

This article was downloaded by:

On: 28 January 2011

Access details: *Access Details: Free Access*

Publisher *Taylor & Francis*

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Physics and Chemistry of Liquids

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713646857>

Viscosity of aqueous solutions of some diamines

Muhammad A. Saleh^a; Shamim Akhtar^a; M. Shamsuddin Ahmed^a

^a Department of Chemistry, University of Chittagong, Chittagong - 4331, Bangladesh

To cite this Article Saleh, Muhammad A. , Akhtar, Shamim and Ahmed, M. Shamsuddin(2004) 'Viscosity of aqueous solutions of some diamines', *Physics and Chemistry of Liquids*, 42: 2, 103 – 115

To link to this Article: DOI: 10.1080/0031910031000136219

URL: <http://dx.doi.org/10.1080/0031910031000136219>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

VISCOSITY OF AQUEOUS SOLUTIONS OF SOME DIAMINES

MUHAMMAD A. SALEH*, SHAMIM AKHTAR
and M. SHAMSUDDIN AHMED

Department of Chemistry, University of Chittagong, Chittagong – 4331, Bangladesh

(Received 8 February 2003)

Viscosities of the systems, ethylenediamine (ED) + water (W), 1,2-diaminopropane (DAP) + W, trimethylenediamine (TMD) + W and *N,N*-dimethyltrimethylenediamine (DMTMD) + W, have been measured for the whole range of composition at temperatures ranging from 303.15 to 323.15 K. The viscosities have been plotted against the mole fraction of diamines, showing some common characteristics for all the systems. On addition of diamines to water viscosities rise up very rapidly and pass through maxima. Following the maxima viscosities decline quite rapidly and monotonously up to about 0.6 mole fraction of diamines, which then fall down rather slowly. The hydrophobic and hydrophilic effects are considered responsible for the ascending part of viscosities in water-rich region, although the former is thought to be much more predominant than the latter. The height of viscosity maxima and their shifting to more water-rich region have been explained preferentially in terms of the hydrophobic effect. The declining part of viscosities is thought to be due to continuous destruction of cage structures formed by hydrophobic interaction. The excess viscosities have been calculated and plotted against mole fractions of diamines. The characteristics of excess viscosities have been explained by the same reasonings as used to explain viscosities.

Keywords: Viscosity; Excess viscosity; Hydrophobic hydration; Ethylenediamine; Trimethylenediamine; 1,2-diaminopropane; *N,N*-dimethyltrimethylenediamine

1. INTRODUCTION

The present study is a part of our programme of studying the physico-chemical properties of aqueous solutions of hydrophobic organic solutes. In pursuance of this programme we reported in the recent past a number of studies on viscometric properties of aqueous solutions of some hydrophobic substances, such as alcohols [1], diols [2], acetone [3], dimethylsulfoxide, 1,4-dioxan, tetrahydrofuran [4], aliphatic amines [5], amides [6]. We noticed, to our surprise, that there is an absolute lack of viscometric data on aqueous solutions of diamines. This prompted us to undertake studies on aqueous solutions of diamines. As a first step towards this, we reported on the viscometric properties of the aqueous systems of ethylenediamine, trimethylenediamine and *N,N*-dimethyltrimethylenediamine, limited only to water-rich region [7]. The present study is an extended work of the above systems covering the whole range of concentration, with an additional system of 1,2-diaminopropane + water.

*Corresponding author.

2. EXPERIMENTAL

The diamines under investigation were procured from the following manufacturers with quoted purities: ethylenediamine (Beijing Chemical Works, 99%), trimethylenediamine (Merk-Schuchardt, 98%), *N,N*-dimethyltrimethylenediamine (Merk-Schuchardt, 98%) and 1,2-diaminopropane (Merk-Schuchardt, >98%). The chemicals were used without further purification except that each of the diamines was kept over molecular sieves (4A) for at least 2 weeks before its use. Thrice distilled water was used in the preparation of all the diamine solutions.

The density was measured by a 5 mL bicapillary pycnometer previously calibrated with distilled water. An Ostwald U-tube viscometer of the British standard Institution, with sufficiently long efflux time, was used so that no kinetic energy correction was necessary in viscosity measurement. The time of flow was recorded by a timer accurate up to ± 0.01 s. An analytical balance of accuracy ± 0.0001 g was used in density measurement. The solutions were prepared by mixing known masses of the components measured by the same balance. Mole fractions were accurate up to fourth place of decimal. For every measurement a thermostatic water bath controlled to ± 0.05 K was used. The maximum uncertainty in the measured viscosity was estimated to be ± 0.3 %.

3. RESULTS AND DISCUSSION

Viscosities of the aqueous solutions of ethylenediamine (ED), trimethylenediamine (TMD), 1,2-diaminopropane (DAP) and *N,N*-dimethyltrimethylenediamine (DMTMD) have been shown in Table I. The variation of viscosity as a function of mole fraction of the diamines, X_2 , can be represented satisfactorily, as indicated by high values of r^2 , by a polynomial equation of the type,

$$\eta = \sum_{i=0}^n A_i X_2^i \quad (1)$$

The values of the coefficients, A_i and r^2 are shown in Table II.

