Thermodynamic Study of Properties in Certain Binary Liquid Mixtures Containing Anisole with 2-Butoxyethanol at Different Temperatures (303.15K to 318.15K)

P. Mahesh, M. Bonju Babu, K. Poornima, K. Samatha

***Abstract:** Comprehensive experimental investigations were carried out on density (ρ), viscosity (η), and ultrasonic velocity (u) for binary mixtures comprising Anisole and 2-Butoxyethanol within the temperature range of 303.15K to 318.15K, covering the complete range of mole fractions. These parameters were measured at intervals of 5K. Derived excess parameters, including acoustic impedance (Z^E), intermolecular free length ($L^E{}_f$), molar volume ($V^E{}_m$), excess ultrasonic velocity (u^E), and excess viscosity (η^E), were calculated to probe the molecular interactions present in the mixture. These excess parameters were correlated with temperature and mole fraction, revealing the complexity and nature of intermolecular interactions. Notably, the Arrhenius, Bingham, Eyring, Grunberg, Kurata, Nissan, and Tamura models were utilized to theoretically validate the acquired empirical data. This study aims to offer invaluable insights into the thermodynamics and molecular dynamics that govern these binary liquid mixtures*

***Keywords:** Viscosity, Density, Ultrasonic Velocity, Excess Parameters, Molecular Interaction*

I. INTRODUCTION

Density (ρ), ultrasonic velocity (u), and viscosity (η) are critical physicochemical properties of liquid mixtures that play a crucial role in various industrial processes. Their relevance extends to optimizing energy efficiency in chemical reactions and is essential for processes such as ion-exchange systems, organic synthesis, and mass-transfer operations involving solvents and adsorbates.

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Understanding the excess thermodynamic properties and transport phenomena in binary liquid mixtures can yield critical insights into molecular-level interactions and the architecture of liquid structures [1]. In the industrial context, the utility of 1-isobutane is especially noteworthy, given its role as an alkylating catalyst in organic reactions. Aromatic hydrocarbons also serve as potent organic solvents in various processes and are particularly instrumental in fuel applications where they act as octane boosters [2]. The behavior of excess properties, such as excess viscosity (η^E) and deviations in molar volume ($V^E{}_m$), can provide vital clues about various kinds of molecular interactions. These excess parameters can be used as indicators to understand molecular mobility, structural packing, and the range and strength of molecular forces in binary mixtures. Factors like the shape, size, and chemical characteristics of the component molecules play a significant role in these interactions [3–5]. In light of the industrial applicability and scientific relevance, the current study focuses on the binary mixture of Anisole and 2-Butoxyethanol, examining its behavior across temperatures ranging from 303.15K to 318.15K at atmospheric pressure. This investigation explores key excess parameters, namely density, ultrasonic velocity, and viscosity, to provide a nuanced understanding of the underlying molecular interactions. For a comprehensive analysis, we have referenced well-established models such as Arrhenius, Bingham, Eyring, Grunberg, Kurata, Nissan, and Tamura to corroborate our experimental findings.

II. MATERIALS AND METHODS

Analytical grade reagents of Anisole, 2-Butoxyethanol (purity > 99%) were procured from SD Fine Chemicals Ltd, Mumbai, India, which were used to prepare the binary mixtures the mole percentage purity of these mixtures was determined adopting Gas Chromatography method (HP 6890) using the FID detector and are reported in Table 1 in the results section. Obtained values are compared with density, velocity and viscosity data measured at the temperature 308.15 K for pure Anisole and 2-Butoxyethanol (2-BE) values already published in the literature. Specially designed conical flasks were used to prepare the binary mixtures of 2-Butoxyethanol and Anisole a digital electronic balance.

