



# EXPERIMENTAL AND NUMERICAL INVESTIGATION ON THERMOPHYSICAL PROPERTIES OF HYDROCARBON LIQUID MIXTURES USING KRISHNAN-LADDHA AND JOUYBAN-ACREE MODELS AT VARIOUS TEMPERATURES

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## ABSTRACT

The thermophysical properties such as density and viscosity of binary liquid mixtures were determined experimentally over the entire composition range at 303.15K, 308.15K and 313.15K. The experimentally determined thermophysical properties of the binary liquid mixtures were used to calculate the excess molar volume  $V^E$  and viscosity deviations  $\Delta\eta$  with two hydrocarbons bromobenzene and ethylbenzene. The excess thermophysical properties of liquid mixtures provide additional information regarding molecular interactions. The calculated excess volumes,  $V^E$  and deviations in viscosities,  $\Delta\eta$  exhibited positive and negative values respectively over the whole range of composition in both binary systems. The Krishnan-Laddha and Jouyban-Acree Models were used to correlate deviations in viscosities,  $\Delta\eta$ , to derive the binary coefficients and standard deviations of these systems. The fitted outcomes and the calculated data clearly indicated that weak interactions present in two mixtures. It is mainly because of the number and position of methyl groups existing in these aromatic hydrocarbons. It can be concluded that the data found with the values fitted by the corresponding Krishnan-Laddha and Jouyban-Acree models gives high degree of precision.

**Keywords:** krishnan-laddha model, jouyban-acree model, viscosity measurement.

## INTRODUCTION

The quantitative viscosity and density data of liquid mixtures are required to solve many engineering problems, involve in chemical separations, heat transfer, mass transfer, and fluid flow. They are important from practical and theoretical points of view, especially for understanding liquid theory. The low polarity of 1,4Dioxane is interesting to be studied with hydrocarbon mixtures, for the type of interaction between the components of binary systems. 1, 4Dioxane commonly known as excellent aprotic solvent, has a zero dipole movement and cyclic ether that has an electron donor ability towards aromatic rings, it act like weak electron acceptors. 1, 4Dioxane is used as a stabilizer in aluminium containers and solvent in inks and adhesives. There are few reports on density and viscosity data of 1, 4 Dioxane with hydrocarbon mixtures (Martin, 2001 and Rameshet *al.*, 2014). In our earlier paper, we had studied thermo physical properties of binary systems (Ramesh *et al.*, 2014). In the present paper, it has been reported density ( $\rho$ ) and viscosity ( $\eta$ ) of pure 1, 4 Dioxane, Bromobenzene and Ethylbenzene for the binary system constituted by these two chemicals at entire range of composition and temperature 303.15K to 313.15K. With this data, the excess molar volume and deviation in viscosity have been computed. These results have been fitted to the Krishnan-Laddha and Jouyban-Acree models and polynomial equations. The Krishnan-Laddha and Jouyban-Acree models were used to correlate the viscosity and

deviations in viscosities,  $\Delta\eta$ . This analysis technique was used to derive the binary coefficients and estimate the standard deviation ( $\sigma$ ) between the experimental and calculated data (Redlich, 1948). The variation of these parameters with the composition and temperature of the mixtures has been discussed in terms of the molecular interactions in these mixtures. The effect of the number and position of the methyl groups in these aromatic hydrocarbons on molecular interactions in these mixtures has also been discussed. A literature search showed that no measurements have been previously reported by using Krishnan-Laddha and Jouyban-Acree models for the mixtures studied in this paper.

## EXPERIMENTAL SECTION

### Materials

Bromobenzene and Ethylbenzene were supplied by M/s E.Merck Ltd, with the stated purities better than 99 %, were stored over molecular sieves (0.3 nm). 1, 4 Dioxane with purity of 99% was provided by Sigma-Aldrich chemicals and it was used without further purification. To minimize the contact of these reagents with moist air, the products were kept in sealed bottles in a desiccator. The densities and viscosities of pure substances and experimental values comparison with literature values are listed in Table-1 (Martin, 2001; Ramesh *et al.*, 2014; Jouyban, 2005 and Redlich, 1948).