Figures 1–4 represent the variation of viscosity as a function of mole fraction of ED, TMD, DAP and DMTMD, respectively, at temperatures ranging from 303.15 to 323.15 K. The viscosities of all the systems have been shown in Fig. 5 at 303.15 and 323.15 K for comparison. The viscosities, in the unit 10^{-4} kg m⁻¹s⁻¹, of the pure liquids at 303.15 K are, ED (12.99), TMD (16.08), DAP (13.25) and DMTMD (12.998) and at 323.15 K, ED (9.04), TMD (10.896), DAP (9.091) and DMTMD (7.013).

The viscosity curves show the following general characteristics:

- On addition of diamines to water, viscosities rise up very rapidly and attain maximum values.
- Following the maxima, viscosities decline quite rapidly up to ~ 0.6 mole fraction of the diamines, which then fall down rather slowly.
- The temperature effect on viscosity is seen to be most prominent at compositions corresponding to maximum viscosities.
- The positions of the maximum are found to occur at 0.331, 0.296, 0.299 and 0.252 mole fractions of diamines for ED + W, TMD + W, DAP + W and DMTMD + W, respectively, and virtually remain unaffected by change of temperature.

TABLE I Experimental viscosities, η , and excess viscosities, η^E in $10^{-4} \text{ kg m}^{-1} \text{ s}^{-1}$, of aqueous diamines at different temperatures

T (K)	303.15		308.15		313.15		318.15		323.15	
	η	η^E	η	η^E	η	η^E	η	η^E	η	η^E
X_2	<i>Water (X₁) + ethylenediamine (X₂)</i>									
0.0000	8.006	0.000	7.226	0.000	6.557	0.000	5.994	0.000	5.501	0.000
0.1030	24.166	15.751	20.779	13.180	18.095	11.197	15.856	9.549	14.023	8.233
0.2041	55.090	46.198	45.126	37.095	37.493	30.202	31.584	24.919	26.793	20.674
0.2483	66.221	57.193	53.777	45.616	44.301	36.892	37.141	30.366	31.402	25.178
0.2962	75.734	66.495	60.886	52.536	49.335	41.749	40.812	33.874	34.081	27.708
0.3518	76.211	66.720	60.945	52.365	49.651	41.855	40.983	33.852	34.197	27.645
0.4036	73.934	64.202	59.630	50.830	48.174	40.176	39.890	32.575	33.359	26.636
0.4508	68.912	58.955	54.278	45.273	44.405	36.220	37.043	29.555	31.405	24.523
0.5066	57.129	46.900	46.856	37.602	39.162	30.749	32.758	25.061	27.874	20.798
0.5996	41.455	30.755	34.971	25.287	29.593	20.786	25.424	17.366	22.003	14.592
0.6989	29.098	17.778	24.914	14.668	21.725	12.407	19.023	10.499	16.803	8.964
0.7936	21.477	9.725	18.859	8.213	16.640	6.951	14.894	6.026	13.350	5.189
0.8925	16.223	3.895	14.436	3.263	13.070	2.898	11.894	2.582	10.813	2.241
1.0000	12.986	0.000	11.775	0.000	10.725	0.000	9.819	0.000	9.042	0.000
	<i>Water (X₁) + trimethylenediamine (X₂)</i>									
0.0500	15.802	7.512	13.797	7.512	12.267	5.480	10.972	4.768	9.913	4.221
0.0966	27.542	18.978	23.555	18.978	20.296	13.288	17.650	11.245	15.488	9.612
0.1458	43.602	34.739	36.192	34.739	30.314	23.064	25.886	19.260	22.223	16.146
0.1990	62.889	53.691	50.881	53.691	41.882	34.361	35.359	28.487	29.506	23.204
0.2473	75.680	66.167	60.548	66.167	49.303	41.528	40.777	33.673	34.250	27.736
0.2961	82.189	72.347	65.354	72.346	53.135	45.094	43.783	36.437	36.764	30.029
0.3465	79.913	69.719	64.011	69.719	52.199	43.874	43.358	35.753	36.320	29.349
0.3974	74.378	63.815	60.215	63.815	49.463	40.841	41.200	33.324	34.701	27.483
0.4955	58.778	47.467	48.319	47.467	40.379	31.154	34.143	25.718	29.346	21.628
0.5995	43.070	30.908	36.440	30.908	31.266	21.356	26.737	17.688	23.137	14.850
0.6969	32.236	19.220	27.792	19.220	24.190	13.592	21.137	11.462	18.658	9.801
0.8006	25.009	11.016	21.774	11.016	19.208	7.825	17.118	6.729	15.341	5.833
0.8936	19.971	5.041	17.616	5.041	15.727	3.591	14.165	3.090	12.814	2.682
1.0000	16.080	0.000	14.447	0.000	13.059	0.000	11.914	0.000	10.896	0.000
	<i>Water (X₁) + 1,2-diaminopropane (X₂)</i>									
0.0998	30.036	21.617	25.288	17.692	21.54	14.645	18.549	12.248	16.250	10.470
0.1997	65.963	57.110	52.584	44.598	42.867	35.617	35.591	28.966	29.770	23.688
0.2522	77.022	67.931	60.951	52.752	49.129	41.685	40.408	33.607	33.647	27.403
0.2992	80.426	71.117	63.825	55.431	51.386	43.764	42.106	35.143	34.955	28.562
0.3412	77.928	68.420	61.961	53.388	50.329	42.544	41.103	33.992	34.525	27.995
0.4012	70.954	61.154	56.777	47.943	46.9	38.198	38.227	30.899	32.044	25.315
0.5022	55.384	45.073	45.038	35.745	37.343	28.901	31.397	23.689	26.711	19.631
0.6011	39.212	28.374	32.885	23.120	27.92	19.048	23.948	15.848	20.796	13.356
0.6913	28.441	17.099	24.431	14.215	21.132	11.848	18.498	10.024	16.321	8.536
0.7912	21.189	9.261	18.542	7.802	16.339	6.576	14.504	5.595	13.025	4.839
0.8998	16.888	4.289	15.012	3.672	13.116	2.805	12.162	2.755	11.012	2.367
1.0000	13.251	0.000	11.924	0.000	10.844	0.000	9.891	0.000	9.091	0.000
	<i>Water (X₁) + N,N-dimethyltrimethylenediamine (X₂)</i>									
0.0996	48.560	40.411	39.463	32.096	32.627	25.931	27.392	21.260	23.232	17.596
0.1504	70.775	62.553	56.368	48.928	45.780	39.012	37.914	31.711	31.604	25.898
0.1994	83.559	75.265	66.234	58.723	53.410	46.571	43.716	37.443	36.236	30.462
0.2521	83.940	75.568	66.313	58.725	53.510	46.595	43.834	37.485	36.361	30.513
0.2995	76.885	68.442	61.333	53.675	49.673	42.688	40.892	34.474	34.021	28.105
0.3809	60.008	51.443	48.615	40.835	40.046	32.940	33.541	27.002	28.310	22.276
0.5000	39.190	30.442	32.816	24.854	27.703	20.416	23.723	17.004	20.490	14.279
0.5994	25.248	16.344	21.165	13.048	18.836	11.395	16.497	9.624	14.612	8.249
0.6826	19.393	10.357	17.013	8.764	15.018	7.445	13.392	6.387	12.008	5.515
0.7798	14.918	5.725	13.294	4.888	11.909	4.179	10.773	3.611	9.811	3.163
0.8918	11.625	2.248	10.416	1.825	9.578	1.663	8.777	1.430	8.099	1.268
1.0000	12.998	0.000	8.773	0.000	8.098	0.000	7.531	0.000	7.013	0.000

