Densities and Viscosities of Aqueous 1-Propanol and 2-Propanol Solutions at Various Temperatures

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ABSTRACT

Densities and viscosities of the binary aqueous solutions of 1-Propanol (PA) and 2-Propanol (IPA) have been determined experimentally throughout the whole concentration range for temperatures between 20°C and 60°C. The data were correlated by an equation based on Erying's absolute rate theory. The energy of activation for viscous flow is presented. The equation correlates the viscosity values of the binary solutions with an average absolute deviation percentage error (AAD%) of 0.7714% and 1.2351% for PA and IPA aqueous solutions, respectively. The AAD values for density correlations of PA and IPA aqueous solutions are less than 0.07%.

Keywords: viscosity, density, binary aqueous solutions

1. INTRODUCTION

A knowledge of thermodynamic and transport properties of binary aqueous solutions are important in engineering, designing new technological processes and also in developing theoretical models. Volumetric properties of aqueous solutions, in conjunction with other thermodynamic properties provide useful information about water-solute interactions. Density and viscosity of aqueous solutions are required in both physical chemistry and chemical engineering calculations involving fluid flow, heat and mass transfer.(1) The values of such quantities may sometimes be obtained from tables but it is usually found that even the most extensive physico-chemical tables do not contain all the data necessary for designing a technological process.(2) Consequently, reliable and

accurate data which can be applied to wide ranges of temperature are required. Alcohols are organic compound which are widely used within the chemical industry. The main uses of alcohols are as solvents for gums, resins, lacquers and varnishes, in the making of dyes and for essential oils in perfumery.

Densities and viscosities of binary aqueous solutions of 1-Propanol have been studied by Mikhail et al.[3] at temperatures 25°, 30°, 35°, 40° and 50°C and by Ling et al. at temperatures 30°, 55°, 75° and 95°C.[4] Viscosities studies of solutions of water in n-Aliphatic alcohols were also reported at 15°, 25°, 35°, and 45°C.[5] Densities and refractive indices of n-Propyl, Isopyl and Methyl alcohols with water were measured at 20-25°C.[6] Densities and refractive indices of pure 1-Propanol were given by Ortega.[7]

As part of our study, we present and discuss density, viscosity data for binary systems of 1-Propanol + water and 2-Propanol + water at temperatures from 20°C and 60°C over the entire composition range.

2. Experimental

2.1 Materials:

1-Propanol (PA) and 2-Propanol (IPA) with minimum purity of 99.5% and 99.8% respectively were obtained from Merck Chemicals. Both were used without further purification. Ultra pure water was used for preparation of various solutions. Mixtures of these alcohols with ultra pure water were made by weighing the known amount of the respective chemicals, with care being taken to minimize exposure to air (carbon dioxide).

2.2 Measurement

2.2.1. Density

An Anton Paar DMA58 vibrating tube digital density meter was used to determine the densities of the solutions from 20- 60°C at 5°C intervals. The U-tube of the density

meter was washed with water and acetone and dried with air before measurement. The density meter was calibrated by dry air and ultra pure water. The density of water at 20°C was 0.99823 g-cm^{-3}.[8] Densities of solution ρ (g-cm^{-3}), were calculated by the equation

$$\rho = AT^2 - B \quad (1)$$

$$A = (\rho_1 - \rho_2) / (T_1^2 - T_2^2) \quad (2)$$

$$B = (T_2^2 \rho_1 - T_1^2 \rho_2) / (T_1^2 - T_2^2) \quad (3)$$

where A and B are calibration constants, ρ the density, T the temperature in Kelvin and index 1 and 2 refer to air and water, respectively. The uncertainty of the density value is $\pm 1 \times 10^{-5}$ g-cm^{-3}.

2.2.2. Viscosity

The kinematic viscosities were determined by using an Ubbelohde viscometer calibrated with ultra pure water. The viscosity of water at 20°C was 1.0020 cP.[8] The viscometer was immersed in a water bath. The temperature of the water bath was controlled to ±0.1°C. The flow time was measured with a stop-watch accurate to 0.01s. Measurements were repeated at least three times for each solution and temperature. The kinematic viscosity of solutions is given by

$$\nu = k_1 t - k_2/t \quad (4)$$

where ν is the kinematic viscosity, t is the flow time and k_1, k_2 are the viscometer constants. The k_2/t term represents the correction due to kinetic energy and can generally be neglected. The dynamic viscosities were then calculated from the measured kinematic viscosities and the densities of the same solutions.