**Table-1.** Experimental densities and viscosities of pure liquids with literature values at 303.15K.

Component	$\rho$ (g·cm <sup>-3</sup> )		$\eta$ (m Pa. s)	
	Literature	Experimental	Literature	Experimental
1, 4 Dioxane	1.0222	1.0271	1.0985 <sup>2</sup>	1.0958
Bromobenzene	1.4815	1.4817	0.9850 <sup>3</sup>	1.0201
Ethylbenzene	0.8645	0.8662	0.5980 <sup>4</sup>	0.6020

### Apparatus and procedure

The measurements of density,  $\rho$ , and kinematic viscosity,  $\gamma$ , of pure liquids and their solutions were carried out using a Pycnometer, Oswald Viscometer and two integrated Pt 100 thermometers. The temperature in the cell was regulated to  $\pm 0.001$ K with a proportional temperature controller. The apparatus was first calibrated with triple distilled water. The uncertainties in density measurements were estimated to be  $0.002 \text{ kg}\cdot\text{m}^{-3}$ . The kinematic viscosities of the pure liquids and their mixtures were measured at 303.15K, 308.15K, and 313.15K. The viscometer was filled with liquid mixtures, and its limbs were closed with Teflon caps taking due precaution to reduce evaporation losses. An electronic digital stopwatch with a readability of 0.01s was used for flow time measurements. Experiments were repeated a minimum of four times for all compositions and the results were averaged. The caps of the limbs were removed during the measurement of flow times. The measured values of kinematic viscosity,  $\gamma$ , were converted to dynamic viscosity,  $\eta$ , after multiplication with density. The reproducibility of dynamic viscosity was found to be within  $0.003 \text{ mPa}\cdot\text{s}$ . A thermostatically controlled, well-stirred water bath, whose temperature was controlled to  $0.01$ K was used for all the measurements. Conductivity measurements were carried out in a jacket containing a conductivity cell of cell constant  $1.0 \text{ cm}^{-1}$ . Water was circulated in the jacket from thermostat, and the temperature maintained within  $\pm 0.01 \text{ K}$ , was used for all the measurements. The kinematic viscosity of solution  $\gamma$  is given by

$$\gamma = a(t) - (b/t) \quad (1)$$

$\gamma$  = kinematic viscosity,

$t$  = flow time,

$a$  = constant

$b$  = constant

The uncertainty for the dynamic viscosity determination is estimated to be  $\pm 0.5 \%$ .

### Standard deviation

It was calculated using the relationship.

$$\sigma = \sum \left( \frac{(V_{ex} - V_{ca})^2}{N-P} \right)^{\frac{1}{2}} \quad (2)$$

$N$  = Number of data points

$V_{ex}$  = Experimental Excess molar volume

$V_{ca}$  = Calculated Excess molar volume

$P$  = Number of coefficients

The calculated values of coefficients along with the standard deviations ( $\sigma$ ) are given in Tables 4 and 5. Interaction parameters as well as predicted kinematic viscosities and excess molar volume of Bromobenzene (Ramesh *et al.*, 2014; Jouyban, 2005; Senthil, 2004; Fabio, 2006; Francesconi, 2005; Redlich, 1948), Ethylbenzene (Ramesh, 2014; Jouyban, 2005 and Baskaran, 2007) and 1, 4 Dioxane mixture at 303.15K, 308.15K and 313.15K are presented in Tables 1 and 2.

### Nonlinear models

The calculated data of viscosity deviation,  $\Delta\eta$  of the binary mixtures 1, 4 Dioxane + Bromo Benzene and 1, 4 Dioxane + Ethyl Benzene were correlated with the composition data by the Jouyban-Acree equation. The size ratio of the two molecules should be less than 1.5.

$$\ln v_m = x_1 \ln v_1 + x_2 \ln v_2 + \left( \frac{x_1 x_2}{T} \right) \sum a_i (x_1 - x_2)^i \quad (3)$$

$v_m$  = viscosity of mixture,

$v_1$  = viscosity of component one,

$v_2$  = viscosity of component two,

$a_i$  = constant

The values of coefficients,  $a_i$ , were evaluated by using the method of least-squares with all points weighted equally. The coefficients and standard deviations of Jouyban-Acree model  $a_1$  to  $a_6$  of  $\Delta\eta$  for all temperatures of binary liquid mixtures as shown in Table-8, variations of  $\Delta\eta$  with mole fraction  $x_1$  of 1, 4 dioxane along with the smoothed  $\Delta\eta$  values calculated by using equation 6 at 303.15K to 313.15K.

