10.134	9.848
	0.250	11.998	11.044	10.877	10.646	10.218
	0.300	13.234	12.996	12.733	12.278	11.892

Table 2.
Ultrasonic velocity (u), Refractive index (n), Molar hydration no. (n_H) of systems at different temperature (K)

C ($mol.m^{-3}$) / T (K)	303.15	308.15	313.15	318.15	323.15
			u x10^{-2}(ms^{-1})		
System [i]					
0.050	12.540	12.378	12.030	11.623	11.448
0.100	12.795	12.580	12.300	12.085	12.008
0.150	13.050	12.620	12.433	12.130	12.075
0.200	13.563	13.275	13.095	13.058	12.598
0.250	13.818	13.430	13.415	13.278	13.090
0.300	13.860	13.565	13.545	13.398	13.288
System [ii]					
0.050	11.750	11.588	11.500	11.415	11.338
0.100	12.000	11.628	11.563	11.418	11.348
0.150	12.323	12.173	12.048	11.890	11.643
0.200	12.593	12.260	12.170	11.893	11.690
0.250	12.750	12.368	12.335	12.175	11.730
0.300	13.300	13.145	12.913	12.470	12.093
			n		
System [i]					
0.050	1.342	1.340	1.338	1.334	1.328
0.100	1.346	1.341	1.340	1.338	1.330
0.150	1.348	1.342	1.341	1.340	1.332
0.200	1.351	1.344	1.343	1.342	1.337
0.250	1.356	1.346	1.345	1.343	1.341
0.300	1.358	1.356	1.347	1.344	1.342
System [ii]					
0.050	1.349	1.349	1.348	1.348	1.347

0.100	1.352	1.351	1.351	1.350	1.349
0.150	1.355	1.355	1.354	1.353	1.352
0.200	1.358	1.358	1.357	1.356	1.355
0.250	1.361	1.361	1.360	1.359	1.358
0.300	1.364	1.364	1.363	1.362	1.361
			$n_H \times 10^3$		
System [i]					
0.050	-1.904	-2.051	-2.308	-2.652	-2.858
0.100	-3.080	-3.405	-3.765	-4.080	-4.233
0.150	-3.823	-4.509	-4.872	-5.457	-5.598
0.200	-3.456	-4.276	-4.675	-4.841	-5.743
0.250	-3.552	-4.447	-4.595	-4.951	-5.464
0.300	-3.656	-4.441	-4.649	-5.020	-5.489
System [ii]					
0.050	-2.446	-2.628	-2.712	-2.865	-2.971
0.100	-3.883	-4.512	-4.677	-4.974	-5.125
0.150	-4.603	-5.098	-5.370	-5.725	-6.277
0.200	-4.485	-5.524	-5.779	-6.438	-7.062
0.250	-4.652	-6.186	-6.484	-7.014	-8.243
0.300	-3.690	-4.160	-4.719	-5.762	-6.763

Table 3.

Thermal expansion coefficient (α), ($\alpha_{L\text{-}L}$), (α_{EYK}) of systems at different temperature (K)

C ($mol.m^{-3}$) / T (K)	303.15	308.15	313.15	318.15	323.15
			$\alpha x10^8$ (K^{-1})		
System [i]					
0.050	-1.023	-1.028	-1.030	-1.036	-1.046
0.100	-0.682	-0.686	-0.687	-0.690	-0.692
0.150	-0.525	-0.525	-0.527	-0.529	-0.530
0.200	-1.916	-1.974	-1.985	-1.997	-2.000
0.250	-1.529	-1.550	-1.560	-1.568	-1.581
0.300	-1.702	-1.723	-1.738	-1.743	-1.767
System [ii]					
0.050	-1.174	-1.180	-1.179	-1.196	-1.201
0.100	-1.205	-1.218	-1.224	-1.233	-1.234
0.150	-1.279	-1.303	-1.306	-1.311	-1.317
0.200	-2.369	-2.455	-2.463	-2.478	-2.506
0.250	-3.366	-3.547	-3.592	-3.623	-3.637
0.300	-0.551	-0.555	-0.556	-0.557	-0.558
			$\alpha_{L\text{-}L} x10^8$ (K^{-1})		
System [i]					