3. RESULTS AND DISCUSSION

The viscosity and density data for the binary aqueous solutions of PA and IPA from 20- 60°C are tabulated in Tables I-IV, respectively. The viscosity of the aqueous PA

and IPA solutions is plotted versus mole fraction in Fig. 1 and Fig. 2. The aqueous PA viscosity data of Mikhail[3], Ling[4] and D'Aprano[5] are also plotted in Fig.1 for comparison. The viscosity measured in this work is in good agreement with these researchers, except the values at 25°C reported by D'Aprano[5], which are slightly higher than the data of present study. From the tables I and II, we can found that viscosity values decrease with increasing temperature. Viscosity of PA and IPA aqueous solutions exhibit a maximum at about 0.3000 mole fraction alcohols and then decrease slowly to the value of pure alcohol. The maximum viscosity is reflects to presence of hydrogen bonding between alcohols and water molecules. To correlate the viscosity of aqueous solutions, a equation based on Erying's absolute rate theory is applied:[9]

$$\eta_C = \frac{\tau_c}{\sigma_c}\cdot\left(\frac{\eta_1}{\tau_c}\cdot\frac{e^{xE}}{1+xV}\right)^{\psi_C} \qquad (5)$$

where, $\psi_C = 1 - x^\beta + x^\beta(1-x^\beta)\psi_{12} + x^\beta\psi_2$

η_C is viscosity of the binary solutions, τ_c is shear stress, σ_c is apparent viscosity rates, component 1 is a known Newtonian fluid, E the activation energy for viscous flow and V the molar volume of holes. The parameters of equation (4) are listed in Table V and VI. PA has higher activation energy than IPA. This could be due to extra energy required to break the hydrogen bond in primary alcohols. The average absolute deviation percentage error (AAD%) of the viscosity measurement are 0.7714% and 1.2351% for aqueous PA and IPA solutions, respectively.

Experimental density data for the binary aqueous solutions of PA and IPA were measured at 9 temperatures between 20- 60°C throughout the whole concentration range. The results are shown in Fig. 3 and 4. The density results of aqueous PA reported by Mikhail[3] and Ling[4] are included in Fig. 3. It is obvious that our measured data agree

well with those researchers referenced above. From Table III and IV, we can find that the densities generally decrease with increasing temperatures and content of alcohol. Densities for binary solutions can be represented by the following polynomial equation which is convenient for interpolation:

$$d = d_0 + \sum_{i=1}^{5} a_i x^i \qquad (6)$$

Where d_0 is density of pure water, a_I is the constant and x is the mole fraction of alcohols. The polynomial coefficients are listed in Table VII and VIII. The average absolute deviation percentage error (AAD%) for density calculations are 0.0682% and 0.0669% for aqueous PA and IPA solutions, respectively.

4. CONCLUSION

The densities and viscosities of aqueous PA and IPA solutions have been measured experimentally over the entire range for temperatures from 20- 60°C. The density data were represented by the polynomial equation. An equation based on Erying's absolute rate theory was used to fit the viscosity data. Satisfactory results were obtained. Further investigation will be carried out to measure and predict the viscosities and densities of the ternary aqueous solutions containing alcohol with an electrolyte and non- electrolyte from the binary data obtained from the binary aqueous solutions.

ACKNOWLEDGMENT

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REFERENCES

1. F.Giro, M. F. Goncalves, A. G. M. Ferreira and I. M. A. Fonseca, *Fluid Phase Equilibri.* **204**, 217 (2003).
2. S. Bretsznajder, *Prediction of Transport and other Physical Properties of Fluids*, (Pergamon, Oxford 1971), p. 1.