The kinematic viscosity was correlated by means of the Krishnan-Laddha model for a two-component mixture, which gives

$$\begin{aligned} \ln &= x_1 \ln v_1 + x_2 \ln v_2 + x_1 \ln M_1 + x_2 \ln M_2 \\ &+ \ln(x_1 M_1 + x_2 M_2) \\ &- 2.30 x_1 x_2 (A + B(x_1 \\ &- x_2) \dots) \end{aligned} \quad (4)$$



$\nu$  = viscosity of mixture,  
 $\nu_1$  = kinematic viscosity of component one,  
 $\nu_2$  = kinematic viscosity of component two  
 $M_1$  = Molefraction of component one,  
 $M_2$  = Molefraction of component two

In equation (4), pure liquids mole fractions  $x_1$  and  $x_2$ , B and C are the interaction parameters. The parameters and standard deviations of Krishnan-Laddha model for mixtures are presented in Table 9.

## RESULTS AND DISCUSSIONS

The densities,  $\rho$  and viscosity,  $\eta$ , of pure liquids shown in Table-1 above, whereas the excess molar volumes,  $V^E$ , viscosity deviation,  $\Delta\eta$ , and predicted kinematic viscosities by Krishnan-Laddha and Jouyban-Acree models at various temperatures and atmospheric pressure are reported in Tables 2, 3, 4, 5, 6 and 7 and sign of excess volume, of a system depends on the relative

magnitude of expansion or contraction on mixing of two liquids.

The sign of excess volume of a system depends on the relative magnitude of expansion or contraction on mixing of two liquids. The variation of viscosity deviation,  $\Delta\eta$ , with the mole fraction of Bromobenzene +1, 4, Dioxane and Ethylbenzene +1, 4 Dioxane was studied at 303.15K to 313.15K. The obtained thermophysical data shows high degree of precision and it is given Krishnan-Laddha and Jouyban-Acree constants and minimum standard deviations, these are shown in Table-7 and Table-8. The excess molar volumes,  $V^E$ , dynamic viscosity,  $\eta$ , and molar refraction changes of mixing were calculated from experimental values using the following expressions and excess molar volumes shown in Figure-1 are calculated using equation 5.

$$V^E = v_M \sum_{i=1}^n X_i v_i \quad (5)$$

$v_M$  = molar volume of the mixture,

$v_i$  = Molar volume of components,

**Table-2.** Comparison of experimental densities, viscosities and predicted excess molar volume, kinematic viscosities by Krishnan-Laddha and Jouyban -Acree model for 1, 4 Dioxane + Bromobenzene at 303.15K.

$x_1$	Experimental properties				Predicted viscosity deviations		
	$\rho$ ( $g.cm^{-3}$ )	$\eta$ (mpa.s)	$V^E$ ( $cc.gmol^{-1}$ )	$\gamma_{\text{expt}}$ (c.s)	$\Delta\eta$ (K-L)	$\Delta\eta$ (J-A)	$\Delta\eta$
0.0000	1.4817	1.0201	0.0000	0.6863	0.0000	0.0000	0.0000
0.1047	1.4432	1.0255	0.7354	0.7106	-0.0001	-0.3328	-0.0073
0.2083	1.3962	1.0302	1.1127	0.7379	-0.0014	-0.3706	-0.0100
0.3109	1.3468	1.0333	1.5952	0.7672	-0.0025	-0.2909	-0.0133
0.4124	1.2965	1.0333	2.0647	0.7919	0.0037	-0.3057	-0.0210
0.5128	1.2496	1.0355	2.1888	0.8229	0.0066	-0.3563	-0.0260
0.6122	1.1999	1.0450	2.4288	0.8655	0.0016	-0.3385	-0.0237
0.7106	1.1578	1.0569	1.9581	0.9129	-0.0040	-0.2970	-0.0183
0.8080	1.1125	1.0688	1.6002	0.9607	-0.0051	-0.1593	-0.0145
0.9045	1.0698	1.0800	0.8876	1.0095	-0.0016	-0.1149	-0.0088
1.0000	1.0271	1.0958	0.0000	1.0669	0.0000	0.0000	0.0000



**Table-3.** Comparison of experimental densities, viscosities and predicted excess molar volume, kinematic viscosities by Krishnan -Laddha and Jouyban- Acree model for 1, 4 Dioxane + Bromobenzene at 308.15K.

