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Estimation of Viscosities and Their Deviations in Organic Liquid Mixtures at 303.15 K-A Comparative Study

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Viscosities and densities are measured experimentally for three binary liquid mixtures of Aniline + Toluene, Aniline + *o*-Xylene and Aniline + Mesitylene using Ostwald's viscometer and specific gravity bottle at T = 303.15 K. Viscosities have also been calculated using empirical relations including Bingham relation, Kendall-Munroe relation, Arrhenius-Eyring relation, Croenaurer-Rothfus-Kermore relation and Gambrill relation. The validity of these correlations has been verified by respective deviations between calculated values and experimental values. These results show that positive deviations are present in all the three binary mixtures at T = 303.15 K. The results of all the relations are comparatively in good agreement with experimental results. These are used to draw the characteristics of the molecular association among the components of respective binary liquid mixtures.

Keywords: Gambrill relation, Bingham relation, Experimental viscosity, Organic liquid mixtures, Deviation

INTRODUCTION

The theoretical studies are very much useful for explaining the nature of molecular interactions between the molecules of binary liquid mixtures. Transport parameters study in binary liquid mixtures provides a lot of knowledge about molecular interactions occurring in liquid mixtures. Viscosity is one of the important transport parameters for design process and fluid transportation mixing, filtration and heat exchange [1]. Therefore, viscosities and densities of binary liquid mixtures have been determined using experimental methods [2-8]. The viscosities and densities of present binary liquid mixtures have been obtained from the previously reported measurements on the liquid mixtures under study [9-11]. The empirical approaches have been reported in the literature survey [12-16], such as Bingham relation, Kendall-Munroe relation, Arrhenius-Eyring relation, Croenaurer-Rothfus-Kermore relation and Gambrill relation. In the present work, experimental viscosity, molar volumes and density values of individual liquids of the binary mixtures are considered for computing theoretical viscosity by various theories. These viscosity models have been proposed especially for binary and non-electrolytic solutions [14]. However, a number of predictive relations are available for estimating viscosity of liquid mixtures. The relations aforementioned provide a good support when compared with the experimental values for the study of physical properties.

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EXPERIMENTAL METHODS

In the present study, the chemicals used are of analytical reagent grade; Aniline is obtained from SDFCL chemical distribution company with 98% of purity, and Toluene, *o*-Xylene and Mesitylene are obtained from MERCK chemical distribution company with 99% of purity, and they are purified by standard procedure. Different concentrations of the liquid mixtures are prepared by varying mole

Table 1. Experimental Values of Density and Viscosity of Three Binary Liquid Mixtures at T = 303.15 K

Aniline + Toluene mixture			Aniline + *o*-Xylene mixture			Aniline + Mesitylene mixture		
Mole fraction (X)	Density (ρ) Kg m^{-3}	Viscosity (η) mPa s	Mole fraction (X)	Density (ρ) Kg m^{-3}	Viscosity (η) mPa s	Mole fraction (X)	Density (ρ) Kg m^{-3}	Viscosity (η) mPa s
0.0000	867.11	0.5955	0.0000	870.72	0.7015	0.0000	856.30	0.6213
0.1145	880.49	0.7749	0.0146	882.49	0.8789	0.0166	881.30	0.7033
0.2254	895.72	0.9543	0.0323	897.72	1.1203	0.0367	892.53	0.8827
0.3328	915.69	1.1337	0.0541	913.69	1.2619	0.0613	915.50	1.0621
0.4369	935.69	1.3131	0.0816	930.69	1.3991	0.0922	936.50	1.2415
0.5379	954.89	1.4925	0.1176	944.89	1.5149	0.1322	957.70	1.4209
0.6358	974.89	1.6719	0.1667	957.89	1.6876	0.1860	970.70	1.6003
0.7309	991.69	1.8513	0.2373	974.69	1.8602	0.2622	988.50	1.7797
0.8232	1005.16	2.0307	0.3478	989.40	2.0813	0.3786	1003.97	1.9591
0.9129	1014.39	2.2508	0.5455	1005.39	2.2876	0.5782	1017.20	2.1385
1.0000	1020.14	2.5416	1.0000	1020.14	2.5416	1.0000	1020.14	2.5416