(Mettler, AE 240, Switzerland) was used to measure the mass of the binary mixtures of different proportions of 2-Butoxyethanol and anisole to an accuracy of 0.01mg five different compositions of binary mixtures were prepared wherein, the proportions of 2-Butoxyethanol and anisole were taken in the ratio of 1:0, 5:1, 2:1, 1:1, 1:2, 1:5, and 0:1. Physical properties of the obtained mixtures were measured for the seven proportions of 2-Butoxyethanol and anisole on the mole fraction scale from 0.23 to 0.88 with an interval of 0.1 unit and remaining mixture ratio first one and last one is pure components, The uncertainty in measured values of the mole fraction was less than 0.0002 units. Density (ρ), ultrasonic velocity (u) and viscosity (η) of binary mixtures in complete range of composition were measured at different temperatures 303.15 K to 318.15 K with an interval of 5K in a thermo-stated water bath consisting of an accuracy of ± 0.1 K, setting the temperature at the required level. Densities of different composition binary mixtures were measured with capillary Pycnometer having bulb volume 5 cm^3 and internal capillary diameter 0.75 mm. The accuracy of density measurements was ±0.2% and the uncertainty was found to be ± $5x10^{-5}$ gcm^{-3}. A 10 ml. capacity specific gravity bottle with ±0.001 g/cm^3 accuracy was used in the measurements. Viscosity was measured using Ostwald's viscometer having an accuracy of 0.001 $Ns.m^{-2}$.

Table- I: Comparison of Experimental and literatures values of densities (ρ) and ultrasonic velocities (u) and viscosity of pure liquids with literature at 308.15 K.

Liquid	Density(ρ) x 10^{-3} Kg m^{-3}		Ultrasonic Velocity (u) $m.s^{-1}$		Viscosity(η) x 10^{-3} $Ns.m^2$	
	EXP	LIT	EXP	LIT	EXP	LIT
Anisole	979.74	979.73[6]	1369.94	1368.00[7]	0.906	0.854[6]
2-Butoxyethanol	891.13	888.70[8]	1276.21	1275.10[9]	2.418	2.287[10]

III. CALCULATIONS

Following are the equations 1, 2 and 3 which were used to calculate the ultrasonic velocity (u) density (ρ) and viscosity(η) the different acoustical parameters namely acoustic impedance (Z), inter molecular free length (L_f) and molar volume (V_m).

$$Z = U\rho \text{ Kg m}^{-2}\text{s}^{-1} \quad \ldots\ldots (1)$$

$$L_f = KT(\beta ad)^{1/2} m \quad \ldots\ldots (2)$$

where 'K ' refers to Jacobson's constant.

$$V_m = \left(\frac{M}{\rho}\right) m^3 mol^{-1} \quad \ldots\ldots (3)$$

The results were presented in the table-2 of the results' section. The excess functions Y^E were computed using the equation:

$$Y^E = Y_{mix} - (X_1Y_1 + X_2Y_2)$$

Where Y indicates u, Z, V_m and L_f commonly, X is the mole fraction and suffixes 1 & 2 represent the components 1 & 2 in binary mixture are shown in Table-3.

IV. RESULTS AND DISCUSSION

From the Table 2, it is clear that the values of u, Z, L_f varied with the mole fraction of anisole. This indicates the presence of interactions between the components in these binary liquid mixtures. The variations of ultrasonic velocity for the mixtures depend on the values of L_f, it is observed that, increase in ultrasonic velocity and the corresponding increase in L_f with mole fraction of anisole (Table 2) for all the systems are in accordance with the view proposed by Eyring and Kincaid [11]. However, the excess functions which are a measure of the deviations from the ideal behaviour are relatively more sensitive to the intermolecular interactions between the unlike molecules of the mixture than the pure acoustical parameters as explained above.

The positive deviations in u^E and Z^E (Figs. 1 and 3) for all the systems (Anisole + 2-Butoxyethanol) are find out the compete ranch. This tendency in this series towards encouragement in the view, that these combinations among unlike molecules are serene achievable. In common, the general media is compact, the ultrasonic velocity estimate will be high and if when it is minor compacted, the ultra-sonic velocity can be low. When the combinations of two liquids mix together by condensing or supressed high the ultra-sonic velocity range may be positive [12]. From the figure 2.1 it is conveyed that u^E range are in acceptance in among the temperatures. It modifies that the mixtures are approval high and, it is in general to get favourable surplus ultrasonic velocity. In the figure 2.3, excess acoustic impedance (Z^E) by composition of fluid minerals displays approval deviations according to the analogy 1. A common attention was monitored by Eswari Bai et al [13], Vijaya lakshmi et al [14] and Sastry et al [15].