TABLE II Coefficients, A_i of Eq. (1) expressing coefficient of viscosity, $\eta \times 10^4/\text{kg m}^{-1} \text{s}^{-1}$, and the square of the regression coefficient, r^2 , for the systems

System	Temperature (K)	A_0	A_1	A_2	A_3	A_4	A_5	A_6	r^2
W + ED	303.15	8.1957	-160.000	445.12	-16870	25913	-18165	4835.7	0.9988
	308.15	7.3391	-106.460	3393.8	-13125	20519	-14672	3995.2	0.9992
	313.15	6.0696	-61.648	2519.3	-9900.8	15591	-11219	3075.6	0.9996
	318.15	6.0181	-37.039	1954.3	-7807.5	12419	-9022.2	2497.5	0.9997
	323.15	5.5075	-17.020	1488.5	-6032.9	96357	-7019.3	1948.5	0.9997
W + TMD	303.15	8.9803	-105.21	4735.2	-19911	33458	-25585	7415.4	0.9976
	308.15	7.8524	-51.549	3425.6	-14585	24566	-18805	5456.5	0.9983
	313.15	7.0004	-19.591	2531.5	-10909	18410	-14102	4094.6	0.9985
	318.15	6.2949	0.0825	1920.7	-8409.5	14257	-10946	3183.4	0.9990
	323.15	5.7506	12.276	1450	-6409.5	10836	-8277.7	2394.5	0.9990
W + DAP	303.15	7.7986	-48.539	4449.7	-19570	33629	-26119	7664.7	0.9989
	308.15	7.0786	-10.869	3192.3	-14221	24467	-18988	5564.7	0.9990
	313.15	6.4589	11.2	2324.1	-10470	17998	-13933	4074.7	0.9995
	318.15	5.8815	29.157	1680	-7760.7	13410	-10391	3036.2	0.9989
	323.15	5.4219	37.555	1233	5816.2	10062	-7778.1	2265.5	0.9991
W + DMTMD	303.15	7.3653	383.28	1866	-15274	32661	-29034	9399.3	0.9946
	308.15	6.7559	317.47	1234.4	-10961	23682	-21114	6843.3	0.9951
	313.15	6.201	267.49	799.6	-7934.5	17358	-15522	5033.6	0.9955
	318.15	5.7219	228.71	494.81	-5768.7	12826	-11521	3741.3	0.9961
	323.15	5.291	195.5	296.12	-4248.4	9611.6	-8675.2	2822.2	0.9964