3. S. Z. Mikhail and W. R. Kimel, *J. Chem. Eng. Data* **8**, 323 (1963).
4. T. D. Ling and M. V. Winkle, *J. Chem. Eng. Data* **3**, 88 (1958).
5. A. D'Aprano, I. D. Donato, E. Caponetti and V. Agrigento, *J. Solution Chem.* **8**, 793 (1979).
6. K. Y. Chu and A. R. Thompson, *J. Chem. Eng. Data* **7**, 358 (1962).
7. J. Ortega, *J. Chem. Eng. Data* **27**, 312 (1982).
8. *Handbook of Chemistry and Physics*, CRC Press, Cleveland, 63rd edn. (1980).
9. C. S. Tan, T. T. Teng, I. Mahamad Hakimi, C. P. Lim, F. M. Pang and C. E. Seng, *Proceeding of the 18th Symposium of Malaysia Chemical Engineers*, (2004). P. 1-190 – 1-196.

Table I. Dynamic viscosity (cP) of 1-Propanol (1) + water (2) at different temperatures.

Mole fraction, x_1	20°C	25°C	30°C	35°C	40°C	45°C	50°C	55°C	60°C
0.00000	1.0020	0.8904	0.7975	0.7194	0.6529	0.5960	0.5468	0.5040	0.4665
0.01000	1.1568	1.0245	0.9057	0.8100	0.7274	0.6588	0.6003	0.5507	0.5071
0.02000	1.3351	1.1607	1.0191	0.9118	0.8069	0.7256	0.6568	0.5992	0.5491
0.04999	1.8983	1.6039	1.3664	1.1873	1.0389	0.9192	0.8197	0.7383	0.6690
0.06999	2.2093	1.8446	1.5557	1.3417	1.1672	1.0265	0.9119	0.8174	0.7383
0.09998	2.5463	2.1172	1.7865	1.5305	1.3298	1.1642	1.0295	0.9197	0.8274
0.19997	3.1099	2.5985	2.1928	1.8787	1.6248	1.4197	1.2502	1.1122	0.9940
0.29997	3.1741	2.6747	2.2677	1.9526	1.6919	1.4790	1.3029	1.1570	1.0339
0.39996	3.0544	2.5930	2.2160	1.9149	1.6657	1.4596	1.2877	1.1461	1.0243
0.49995	2.8811	2.4662	2.1186	1.8398	1.6094	1.4160	1.2515	1.1166	0.9991
0.59998	2.7079	2.3339	2.0228	1.7647	1.5472	1.3654	1.2115	1.0844	0.9712
0.70003	2.5383	2.2030	1.9203	1.6865	1.4848	1.3152	1.1708	1.0501	0.9442
0.80002	2.4034	2.0980	1.8397	1.6232	1.4368	1.2779	1.1418	1.0261	0.9256
0.89995	2.3011	2.0228	1.7828	1.5807	1.4048	1.2534	1.1229	1.0116	0.9144
1.00000	2.1976	1.9480	1.7265	1.5420	1.3790	1.2358	1.1110	1.0032	0.9086

Table II. Dynamic viscosity (cP) of 2-Propanol (1) + water (2) at different temperatures

Mole fraction, x_1	20°C	25°C	30°C	35°C	40°C	45°C	50°C	55°C	60°C
0.0000	1.0020	0.8904	0.7975	0.7194	0.6529	0.5960	0.5468	0.5040	0.4665
0.0100	1.1702	1.0294	0.9120	0.8150	0.7328	0.6637	0.6039	0.5544	0.5104
0.0200	1.3692	1.1882	1.0404	0.9233	0.8231	0.7385	0.6679	0.6089	0.5565
0.0500	2.0623	1.7257	1.4676	1.2627	1.0981	0.9659	0.8559	0.7667	0.6911
0.0707	2.5446	2.0896	1.7373	1.4789	1.2691	1.1033	0.9710	0.8630	0.7727
0.1000	3.0555	2.4732	2.0412	1.7167	1.4582	1.2606	1.1013	0.9727	0.8681
0.2000	3.7429	3.0411	2.5040	2.1094	1.7888	1.5385	1.3369	1.1751	1.0375
0.3000	3.7275	3.0690	2.5517	2.1535	1.8350	1.5793	1.3734	1.2068	1.0661
0.4000	3.4825	2.8950	2.4258	2.0621	1.7651	1.5248	1.3278	1.1681	1.0333
0.5000	3.1814	2.6682	2.2529	1.9258	1.6571	1.4368	1.2559	1.1070	0.9816
0.6000	2.8889	2.4415	2.0763	1.7868	1.5435	1.3446	1.1786	1.0414	0.9262
0.7001	2.6562	2.2570	1.9338	1.6689	1.4488	1.2650	1.1126	0.9852	0.8768
0.7999	2.4845	2.1277	1.8247	1.5851	1.3790	1.2076	1.0642	0.9437	0.8403
0.8999	2.3955	2.0548	1.7722	1.5379	1.3409	1.1754	1.0346	0.9189	0.8181
1.0000	2.4150	2.0702	1.7849	1.5465	1.3464	1.1761	1.0329	0.9138	0.8113