$x_1$	Experimental properties				Predicted viscosity deviations		
	$\rho$ (g. cm <sup>-3</sup> )	$\eta$ (mpa. s)	$V^E$ (cc. gmol <sup>-1</sup> )	$\gamma_{\text{expt}}$ (c.s)	$\Delta\eta$ (K-L)	$\Delta\eta$ (J-A)	$\Delta\eta$
0.0000	1.4682	0.9815	0.0000	0.6685	0.0000	0.0000	0.0000
0.1047	1.4267	0.9785	0.5469	0.6859	0.0002	-0.0001	-0.0059
0.2083	1.3819	0.9795	0.7984	0.7091	-0.0021	-0.0002	-0.0079
0.3109	1.3356	0.9886	1.2546	0.7349	-0.0038	-0.0012	-0.0099
0.4124	1.2826	0.9875	1.6914	0.7570	0.0011	-0.0016	-0.0156
0.5128	1.2373	0.9735	1.8053	0.7808	0.0072	-0.0059	-0.0197
0.6122	1.1899	0.9555	1.9880	0.8787	-0.0577	-0.0130	-0.0184
0.7106	1.1499	0.9589	1.4459	0.8818	-0.0244	-0.0207	-0.0141
0.8080	1.1036	0.9705	1.2838	0.9011	-0.0035	-0.0242	-0.0105
0.9045	1.0596	0.9717	0.7805	0.9445	-0.0021	-0.0300	-0.0061
1.0000	1.0169	1.0094	0.0000	0.9927	0.0000	0.0000	0.0000

**Table-4.** Comparison of experimental densities, viscosities and predicted excess molar volume, kinematic viscosities by Krishnan -Laddha and Jouyban -Acree model for 1, 4 Dioxane + Bromobenzene at 313.15 K.

$x_1$	Experimental properties				Predicted viscosity deviations		
	$\rho$ (g. cm <sup>-3</sup> )	$\eta$ (mpa. s)	$V^E$ (cc. gmol <sup>-1</sup> )	$\gamma_{\text{expt}}$ (c.s)	$\Delta\eta$ (K-L)	$\Delta\eta$ (J-A)	$\Delta\eta$
0.0000	1.4549	0.9550	0.0000	0.6564	0.0000	0.0000	0.0000
0.1047	1.4129	0.9429	0.2930	0.6700	0.0043	-0.0030	-0.0067
0.2083	1.3698	0.9489	0.5855	0.6980	-0.0050	-0.0167	-0.0223
0.3109	1.3256	0.9480	0.8719	0.7182	-0.0056	-0.1871	-0.0502
0.4124	1.2775	0.9467	1.3704	0.7411	-0.0078	-0.1549	-0.0776
0.5128	1.2308	0.9370	1.6700	0.7613	-0.0057	-0.2191	-0.0910
0.6122	1.1873	0.9162	1.7245	0.7746	0.0057	-0.2086	-0.0986
0.7106	1.1467	0.9011	1.1760	0.7958	0.0127	-0.1191	-0.1142
0.8080	1.1026	0.9203	0.8960	0.8457	-0.0038	-0.0648	-0.1208
0.9045	1.0568	0.9145	0.6064	0.8757	0.0067	-0.0807	-0.0737
1.0000	1.0128	0.9447	0.0000	0.9327	0.0000	0.0000	0.0000



**Table-5.** Comparison of experimental densities, viscosities and kinematic viscosities by Krishnan-Laddha and Jouyban-Acree model for 1, 4 Dioxane + Ethylbenzene at 303.15K.

$x_1$	Experimental Properties				Predicted viscosity deviations		
	$\rho$ ( $g \cdot cm^{-3}$ )	$\eta$ (mpa.s)	$V^E$ ( $cc \cdot gmol^{-1}$ )	$\gamma_{expt}$ (c.s)	$\Delta\eta$ (K-L)	$\Delta\eta$ (J-A)	$\Delta\eta$
0.0000	0.8662	0.6020	0.0000	0.7042	0.0000	0.0000	0.0000
0.1047	0.9068	0.6514	0.7737	0.7193	0.0030	-0.3327	-0.0340
0.2083	0.9135	0.6663	1.1728	0.7298	0.0032	-0.3549	-0.0624
0.3109	0.9218	0.6934	1.4122	0.7522	-0.0084	-0.2674	-0.0858
0.4124	0.9301	0.7161	1.6919	0.7689	-0.0090	-0.2753	-0.1123
0.5128	0.9399	0.7489	1.8462	0.7924	-0.0073	-0.3199	-0.1251
0.6122	0.9534	0.7925	1.6595	0.8302	-0.0087	-0.2979	-0.1224
0.7106	0.9687	0.839	1.3748	0.8677	0.0022	-0.2472	-0.1203
0.8080	0.9876	0.8986	0.8473	0.9236	0.0059	-0.2948	-0.1151
0.9045	1.0069	0.9711	0.4005	0.9722	0.0250	-0.2541	-0.0693
1.0000	1.0271	1.0958	0.0000	1.0669	0.0000	0.0000	0.0000

**Table-6.** Comparison of experimental densities, viscosities and kinematic viscosities by Krishnan-Laddha and Jouyban-Acree model for 1, 4 Dioxane + Ethylbenzene at 308.15K.