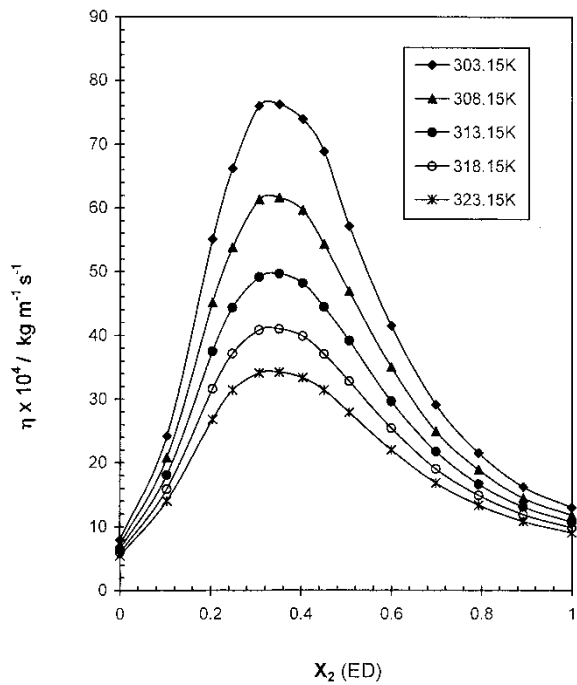


FIGURE 1 Viscosity as a function of mole fraction of ethylenediamine, X_2 (ED), at different temperatures.

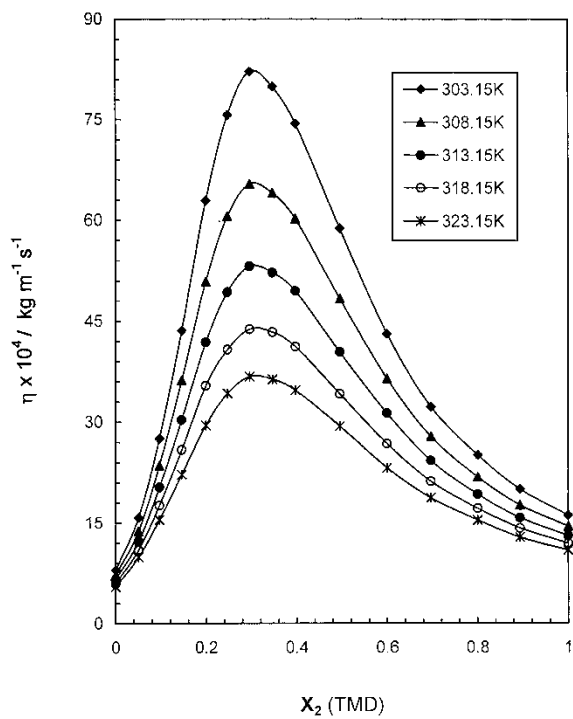


FIGURE 2 Viscosity as a function of mole fraction of trimethylenediamine, X_2 (TMD), at different temperatures.

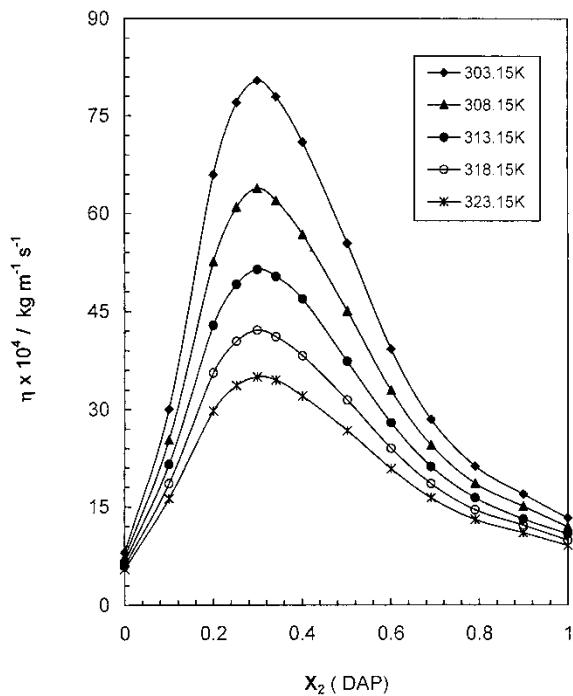


FIGURE 3 Viscosity as a function of mole fraction of 1,2-diaminopropane, X_2 (DAP), at different temperatures.

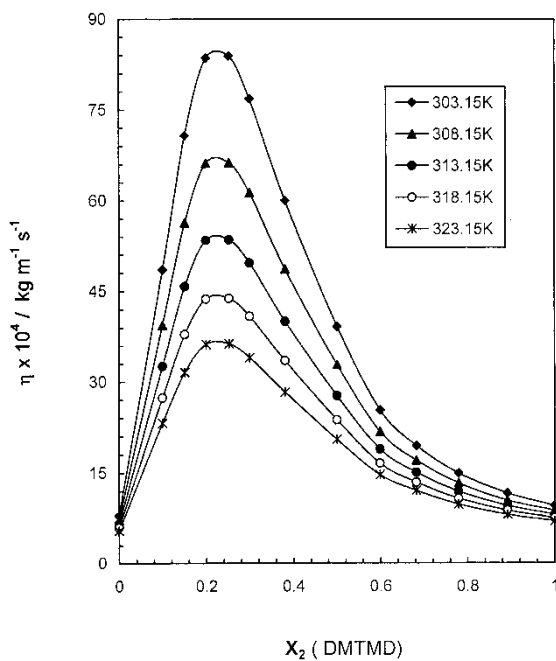


FIGURE 4 Viscosity as a function of mole fraction of *N,N*-dimethyltrimethylenediamine, X_2 (DMTMD), at different temperatures.

