NOTE

Prediction of Viscosity in Ternary Systems

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By using various empirical relations, which are applicable to binary liquid mixture, viscosities of three ternary liquid mixtures in different compositions have been evaluated theoretically. These theoretical values are compared with experimental values. It is observed that good agreement between experimental and theoretical values calculated by Bingham and Kendall is observed in benzene and toluene systems (except in 0.0322 composition) whereas in THF system, these deviations are higher. The values calculated by Arrhenius relation are highest in all the three systems.

A literature survey reveals that very little work has been done on the applications of various models to multi-component liquid mixtures[1-3]. In the present study, an attempt has been made to apply various viscosity models of binary mixtures to ternary mixtures. In the present work, viscosities and densities are measured for various compositions of three ternary liquid systems: chloroform-dioxane-benzene, chloroform-dioxane-toluene and chloroform-dioxane-THF, and the results are interpreted in the light of structure of molecules and the interactions involved.

The liquids used were purified by standard methods prior to use. All the mixtures of different compositions were prepared by volume and were kept in stoppered bottles to minimize the evaporation of components. The densities and viscosities were measured by specific gravity bottle and Ubbholdhe viscometer at 298 K.

Considering the ideal mixing of solutions, the following relations were proposed:

Additive relation based on Arrehenius and Eyring's model[4] for the viscosity of pure liquids can be modified as:

$$\ln \eta = \Sigma\, x_i\, \ln\text{-}\eta_i V_i \tag{1}$$

where x_i, η_i and V_i are the mole fraction, viscosity and volume of the ith component respectively.

For ternary liquid mixtures, Bingham relation[5] was modified to:

$$\eta = x_1\eta_1 + x_2\eta_2 + x_3\eta_3 \tag{2}$$

where x_1, x_2, x_3 and η_1, η_2, η_3 are mole fraction and viscosity of the different pure components.

Kendall and Munroe[6] gave the following equation for multi-component system:

$$\ln \eta = \Sigma\, x_i \ln \eta_i \tag{3}$$

The densities, experimental and theoretical viscosity values calculated by different equations in the three systems are reported in Table-1. The percentage deviations between experimental and theoretical values are given in Table-2.

TABLE-1
EXPERIMENTAL AND THEORETICAL VISCOSITIES
IN THE THREE SYSTEMS AT 30°C

x_3	$\eta_{expl.} \; 10^{-3}$	$\eta_{Bingham} \times 10^{-3}$	$\eta_{Kendall} \times 10^{-3}$	$\eta_{Arrhenius} \times 10^{-3}$
		Chloroform-Dioxane-Benzene		
0.0361	6.2179	6.1447	6.1004	11.1255
0.0381	10.1190	10.1647	10.0461	17.9462
0.1855	7.0328	6.7787	6.5529	6.4945
0.1878	7.9799	7.6866	7.3564	6.4585
0.1901	8.3657	8.6174	8.2566	7.9641
0.3790	6.9790	6.6999	6.4368	5.6215
0.3838	7.2996	7.6205	7.2573	6.2577
0.5811	6.9033	6.6053	6.3639	6.0248
0.9140	5.7731	5.6901	5.6692	9.8870
		Chloroform-Dioxane-Toluene		
0.0322	6.3376	10.1804	10.0583	10.2918
0.1620	7.9144	7.6895	7.3306	6.5522
0.1956	7.6234	7.1044	6.9650	6.1127
0.2477	6.9295	7.1730	6.8355	5.8487
0.3435	7.4279	7.6165	7.1919	5.1413
0.4564	6.4844	6.9634	6.5907	5.6553
0.5623	6.2257	6.3104	6.0423	5.5989
0.7093	5.6742	5.9544	5.7345	6.3712
0.8992	5.2666	5.3533	5.2772	8.8303
		Chloroform-Dioxane-THF		
0.1025	9.0144	8.5329	9.7848	8.1930
0.1662	9.2893	9.3913	9.0118	12.1629
0.2031	8.2959	7.4926	7.0986	6.1693
0.3039	7.7509	7.1860	6.7779	5.6592
0.4070	7.5557	7.2341	6.7604	5.8600
0.4977	7.0015	5.4379	5.1582	6.1922
0.6042	6.6668	6.0895	5.7705	5.6044
0.7095	6.0616	6.3104	5.8804	7.4710
0.8029	5.4070	5.3942	5.2084	6.9145

It is clear from Table 1 that Bingham and Kendall relation gives better results for benzene and toluene systems, whereas Kendall relation does not give very

good results in THF system. This proves that THF system is not ideal. Kendall relation is more significant in case of mixtures where an ideal mixture is expected.

TABLE-2
COMPARISON BETWEEN VARIOUS VISCOSITY DATA
IN THE THREE SYSTEMS AT 30°C

x_3	$\Delta\eta_{exptl\text{-}Bingham}$ %	$\Delta\eta_{exptl\text{-}Kendall}$ %	$\Delta\eta_{exptl\text{-}Arrhenius}$ %
Chloroform-Dioxane-Benzene			
0.0361	1.18	1.89	−78.93
0.0381	−0.45	0.72	−77.35
0.1855	3.61	6.82	7.65
0.1878	3.68	7.81	19.07
0.1901	−3.01	1.30	4.80
0.3790	3.99	7.77	19.45
0.3838	4.39	0.58	14.27
0.5811	4.32	7.81	12.72
0.9140	1.44	1.80	71.26
Chloroform-Dioxane-Toluene			
0.0322	60.63	58.71	62.39
0.1620	2.84	7.38	17.21
0.1956	6.81	8.64	19.82
0.2477	−3.51	1.36	15.60
0.3435	−2.54	3.18	17.32
0.4564	−7.39	−1.64	12.79
0.5623	−1.36	2.96	10.07
0.7093	−4.94	−1.06	−12.28
0.8992	−1.65	−0.20	67.67
Chloroform-Dioxane-THF			
0.1025	5.34	8.55	9.11
0.1662	−1.10	2.99	30.93
0.2031	9.68	14.43	25.63
0.3039	7.29	12.55	26.99
0.4070	4.26	10.53	22.44
0.4977	13.03	17.58	11.56
0.6042	8.66	13.44	15.94
0.7095	−4.66	2.99	−23.25
0.8029	0.24	3.67	27.88

In benzene and toluene systems, to some extent interactions are inhibited by the presence of benzene molecule to its planar structure and presence of π electron cloud. This ultimately may lead to an ideal behaviour. Due to absence of benzene

ring and due to lone pair of electrons in THF system, more interactions were expected which is proved by higher deviation (Table-2). However, results calculated by Arrhenius relation give quite high deviation. This relation was proposed considering ideal mixing of solution which is not always true.

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