Table III. Density (g-cm^{-3}) of 1-Propanol (1) + water (2) at different temperatures.

Mole fraction, x_1	20°C	25°C	30°C	35°C	40°C	45°C	50°C	55°C	60°C
0.0000	0.9982	0.9971	0.9957	0.9941	0.9922	0.9903	0.9881	0.9857	0.983
0.0100	0.9929	0.9917	0.9903	0.9886	0.9867	0.9844	0.9825	0.9802	0.977
0.0200	0.9885	0.9871	0.9856	0.9839	0.9819	0.9796	0.9774	0.9750	0.972
0.0500	0.9773	0.9753	0.9730	0.9707	0.9685	0.9663	0.9633	0.9604	0.957
0.0700	0.9698	0.9671	0.9642	0.9612	0.9584	0.9553	0.9525	0.9491	0.946
0.1000	0.9562	0.9530	0.9501	0.9468	0.9438	0.9403	0.9373	0.9337	0.931
0.2000	0.9180	0.9146	0.9108	0.9071	0.9034	0.8995	0.8958	0.8928	0.887
0.3000	0.8905	0.8867	0.8828	0.8788	0.8748	0.8711	0.8667	0.8624	0.859
0.4000	0.8698	0.8657	0.8616	0.8574	0.8533	0.8490	0.8448	0.8404	0.835
0.5000	0.8538	0.8497	0.8448	0.8405	0.8368	0.8324	0.8281	0.8236	0.819
0.6000	0.8407	0.8367	0.8329	0.8286	0.8237	0.8193	0.8149	0.8103	0.805
0.7000	0.8293	0.8251	0.8209	0.8165	0.8122	0.8077	0.8033	0.7987	0.794
0.8000	0.8199	0.8157	0.8114	0.8071	0.8029	0.7985	0.7942	0.7897	0.785
0.9000	0.8124	0.8083	0.8039	0.7999	0.7959	0.7913	0.7872	0.7827	0.778
1.0000	0.8043	0.8002	0.7964	0.7923	0.7885	0.7843	0.7810	0.7767	0.772

Table IV. Density (g-cm^{-3}) of 2-Propanol (1) + water (2) at different temperatures.

Mole fraction, x_1	20°C	25°C	30°C	35°C	40°C	45°C	50°C	55°C	60°C
0.0100	0.9923	0.9914	0.9898	0.9882	0.9863	0.9844	0.9821	0.9799	0.977
0.0200	0.9874	0.9861	0.9846	0.9830	0.9812	0.9791	0.9772	0.9752	0.971
0.0500	0.9759	0.9741	0.9720	0.9697	0.9674	0.9655	0.9620	0.9590	0.956
0.0707	0.9689	0.9663	0.9634	0.9604	0.9581	0.9549	0.9535	0.9501	0.946
0.1000	0.9574	0.9540	0.9503	0.9467	0.9427	0.9408	0.9383	0.9344	0.933
0.2000	0.9171	0.9132	0.9093	0.9058	0.9012	0.8970	0.8936	0.8900	0.884
0.3000	0.8855	0.8813	0.8773	0.8730	0.8687	0.8642	0.8599	0.8553	0.850
0.4000	0.8614	0.8571	0.8529	0.8485	0.8441	0.8395	0.8351	0.8304	0.825
0.5000	0.8428	0.8385	0.8342	0.8296	0.8252	0.8205	0.8161	0.8112	0.806
0.6000	0.8274	0.8231	0.8187	0.8141	0.8095	0.8048	0.8001	0.7952	0.790
0.7001	0.8146	0.8102	0.8057	0.8013	0.7965	0.7917	0.7870	0.7821	0.777
0.7999	0.8037	0.7996	0.7946	0.7901	0.7855	0.7807	0.7761	0.7712	0.766
0.8999	0.7943	0.7898	0.7856	0.7810	0.7767	0.7719	0.7675	0.7630	0.757
1.0000	0.7854	0.7811	0.7771	0.7729	0.7688	0.7640	0.7597	0.7549	0.750