fractions with respect to Job's method of continuous variation and preserved to attain thermal equilibrium. The temperature of the pure liquids or liquid mixtures is adjusted using temperature controlled water bath. Specific gravity bottle is used for the measurement of densities of pure liquids and liquid mixtures. An electronic weighing balance (Shimadzu AUY220, Japan-precision + or -0.1 mg) is used for the measurements of mass of pure liquids or liquid mixtures. The temperature of the solution under study is maintained constant using the electronic thermostat. This thermostat is equipped with a heater, stirrer, and a highly accurate platinum thermo meter, a regulator and automatic viscosity correction (range 0-70 ºC, ±0.01 ºC). Ostwald's viscometer is used for the measurement of viscosity of pure liquids or liquid mixtures. The time of liquid flow in the viscometer is measured with an electronic stopwatch with a precision of 0.01 s. Both the specific gravity bottle and Ostwald's viscometer are calibrated using benzene at room temperature and verified with the standard values.

Standard uncertainities (U_c) are given as:

$U_c(\rho)$ = + or - 0.01 Kg m^{-3}; $U_c(\eta)$ = + or - 0.001 mPa s

THEORY

The different theoretical relations used for the estimation of viscosity are as follows,

Bingham Relation [12]

$$\eta_m = \sum x_i \eta_i$$

where η_m is the viscosity of the binary liquid mixture, x_i and η_i are the mole fraction and viscosity of pure liquids, respectively.

Kendall-Munroe Relation [13]

$$\log(\eta_m) = \sum x_i \log(\eta_i)$$

where η_m is the viscosity of the binary liquid mixture, x_i and η_i are the mole fraction and viscosity of pure liquids, respectively.

Arrhenius-Eyring Relation [14]

$$\log(\eta_m V_m) = \sum x_i \log(V_i \eta_i)$$

where η_m, V_m respectively are viscosity, and molar volume of the binary liquid mixture, and x_i and V_i are the mole fraction and molar volume of individual pure liquids, respectively.

Croenauer-Rothfus-Kermore Relation [15]

$$\log(\nu_m) = \sum x_i \log(\nu_i)$$

where ν_m is the kinematic viscosity of the binary liquid mixture, x_i and ν_i are the mole fraction and kinematic viscosity of individual pure liquids, respectively.

Gambrill Relation [16]

$$\nu_m^{1/3} = \sum x_i (\nu_i)^{1/3}$$

where ν_m is the kinematic viscosity of the binary liquid mixture, x_i and ν_i are the mole fraction and kinematic viscosity of individual pure liquids, respectively.

RESULTS and DISCUSSION

In the present study, viscosity of three binary liquid mixtures (Aniline + Toluene, Aniline + *o*-Xylene and Aniline + Mesitylene) at temperature T = 303.15 K is calculated using Bingham, Kendall-Munroe, Arrhenius-Eyring, Croenaurer-Rothfus-Kermore and Gambrill relations. The experimental values of viscosities and densities of the three binary liquid mixtures at T = 303.15 K are given in Table 1. The results of the estimated viscosities of the binary liquid mixtures, calculated using the empirical relations, are presented in Table 2. As indicated by the results in Table 3, the validity of the relations has been verified by calculating deviations for all the three binary liquid mixtures. The plots of these results with respect to different empirical relations are represented in Figs. 1, 2 and 3.