0.050	-1.039	-1.046	-1.053	-1.067	-1.091
0.100	-1.020	-1.037	-1.041	-1.048	-1.077
0.150	-1.011	-1.031	-1.035	-1.038	-1.068
0.200	-0.853	-0.873	-0.876	-0.879	-0.893
0.250	-0.918	-0.948	-0.951	-0.957	-0.964
0.300	-1.212	-1.220	-1.256	-1.269	-1.277
System [ii]					
0.050	-0.179	-0.179	-0.180	-0.180	-0.181
0.100	-0.196	-0.197	-0.197	-0.198	-0.198
0.150	-0.208	-0.208	-0.208	-0.209	-0.210
0.200	-0.205	-0.205	-0.205	-0.206	-0.207
0.250	-0.202	-0.202	-0.202	-0.203	-0.204
0.300	-0.199	-0.199	-0.200	-0.200	-0.201
			α_{EYK} x10^8(K^{-1})		
System [i]					
0.050	-1.090	-1.097	-1.104	-1.118	-1.140
0.100	-1.073	-1.089	-1.092	-1.099	-1.126
0.150	-1.064	-1.083	-1.086	-1.089	-1.118
0.200	-0.898	-0.917	-0.920	-0.923	-0.937
0.250	-0.967	-0.996	-0.999	-1.005	-1.012
0.300	-1.279	-1.286	-1.321	-1.333	-1.341
System [ii]					
0.050	-0.189	-0.189	-0.189	-0.189	-0.190
0.100	-0.207	-0.208	-0.208	-0.208	-0.209
0.150	-0.219	-0.219	-0.219	-0.220	-0.221
0.200	-0.216	-0.216	-0.217	-0.217	-0.218
0.250	-0.213	-0.213	-0.214	-0.214	-0.215
0.300	-0.210	-0.211	-0.211	-0.212	-0.212

Table 4.

Values of excess properties of systems at different temperature (K)

X_1	303.15	308.15	313.15	318.15	323.15
			V^E X 10^6 (m^3 mol^{-1})		
System [i]					
0.050	7.037	7.161	7.137	7.240	7.540
0.100	5.398	5.576	5.543	5.550	5.594
0.150	4.325	4.306	4.331	4.370	4.334
0.200	2.540	3.199	3.267	3.326	3.321
0.250	2.148	2.407	2.480	2.514	2.642
0.300	1.473	1.669	1.782	1.764	1.977
System [ii]					
0.050	6.983	7.162	7.041	7.441	7.543
0.100	5.167	5.481	5.565	5.683	5.678

0.150	3.821	4.307	4.296	4.321	4.396
0.200	1.982	2.636	2.658	2.707	2.902
0.250	1.002	1.955	2.149	2.245	2.288
0.300	0.013	0.098	0.096	0.054	0.043
		$R^E X10^6 (m^3 mol^{-1})$			
System [i]					
0.050	2.122	2.163	2.126	2.080	2.029
0.100	2.307	2.301	2.285	2.264	2.136
0.150	2.473	2.400	2.401	2.410	2.261
0.200	2.436	2.547	2.562	2.579	2.509
0.250	2.625	2.579	2.598	2.593	2.618
0.300	1.473	1.669	1.782	1.764	1.977
System [ii]					
0.050	2.164	2.257	2.224	2.321	2.349
0.100	2.358	2.465	2.488	2.525	2.527
0.150	2.451	2.617	2.617	2.622	2.646
0.200	2.887	3.133	3.144	3.162	3.229
0.250	2.589	2.938	3.007	3.041	3.057
0.300	2.304	2.359	2.363	2.353	2.353
		β_s^E x 10^{10} $(kg^{-1}ms^2)$			
System [i]					
0.050	4.382	5.061	5.904	6.939	7.529
0.100	3.870	4.612	5.327	6.006	6.347
0.150	3.456	4.379	4.981	5.770	6.055
0.200	2.595	3.495	4.064	4.502	5.236
0.250	2.319	3.184	3.585	4.108	4.557
0.300	2.141	2.898	3.319	3.827	4.225
System [ii]					
0.050	5.339	6.156	6.636	7.741	7.908
0.100	4.713	5.867	6.361	7.489	7.612
0.150	4.042	4.892	5.423	6.506	6.901
0.200	3.427	4.595	5.085	6.334	6.715
0.250	2.888	4.183	4.661	5.751	6.372
0.300	2.032	2.715	3.291	4.567	4.983
			n^E x 10		
System [i]					
0.050	1.518	2.910	4.035	5.187	5.810
0.100	1.558	2.920	4.055	5.227	5.835
0.150	1.578	2.930	4.065	5.247	5.850
0.200	1.608	2.950	4.085	5.267	5.905
0.250	1.658	2.970	4.105	5.277	5.945
0.300	1.678	3.070	4.125	5.287	5.955
System [ii]					
0.050	1.326	2.992	4.126	6.904	6.874
0.100	1.356	3.014	4.151	6.929	6.899