In the figures 2.2,2.4, and 2.5 ηE, L^E and V_m^E in negative in all the systems above the whole mole fractions range. In general, these three values ηE, L^E and V_m^E are dependable.

(i) The corelated disruption of related present in the pure liquids, stated by Jacobson [16]

(ii) Creation of weak H- bonding by dipole-induced dipole interaction between unlike molecules.

(iii) Geometrical complex fitting creation among the component molecules [17].

In advance it is monitored from the observational end results that the negative amalgamation increases in the chain length of 2-Butoxyethanol. This shift in magnitude of negative range of ηE, L^E and V_m^E from the above homologue's components. This data provokes that the vigour of deferent formations among the chemicals. From this epilogue is stated by Fort and Moore [18], Mahendran Roy [19], Douhéreta [20] and Sastry et al [21].

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Table- II: Values of Density (ρ), ultrasonic velocity (u), viscosity(η), acoustic impedance (Z), Inter molecular free length (L_f) for the binary liquid mixtures of anisole with 2-Alkoxy Ethanol's at 303.15K to 318.15K

Mole fraction of Anisole	$\rho \times 10^{-3}$ Kg m^{-3}	u $m.s^{-1}$	Z x 10^{-4} $Kg.m^2s^{-1}$	η x 10^{-3} $Ns.m^2$	$L_f \times 10^{12}$ m	$V_m \times 10^{-5}$ m^3/mol^{-1}
Anisole + 2-Butoxy Ethanol (2BE) at 303.15 K						
0	895.38	1295.39	1.6214	2.741	4.9031	106.7178
0.2386	915.24	1316.84	1.5881	2.356	4.9614	102.1742
0.4396	933.17	1335.34	1.544	2.014	5.0128	99.2587
0.6105	948.47	1350.67	1.4951	1.708	5.0595	96.5114
0.7581	961.82	1364.19	1.4411	1.428	5.1025	93.7412
0.8868	973.54	1377.95	1.3764	1.178	5.1402	91.1751
1	984.46	1390.13	1.2978	0.971	5.171	88.8471
Anisole + 2-Butoxy Ethanol (2BE) at 308.15 K						
0	891.13	1276.21	1.5842	2.418	5.0099	112.2147
0.2386	910.24	1295.52	1.5491	2.095	5.0704	107.3215
0.4396	927.41	1313.82	1.5063	1.792	5.1244	104.0147
0.6105	942.54	1328.97	1.4571	1.532	5.1714	101.2178
0.7581	955.59	1343.98	1.4024	1.287	5.2154	98.5214
0.8868	968.34	1357.87	1.3414	1.072	5.2575	95.8725
1	979.74	1369.94	1.2654	0.906	5.2901	93.7125
Anisole + 2-Butoxy Ethanol (2BE) at 313.15 K						
0	885.94	1256.24	1.544	2.147	5.1124	117.7471
0.2386	904.26	1275.18	1.5091	1.835	5.1802	112.8852
0.4396	921.29	1291.89	1.4661	1.555	5.2321	109.4147
0.6105	936.37	1307.26	1.4204	1.335	5.2756	106.3471
0.7581	949.54	1320.97	1.3652	1.132	5.3182	103.4751
0.8868	962.24	1336.26	1.3052	0.967	5.3582	100.8246
1	975.02	1349.83	1.2318	0.841	5.3914	99.0712
Anisole + 2-Butoxy Ethanol (2BE) at 318.15 K						
0	881.72	1236.25	1.5071	1.8778	5.219	117.7471
0.2386	899.28	1255.44	1.4702	1.587	5.286	112.8852
0.4396	915.41	1270.27	1.4282	1.325	5.3428	109.4147
0.6105	930.27	1285.24	1.3811	1.132	5.3881	106.3471
0.7581	944.27	1301.25	1.3277	0.976	5.4274	103.4751
0.8868	956.57	1314.81	1.2701	0.869	5.4615	100.8246
1	970.3	1329.14	1.2002	0.793	5.219	99.0712