From Tables 1, 2 and 3, it is found that experimental and estimated values of viscosity show deviations. Considering the limitations on the physical quantities employed in the theoretical formulae and approximations of logarithmic functions, their powers are responsible for the deviations. All four correlations show positive systematic deviations with a maximum at around mole fraction ~ 0.4 of aniline while the extent of the deviation is in the order of (Aniline + Toluene) < (Aniline + *o*-Xylene) ~ (Aniline + Mesitylene). Small magnitudes of positive deviations are observed in Bingham and Gambrill relations when compared to the other relations studied. Similar results are reported by Kumud Dwivedi and Indra Prasad Tripathi [15], Fakrudin *et al.* [16], Siddharthan and Jayakumar [17] and many other researchers [18-22] in their studies.

Based on the results, Gambrill relation gives the best results followed by Croenaurer-Rothfus-Kermore relation in Aniline + Toluene binary liquid mixture. Whereas, in the other two binary liquid mixtures (Aniline + *o*-Xylene and Aniline + Mesitylene), Bingham relation gives the best results followed by Arrhenius-Eyring relation at T = 303.15 K. Accordingly, a strong association (close packing) is present between the components of the liquid mixtures of Aniline + *o*-Xylene and Aniline + Mesitylene, while a weaker molecular association is observed for the liquid mixture of Aniline + Toluene. The results are supported by the density variations with mole fraction of Aniline for all the binary liquid mixtures studied.

CONCLUSIONS

Estimation of viscosities of binary liquid mixtures Aniline + Toluene, Aniline + o-Xylene and Aniline + Mesitylene at temperature T = 303.15K is done by using Bingham, Kendall-Munroe, Arrhenius-Eyring, Croenaurer-Rothfus-Kermore and Gambrill relations. The detailed analysis of the present study shows deviations between theoretical and experimental values. Small magnitudes of positive deviations are observed in Bingham and Gambrill relations when compared to the other theories studied. This is well supported by the variation of densities of the respective binary liquid mixtures at T = 303.15 K. Finally, it is concluded that since the deviations are basically small and close to each other for different mixtures, a closer packing of molecules is present between the components of

Table 2. Estimated Values of Viscosities Using Bingham Relation (η_B), Kendall-Munroe relation (η_{KM}), Arrhenius-Eyring Relation (η_{AE}), Croenaurer-Rothfus-Kermorerelation (η_{CRK}) and Gambrill Relation (η_G) in all the Three Binary Liquid Mixtures at Temperature T = 303.15 K

Mole fraction of Aniline (X)	η_B mPa s	η_{KM} mPa s	η_{AE} mPa s	η_{CRK} mPa s	η_G mPa s
Aniline + Toluene					
0.0000	0.5955	0.5955	0.5955	0.5955	0.5955
0.1145	0.8183	0.7031	0.7008	0.7959	0.8212
0.2254	1.0341	0.8259	0.8224	0.9182	0.9672
0.3328	1.2431	0.9652	0.9656	1.0545	1.1242
0.4369	1.4457	1.1226	1.1283	1.2059	1.2917
0.5379	1.6423	1.2998	1.3115	1.3735	1.4695
0.6358	1.8328	1.4982	1.5190	1.5582	1.6566
0.7309	2.0179	1.7199	1.7467	1.7613	1.8530
0.8232	2.1975	1.9664	1.9940	1.9838	2.0578
0.9129	2.3720	2.2398	2.2589	2.2269	2.2709
1.0000	2.5416	2.5416	2.5416	2.5416	2.5416
Aniline + *o*-Xylene					
0.0000	0.7015	0.7015	0.7015	0.7015	0.7015
0.0146	0.7283	0.7148	0.7329	0.8190	0.8218
0.0323	0.7609	0.7312	0.7703	0.8355	0.8418
0.0541	0.8010	0.7520	0.8129	0.8563	0.8668
0.0816	0.8516	0.7791	0.8628	0.8834	0.8991
0.1176	0.9178	0.8161	0.9200	0.9200	0.9426
0.1667	1.0082	0.8694	0.9919	0.9724	1.0041
0.2373	1.1381	0.9521	1.0961	1.0531	1.0971
0.3478	1.3414	1.0976	1.2570	1.1930	1.2540
0.5455	1.7052	1.4158	1.5736	1.4914	1.5706
1.0000	2.5416	2.5416	2.5416	2.5416	2.5416
Aniline + Mesitylene					
0.0000	0.6213	0.6213	0.6213	0.6213	0.6213
0.0166	0.6531	0.6360	0.6716	0.7405	0.7440
0.0367	0.6917	0.6542	0.7154	0.7591	0.7669
0.0613	0.7390	0.6773	0.7738	0.7825	0.7955
0.0922	0.7983	0.7074	0.8383	0.8129	0.8325
0.1322	0.8751	0.7484	0.9146	0.8540	0.8819
0.1860	0.9784	0.8074	1.0010	0.9127	0.9515
0.2622	1.1248	0.8989	1.1237	1.0026	1.0563
0.3786	1.3483	1.0590	1.3071	1.1574	1.2306
0.5782	1.7316	1.4029	1.6438	1.4806	1.5724
1.0000	2.5416	2.5416	2.5416	2.5416	2.5416