Table V. Parameters from Equation 5 for binary aqueous PA solutions.

t/ °C	20	25	30	35	40	45	50	55	60
E	1.1731	1.1382	1.1300	1.1004	1.1014	1.0969	1.0987	1.1006	1.1018
V	8.9237	8.5430	8.2256	7.9922	7.7804	7.6242	7.5580	7.4248	7.4021
ψ	0.8822	0.8902	0.9044	0.9095	0.9231	0.9335	0.9435	0.9498	0.9569
ψ_{12}	5.3900	5.0102	4.9037	4.5506	4.5578	4.4949	4.4698	4.4372	4.3959
β	3.7406	3.7775	3.7988	3.8208	3.8470	3.8606	3.8732	3.8452	3.8371
σ	32.7667	29.6323	27.7891	25.1850	23.9903	22.5868	21.2379	20.1432	18.9129
AAD%	1.3984	1.0876	0.9077	0.6818	0.6950	0.6082	0.5551	0.5279	0.4816

Table VI. Parameters from Equation 5 for binary aqueous IPA solutions.

t/ °C	20	25	30	35	40	45	50	55	60
E	1.1195	1.0967	1.0723	1.0563	1.0275	1.0240	1.0236	1.0162	1.0148
V	9.6951	9.3122	8.9873	8.7079	8.4304	8.2195	8.0680	7.8994	7.7074
ψ	0.9176	0.9151	0.9113	0.9174	0.9227	0.9304	0.9387	0.9445	0.9487
ψ_{12}	6.4924	5.8999	5.2857	5.0203	4.6394	4.5410	4.4792	4.3664	4.2804
β	5.0262	4.6997	4.6046	4.5349	4.5014	4.4112	4.3256	4.2620	4.1381
σ	34.5774	30.4144	27.3282	25.1252	23.0022	21.5665	20.2460	19.0483	18.0365
AAD%	2.1224	1.8067	1.6076	1.3581	1.1074	0.9542	0.8339	0.6767	0.6486

Table VII. Coefficients from Equation 6 for binary aqueous IPA solutions.

t/ oC	a_0	a_1	a_2	a_3	a_4	a_5	AAD%
20	0.99808	-0.43977	0.11402	0.85714	-1.22295	0.49814	0.08275
25	0.99706	-0.46729	0.21743	0.66819	-1.05977	0.44496	0.07599
30	0.99577	-0.48995	0.28516	0.57364	-1.00091	0.43303	0.06547
35	0.99431	-0.51569	0.38701	0.37212	-0.81090	0.36573	0.06694
40	0.99262	-0.53444	0.45797	0.22718	-0.67025	0.31575	0.06964
45	0.99066	-0.55244	0.51985	0.11822	-0.57917	0.28747	0.07094
50	0.98863	-0.56497	0.53736	0.13211	-0.62881	0.31699	0.06479
55	0.98631	-0.57874	0.58887	0.01721	-0.50565	0.26890	0.05687
60	0.98385	-0.58630	0.58756	0.05396	-0.55723	0.29122	0.06020

Table VIII. Coefficients from Equation 6 for binary aqueous IPA solutions.

t/ oC	a_0	a_1	a_2	a_3	a_4	a_5	AAD%
20	0.99599	-0.38447	-0.27041	1.59392	-1.84029	0.69090	0.07137
25	0.99551	-0.42322	-0.12047	1.32028	-1.60457	0.61381	0.06177
30	0.99450	-0.45961	0.03907	1.00152	-1.31895	0.52083	0.05459
35	0.99315	-0.48573	0.13322	0.82983	-1.16856	0.47117	0.04199
40	0.99197	-0.51937	0.26237	0.59956	-0.97967	0.41416	0.06139
45	0.99013	-0.52635	0.22657	0.74625	-1.15648	0.48413	0.06826
50	0.98789	-0.52462	0.16007	0.93630	-1.36059	0.56095	0.07573
55	0.98604	-0.55157	0.28087	0.66333	-1.07613	0.45266	0.06849
60	0.98346	-0.55125	0.20645	0.90692	-1.36463	0.56984	0.09826

