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Metformin hydrochloride: Density & Viscosity studies in mixed binary solvent in presence of additives

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ABSTRACT

The densities and viscosities of metformin hydrochloride is determined in binary solvent ethanol-water containing salt NaCl, KCl, $NiCl_2$, $CuCl_2$ and a non electrolyte Glucose. The values are used to calculate excess viscosities, excess molar volume, excess Gibbs free energy of viscous flow and d_{12}, T_{12} and H_{12} parameters. The result reveals that there are specific interaction between drug-metal ion, drug-water, drug-ethanol and water-ethanol.

Keywords: Density; viscosity; binary solvent; metformine hydrochloride; excess properties; thermodynamic properties.

INTRODUCTION

Mixed solvents are often used in chemistry to modify molecular environment in order to modulate processes such as chromatographic separation, organic synthesis, and reaction kinetics & protein folding[1]. Physical properties of binary mixtures are often studied to get information about the mutual interaction between the solvent molecules[2]. The solvent mixtures are used in chemical industries and in laboratories due to enhancement of the solubility of substances that have too low solubility in neat solvent i.e. for their solubilization. The components of the solvent may interact with the different parts of the intended solute and thus have a synergistic effect on the solubility. This aspect is of wide use in the pharmaceutical industry. In other cases the components may confer on the mixture physical properties that enhance solubility, apart from specific solvation of parts of the solute. In still other cases the mixed solvent may have improved physical properties compared with its neat components e.g. with respect to density, viscosity, vapor pressure and the freezing or the boiling temperature. Hence we decided to study viscosities and densities of a medicinal drug metformine-HCl (mfm-HCl) in binary solvent i.e. ethanol and water and in presence of additives.

MATERIALS AND METHODS

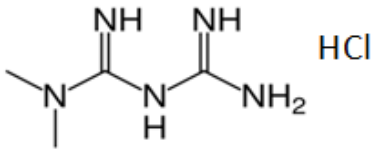
2.1 *Materials*:-The salts KCl, NaCl, $NiCl_2$, $CuCl_2$ and nonelectrolyte glucose used were of AR grade. Water used was double distilled over alkaline $KMnO_4$ in quick fit glass assembly (Conductance=$2x10^{-6}$ mhos) Commercial alcohol was refluxed with lime for two hours and then distilled using long fractionating column[3]. The purity of these water and ethanol was checked by comparing their measured densities and viscosities with those reported in the literature. The purity of mfm-HCl was checked by its mp.

2.2 *Apparatus and procedure*: A set of solutions of binary solvent mixture (10 to 90% V/V) was prepared. In each solution definite quantity of mfm-HCl and additives were added. The density of different solution mixtures were measured with a set of three pyknometers with single arm capillary and single pan electronic balance (Contech CA, Mumbai) with a precision of 0.0001g. The weighing was repeated thrice to ensure the accuracy in weights with a little interval of time. The reproducibility of the result was close to 100%. Viscosity measurements were performed by using Ostwald's viscometer. The viscometer was clamped vertically in a thermostatistically controlled waterbath, whose temperature was maintained constant at 301.15K (± 0.02). The measurement of flow time of the solution between the two points on the viscometer was performed at least five times for each solution and the result was averaged. The accuracy of flow time was ± 0.15 s.

RESULT AND DISCUSSION

Many of the solvents commonly used in laboratories and in the chemical industries are considered as unsafe for reasons of environmental protection. They are often used in huge amounts. It is then expedient to use solvent mixtures.

3.*1Drug profile*: mfm-HCl has molecular formula is $C_4 H_{11} N_5$ –HCl. Its molecular weight is 165.6.The IUPAC name of mfm-HCl is N, N-dimethylimidodicarbonimidic diamide; 1, 1-Dimethylbiguanide; N, N- Dimethyl diguanide.



Mfm-HCl is an oral anti-diabetic drug from the biguanide class. It is the first-line drug for the treatment of type 2 diabetes, particularly in overweight and obese people and those with normal kidney function, and evidence suggests it may be the best choice for people with heart failure. It is also used in the treatment of polycystic ovary syndrome. The structure of mfm-HCl reveals that, it contains one amino group, two imino groups, one secondary amino group and one tertiary amino group.

3.2 *Density and viscosity*: The density and viscosity data of mfm-HCl is represented in table 1. We observed maximum density and viscosity around 50% alcohols. These values are used to calculate various physico- chemical parameters of the mixture.

3.3 *Excess parameters*: The excess volume of binary solvent, in presence of drug and additives solution was calculated by equation,

$$V^E = V_{mix} - X_1V_1 - X_2V_2 \qquad \text{…….. (1)}$$

Over entire range of concentration for binary system V^E values are found to be negative. The V^E depend on the drug, its size, shape and the number of non polar groups attached to it. Liquid mixtures containing hydrogen bonded molecules such as water, alcohols, phenols etc., show pronounced non ideal thermodynamic behavior [4]. The negative values of V^E indicate the packing effect and/or strong interactions between unlike components [5]. The graph V^E against x_1 is of parabolic nature (not shown). The V^E values decreases linearly, attains a minimum value at 60% aq. ethanol and then increases linearly with mole fraction of ethanol and attains a maximum at 90% aq. ethanol.