Table 3. Deviations of Estimated Values of Viscosities in Bingham Relation ($\Delta\eta_B$), Kendall-Munroe Relation ($\Delta\eta_{KM}$), Arrhenius-Eyring Relation ($\Delta\eta_{AE}$), Croenaurer-Rothfus-Kermorerelation ($\Delta\eta_{CRK}$) and Gambrill Relation ($\Delta\eta_G$) with that of Experimental Values in all the Three Binary Liquid Mixtures at Temperature T = 303.15K

Mole fraction of Aniline (X)	$\Delta\eta_B$	$\Delta\eta_{KM}$	$\Delta\eta_{AE}$	$\Delta\eta_{CRK}$	$\Delta\eta_G$
Aniline + Toluene					
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.1145	0.0434	0.0718	0.0741	-0.0210	-0.0464
0.2254	0.0799	0.1284	0.1318	0.0361	-0.0130
0.3328	0.1095	0.1685	0.1681	0.0792	0.0094
0.4369	0.1327	0.1905	0.1848	0.1072	0.0213
0.5379	0.1498	0.1927	0.1809	0.1190	0.0230
0.6358	0.1609	0.1737	0.1528	0.1137	0.0153
0.7309	0.1666	0.1314	0.1046	0.0899	-0.0017
0.8232	0.1668	0.0642	0.0367	0.0469	-0.0272
0.9129	0.1213	0.0110	-0.0081	0.0239	-0.0201
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Aniline + *o*-Xylene					
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0146	0.1505	0.1641	0.1460	0.0599	0.0570
0.0323	0.3594	0.3890	0.3499	0.2847	0.2784
0.0541	0.4609	0.5098	0.4490	0.4055	0.3950
0.0816	0.5474	0.6199	0.5363	0.5157	0.4999
0.1176	0.5970	0.6987	0.5949	0.5949	0.5723
0.1667	0.6794	0.8182	0.6957	0.7151	0.6835
0.2373	0.7220	0.9081	0.7640	0.8070	0.7630
0.3478	0.7398	0.9836	0.8243	0.8882	0.8273
0.5455	0.5823	0.8718	0.7140	0.7962	0.7169
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Aniline + Mesitylene					
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0166	0.0502	0.0674	0.0317	-0.0372	-0.0410
0.0367	0.1910	0.2285	0.1673	0.1236	0.1158
0.0613	0.3231	0.3848	0.2883	0.2796	0.2666
0.0922	0.4432	0.5341	0.4032	0.4286	0.4091
0.1322	0.5458	0.6725	0.5063	0.5669	0.5390
0.1860	0.6219	0.7929	0.5993	0.6877	0.6488
0.2622	0.6550	0.8808	0.6560	0.7771	0.7235
0.3786	0.6108	0.9001	0.6520	0.8017	0.7285
0.5782	0.4069	0.7356	0.4947	0.6579	0.5661
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000