0.150	1.386	3.049	4.186	6.959	6.929
0.200	1.416	3.079	4.216	6.989	6.959
0.250	1.446	3.109	4.246	7.019	6.989
0.300	1.476	3.139	4.276	7.049	7.019
		L_f^E x 10^{11} ($kg^{-1/2}m^{1/2}s$)			
System [i]					
0.050	2.150	2.704	3.273	3.923	4.312
0.100	1.958	2.537	3.063	3.590	3.892
0.150	1.798	2.449	2.933	3.503	3.784
0.200	1.450	2.101	2.575	3.011	3.470
0.250	1.334	1.973	2.378	2.849	3.197
0.300	1.257	1.853	2.265	2.731	3.058
System [ii]					
0.050	2.437	3.091	3.528	4.541	4.634
0.100	2.217	2.990	3.433	4.455	4.532
0.150	1.971	2.641	3.097	4.105	4.280
0.200	1.736	2.530	2.971	4.041	4.212
0.250	1.522	2.373	2.809	3.822	4.086
0.300	1.162	1.773	2.252	3.349	3.545

Table 5.
Redlich- Kister coefficients for third order polynomial and standard deviation for excess properties for systems at different temperatures

	A_3	A_2	A_1	A_0	□
			303.15 K		
System [i]					
V_m^E x 10^4 (m^3 mol^{-1})	1.526	-0.264	-0.292	0.0853	0.0032
n^E	-0.148	0.092	0.048	0.1494	0.0011
R_m^E x 10^4 (m^3 mol-^{1})	-3.938	1.600	-0.161	0.0262	0.0022
β_s^Ex 10^8 ($kg^{-1}ms^2$)	2.284	-1.042	0.030	0.044	0.001
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s$)	9.588	-4.506	0.193	0.215	0.006
System [ii]					
V_m^E x 10^4 (m^3 mol^{-1})	0.000	-0.247	-0.323	0.0862	0.0020
n^E	0.000	0.000	0.060	0.1296	0.0000
R_m^E x 10^4 (m^3 mol-^{1})	-1.972	0.753	-0.047	0.0224	0.0015
β_s^Ex 10^8 ($kg^{-1}ms^2$)	-0.962	0.460	-0.190	0.062	0.001
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s$)	-4.226	1.811	-0.689	0.275	0.003
			308.15 K		
System [i]					
V_m^E x 10^4 (m^3 mol^{-1})	-0.625	0.766	-0.420	0.091	0.000
n^E	2.733	-1.087	0.150	0.286	0.001