The excess viscosities of the solutions were calculated from the viscosity data reveals that the values vary with percentage of alcohol parabolically with maxima at 50% alcohol. The excess viscosities of mixture in presence of Cu^{+2} is found to be higher than other, which may be attributed to the complex formation between copper and mfm-HCl and the maxima is also shifted to 40% instead of 50%. The excess values are calculated using the following equation.

$$n^E = n_{mix} - n_1x_1 - n_2x_2 \text{ ……. (2)}$$

The viscosity of pure components to their mixtures is related by Eyring's theory[6,7]

$$\eta = (hN/M) \exp. (\Delta G^*/RT) \qquad \text{……. (3)}$$

Where η is viscosity, M is the molecular weight, T is the absolute temperature and h, N & R are Plank's constant, Avogadro's number and the gas constant respectively. ΔG^* represents the free energy of activation for viscous flow. The excess free energy of activation, ΔG^{*E} is given by the difference between the free energy of activation of the mixture and the free energy of activation of the ideal mixture. Thus eqn. (3) can be written as,

$$\Delta G^{*E} = RT(\ln nM - x_1 \ln n_1M_1 - x_2 ln n_2M_2) \text{…….. (4)}$$

Where η & M are the viscosity of mixture and the average molecular weight of the components in the mixture respectively η_1, x_1 & M_1 represent the viscosity, mole fraction & the molecular weight of the i^{th} component. These values are found to be varying with percentage of alcohol and maximum at 60-70% and then decreases. The values are maximum for again for Cu^{+2} compared to other metal ions and it is also greater for glucose. The Gibbs free energy is observed to be positive. We also observed that the ΔG^{*E} values vary with atomic radius with cations i.e. ΔG^{*E} for KCl > NaCl and ΔG^{*E} for $CuCl_2$ > $NiCl_2$.

There are several semi-empirical relations used to correlate the viscosity of binary liquid mixtures. The Gruenberg-Nissan interactions parameter, d_{12}, which is regarded as a measure of the strength of interactions between two dissimilar molecules were calculated as,

$$d_{12} = \left[\frac{1n\,\eta - X_1 \ln \eta_1 - X_2 \ln \eta_2}{X_1 X_2} \right] \qquad \text{…….. (5)}$$

Tamura and Kurata developed the following equations for the viscosity of binary liquid mixtures.

$$\eta = \sum_{i=1}^{2} X_i \phi_i \eta_i + 2\, T_{12} \prod_{i=1}^{2} (X_i \phi_i)^{½} \qquad \text{…….. (6)}$$

ϕ_i is the volume fraction. Hind suggested following equation for the viscosity of binary liquid mixtures.

$$\eta = \sum_{i=1}^{2} X_i^2 \eta_i + 2\, H_{12} \prod_{i=1}^{2} X_i \qquad \text{…….. (7)}$$

H_{12} is the interaction parameter. Among these three parameters, the Gruenberg-Nissan parameter provides the best measure to ascertain the strength of interaction for any binary mixture[8]. The Gruenberg-Nissan and other parameters decrease with increase in percentage of ethanol. The trend for these excess parameters among the additives at a particular mole fraction and at a particular concentration of the additives was found to follow the order NaCl < $NiCl_2$ < $CuCl_2$ < KCl < glucose.

3.4 *Jones-Dole parameters*: The viscosity data was used to calculate Jones-Dole parameters.(table 2)

$$\eta_r - 1 = A\sqrt{C} + B \qquad \text{…….. (8)}$$

In the equation 8, B is called as B-viscosity coefficient. This coefficient is a measure of the effective hydrodynamic volume of the solvated ions[9] and it denote the order or disorder introduced by the ions into solvent structure. A-coefficient represents the contribution from interionic electrostatic force. S.Chauhan et.al[10] studied viscosities of some narcotic analgesic drugs in aqueous alcohol mixture. They reported a maximum at around 50% (V/V) aqueous mixtures of alcohol. They used Jones-Dole equation and calculated B - coefficient. They observed that irrespective of the nature of drugs, B- co-efficient of NaCl is practically constant in each solvent system. This indicates loss of hydrophobic interactions. We observed that B-coefficient increase with ethanol percentage and then decreases. It varies for each additive. d-block elements, may have greater electrostatic interactions, may form a complex, and hence the greater is the size of solvation. The drug has amino group which is capable of donating an electron pair to metal ion. If complex formation takes place the solution sheath around metal ion breaks and a new solvation sheath will form around newly formed complex. When a non electrolyte is added to the solvent system the solubility of nonelctrolyte changes due to primary and secondary salvation effect. Salting out of soap, manufacturing of dyes etc. are examples of which affect the solubility of non electrolytes in presence of ions. The ion-ion interactions are important because they affect the equilibrium properties and also because they interfere with the

drift of ions under an externally applied electric field. The effect of ion-ion interaction depends on inter-ionic distance i.e. on how densely the solution is populated with ions.