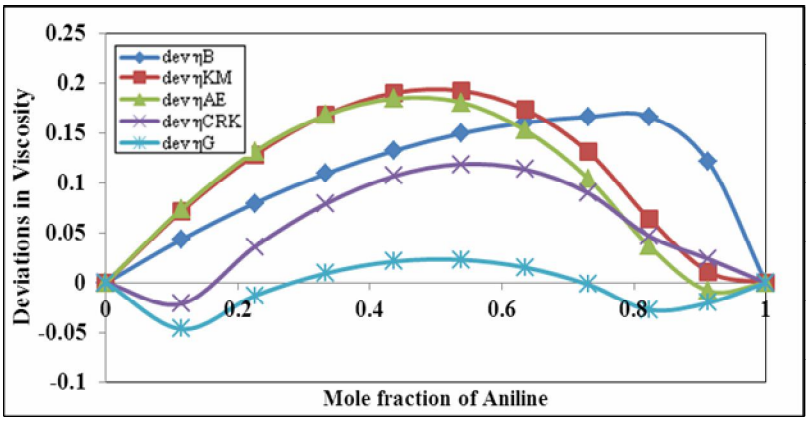

Fig. 1. Deviations in viscosity for different relations with mole fraction of aniline in (Aniline + Toluene) liquid mixture at temperature T = 303.15K.

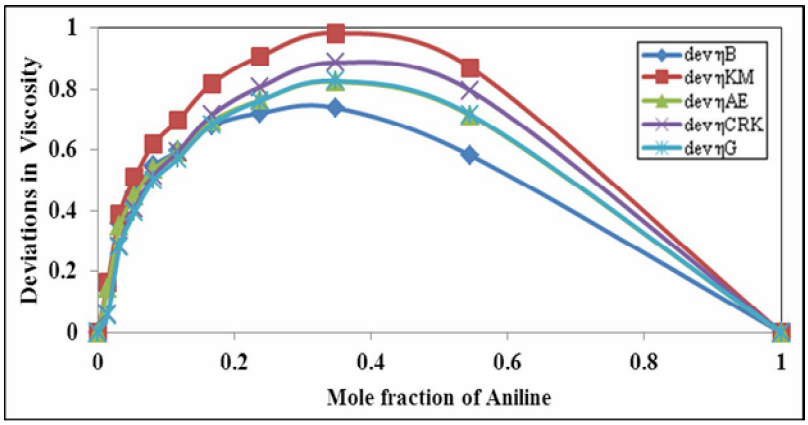

Fig. 2. Deviations in viscosity for different relations with mole fraction of aniline in (Aniline + *o*-Xylene) liquid mixture at temperature T = 303.15 K.

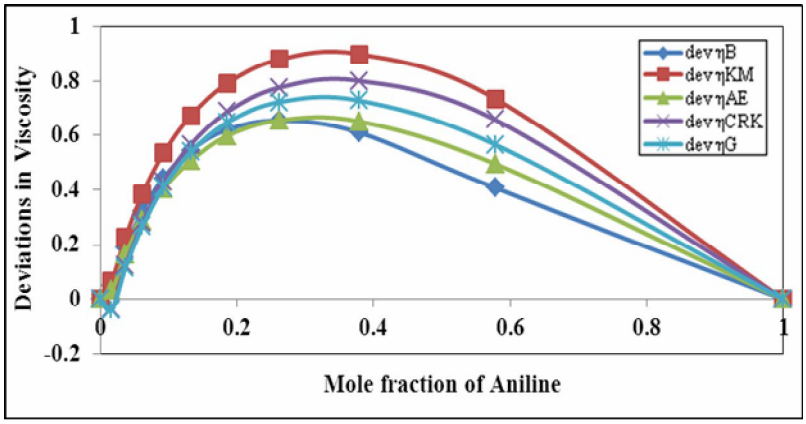

Fig. 3. Deviations in viscosity for different relations with mole fraction of aniline in (Aniline + Mesitylene) liquid mixture at temperature T = 303.15K.

the three binary liquid mixtures at T = 303.15 K studied.

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