Evaluation of Sound Velocity and Interaction Study in Binary Liquid Mixtures

M.C. SAXENA* and ASHUTOSH TRIPATHI

Chemical Laboratories, Post Graduate Department of Chemistry
K.S. Saket P.G. College (Dr. R.M.L. Avadh University), Faizabad-224 001, India

Sound velocities have been predicted in the binary liquid mixtures of cyclohexane-benzene, cyclohexane-toluene and cyclohexane-*p*-xylene at 30°C in the light of ideal mixing and Nomoto's relations. The relative merits of both relations have been assessed.

Key Words: Sound velocity, Interaction study, Binary liquid mixtures.

INTRODUCTION

Nomoto's relation[1, 2] and ideal mixing relation[3, 4] have been used to evaluate sound velocity of binary liquid mixtures. A number of workers[5–13] have observed and compared the relative merits of both relations and evaluated the sound velocities. The aim of the present work is two-fold, firstly to compare the merits of Nomoto's relation with ideal mixing relation and secondly to evaluate the extent and magnitude of interaction between the conformation of cyclohexane, which has chair and boat conformation, with that of planar structure of benzene and the benzene ring containing methyl groups.

Theory

The Nomoto's empirical relation of sound velocity (u) in binary liquid mixtures has been extended to binary systems as:

$$R = X_1R_1 + X_2R_2 \tag{1}$$

where R is related to the molecular weight M and density ρ as

$$R = \frac{M}{\rho} u^{1/3} = Vu^{1/3} \tag{2}$$

The additive molar volume is given by

$$V = X_1V_1 + X_2V_2 \tag{3}$$

In the light of the above equations,

---

* Address for correspondence: Madhuban, Hospital Road, 368/F, Balla Hata, Opposite Sona Bakers, Faizabad-224 001, India.

$$u = \left(\frac{R}{V}\right)^3 = \frac{X_1R_1 + X_2R_2}{X_1V_1 + X_2V_2} \tag{4}$$

The deviations from linearity are given by

$$\Delta A = A_{cal} - A_{exp} \tag{5}$$

where A may be R, u, v.

Van Dael's relation for adiabatic compressibility in the light of Richardson[14] and Blandamer's[15] assumption can be extended to the binary mixtures, as follows:

$$\beta_S(im) = \phi_1 \frac{\gamma_1}{(im)} (\beta_S)_1 + \phi_2 \frac{\gamma_2}{(im)} (\beta_S)_2 \tag{6}$$

The above equation which holds true in the mixtures is an ideal one and also $\gamma_1 = \gamma_2 = \gamma_{(im)}$. Using the additional assumption that $V_1 = V_2$, eqn. (6) takes the form

$$\beta_S(im) = X_1(\beta_S)_1 + X_2(\beta_S)_2 \tag{7}$$

The sound velocities with eqns. (6) and (7) are respectively

$$\frac{X_1V_1 + X_2V_2}{X_1M_1 + X_2M_2} \times \frac{1}{u^2(im)} = \phi_1 \frac{V_1}{M_1u_1^2} + \phi_2 \frac{V_2}{M_2u_2^2} \tag{8}$$

and

$$\frac{1}{X_1M_1 + X_2M_2} \times \frac{1}{u^2(im)} = \frac{X_1}{M_1u_1^2} + \frac{X_2}{M_2u_2^2} \tag{9}$$

where ϕ and γ are the volume fraction and principal specific heat ratio respectively and quantities with suffixes 1 and 2 refer to the component liquids 1 and 2 respectively.

RESULTS AND DISCUSSION

The values of experimental sound velocities and other essential data required for the calculation have been taken from literature[16, 17]. The experimental sound velocity values were accurate to + 0.50%, whereas the density values were accurate to two part to 10^5.

Table 1 lists the percentage deviation of sound velocity computed from Nomoto's empirical relation ($\Delta U/U$) percentage deviation of V and R, along with experimental and theoretical sound velocities predicted from Nomoto and ideal mixing relation, for all the three mixtures under the present investigation. An inspection of Table-1 shows that all the quantities vary with the composition of mixture. The negative as well as positive deviations in R from additive rule are observed. It is negative in systems 1 and 2 and positive in system 3. However, $\Delta\%$ in molar volume are all negative in the systems 1, 2 and 3.