R_m^E x 10^4 (m^3 mol-^{1})	-3.695	1.549	-0.164	0.027	0.001
β_s^Ex 10^8 ($kg^{-1}ms^2$)	2.007	-1.018	0.055	0.050	0.002
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s^{)}$	8.025	-4.165	0.259	0.266	0.007
System [ii]					
V_m^E x 10^4 (m^3 mol^{-1})	-0.00029	1.614	-0.531	0.0947	0.0031
n^E	-0.370	0.209	0.026	0.2973	0.0003
R_m^E x 10^4 (m^3 mol-^{1})	-3.600	1.510	-0.138	0.0263	0.0013
β_s^Ex 10^8 ($kg^{-1}ms^2$)	-3.136	1.386	-0.286	0.074	0.003
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s$)	-13.492	5.849	-1.126	0.356	0.012
		313.15 K			
System [i]					
V_m^E x 10^4 (m^3 mol^{-1})	-0.79067	0.85611	-0.429	0.091	0.000
n^E	0.14774	-0.04912	0.037	0.402	0.000
R_m^E x 10^4 (m^3 mol-^{1})	-3.36542	1.39828	-0.141	0.026	0.001
β_s^Ex 10^8 ($kg^{-1}ms^2$)	2.17192	-1.06862	0.038	0.059	0.002
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s^{)}$	8.79554	-4.46564	0.218	0.325	0.006
System [ii]					
V_m^E x 10^4 (m^3 mol^{-1})	-0.00032	1.66673	-0.520	0.0931	0.0039
n^E	-0.25926	0.13968	0.039	0.4103	0.0002
R_m^E x 10^4 (m^3 mol-^{1})	-3.74076	1.56380	-0.141	0.0261	0.0014
β_s^Ex 10^8 ($kg^{-1}ms^2$)	-2.57715	1.10855	-0.245	0.077	0.003
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s$)	-11.20195	4.73001	-0.964	0.394	0.011
		318.15 K			
System [i]					
V_m^E x 10^4 (m^3 mol^{-1})	-1.43876	1.19617	-0.483	0.094	0.0004
n^E	0.51709	-0.40719	0.127	0.513	0.000
R_m^E x 10^4 (m^3 mol-^{1})	-3.36643	1.37037	-0.130	0.025	0.0010
β_s^Ex 10^8 ($kg^{-1}ms^2$)	2.06837	-0.89964	-0.030	0.072	0.0031
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s^{)}$	8.78927	-4.06554	0.009	0.399	0.012
System [ii]					
V_m^E x 10^4 (m^3 mol^{-1})	-0.00048	2.59665	-0.692	0.1036	0.0041
n^E	-0.18519	0.11508	0.038	0.6882	0.0001
R_m^E x 10^4 (m^3 mol-^{1})	-4.16111	1.80368	-0.184	0.0287	0.0014
β_s^Ex 10^8 ($kg^{-1}ms^2$)	-2.22954	0.95190	-0.222	0.087	0.003
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s$)	-9.46804	3.96349	-0.851	0.491	0.010
		323.15 K			
System [i]					
V_m^E x 10^4 (m^3 mol^{-1})	-2.28519	1.82321	-0.615	0.102	0.0004
n^E	-1.95757	1.04649	-0.098	0.584	0.001
R_m^E x 10^4 (m^3 mol-^{1})	-3.40949	1.52024	-0.167	0.026	0.001
β_s^Ex 10^8 ($kg^{-1}ms^2$)	-0.52687	0.46928	-0.239	0.085	0.002
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s^{)}$	-1.08291	1.09881	-0.767	0.464	0.009

System [ii]					
V_m^E x 10^4 (m^3 mol^{-1})	-0.00058	3.08602	-0.758	0.1067	0.0034
n^E	-0.18519	0.11508	0.038	0.6852	0.0001
R_m^E x 10^4 (m^3 mol-^{1})	-4.46361	1.94518	-0.202	0.0295	0.0015
β_s^Ex 10^8 ($kg^{-1}ms^2$)	-3.85603	1.73926	-0.312	0.092	0.003
L_f^Ex 10^{10} ($kg^{-1/2}m^{1/2}s^{)}$	-15.20797	6.77639	-1.174	0.510	0.009