3.5 *Apparent molar volume*: The apparent molar volume of mfm-HCl in 0.002, 0.004, 0.006, 0.008 and 0.01M additives, prepared in binary solvent, have been calculated from density data by using equation 9.

$$\phi_v = \frac{M_2}{\rho^o} - \frac{1000\,(\rho - \rho^o)}{m\rho\rho^o} \qquad \text{…….. (9)}$$

Where ρ^o is the density of binary solvent, ρ is the density of solution, m is the molality of solution and M_2 is the molecular weight of mfm-HCl. These values are used to calculate the limiting apparent volume. (table3)

$$\phi_v = \phi^o_v + S_v\, C^{1/2} \qquad \text{…….. (10)}$$

Where ϕ^o_v and S_v are calculated from the intercept and slope of the extrapolation of ϕ_v versus $C^{1/2}$ (not shown) The Sv in above equation can be attributed to be as a measure of ion-ion or solute-solute interactions. The ion solvent interaction cannot be calculated appropriately nor can they be experimentally determined. Naturally extra thermodynamic methods are necessary to get ideas about the ion-solvent interaction[11].

At low alcohol content, water structure is stronger than that in pure water[12]. At higher alcohol concentration, however, the water structure breaks down and the characteristic chain like structure of pure alcohol predominates. At high water content, at infinitely dilute third component (an ion or a neutral solute) competes with the alcohol molecules to be properly ‘surrounded’ by water structure. This is dictated by the relative interaction strengths between the solute and the solvent molecules of different species. As a result the structure forming and breaking ability of alcohol in water is modified in presence of an ion or a solute. A drug interacts with water to yield the intermolecular H-bonding between them. The formation of H-bonds results in the decrease in the partial molar volume due to shortening of the interatomic distance

Table 1: Density, viscosity, excess properties and other thermodynamic parameters of Metformin hydrochloride

% EtOH	ρ (g cm^{-3})	η (m Pa. s)	η^E (cm^3 mol^{-1})	v^E (J mol^{-1})	G^E	d_{12}	T_{12}	H_{12}
				0.002M KCl				
10	0.9669	11.0418	3.9636	-0.0302	20.6600	13.8024	45.6514	69.5303
20	0.9526	14.1751	6.9999	-0.1619	33.0159	10.2076	42.7104	60.4555
30	0.9403	16.9206	9.6315	-0.3689	42.8505	8.1547	41.5156	54.5885
40	0.9247	18.7732	11.3485	-0.5332	50.4816	6.5642	39.6096	48.0930
50	0.9055	20.2635	12.6748	-0.6290	58.5525	5.4722	38.6987	43.2368
60	0.8839	19.1684	11.3772	-0.6668	59.0973	4.1961	33.8399	34.4540
70	0.8590	17.7366	9.6891	-0.5799	58.8403	3.2895	30.3284	28.1204
80	0.8330	15.0858	6.7035	-0.4012	50.4222	2.4251	25.7756	21.8149
90	0.8047	12.3455	3.5071	-0.0006	35.0811	1.7690	22.1930	17.2938
				0.004M KCl				
10	0.9655	10.9145	3.8363	-0.0018	20.2628	13.4438	44.4715	67.5620
20	0.9531	14.5123	7.3371	-0.1729	34.1749	10.5583	44.3384	62.9706
30	0.9402	16.7019	9.4128	-0.3665	42.1325	8.0296	40.7753	53.5362
40	0.9244	18.2340	10.8093	-0.5252	48.7462	6.3595	38.1513	46.1997
50	0.9036	19.5956	12.0069	-0.5718	56.7015	5.2871	37.1293	41.3929
60	0.8834	18.3424	10.5512	-0.6496	55.8767	3.9932	32.0304	32.5512
70	0.8599	17.6560	9.6085	-0.6162	58.1865	3.2708	30.1503	27.9550
80	0.8336	15.3852	7.0029	-0.4302	52.1979	2.5047	26.5286	22.4209
90	0.8055	13.0082	4.1698	-0.0483	41.0381	2.0388	24.7020	19.0037
				0.006M KCl				
10	0.9662	10.6995	3.6213	-0.0160	19.2055	12.8286	42.4789	64.2376
20	0.9538	14.5230	7.3478	-0.1883	34.1106	10.5693	44.3901	63.0504
30	0.9402	16.2681	8.9790	-0.3665	40.6456	7.7763	39.3070	51.4489
40	0.9248	18.1352	10.7105	-0.5359	48.3345	6.3214	37.8840	45.8528
50	0.9040	19.2915	11.7028	-0.5839	55.5482	5.2007	36.4147	40.5534
60	0.8845	18.7733	10.9821	-0.6875	57.3643	4.1002	32.9743	33.5438
70	0.8612	16.7886	8.7411	-0.6685	53.4664	3.0641	28.2333	26.1757
80	0.8347	15.5018	7.1195	-0.4832	52.5930	2.5353	26.8219	22.6570
90	0.8073	12.8511	4.0127	-0.1552	38.9032	1.9761	24.1073	18.5983
				0.008M KCl				
10	0.9664	10.8132	3.7350	-0.0201	19.6982	13.1554	43.5327	65.9957
20	0.9534	14.2969	7.1217	-0.1795	33.3475	10.3353	43.2985	61.3640
30	0.9415	17.1594	9.8703	-0.3978	43.4376	8.2896	42.3239	55.7375
40	0.9234	17.8947	10.4700	-0.4984	47.7822	6.2276	37.2336	45.0084
50	0.9036	19.0745	11.4858	-0.5718	54.8676	5.1383	35.9048	39.9543
60	0.8839	18.5567	10.7655	-0.6668	56.6339	4.0467	32.4998	33.0449
70	0.8602	17.9599	9.9124	-0.6283	59.5739	3.3408	30.8219	28.5784
80	0.8336	15.4813	7.0990	-0.4302	52.8227	2.5299	26.7703	22.6155
90	0.8067	13.0171	4.1787	-0.1196	40.6632	2.0424	24.7357	19.0267
				0.01M KCl				
10	0.9666	10.9269	3.8487	-0.0241	20.1852	13.4789	44.5865	67.7537
20	0.9538	13.8629	6.6877	-0.1883	31.6749	9.8754	41.2032	58.1269
30	0.9415	18.1369	10.8478	-0.3978	46.5635	8.8228	45.6324	60.4409
40	0.9250	18.4592	11.0345	-0.5412	49.3854	6.4457	38.7603	46.9905
50	0.9059	19.4365	11.8478	-0.6411	55.6342	5.2421	36.7554	40.9537
60	0.8831	18.4380	10.6468	-0.6392	56.3470	4.0171	32.2398	32.7714
70	0.8612	17.6827	9.6352	-0.6685	57.9424	3.2770	30.2093	28.0098
80	0.8353	15.2238	6.8415	-0.5121	50.5837	2.4620	26.1227	22.0942
90	0.8134	13.7926	4.9542	-0.5142	44.9942	2.3410	27.6719	21.0276