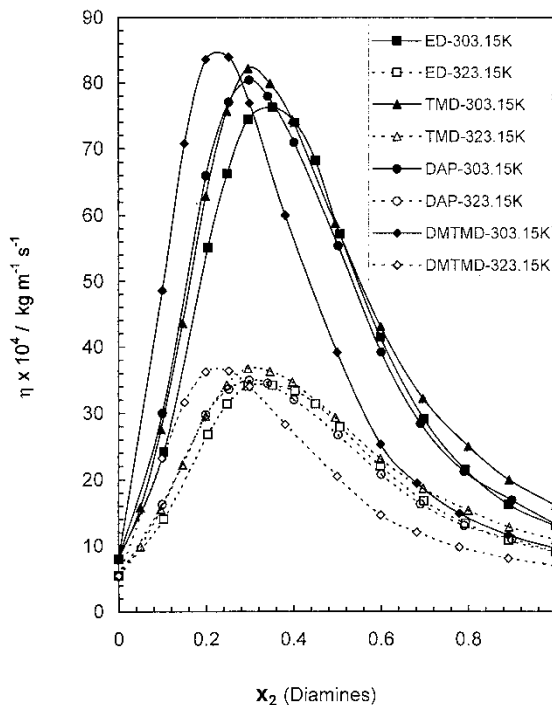
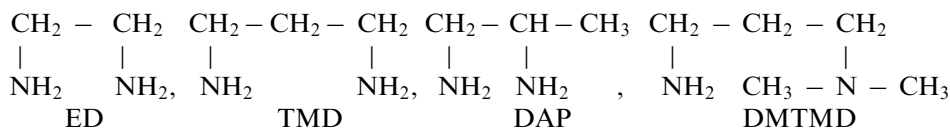


FIGURE 5 Comparison of viscosities of different systems at 303.15 and 323.15 K against mole fractions of diamines (X_2).

The viscosity curves of aqueous solutions of diamines are found to be typical of those of aqueous solutions of amphiphiles, such as, alcohols, amines, amides etc. [8–14]. The rapidly ascending part of the viscosity may be ascribed primarily to two effects: (i) hydrophilic effect and (ii) hydrophobic hydration. In the first, it is envisaged that diamines form complexes with water through hydrogen bonding, and in the second, the hydrocarbon moieties of the diamines are surrounded by water molecules forming cage-like structures, which are thought to be predominantly responsible for sharp rise of viscosity. The existence of unusually large negative excess molar volumes, V_m^E , and deep minima in water-rich region of these systems is inconsistent with this proposition [15]. With increased addition of diamines, more and more of such cages are formed, and hence the rapid rise of viscosity.

The maximum viscosity, η_{\max} (in the unit $10^{-4} \text{ kg m}^{-1} \text{ s}^{-1}$), for different systems at 303.15 K are found to be in the order, DMTMD + W (83.94) > TMD + W (82.19) > DAP + W (80.4) > ED + W (76.24). The η_{\max} are considered to be extremely large compared to the viscosity of pure water and that their positions along the composition axis are different. These facts may conveniently be explained by the phenomenon of hydrophobic hydration. But before we proceed to do this we need to consider the structures of the diamines, which are shown below:



To understand the degree of hydrophobic effect of the diamines, at least qualitatively, we can make use of the fact that CH_3 group is the most potent hydrophobic group, followed by CH_2 and CH groups, as formulated by Andini *et al.* [16]. Taking into consideration of this fact and perusal of the structures of these diamines above, we can easily arrive at the conclusion that, hydrophobic capacity of the diamines follows the order: $\text{DMTMD} > \text{TMD} \sim \text{DAP} > \text{ED}$. As the hydrophobicity is related to the extent of formation of cage structures, heights of η_{max} should follow the same order as above – which is indeed found to be the case.

It is to be noted that the positions of the η_{max} for different systems depend upon the degree of hydrophobicity in a manner that the greater the hydrophobicity the larger is the shifting of η_{max} towards more water-rich region. This is expected, because the greater the degree of hydrophobicity of diamines the larger is the number of water molecules to be required for the formation of cage structure, and hence, the shifting of η_{max} towards more water-rich region.