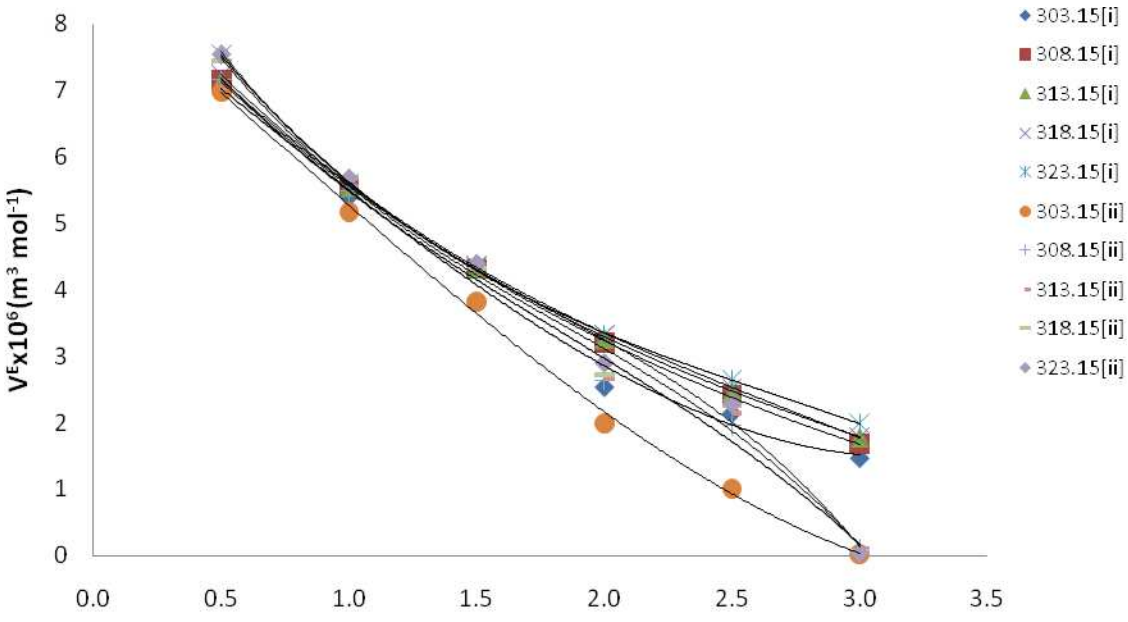

Fig 1 Variation of Excess Molar free Volume (V^E) with mole fraction (X_1) for system [i] and [ii] at 303.15, 308.15, 313.15, 318.15, 323.15 K