$x_1$	Experimental properties				Predicted viscosity deviations		
	$\rho$ ( $g \cdot cm^{-3}$ )	$\eta$ (mpa.s)	$V^E$ ( $cc \cdot gmol^{-1}$ )	$\gamma_{expt}$ (c.s)	$\Delta\eta$ (K-L)	$\Delta\eta$ (J-A)	$\Delta\eta$
0.0000	0.8595	0.5893	0.0000	0.6855	0.0000	0.0000	0.0000
0.1047	0.8948	0.6220	0.6049	0.6951	0.0054	-0.0027	-0.0311
0.2083	0.9030	0.6399	0.8638	0.7086	0.0012	-0.0068	-0.0498
0.3109	0.9118	0.6665	1.0935	0.7310	-0.0122	-0.0001	-0.0671
0.4124	0.9207	0.6844	1.3569	0.7433	-0.0119	-0.0079	-0.0938
0.5128	0.9310	0.7073	1.5074	0.7597	-0.0089	-0.0042	-0.1092
0.6122	0.9445	0.7421	1.3707	0.7857	-0.0068	-0.0100	-0.1083
0.7106	0.9602	0.7874	1.0924	0.8200	-0.0029	-0.0088	-0.1084
0.8080	0.9786	0.8440	0.6535	0.8625	0.0035	-0.0185	-0.1083
0.9045	0.9976	0.8858	0.2810	0.8879	0.0372	-0.0059	-0.0681
1.0000	1.0169	1.0095	0.0000	0.9927	0.0000	0.0000	0.0000



**Table-7.** Comparison of experimental densities, viscosities and kinematic viscosities by Krishnan-Laddha and Jouyban - Acree model for 1, 4 Dioxane + Ethylbenzene at 313.15K.

$x_1$	Experimental Properties				Predicted viscosity deviations		
	$\rho$ ( $g \cdot cm^{-3}$ )	$\eta$ (mpa.s)	$V^E$ ( $cc \cdot gmol^{-1}$ )	$\gamma_{expt}$ (c.s)	$\Delta\eta$ (K-L)	$\Delta\eta$ (J-A)	$\Delta\eta$
0.0000	0.8519	0.5699	0.0000	0.6690	0.0000	0.0000	0.0000
0.1047	0.8615	0.5957	0.3975	1.0437	-0.3587	-0.3625	-0.0142
0.2083	0.8725	0.6161	0.6663	1.0990	-0.4044	-0.4080	-0.0301
0.3109	0.8845	0.6379	0.8803	0.9172	-0.2146	-0.2072	-0.0480
0.4124	0.8974	0.6600	1.0629	0.9061	-0.1930	-0.1795	-0.0678
0.5128	0.9120	0.6808	1.1312	0.9895	-0.2606	-0.2484	-0.0814
0.6122	0.9300	0.7068	0.9261	0.9905	-0.2384	-0.2298	-0.0894
0.7106	0.9498	0.7379	0.6624	0.9199	-0.1360	-0.1314	-0.0974
0.8080	0.9712	0.7814	0.3894	0.9138	-0.0889	-0.1039	-0.0942
0.9045	0.9935	0.8539	0.1881	0.9581	-0.0831	-0.1126	-0.0538
1.0000	1.0128	0.9446	0.0000	0.9327	0.0000	0.0000	0.0000

**Table-8.** Parameters of studied Jouyban-Acree nonlinear model, constants and standard deviations ( $\sigma$ ) of 1, 4 Dioxane + Bromobenzene, 1, 4 Dioxane + Ethylbenzene at 303.15K, 308.15K and 313.15K.