An inspection of Table-1 reveals that U_{Nomoto} values are in better agreement with the experimental values for systems 2 and 3, whereas $U_{(im)}$ is showing better agreement in system 1. The ratio $u_{exp}^2/u_{(im)}^2$ of the last column of Table-1 reveals that the magnitude of $u_{exp}^2/u_{(im)}^2$ is appreciable nearing unity showing interactions

TABLE-1

MAXIMUM PERCENTAGE DEVIATION OF MOLECULAR SOUND VELOCITY (R), MOLAR VOLUME (v), FROM LINEARITY, MAXIMUM PERCENTAGE DEVIATION OF THE SOUND VELOCITY (u) FROM NOMOTO'S EMPIRICAL RELATION AND THE RATIO u_{exp}^2/u_{im}^2

Cyclohexane x_1	$\Delta U/U$ (%)	$\Delta V/V$ (%)	$\Delta R/R$ (%)	U_{exp} (%)	U_{Nomoto} (m/s)	U_{im} (m/s)	u_{exp}^2/u_{im}^2
			Cyclohexane-Benzene (30°C)				
0.0000	0.0000	0.0000	−0.0235	1277	1277.0070	1277.0000	1.0000
0.1009	0.8048	−0.1944	−0.0205	1262	1273.5271	1272.1568	0.9840
0.2002	1.3912	−0.4537	−0.1910	1250	1269.8435	1268.3904	0.9727
0.3008	1.6555	−0.5570	−0.0170	1242	1265.7065	1262.5616	0.9676
0.3991	1.8496	−0.6503	−1.5206	1235	1261.3929	1257.8432	0.9640
0.5014	1.8644	−0.6476	−1.2960	1230	1256.5746	1252.9328	0.9637
0.6009	1.8072	−0.6144	−1.0726	1226	1251.5395	1248.1568	0.9648
0.7007	1.5822	−0.5231	−0.8454	1224	1246.2900	1243.3664	0.9690
0.8007	1.1074	−0.4020	−0.6763	1225	1240.7267	1238.5664	0.9782
0.9005	0.5522	−0.1306	−0.3850	1227	1234.9601	1233.7760	0.9890
1.0000	0.0000	0.0000	−0.2368	1229	1229.0098	1229.0000	1.0000
			Cyclohexane-Toluene (30°C)				
0.0000	0.0000	0.0000	−8.9562	1284	1284.0100	1284.0000	1.0000
0.1017	−0.5036	−0.1411	−48.1835	1272	1277.5110	1278.4065	0.9900
0.2004	−0.7900	−0.2143	−48.6212	1263	1271.6184	1272.9780	0.9843
0.2995	−1.0787	−0.2751	−0.4905	1254	1265.7841	1267.5275	0.9787
0.3989	−1.2889	−0.3262	−49.4970	1246	1260.0003	1262.0605	0.9747
0.4988	1.4177	−0.3647	−49.9484	1239	1254.2846	1256.5660	0.9722
0.5989	−1.3825	−0.3931	−50.4222	1234	1248.5995	1251.0605	0.9729
0.6995	−1.2623	−0.7145	−53.1141	1230	1243.2193	1245.5274	0.9752
0.8004	−1.1401	−0.2969	−51.3259	1226	1238.1463	1239.9780	0.9775
0.8983	−0.7009	−0.1950	−51.7890	1226	1233.3957	1234.5935	0.9861
1.0000	−0.0000	−0.0015	9.8375	1229	1229.0098	1229.0000	1.0000
			Cyclohexane-p-Xylene (30°C)				
0.0000	0.0000	0.0000	0.0000	1289	1289.0098	1289.0024	1.0000
0.1012	0.5429	−0.1492	0.7113	1279	1282.1230	1311.1053	0.9938
0.2000	0.5511	−0.2577	1.2496	1270	1275.5874	1327.2752	0.9890
0.2999	0.7136	−0.3863	1.7738	1262	1269.2366	1341.3209	0.9858
0.4007	0.9543	−0.4523	2.0659	1253	1262.9456	1346.7049	0.9811
0.5024	1.0317	−0.4971	2.2290	1246	1256.6576	1346.7379	0.9796
0.6015	1.0411	−0.5059	2.2113	1240	1250.8366	1339.6360	0.9794
0.7012	0.9658	−0.6203	2.0075	1235	1243.3110	1325.0860	0.9809
0.8015	0.8050	−0.4443	1.5839	1231	1239.4229	1301.9861	0.9840
0.8991	0.4108	−0.3180	0.9390	1230	1234.1232	1270.8366	0.9918
1.0000	0.0000	−0.7019	0.0001	1229	1229.0098	1228.9970	1.0000