% EtOH	ρ (g cm^{-3})	η (m Pa. s)	η^E (cm^3 mol^{-1})	v^E (J mol^{-1})	ΔG^E	d_{12}	T_{12}	H_{12}
				0.002M NaCl				
10	0.9651	10.3533	3.2719	0.0063	17.7279	11.8114	39.2702	58.8847
20	0.9533	13.4157	6.2405	-0.1773	30.0293	9.3863	39.0441	54.7913
30	0.9396	16.9080	9.6189	-0.3521	42.9274	8.1476	41.4729	54.5279
40	0.9244	18.6605	11.2358	-0.5252	50.1695	6.5219	39.3048	47.6973
50	0.9043	20.3410	12.7523	-0.5929	59.0832	5.4932	38.8808	43.4508
60	0.8843	20.5032	12.7120	-0.6806	64.1067	4.5063	36.7640	37.5289
70	0.8604	18.2618	10.2143	-0.6363	60.9553	3.4092	31.4891	29.1977
80	0.8378	16.6224	8.2401	-0.6319	58.5446	2.8178	29.6403	24.9254
90	0.8133	13.7909	4.9525	-0.5083	45.0179	2.3404	27.6654	21.0232
				0.004M NaCl				
10	0.9648	10.3501	3.2719	0.0124	17.7483	11.8019	39.2406	58.8352
20	0.9517	13.7226	6.5474	-0.1420	31.4449	9.7237	40.5258	57.0804
30	0.9395	17.3397	10.0506	-0.3496	44.3700	8.3902	42.9341	56.6051
40	0.9233	18.3188	10.8941	-0.4958	49.2451	6.3921	38.3806	46.4975
50	0.9057	20.0591	12.4704	-0.6350	57.8191	5.4162	38.2184	42.6725
60	0.8862	20.4450	12.6538	-0.7459	63.3997	4.4932	36.6365	37.3948
70	0.8605	17.8669	9.8194	-0.6404	59.0387	3.3195	30.6164	28.3876
80	0.8379	16.6244	8.2421	-0.6366	58.5232	2.8183	29.6454	24.9295
90	0.8151	14.5736	5.7352	-0.6132	50.8581	2.6252	30.6288	23.0428
				0.006M NaCl				
10	0.9666	10.6917	3.6135	-0.0018	19.2539	12.8060	42.4066	64.11704
20	0.9533	13.4157	6.2405	-0.1773	30.0293	9.3863	39.0441	54.79134
30	0.9399	16.5882	9.2991	-0.3593	41.7972	7.9638	40.3905	52.98909
40	0.9248	19.2020	11.7773	-0.5359	51.8517	6.7228	40.7694	49.59865
50	0.9063	19.6542	12.0655	-0.6531	56.3010	5.3036	37.2670	41.55472
60	0.8840	20.3942	12.6030	-0.6703	63.7797	4.4817	36.5253	37.27776
70	0.8618	18.6291	10.5816	-0.6926	62.2645	3.4909	32.3008	29.95114
80	0.8383	16.2455	7.8632	-0.6557	56.0889	2.7250	28.6924	24.16246
90	0.8145	13.9992	5.1608	-0.5783	46.3336	2.4177	28.4541	21.5607
				0.008M NaCl				
10	0.9653	10.4668	3.3886	0.0022	18.2377	12.1486	40.3222	60.6397
20	0.9526	13.4059	6.2307	-0.1619	30.0909	9.3754	38.9968	54.7182
30	0.9392	16.4675	9.1784	-0.3424	41.5024	7.8935	39.9820	52.4083
40	0.9249	19.8442	12.4195	-0.5385	53.8561	6.9538	42.5063	51.8536
50	0.9061	19.8589	12.2702	-0.6471	57.0486	5.3608	37.7480	42.1198
60	0.8936	20.8219	13.0307	-0.9974	62.8789	4.5773	37.4622	38.2630
70	0.8373	17.9724	9.9249	0.3187	66.4578	3.3437	30.8495	28.6041
80	0.8152	16.1334	7.7511	0.4778	63.2604	2.6970	28.4104	23.9355
90	0.8145	14.1052	5.2668	-0.5783	47.2261	2.4567	28.8554	21.8342
				0.01M NaCl				
10	0.9658	10.5836	3.5054	-0.0079	18.7209	12.4918	41.4047	62.4456
20	0.9531	13.5229	6.3477	-0.1729	30.4749	9.5050	39.5617	55.5909
30	0.9399	16.0461	8.7570	-0.3593	39.9193	7.6441	38.5556	50.3807
40	0.9254	19.4279	12.0032	-0.5518	52.4531	6.8049	41.3803	50.3919
50	0.9062	20.2792	12.6905	-0.6501	58.4472	5.4764	38.7356	43.2802
60	0.8841	19.2747	11.4835	-0.6737	59.4665	4.2216	34.0728	34.6989
70	0.8633	18.7217	10.6742	-0.7526	62.2532	3.5112	32.5055	30.1411
80	0.8370	16.0272	7.6449	-0.5936	55.1690	2.6702	28.1433	23.7206
90	0.8196	14.8432	6.0048	-0.8735	51.2742	2.7198	31.6496	23.7384