Jouyban-Acree constants	1, 4 Dioxane + Bromobenzene			1,4Dioxane + Ethylbenzene		
	(Viscosity deviation)			(Viscosity deviation)		
	Temperature			Temperature		
	303.15K	308.15K	313.15K	303.15K	308.15K	313.15K
$a_1$	11694	331.1	-6087.9	11694	1301.3	-6087.9
$a_2$	- 2606.2	-30.75	3534.4	- 2606.2	429.78	3534.4
$a_3$	- 13119	- 424.2	6983.1	- 13119	- 1570.8	6983.1
$a_4$	2844.8	35.53	- 3818.1	2844.8	- 449.84	- 3818.1
$a_5$	2156.3	150.1	-1164.5	2156.3	383.34	-1164.5
$a_6$	- 229.06	-4.764	266.98	- 229.06	16.199	266.98
$a_7$	- 738.22	- 56.97	271.41	- 738.22	- 114.88	271.41
Standard deviations : $\sigma$	0.3326	0.2349	0.2013	0.4438	0.3876	0.2901

**Table-9.** Parameters of studied Krishnan-Laddha model, constants and standard deviations ( $\sigma$ ) of 1, 4 Dioxane + Bromobenzene, 1, 4 Dioxane + Ethylbenzene at 303.15K, 308.15K and 313.15K.

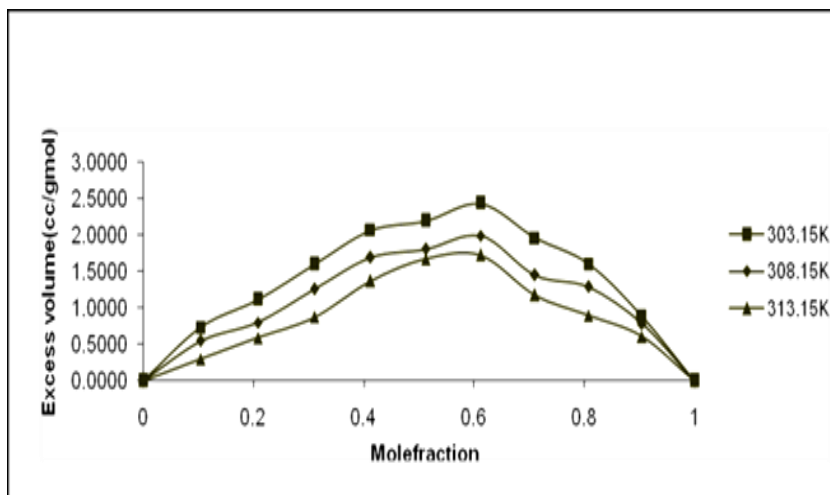
Krishnan – Laddha constants	1, 4 Dioxane + Bromobenzene			1,4Dioxane + Ethylbenzene		
	(Viscosity deviation)			(Viscosity deviation)		
	Temperature			Temperature		
	303.15K	308.15K	313.15K	303.15K	308.15K	313.15K
$a_1$	-0.0035	0.0057	0.0135	-0.1074	-0.0668	-0.0619
$a_2$	-0.0013	-0.0142	0.0264	0.0367	0.0617	0.0696
$a_3$	-0.0084	-0.0057	-0.0042	0.1729	0.1628	0.1379
Standard deviations : $\sigma$	0.0575	0.0583	0.0028	0.0131	0.0352	0.0417



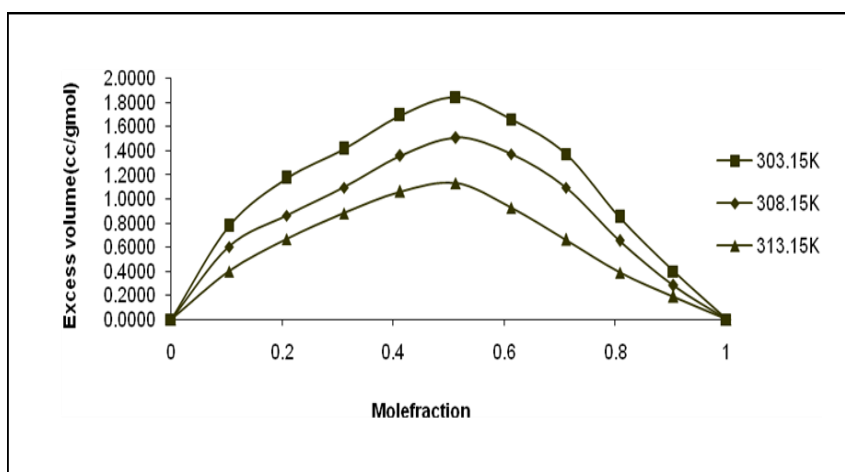
The variation of excess volumes with the mole fraction of Bromobenzene and Ethylbenzene with 1, 4 Dioxane at 303.15K, 308.15K and 313.15 K is represented in Figure-1 and Figure-2.