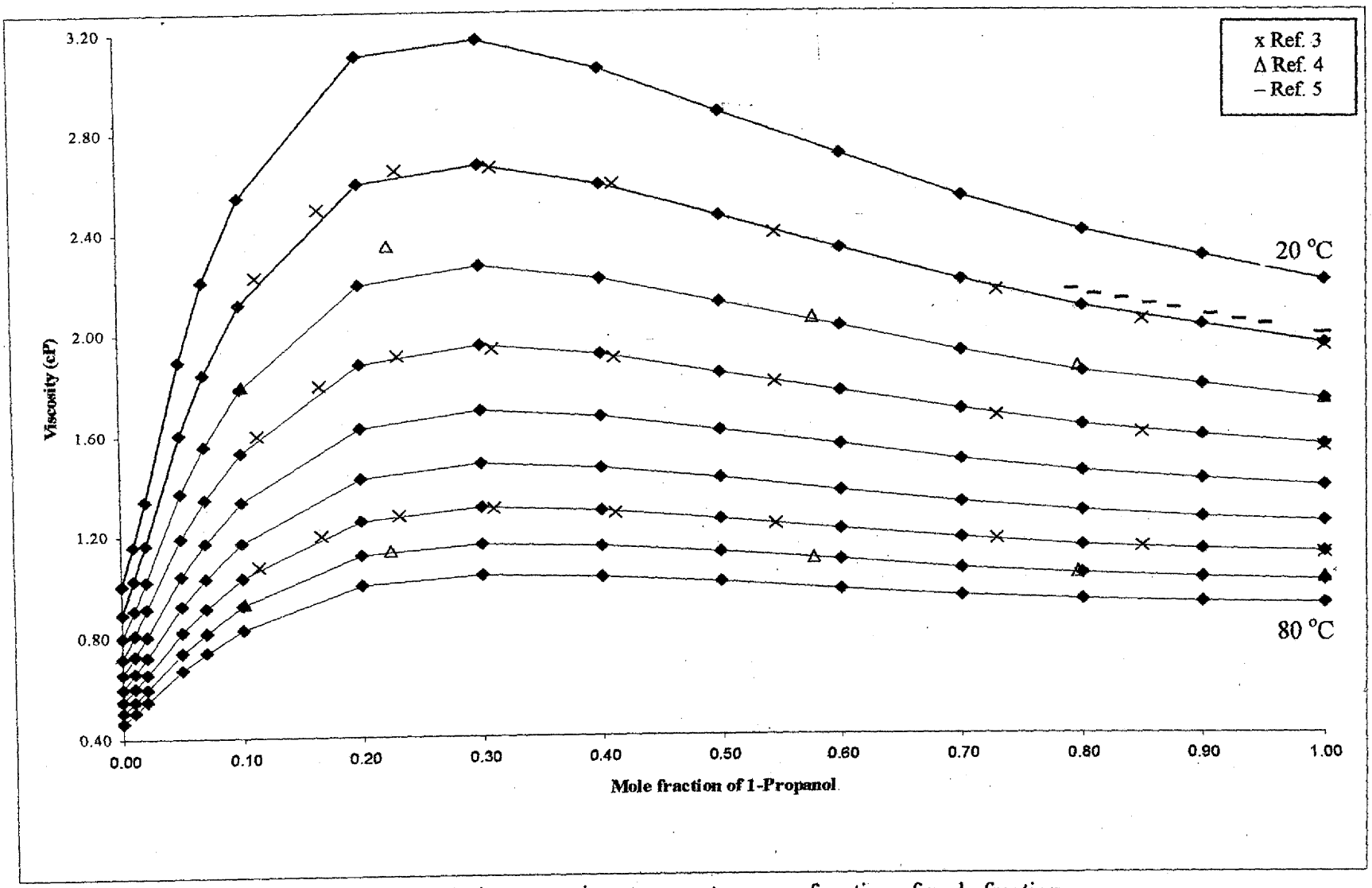

Fig. 1. Viscosities of binary aqueous PA solutions at various temperatures as s function of mole fraction.