% EtOH	ρ (g cm^{-3})	η (m Pa. s)	η^E (cm^3 mol^{-1})	v^E (J mol^{-1})	ΔG^E	d_{12}	T_{12}	H_{12}
				0.002M $NiCl_2$				
10	0.9657	10.5825	3.5043	-0.0059	18.7277	12.4885	41.3945	62.4286
20	0.9527	12.9677	5.7925	-0.1641	28.3345	8.8796	36.8812	51.4498
30	0.9412	16.394	9.1049	-0.3906	40.9133	7.8505	39.7332	52.0547
40	0.9256	19.005	11.5803	-0.5572	51.0606	6.6504	40.2365	48.9069
50	0.9079	19.4794	11.8907	-0.7010	55.3399	5.2543	36.8562	41.0721
60	0.8875	19.2458	11.4546	-0.7904	58.4923	4.2147	34.0094	34.6323
70	0.8645	18.1074	10.0599	-0.8005	59.0361	3.3744	31.1479	28.8810
80	0.8467	16.8671	8.4848	-1.0526	57.0387	2.8770	30.2558	25.4208
90	0.8081	13.5224	4.6840	-0.2026	44.6739	2.2389	26.6489	20.3304
				0.004M $NiCl_2$				
10	0.9662	10.6995	3.6213	-0.0160	19.2055	12.8286	42.4789	64.2376
20	0.9538	13.9179	6.7427	-0.1883	31.8822	9.9345	41.4687	58.5371
30	0.9401	16.0495	8.7604	-0.3641	39.8979	7.6461	38.5671	50.3970
40	0.9254	18.8942	11.4695	-0.5518	50.7402	6.6093	39.9369	48.5179
50	0.9076	19.5253	11.9366	-0.6920	55.5658	5.2673	36.9641	41.1989
60	0.8849	18.5776	10.7864	-0.7012	56.4686	4.0519	32.5456	33.0930
70	0.8647	17.8162	9.7687	-0.8085	57.5856	3.3079	30.5043	28.2836
80	0.8349	15.8717	7.4894	-0.4928	54.8896	2.6307	27.7522	23.4058
90	0.8015	12.5908	3.7524	-0.1911	38.6485	1.8705	23.1217	17.9267
				0.006M $NiCl_2$				
10	0.9662	10.5880	3.5098	-0.0160	18.6934	12.5046	41.4455	62.5136
20	0.9542	13.8687	6.6935	-0.1971	31.6391	9.8817	41.2312	58.1702
30	0.9411	16.3922	9.1031	-0.3882	40.9239	7.8494	39.7271	52.0460
40	0.9250	18.9927	11.5680	-0.5412	51.1382	6.6458	40.2033	48.8637
50	0.9082	19.6954	12.1067	-0.7100	56.0200	5.3151	37.3638	41.6685
60	0.8863	18.9675	11.1763	-0.7493	57.6918	4.1476	33.3998	33.9912
70	0.8655	18.2268	10.1793	-0.8403	59.3127	3.4013	31.4117	29.1259
80	0.8372	16.8684	8.4861	-0.6032	60.2134	2.8773	30.2591	25.4234
90	0.8090	13.4454	4.6070	-0.2558	43.6481	2.2094	26.3573	20.1318
				0.008M $NiCl_2$				
10	0.9674	10.1548	3.0766	-0.0403	16.5107	11.2128	37.4305	55.8155
20	0.9539	13.4242	6.2490	-0.1905	29.9769	9.3957	39.0852	54.8547
30	0.9416	16.5095	9.2204	-0.4002	41.2423	7.9181	40.1241	52.6104
40	0.9263	18.6454	11.2207	-0.5758	49.7502	6.5162	39.2639	47.6443
50	0.9094	19.7725	12.1838	-0.7458	56.0179	5.3367	37.5450	41.8813
60	0.8886	19.9271	12.1359	-0.8279	60.8437	4.3750	35.5020	36.2017
70	0.8652	17.9250	9.8775	-0.8284	57.9654	3.3328	30.7448	28.5068
80	0.8357	16.1247	7.7424	-0.5313	56.2073	2.6948	28.3886	23.9179
90	0.8077	13.0560	4.2176	-0.1789	40.6397	2.0578	24.8830	19.1270
				0.01M $NiCl_2$				
10	0.9670	10.1506	3.0724	-0.0323	16.5373	11.2000	37.3916	55.7506
20	0.9541	13.2069	6.0317	-0.1949	29.0941	9.1523	38.0361	53.2340
30	0.9419	16.7321	9.4430	-0.4074	41.9473	8.0469	40.8776	53.6815
40	0.9253	18.1450	10.7203	-0.5492	48.2714	6.3252	37.9105	45.8872
50	0.9093	19.4598	11.8711	-0.7428	54.9622	5.2487	36.8102	41.0180
60	0.8901	20.1128	12.3216	-0.8789	61.1624	4.4177	35.9088	36.6295
70	0.8654	18.3232	10.2757	-0.8364	59.7943	3.4230	31.6248	29.3236
80	0.8375	16.3978	8.0155	-0.6175	57.2865	2.7628	29.0754	24.4708
90	0.8134	13.9815	5.1431	-0.5142	46.6059	2.4112	28.3871	21.5150