The sign of excess volume of a system depends on the relative magnitude of expansion/contraction on mixing of two liquids. If the factors causing expansion dominate the contraction factors, the ( $V^E$ ) becomes

positive. On the other hand, if the contraction factors dominate the expansion factors, then  $V^E$  become negative. The factors that are responsible for expansion in volume are as follows, i. Loss of dipolar association, ii. The geometry of molecular structure, which does not allow fitting of one component into other component, iii. Steric hindrance opposes proximity of the constituent molecules.



**Figure 1.** Excess molar volume ( $V^E$ ) for 1, 4 Dioxane + Bromobenzene at 303.15K, 308.15K and 313.15 K.



**Figure-2.** Excess molar volume ( $V^E$ ) for 1, 4 Dioxane + Ethylbenzene at 303.15K, 308.15K and 313.15 K.

The negative  $V^E$  values arise due to dominance of the following factors. i. Chemical interaction between constituent chemicals. ii. Accommodation of molecules of one component into the interstitials of the molecules of the other component (Fabio, 2006; Francesconi, 2005 and Senthil Raja, 2004). iii. Geometry of the molecular structure that favors fitting of the component molecules with each other (Francesconi, 2005; Hiannie, 2005).

The negative  $V^E$  values in the mixtures under study indicate that interactions between molecules of the

mixtures are stronger than interactions between molecules in the pure liquids and that associative force dominate the behaviour of the solution.

$$\Delta\eta = \eta - \sum_{i=1}^n X_i \eta_i \quad (6)$$

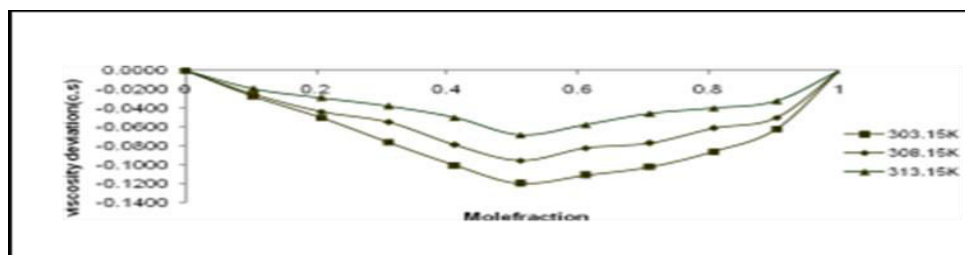
Where, ( $\Delta\eta$ ) is the viscosity deviation of the mixture,  $\eta$  is the dynamic viscosity.



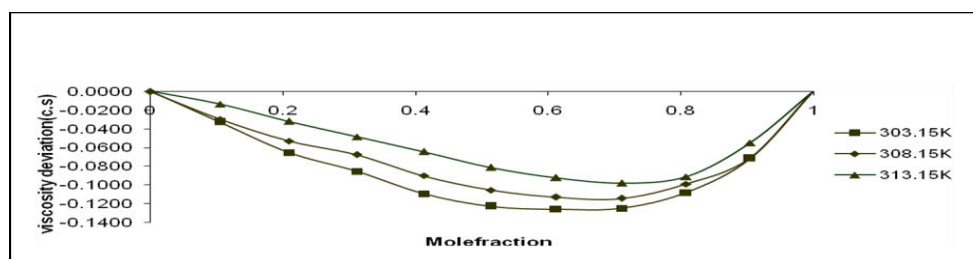


The results of variation in viscosity deviations of binary systems consisting of Bromobenzene and Ethylbenzene with 1, 4 Dioxane at temperatures of

303.15K, 308.15K, and 313.15K are represented in Figure 3 and 4.



**Figure-3.** Deviation in viscosity ( $\Delta\eta$ ) for 1,4 Dioxane + Bromobenzene at 303.15K, 308.15K and 313.15 K.



**Figure-4.** Deviation in viscosity ( $\Delta\eta$ ) for 1,4 Dioxane + Ethylbenzene at 303.15K, 308.15K and 313.15 K.

This result shows negative deviations (Senthil Raja, 2004, Baskaran, 2007) over the entire range of mole fraction. The viscosity of the mixture strongly depends on the entropy of mixture, which is related with liquid's structure and enthalpy. It will consequently with molecular interactions between the components of the mixtures. Therefore the viscosity deviation depends on molecular interactions as well as on the size and shape of the molecules.