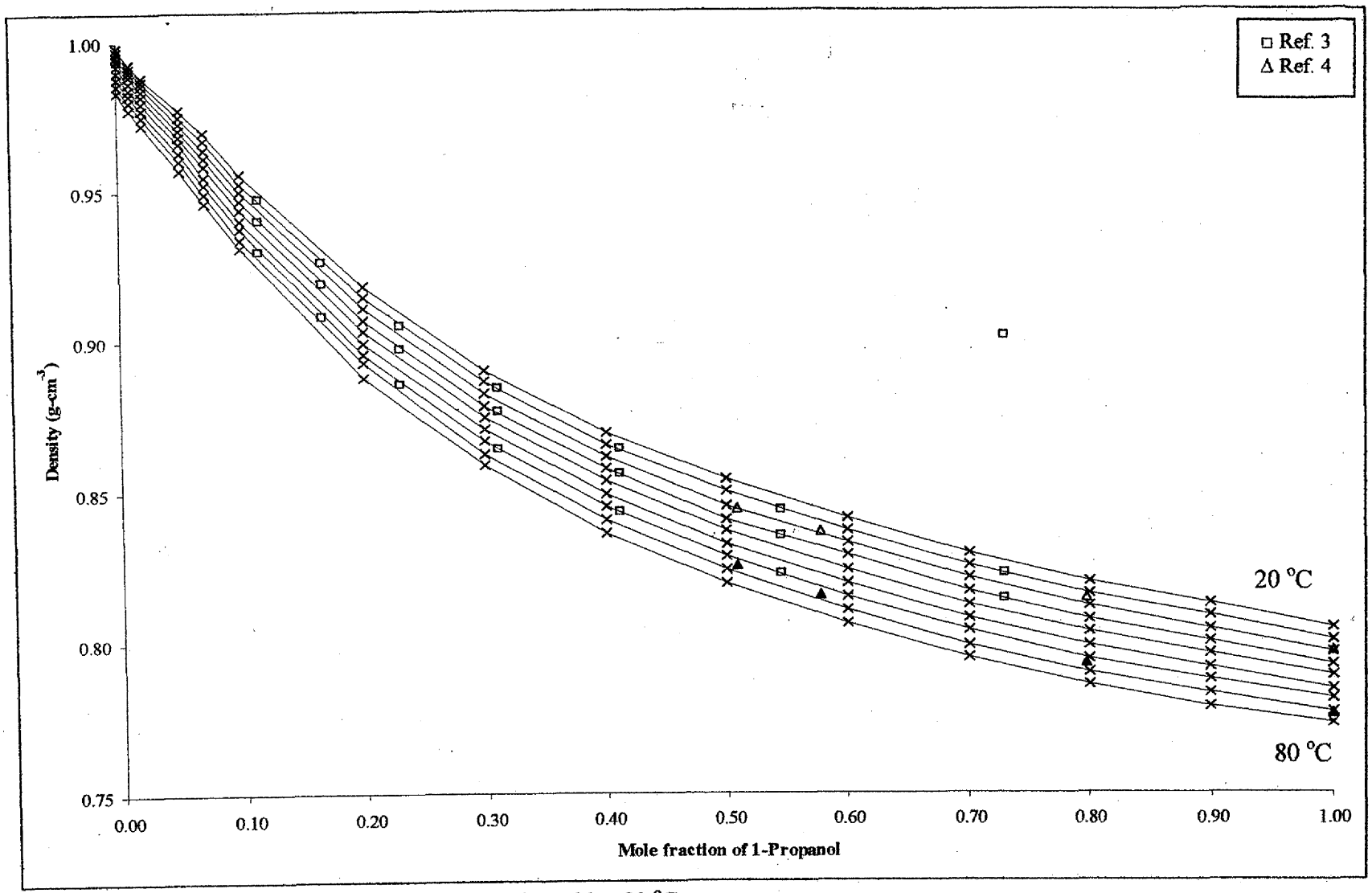

Fig. 3. Densities of binary aqueous PA solutions from 20 – 80 °C.