% EtOH	ρ (g cm^{-3})	η (m Pa. s)	η^E (cm^3 mol^{-1})	v^E (J mol^{-1})	ΔG^E	d_{12}	T_{12}	H_{12}
			0.002M $CuCl_2$					
10	0.9663	10.6698	3.5916	-0.0181	19.0577	12.7426	42.2036	63.7784
20	0.9564	14.5887	7.4135	-0.2454	33.9654	10.6367	44.7073	63.5405
30	0.9438	17.9419	10.6528	-0.4529	45.5566	8.7187	44.9724	59.5026
40	0.9305	22.1378	14.7131	-0.6870	59.4387	7.7219	48.7097	59.9071
50	0.9080	21.6025	14.0138	-0.7040	62.3229	5.8255	41.8450	46.9334
60	0.8866	20.3869	12.5957	-0.7596	63.0810	4.4801	36.5093	37.2609
70	0.8711	20.0305	11.9830	-1.0616	65.7586	3.7885	35.3979	32.8258
80	0.8476	17.8499	9.4676	-1.0946	62.3308	3.1063	32.7277	27.4103
90	0.8152	14.9404	6.1020	-0.6191	53.7579	2.7535	32.0176	23.9892
			0.004M $CuCl_2$					
10	0.9662	10.7787	3.7005	-0.0160	19.5661	13.0566	43.2129	65.4622
20	0.9574	14.6039	7.4287	-0.2673	33.8736	10.6522	44.7807	63.6539
30	0.9429	17.6028	10.3137	-0.4314	44.6367	8.5351	43.8246	57.8710
40	0.9286	22.6212	15.1965	-0.6368	61.1500	7.8736	50.0171	61.6044
50	0.9059	20.2120	12.6233	-0.6411	58.2896	5.4581	38.5777	43.0947
60	0.8845	19.3821	11.5909	-0.6875	59.7867	4.2472	34.3080	34.9463
70	0.8700	20.0052	11.9577	-1.0184	65.9739	3.7833	35.3420	32.7739
80	0.8484	17.9633	9.5810	-1.1320	62.6870	3.1319	33.0129	27.6398
90	0.8103	14.6661	5.8277	-0.3324	53.4871	2.6579	30.9790	23.2815
			0.006M $CuCl_2$					
10	0.9669	10.7865	3.7083	-0.0302	19.5172	13.0790	43.2852	65.5828
20	0.9577	14.6085	7.4333	-0.2738	33.8462	10.6569	44.8029	63.6882
30	0.9446	19.2475	11.9584	-0.4720	49.3692	9.3947	49.3915	65.7847
40	0.9299	22.8645	15.4398	-0.6712	61.5375	7.9487	50.6752	62.4587
50	0.9088	21.5181	13.9294	-0.7279	61.8749	5.8038	41.6467	46.7004
60	0.8848	19.3383	11.5471	-0.6978	59.5387	4.2368	34.2121	34.8454
70	0.8719	20.4459	12.3984	-1.0930	67.2731	3.8727	36.3159	33.6779
80	0.8465	17.6340	9.2517	-1.0432	61.4980	3.0570	32.1847	26.9732
90	0.8113	14.6842	5.8458	-0.3912	53.2399	2.6642	31.0476	23.3282
			0.008M $CuCl_2$					
10	0.9674	11.2325	4.1543	-0.0403	21.4353	14.3319	47.4188	72.4789
20	0.9582	14.6707	7.4955	-0.2847	33.9946	10.9203	45.1032	64.1521
30	0.9435	19.3324	12.0433	-0.4457	49.8109	9.4371	49.6788	66.1932
40	0.9257	21.2860	13.8613	-0.5598	58.0089	7.4463	46.4059	56.9162
50	0.9084	21.3018	13.7131	-0.7159	61.2825	5.7481	41.1385	46.1033
60	0.8861	19.4676	11.6764	-0.7424	59.7139	4.2675	34.4953	35.1432
70	0.8100	19.9062	11.8587	-1.5177	84.4699	3.7629	35.1232	32.5709
80	0.8486	18.9335	10.5512	-1.1413	67.8045	3.3449	35.4531	29.6038
90	0.8102	14.4798	5.6414	-0.3266	52.0059	2.5919	30.2737	22.8008
			0.01M $CuCl_2$					
10	0.9666	10.4530	3.3748	-0.0241	18.0187	12.1078	40.1943	60.4263
20	0.9547	15.1061	7.9309	-0.2081	36.0378	11.1566	47.2052	67.3997
30	0.9445	19.5680	12.2789	-0.4696	50.3157	9.5536	50.4763	67.3269
40	0.9254	21.0684	13.6437	-0.5518	57.4379	7.3742	45.8173	56.1521
50	0.9107	21.1484	13.5597	-0.7845	60.2717	5.7082	40.7780	45.6798
60	0.8869	19.3842	11.5930	-0.7698	59.1860	4.2477	34.3126	34.9511
70	0.8715	19.9405	11.8930	-1.0773	65.2574	3.7700	35.1990	32.6412
80	0.8482	18.4418	10.0595	-1.1226	65.3465	3.2384	34.2164	28.6085
90	0.8160	14.7693	5.9309	-0.6655	52.0841	2.6941	31.3698	23.5477