The effect of temperature on viscosity of the systems has been found to be highly significant, particularly on η_{max} . It is seen that, reduction of η_{max} for rise of temperature from 303.15 to 323.15 K, $|\Delta\eta_{\text{max}}|$, in the unit $10^{-4} \text{ kg m}^{-1} \text{ s}^{-1}$, has been found to be $\text{DMTMD} + \text{W} (47.58) > \text{TMD} + \text{W} (45.43) \sim \text{DAP} + \text{W} (45.47) > \text{ED} + \text{W} (42.01)$. Such drastic reductions in η_{max} are expected, as water–water bonds formed by the cage structure are supposed to be less stable thermally than the normal water–water bonds [17,18]. The fragile nature of the water structure formed around the hydrocarbon residues of the diamines can be supported by large positive excess entropies of activation for viscous flow, $\Delta S^{\#E}$, of the solutions [15]. The above order of η_{max} can easily be justified by the hydrophobic capacity of the diamines.

When a reasonable number of cages are formed on addition of diamines to water, destruction of cages begins, probably through a process known as hydrophobic interaction [19]. However, as long as the rate of formation of cages is larger than the rate of destruction of cages, obviously, occurring in water-rich region, viscosity continues to increase. The maxima can be viewed as turning points when the two rates are equal. Following the maxima the rate of destruction becomes increasingly greater giving rise to the formation of more and more normal water structures and diamines, and hence the fairly rapid decrease of viscosity. The process is thought to continue until the pure state of diamines is reached.

The excess viscosities, η^E , of the systems were calculated by using the equation,

$$\eta^E = \eta - \exp(X_1 \ln \eta_1 + X_2 \ln \eta_2) \quad (2)$$

where η is the observed viscosity of the solution. X_1 and X_2 are the mole fractions of water and diamines respectively, and η_1 and η_2 are the corresponding viscosities of the pure components. The excess viscosities are shown in Table I at different temperatures. The values can be expressed satisfactorily by a Redlich–Kister polynomial equation of the form,

$$\eta^E = X_1 X_2 \sum_{i=0}^n A_i (1 - 2X_1)^i \quad (3)$$

The coefficients, A_i , and standard deviations, σ , have been obtained by the least-squares method. The values of A_i and σ are listed in Table III. The η^E values have been plotted in Figs. 6–9 for different systems as a function of mole fractions of diamines at

TABLE III Coefficients, A_i , of Redlich–Kister equation, Eq. (3), expressing excess viscosity, η^E , and standard deviation, σ , in $10^{-4} \text{ kg m}^{-1} \text{ s}^{-1}$ for the systems

System	Temperature (K)	A_0	A_1	A_2	A_3	A_4	A_5	σ
W + ED	303.15	196.8861	-382.6084	48.8076	639.3310	-316.1813	-260.0907	1.00387
	308.15	155.826	-286.4560	49.8241	429.5844	-255.9360	-133.4936	0.70746
	313.15	125.8152	-216.8419	39.8740	286.0087	-193.7383	-52.2017	0.40772
	318.15	102.7861	-169.5302	36.5213	202.7203	-155.6187	-15.7798	0.30967
	323.15	85.1890	-133.9003	28.8246	145.0742	-120.3291	3.0652	0.26999
W + TMD	303.15	188.9368	-387.6567	223.4220	520.8985	-478.5675	-151.048	1.73600
	308.15	152.1279	292.2079	162.5013	365.7965	-349.2910	-89.8685	1.15482
	313.15	124.4372	-224.9259	120.9057	265.0433	-260.2442	-55.9037	0.86502
	318.15	102.3049	-177.8599	95.9703	197.8406	-200.9278	-34.7398	0.58100
	323.15	85.4952	-143.6976	73.3333	162.8661	-153.4328	-38.1218	0.45230
W + DAP	303.15	179.6054	-353.9753	245.3031	151.1257	-470.0440	335.6977	0.60336
	308.15	142.8805	-268.7546	180.2639	110.7420	-341.1065	246.5402	0.46127
	313.15	115.4734	-207.9103	135.5855	82.4100	-256.6871	178.6314	0.30732
	318.15	78.4543	-128.8654	77.5609	34.0834	-138.2045	124.1244	0.16328
	323.15	94.4765	-160.3346	101.6875	37.2824	-185.1873	172.3875	0.22839
W + DMTMD	303.15	114.0240	-296.6553	556.8312	-503.5781	-552.0907	861.1757	1.44165
	308.15	92.5602	-235.7194	418.3454	-345.5874	-406.0019	598.0644	1.23259
	313.15	76.9642	-183.7923	314.9245	-277.3597	-295.3845	467.7151	0.88246
	318.15	64.3437	-148.5349	242.5957	-207.4651	-219.6091	346.7598	0.69654
	323.15	54.1982	-120.3688	189.3426	-160.9532	-165.5002	265.3007	0.56034