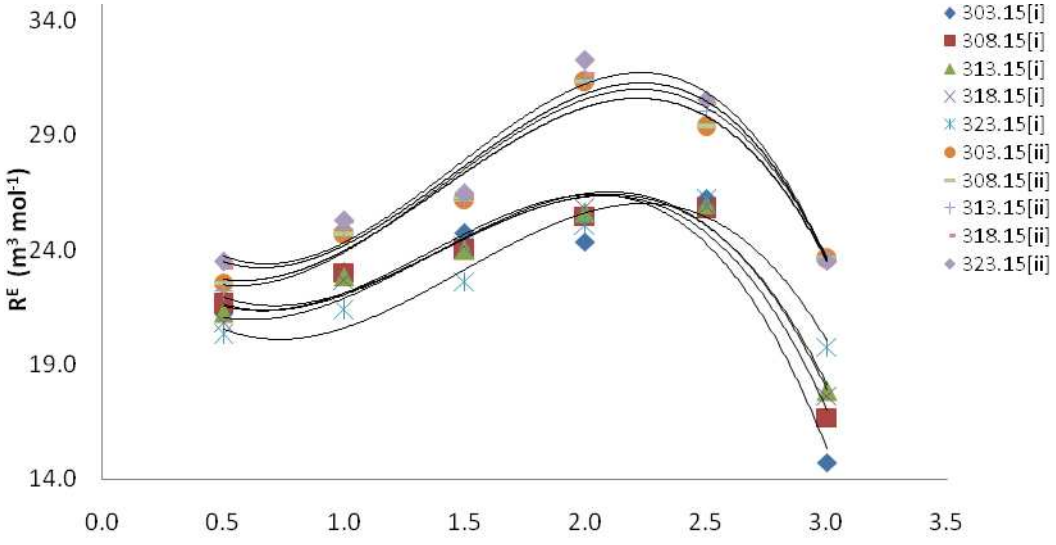

Fig 2 Variation of Excess free Molar refraction (R^E) with mole fraction (X_1) for system [i] and [ii] at 303.15, 308.15, 313.15, 318.15, 323.15 K

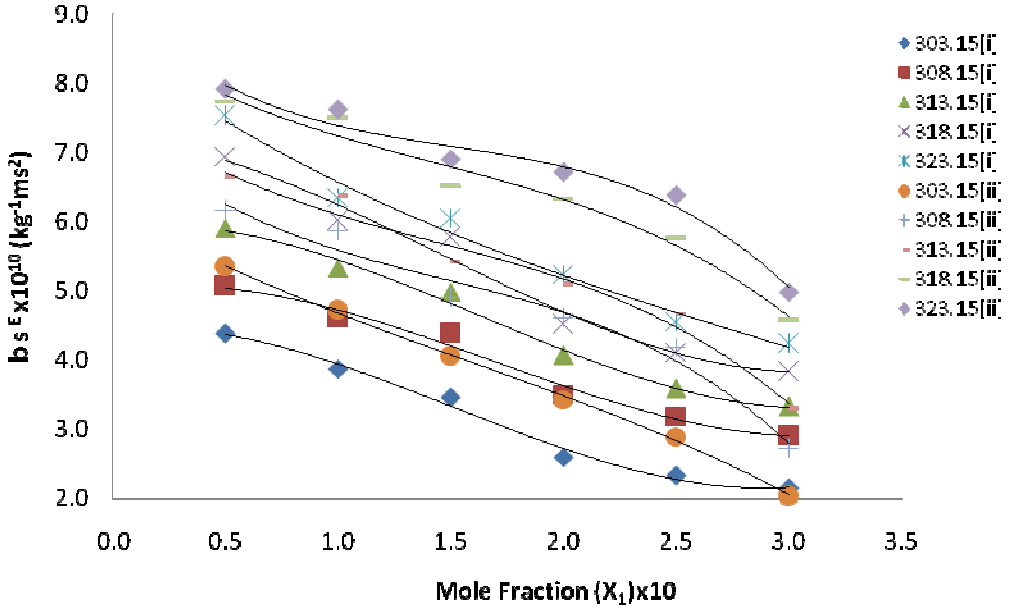

Fig 3 Variation of Excess adiabatic compressibility (bs^E) with mole fraction (X_1) for system [i] and [ii] at 303.15, 308.15, 313.15, 318.15, 323.15 K