% EtOH	ρ (g cm^{-3})	η (m Pa. s)	η^E (cm^3 mol^{-1})	v^E (J mol^{-1})	ΔG^E	d_{12}	T_{12}	H_{12}
			0.002M Glucose					
10	0.9668	11.6658	4.5876	-0.0282	23.3578	15.5024	51.4347	79.1785
20	0.9537	14.3304	7.1552	-0.1861	33.4262	10.3702	43.4602	61.6139
30	0.9410	19.7097	12.4206	-0.3858	51.3451	9.6231	50.9559	68.0087
40	0.9258	20.656	13.2313	-0.5625	56.1419	7.2354	44.7019	54.7041
50	0.9059	21.8619	14.2732	-0.6411	63.6153	5.8914	42.4546	47.6496
60	0.8861	21.3841	13.5929	-0.7424	66.8281	4.7001	38.6938	39.5581
70	0.8624	18.9469	10.8994	-0.7166	63.5463	3.5603	33.0031	30.6030
80	0.8375	15.6351	7.2528	-0.6175	52.5299	2.5699	27.1571	22.9268
90	0.8071	13.0463	4.2079	-0.1434	40.7788	2.0539	24.8463	19.1020
			0.004M Glucose					
10	0.9657	11.5426	4.4644	-0.0059	22.9752	15.1741	50.2929	77.2736
20	0.9534	14.7600	7.5848	-0.1795	35.0173	10.8108	45.5343	64.8182
30	0.9413	19.0731	11.7840	-0.3930	49.4386	9.3071	48.8012	64.9456
40	0.9271	21.0016	13.5769	-0.5971	56.8994	7.3519	45.6367	55.9176
50	0.9068	22.7095	15.1208	-0.6681	65.9867	6.1014	44.4462	49.9896
60	0.8868	21.6029	13.8117	-0.7664	67.4157	4.7470	39.1732	40.0622
70	0.8623	19.3373	11.2898	-0.7126	65.3329	3.6440	33.8659	31.4039
80	0.8345	16.3391	7.9568	-0.4736	57.9314	2.7482	28.9278	24.3519
90	0.8074	13.0512	4.2129	-0.1612	40.7100	2.0559	24.8650	19.1147
			0.006M Glucose					
10	0.9653	10.8785	3.8003	0.0022	22.9752	15.17406	50.29289	77.2736
20	0.9546	14.9959	7.8207	-0.2059	35.0173	10.81082	45.53429	64.81817
30	0.9416	18.8648	11.5757	-0.4002	49.4386	9.30711	48.80119	64.94558
40	0.9275	21.7497	14.3250	-0.6077	56.8994	7.351883	45.63666	55.91756
50	0.9080	21.6025	14.0138	-0.7040	65.9867	6.10139	44.44625	49.98957
60	0.8859	20.5725	12.7813	-0.7356	67.4157	4.746985	39.17316	40.06215
70	0.8612	18.1363	10.0888	-0.6685	65.3329	3.643976	33.86592	31.40387
80	0.8349	15.2064	6.8241	-0.4928	57.9314	2.748247	28.9278	24.35194
90	0.8072	13.2317	4.3933	-0.1493	40.7100	2.055883	24.86497	19.11472
			0.008M Glucose					
10	0.9659	10.9952	3.9170	-0.0100	20.5746	13.6716	45.21948	68.80974
20	0.9545	15.6463	8.4711	-0.2037	37.9059	11.68071	49.81326	71.42888
30	0.9393	18.6048	11.3157	-0.3448	48.3870	9.067881	47.21613	62.69228
40	0.9260	21.2929	13.8682	-0.5678	57.9679	7.448619	46.42453	56.94039
50	0.9087	21.6192	14.0305	-0.7249	62.2149	5.829726	41.88429	46.97955
60	0.8852	21.1608	13.3696	-0.7116	66.2679	4.651720	38.20465	39.04372
70	0.8615	17.8484	9.8009	-0.6806	58.6605	3.315268	30.57548	28.34969
80	0.8337	14.8049	6.4226	-0.4350	48.3077	2.349042	25.06906	21.24624
90	0.8107	13.7505	4.9121	-0.3560	45.6663	2.325222	27.51248	20.91900
			0.01M Glucose					
10	0.9665	11.1121	4.0339	-0.0221	21.0187	13.99865	46.30293	70.6172
20	0.9546	15.4306	8.2554	-0.2059	37.1646	11.47363	48.77188	69.8200
30	0.9433	18.5767	11.2876	-0.4410	47.6008	9.053335	47.12101	62.5571
40	0.9267	20.9925	13.5678	-0.5864	56.9534	7.348839	45.61205	55.8856
50	0.9065	21.7732	14.1845	-0.6591	63.2010	5.868918	42.24615	47.4047
60	0.8854	20.2585	12.4673	-0.7184	62.9114	4.450955	36.22797	36.9652
70	0.8616	17.6543	9.6068	-0.6846	57.6888	3.270409	30.14652	27.9515
80	0.8343	14.8156	6.4333	-0.4639	48.1857	2.351967	25.09598	21.2679
90	0.8075	14.5235	5.6851	-0.1671	53.4285	2.607463	30.43914	22.9135