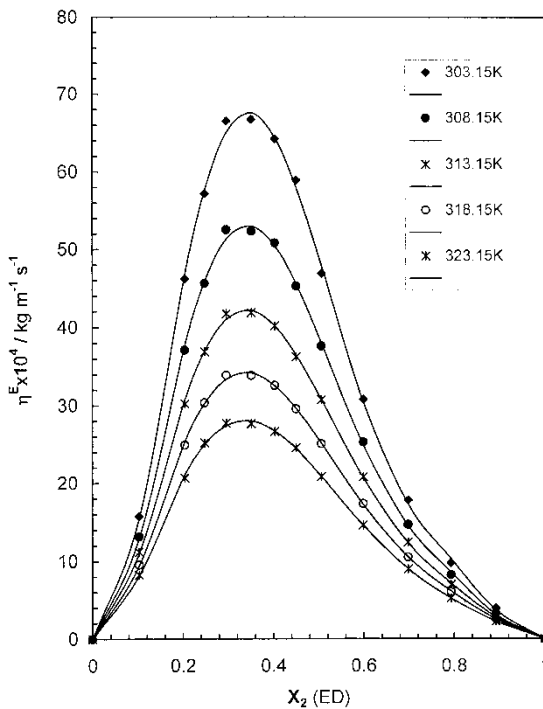


FIGURE 6 Excess viscosity of the system water (X_1) + ethylenediamine (X_2) at different temperatures.

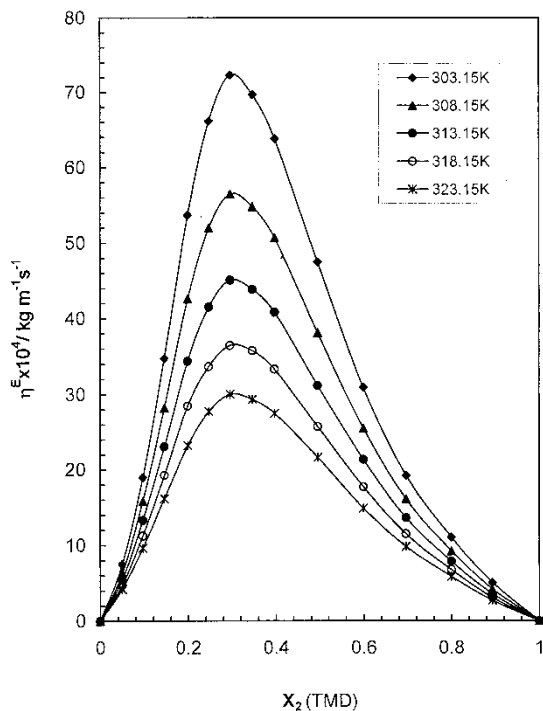


FIGURE 7 Excess viscosity of the system water (X_1) + trimethylenediamine (X_2) at different temperatures.

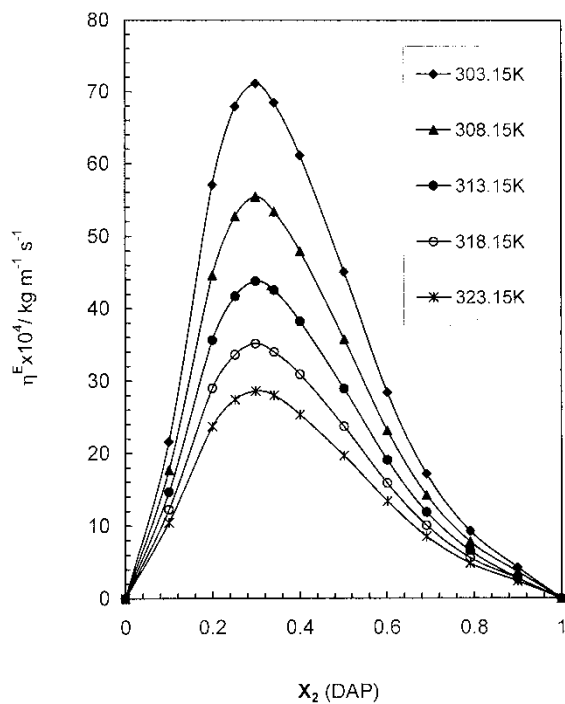


FIGURE 8 Excess viscosity of the system water (X_1) + 1,2-diaminopropane (X_2) at different temperatures.

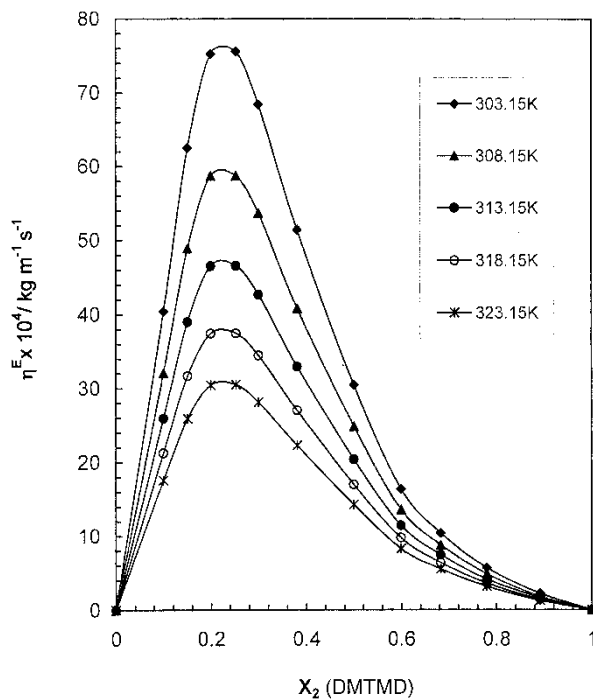


FIGURE 9 Excess viscosity of the system water (X_1) + *N,N*-dimethyltrimethylenediamine (X_2) at different temperatures.