## CONCLUSIONS

In this research, Viscosities ( $\eta$ ) and densities ( $\rho$ ) for the binary liquid mixture of 1, 4 Dioxane + Bromobenzene + Ethylbenzene system was found out as a function of mole fraction at atmospheric pressure and at temperatures of 303.15K, 308.15K, and 313.15K. The excess values of the mixtures show a systematic change with increasing temperature. With an increase in temperature the intermolecular interactions between molecules become weak. 1, 4 Dioxane is repulse towards the Bromine group in bromobenzene and it forms dipole-dipole bond. In this case, the force between unlike molecules is lesser than the force between like molecules in mixtures. Inductive effect of ethyl group in ethyl benzene is donating electron, due to this Ethyl group becomes slightly positive and at the same time phenyl group becomes negative, this makes the compound to feebly dipolar. In this case, the force between unlike molecules is lesser than the force between like molecules in mixtures. It can be concluded that the positive excess

molar volumes and negative deviations viscosity due to weak molecular interactions in mixtures. Viscosity and density of the binary mixture and the Krishnan-Laddha and Jouyban-Acree is very well suited for correlating Kinematic viscosity of the binary mixture with minimum standard deviation in current study and it is far superior to the other predictive models

## REFERENCES

- Martin Contreras S. 2001. Densities and Viscosities of Binary Mixtures of 1, 4-Dioxane with 1-Propanol and 2-Propanol at (25, 30, 35, and 40) °C. Journal of Chemical Engineering Data. 46, 1149 - 1152.
- Ramesh, R., Hisyam A. and Ramesh K. 2014. Measurement and Prediction of Thermo Physical Properties of Binary Liquid Mixtures at Various Temperatures Using McAllister Model. International Journal of Engineering and Science. 3, 68-74
- Jouyban, A., Khoubnasabjafari, M., Vaezgharamaleki, Z., Fekari, Z. and Jr. Acree, W.E. 2005. Calculation of the viscosity of binary liquid mixture at various temperatures using Jouyban-Acree model, Chemical and Pharmaceutical Bulletin. 53, 519-523.





Redlich, O. and Kister, A.T. 1948. Algebraic representation of thermodynamic properties and the classification of solutions, *Ind. Eng. Chem*, 40, 345-349

Vadamalar, R., Mani, D., and BalaKrishnan. 2011. Ultrasonic Study of Binary Liquid Mixtures of Methyl Methacrylate with Alcohols, *Res. J. Chem. Sci.* 1(9), 79-82

Senthil Raja S. and Kubendran T. R. 2004. Viscosities and Densities of Binary Mixtures of 1, 4-Dioxane, Carbon Tetrachloride, and Butanol at 303.15K, 308.15K, and 313.15K *Journal of Chemical Engineering Data.* 49, 421-425.

Baskaran, R. and Kubendran, T. R. 2007. Intermolecular Interactions in Binary Liquid Mixtures, Of Anisaldehyde with Nitrobenzene and Ethyl Benzene by Ultrasonic Measurements at (303.15, 313.15 and 313.15) K, *Chemical Physics Research Journal.* 2, 1-14.

Comelli, F., Francesconi, R., Bigi, A. and Rubini, K. 2006. Excess Molar Enthalpies, Molar Heat Capacities, Densities, Viscosities, and Refractive Indices of Dimethyl Sulfoxide + Esters of Carbonic Acid at 308.15 K and Atmospheric Pressure *Journal of Chemical Engineering Data.* 51, 665-670.

Francesconi, R., Bigi, A., Rubini, K. and Comelli, F. 2005. Excess enthalpies, heat Capacities, densities, viscosities, and refractive indices of dimethyl sulfoxide + three aryl alcohols at 308.14 K and atmospheric pressure. *Journal of Chemical Engineering Data*, 50, 1932-1937.

Hiannie, D. and Suryadi, I. 2005. Density and viscosity of several aldehydes fragrance compounds in their binary mixtures with ethanol at 298.15, 308.15 and 318.15 K. *Journal of Chemical Engineering Data*, 50, 2003-2007.

Senthil Raja, S. and Kubendran, T. R. 2004. Viscosities and Densities of Binary Mixtures of 1, 4 Dioxane, Carbon Tetrachloride, and Butanol at 303.15K, 308.15K, and 313.15K *Journal of Chemical Engineering Data*, 49, 421-425.

Ramesh, R., Hisyam, A., Sulaiman, A. Z. and Ramesh, K. 2014. Measurement and Prediction of Thermo Physical Properties of Binary Liquid Mixtures at Various Temperatures Using Redlich-Kister Model, *Chemical Engineering and Science.* 2(2) 18-23.