Table- III: - Values of excess Ultrasonic velocity (u^E), excess Viscosity (η^E), excess Acoustic impedance (Z^E), Intermolecular free length (L_f^E), and Molar volume (V_m^E), for the binary liquid mixtures of anisole with 2-Alkoxy Ethanol's at 303.15 to 318.15K

Mole fraction of Anisole	u^E $m.s^{-1}$	$\eta^E \times 10^{-3}$ $Ns.m^{-2}$	Z^E x 10-4 Kg m^{-2} s^{-1}	$L_f^E \times 10^{12}$ m	$V_m^E \times 10^{-5}$ m^3/mol^{-1}
Anisole + 2-Butoxy Ethanol (2BE) at 303.15K					
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2386	12.5412	-0.0556	0.0402	-0.0174	-0.1827
0.4394	19.2145	-0.0941	0.0668	-0.0275	-0.2721
0.6105	20.7414	-0.1071	0.0745	-0.0295	-0.2841
0.7581	15.4565	-0.0931	0.0637	-0.0257	-0.2421
0.8868	12.5412	-0.0552	0.0367	-0.0159	-0.1481
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Anisole + 2-Butoxy Ethanol (2BE) at 308.15K					
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2386	17.2854	-0.0471	0.0351	-0.0149	-0.2074
0.4394	25.8749	-0.0822	0.0577	-0.0239	-0.2997
0.6105	26.9412	-0.0968	0.0640	-0.0259	-0.3151
0.7581	20.7172	-0.0837	0.0557	-0.0220	-0.2744
0.8868	11.2251	-0.0468	0.0314	-0.0132	-0.1731
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Anisole + 2-Butoxy Ethanol (2BE) at 313.15 K					
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2386	21.8575	-0.0384	0.0301	-0.0128	-0.2324
0.4394	32.4815	-0.0698	0.0492	-0.0207	-0.3314
0.6105	33.3874	-0.0855	0.0544	-0.0227	-0.3481

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0.7581	26.5247	-0.0738	0.0469	-0.0189	-0.3079
0.8868	15.2971	-0.0397	0.0264	-0.0108	-0.2045
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Anisole + 2-Butoxy Ethanol (2BE) at 318.15K					
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2386	27.1412	-0.0308	0.0253	-0.0109	-0.2614
0.4394	38.2941	-0.0578	0.0412	-0.0177	-0.3659
0.6105	39.3699	-0.0736	0.0448	-0.0193	-0.3840
0.7581	32.6475	-0.0631	0.0382	-0.0158	-0.3451
0.8868	19.4127	-0.0317	0.0214	-0.0087	-0.2295
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Figures-I:- Density (ρ), ultrasonic Velocity (u), acoustic impedance (Z),viscosity (η), intermolecular free-length (L_f) for the binary liquid mixtures of anisole with 2 -butoxy ethanol at 303.15K and 308.15K.