Table 2: A- and B- Coefficient Values

%	KCl		NaCl		$NiCl_2$		$CuCl_2$		Glucose	
	A	B	A	B	A	B	A	B	A	B
10	-88.9575	12.0121	-60.5659	9.0869	-85.9028	11.0232	-73.7968	10.6399	-119.2713	15.0401
20	-111.4983	14.6582	-80.5473	11.3301	-69.6960	10.4338	-97.5617	14.3353	-76.4142	13.0722
30	-55.5248	8.8261	-85.5614	10.8683	-54.5283	8.0992	-57.7246	10.7722	-133.7243	17.0886
40	-109.8321	14.6356	-102.4866	14.4266	-119.1150	15.8174	-113.6448	17.5374	-130.6717	19.2489
50	-105.6981	13.4730	-97.8540	13.3213	-80.6073	11.5167	-111.6569	15.4766	-127.5950	17.4629
60	-79.2616	10.3447	-103.7426	13.8207	-58.9763	9.3825	-101.8743	13.0241	-122.2776	15.9618
70	-66.8130	9.2346	-69.6652	10.1752	-69.9152	9.9885	-105.2692	14.7653	-110.0032	13.4946
80	-31.3524	4.7961	-69.1808	8.8406	-65.1723	8.6314	-68.2794	10.6338	-62.3800	7.3033
90	-21.2105	-1.3731	-15.4883	2.8109	-5.6779	1.1092	-42.0715	5.4802	14.2203	-0.2697

Table 3: Limiting apparent molar volumes in ethanol

Conc. (M)	KCl		NaCl		$NiCl_2$		$CuCl_2$		Glucose	
	ϕ_v^0	S_v	ϕ_v^0	S_v	ϕ_v^0	S_v	ϕ_v^0	S_v	ϕ_v^0	S_v
0.002	49.1564	0.5126	50.147	0.3816	49.8296	0.3729	49.0947	0.3818	49.2238	0.2735
0.004	49.6294	0.4693	50.5391	0.3371	49.1164	0.4984	49.023	0.4169	49.3561	0.4582
0.006	49.3994	0.4724	50.0135	0.3800	49.3318	0.4403	48.5344	0.4463	49.2445	0.4678
0.008	49.3093	0.4912	49.3682	0.5508	48.7912	0.4837	47.9604	0.6669	49.4115	0.4501
0.01	49.3806	0.4495	50.098	0.3551	49.1589	0.4283	49.3882	0.3538	48.8261	0.5074

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