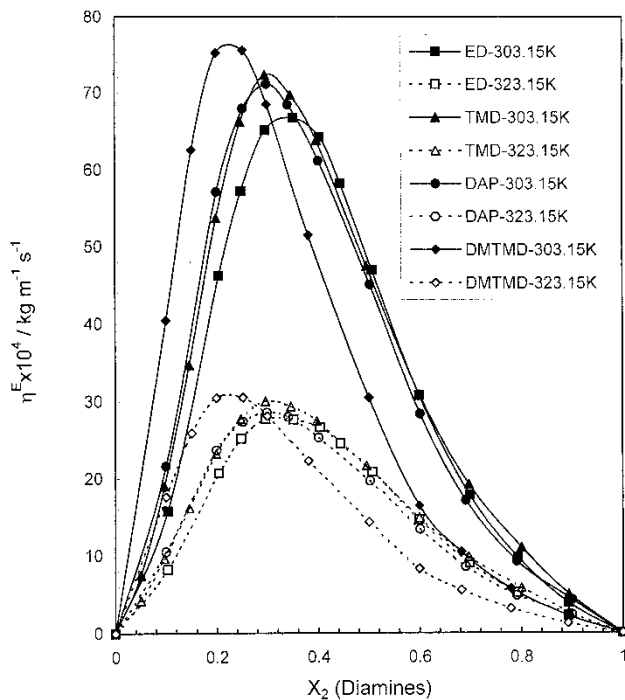


FIGURE 10 Comparison of excess viscosity of different systems against mole fractions of diamines (X_2) at 303.15 and 323.15 K.

different temperatures. Figure 10 shows the comparison of η^E vs. X_2 curves at 303.15 and 323.15 K for all the systems.

The excess viscosities have been found to be positive and large in magnitude, indicating that the solutions are highly nonideal. The characteristics of the η^E curves are very much similar to those of η curves as described earlier. The excess viscosities can be explained by the same reasonings as those put forward for the explanation of viscosities.

Acknowledgement

The authors gratefully acknowledge the financial support of the Ministry of Science, Information and Communication Technology, Govt. of the People's Republic of Bangladesh, as a special allocation for the project, "Physical Properties and Molecular Interactions in Liquid Systems".

References

- [1] S. Akhtar, M.M.H. Bhuiyan, M.S. Uddin, B. Sultana, M. Nessa and M.A. Saleh (1999). *Phys. Chem. Liq.*, **37**, 215.
- [2] M.A. Saleh, S. Begum, S.K. Begum and B.A. Begum (1999). *Phys. Chem. Liq.*, **37**, 785.
- [3] M.A. Saleh, D. Biswas, O. Ahmed, S. Akhtar and M. Habibullah (1993). *Chittagong University Stud. Part II: Sci.*, **17**(2), 127.
- [4] M.A. Saleh, S. Akhtar, M.S. Ahmed and M.H. Uddin (2001). *Phys. Chem. Liq.*, **39**, 551.
- [5] M.A. Saleh, S. Akhtar and A.R. Khan (2001). *Phys. Chem. Liq.*, **39**, 85.
- [6] S. Akhtar, A.N.M.O. Faruk and M.A. Saleh (2001). *Phys. Chem. Liq.*, **39**, 383.

- [7] M.A. Saleh, M.S. Ahmed and M.S. Islam (2002). *Phys. Chem. Liq.*, **40**, 447.
- [8] D. Wolf and A. Kudish (1980). *J. Phys. Chem.*, **84**, 921.
- [9] Y. Tanaka, Y. Matsuda, H. Fujiwara, H. Kubota and T. Makita (1987). *Int. J. Thermophys.*, **8**, 147.
- [10] P.C. Senanayaka, N. Gee and G.R. Freeman (1987). *Can. J. Chem.*, **65**, 2441.
- [11] P.K. Kimkemboi and A.J. Eastel (1994). *Can. J. Chem.*, **72**, 1937.
- [12] H. Kubota, S. Tsuda and M. Murata (1979). *Rev. Phys. Chem., Japan*, **49**, 59.
- [13] Y. Tanaka, T. Yamamoto and Y. Satomi (1977). *Rev. Phys. Chem., Japan*, **47**, 12.
- [14] P. Assarson and F.R. Eirich (1968). *J. Phys. Chem.*, **72**, 2970.
- [15] M.S. Ahmed. *Ph.D. Thesis*. Department of Chemistry, Chittagong University (to be submitted).
- [16] S. Andini, G. Castronuovo, V. Elia and L. Fasano (1990). *J. Chem. Soc. Faraday Trans.*, **86**, 3567.
- [17] A.K. Covington and P. Jones (Eds.) (1968). *Hydrogen-bonded Solvent Systems*, p. 221. Taylor and Francis Ltd., London.
- [18] F. Franks (1983). *Water*, p. 44. The Royal Society of Chemistry, London.
- [19] *ibid*, p. 47.