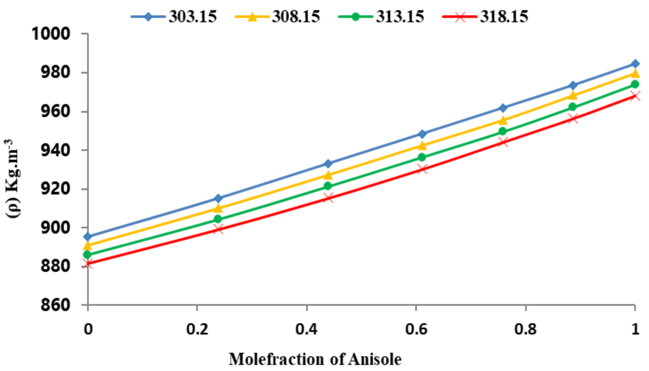

Fig. 1. 1 Variation of Density

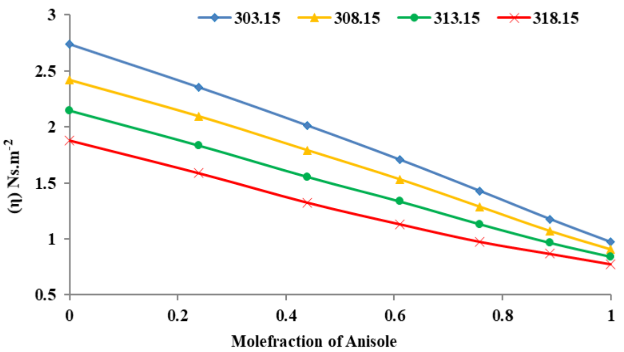

Fig. 1. 4 Variation of Viscosity

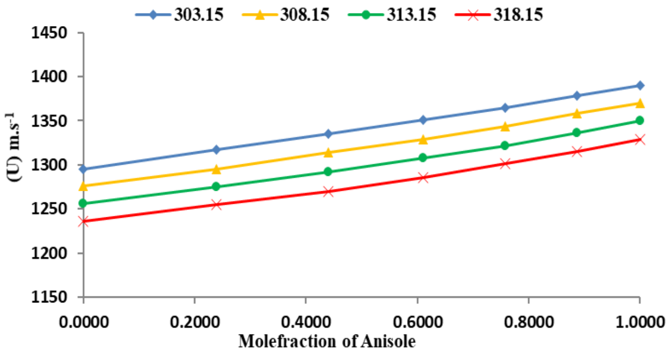

Fig. 1. 2 Variation of ultrasonic Velocity

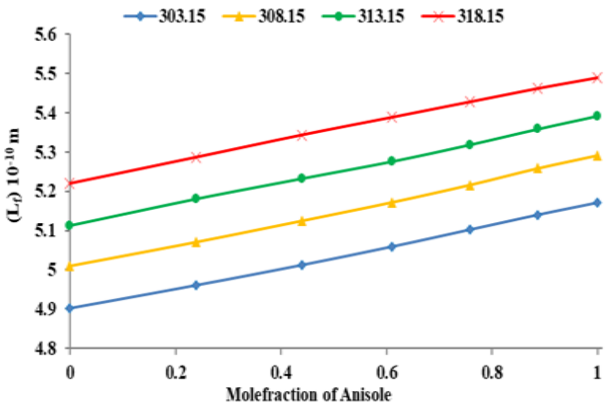

Fig. 1. 5 Variation of free length

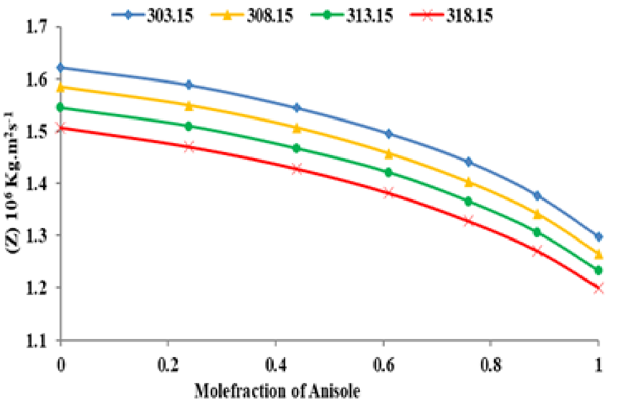

Fig. 1. 3 Variation of Acoustic impedance

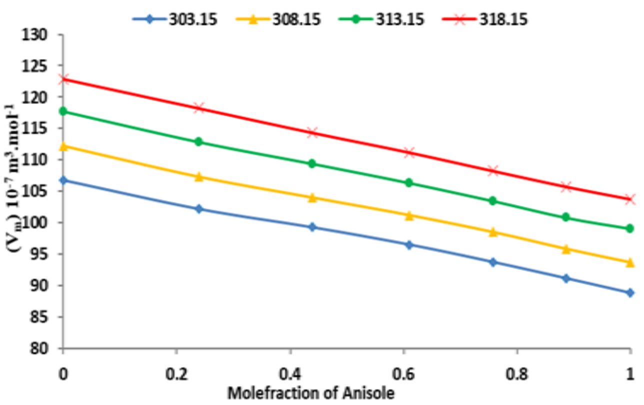

Fig. 1. 6 Variation of molar volume

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Figures-II :- Figures for excess Ultrasonic velocity (u^E), excess Viscosity (η^E), excess Acoustic impedance (Z^E), Intermolecular free length (L_f^E), and Molar volume (V_m^E), for the binary liquid mixtures of anisole with 2-Alkoxy Ethanol's at 303.15 to 318.15K (L_f) for the binary liquid mixtures of anisole with 2 - ethoxy ethanol at 303.15K to 308.15K.