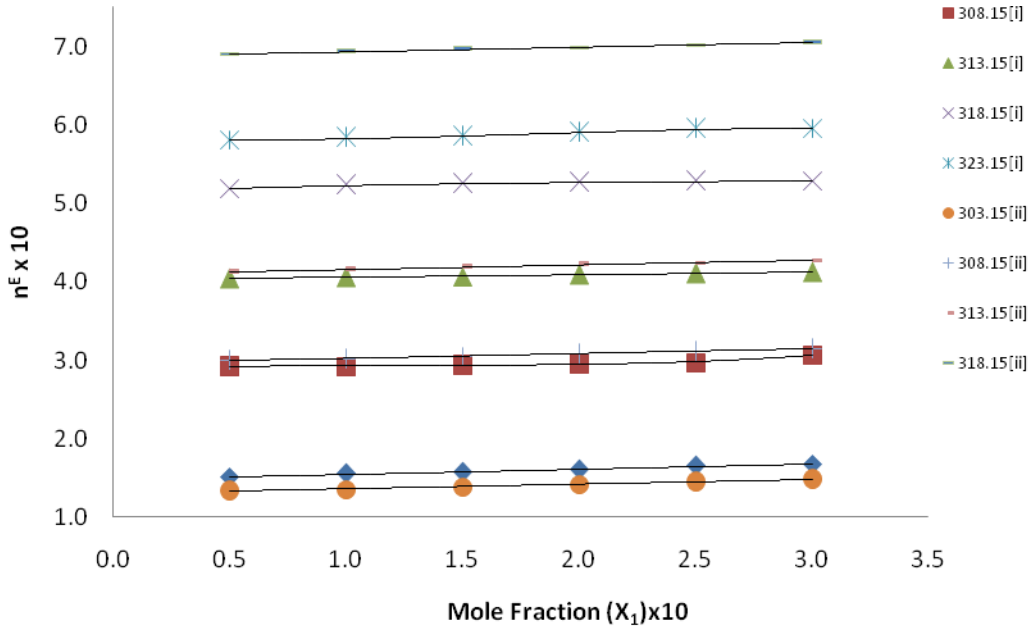

Fig 4 Variation of Excess refractiveIndex (n^E) with mole fraction (X_1) for system [i] and [ii] at 303.15, 308.15, 313.15, 318.15, 323.15 K

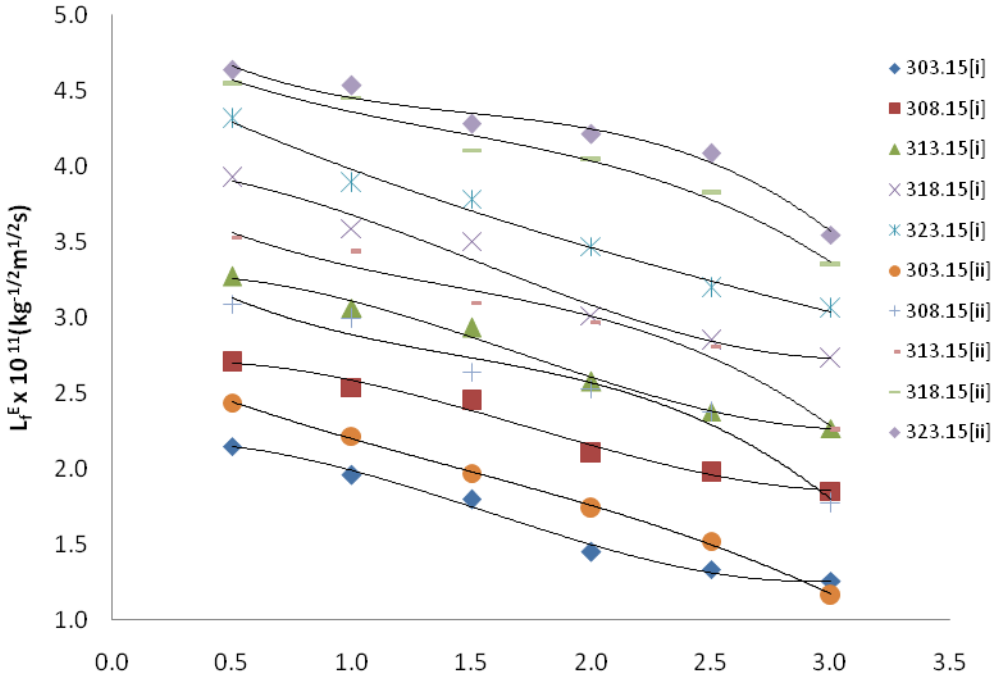

Fig 5 Variation of Excess free length (L_f^E) with mole fraction (X_1) for system [i] and [ii] at 303.15, 308.15, 313.15, 318.15, 323.15 K

Caption for Tables & Figures:

System (i) Curcumin + NaCl + Methanol, System (ii) Curcumin + $MgCl_2$ + Methanol, (X_1) is mole fraction of salt NaCl in System (i) and salt $MgCl_2$ in System (ii)