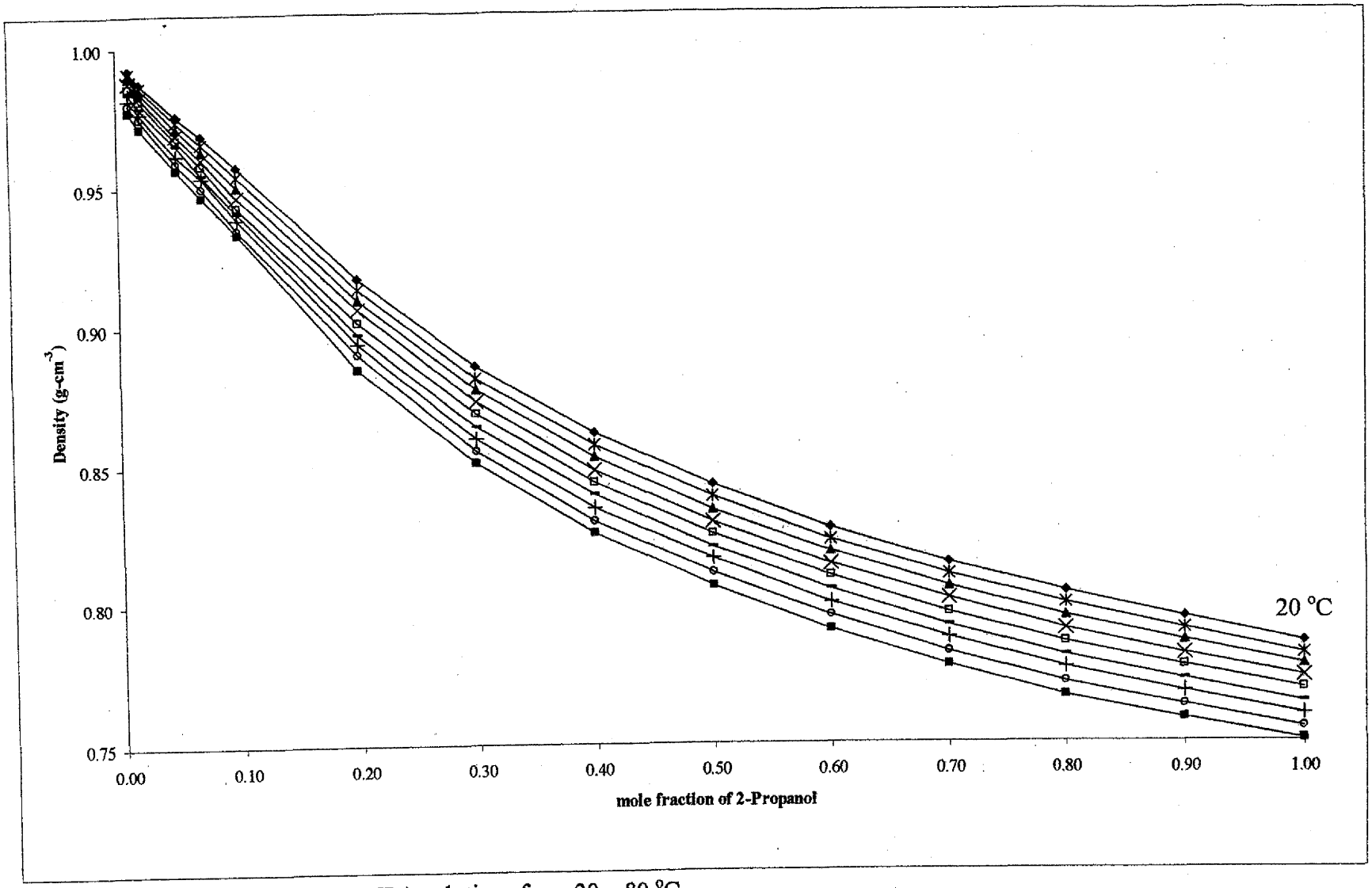

Fig. 4. Densities of binary aqueous IPA solutions from 20 – 80 °C.