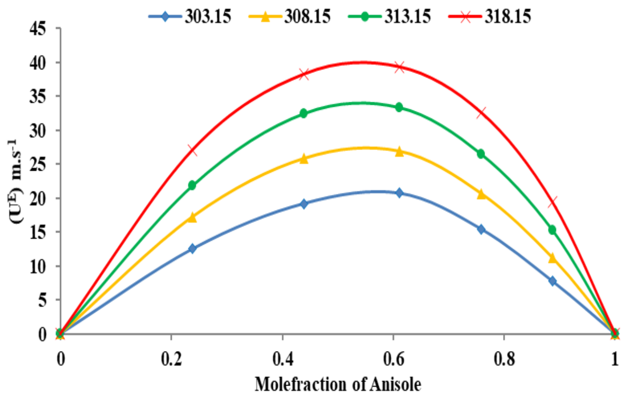

Fig. 2. 1 Variation of excess Ultrasonic velocity

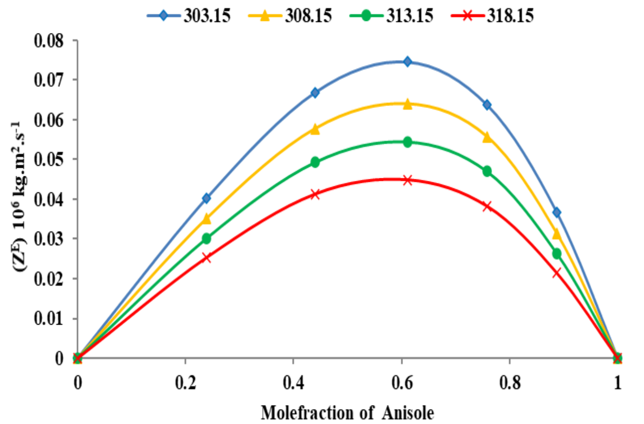

Fig. 2. 3 Variation of excess Acoustic impedance

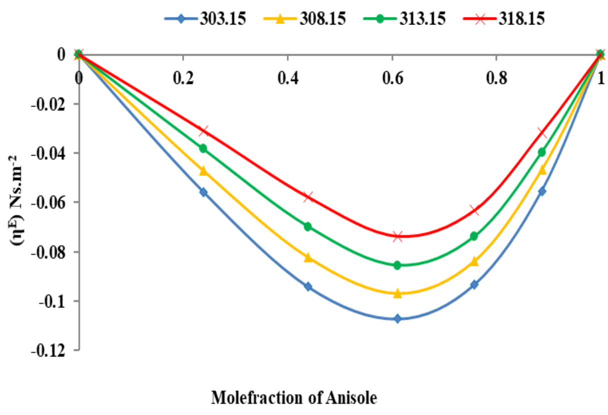

Fig. 2. 2 Variation of ultrasonic excess Viscosity

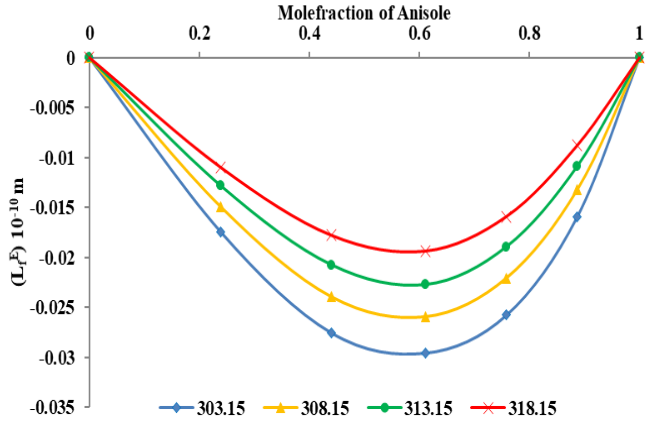

Fig. 2. 4 Variation of excess Inter molecular free-length

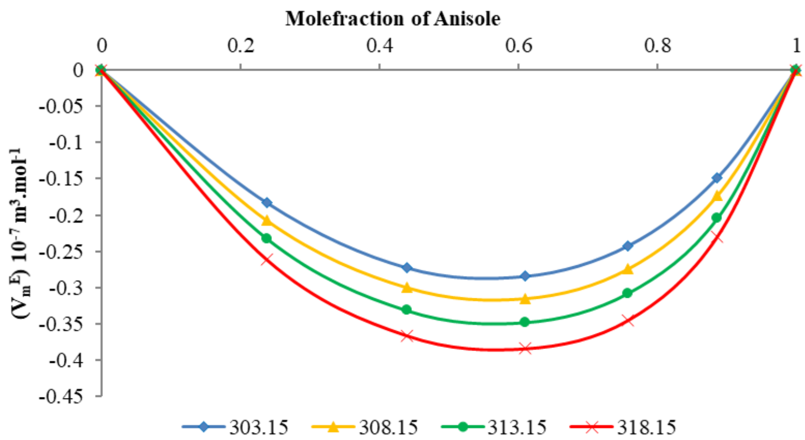

Fig. 2. 5 Variation of excess molar volume

V. CONCLUSIONS

The following conclusions are monitored by above statements

- Density, ultrasonic velocity, intermolecular free length for binary liquid mixtures of anisole and 2-Butoxyethanol observed at different temperature 303.15 to 315.18 increases with the increase in proportion of anisole.
- The value of acoustic impedance, viscosity and molar volume decreases with the increase in the mole fraction of anisole in all the four observed temperatures.

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- There is a linear positive relationship between the mole fraction of anisole and its density, ultrasonic velocity & intermolecular free length and the relationship is linear but negative for acoustic impedance, viscosity and molar volume.
- The excess parameters of ultrasonic velocity (u^E), acoustic impedance (Z^E) showed positive deviation. The deviation is maximum between 0.4394 and 0.6105 mole fraction of anisole at the four different temperatures. For acoustic impedance the deviation is maximum at 0.6105 mole fraction of anisole.
- The excess parameters for viscosity, intermolecular free length and molar volume showed negative deviations which are maximum at 0.6 mole fractions for all the three parameters at four observed temperatures.
- The deviations are attributed to the compression of liquid mixtures, chain length and creation of weak hydrogen bonds between the component molecules.
- The vigour of binary mixture is more at mole fraction 0.6105 of anisole at 1:1 proportion of 2-Butoxyethanol +Anisole.

DECLARATION STATEMENT

Authors are required to include a declaration of accountability in the article, counting review-type articles, that stipulates the involvement of each author. The level of detail differs; Some subjects yield articles that consist of isolated efforts that are easily voiced in detail, while other areas function as group efforts at all stages. It should be after the conclusion and before the references.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	Under the guidance of fourth author, first author working for Ph.D Degree and the remaining authors helped in the preparation of paper for publication.

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