between the components of the system. The molecular interaction in the system may be explained on the concept that the cyclohexane has no planar structure but it exists in chair and boat forms. Contrary to it, benzene has a planar structure. When the concentration of cyclohexane is increased in benzene, the tilted ends of the molecules of the former keep the molecules of the latter farther. Due to this more space is created when we compare the value of $u^2_{exp}/u^2_{(im)}$ at almost the same amount of X ($X_1 = 0.6009$ in the 1st system, $X_2 = 0.5989$ in the 2nd system and $X = 0.6015$ in the 3rd system) the values are in the increasing order showing that there is a weak interaction between unlike molecules. The interaction between cyclohexane-*p*-xylene is more than that in the cyclohexane -toluene, further more than cyclohexane-benzene. The presence of methyl group present in toluene and *p*-xylene molecules creates hindrance producing more space which has also been noted by Pande *et al.*[16] on the basis of molar volume, available volume and free volume data.

ACKNOWLEDGEMENTS

REFERENCES

1. O. Nomoto, *J. Phys. Chem.*, **13**, 1528 (1958).
2. K.C. Reddy, S.V. Subramanyam and Blumsenachary, *Trans. Farad. Soc.*, **68**, 2352 (1962).
3. W. Van Doel and E. Vangeel, Proceedings of the First Lnternational Confrence on Calorimetry and Thermodynamics, Warsaw, p. 555 (1969).
4. ————, Thermodynamic Properties and the Velocity of Sound, Butterworth Publications, Ch. 2 (1975).
5. R.P. Rastogi, Jagannath and V. Mishra, *J. Phys. Chem.*, **71**, 1277 (1967).
6. D.V.S. Jain, V.K. Gupta and B.S. Lark, *Indian J. Chem.*, **8**, 815 (1970).
7. V. Haider Khan and S.V. Subrmnanyam, *Trans. Farad. Soc.*, **67**, 2282 (1971).
8. D.I.R. Law and E.A. Moelwyn Hughes, *Proc. Roy. Soc. (London)*, **267A**, 384 (1962).
9. J.K. Holzhauer and W.T. Ziegler, *Phys. Chem.*, **79**, 590 (1975).
10. G. Delmas and S. Turrell, *Trans. Farad. Soc.*, **70**, 572 (1974).
11. K. Sheshadri, N. Prabhakara and K.C. Reddy, *Z. Phys. Chem. (Neue Folge)*, **89**, 108 (1974).
12. P.P. Naidu and V.R. Krishnan, *J. Phys. Chem. (Japan)*, **30**, 1554 (1965).
13. M.C. Saxena and N. Pant, *Curr. Sci. (India)*, **50**, 572 (1981).
14. E.G. Richardsan, Ultrasonics Physics, Elsevier, Amsterdem (1962).
15. M.J. Blandamer and D. Waddington, *J. Phys. Chem.*, **74**, 2569 (1970).
16. P. Pande, O. Prakash and S. Prakash, *J. Pure Appl. Ultrason.*, **4**, 12 (1982).
17. R.C, Handbook of Chemistry and Physics, Cole Press, Boca Raton, Florida, 60th Edn. (1979–80).