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Characterization of Non-Ideal Behavior in Acetonitrile-Based Binary liquid mixtures via Excess Viscosity and Viscosity Measurements at Different Temperatures

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Abstract

This paper is concerned with the excess viscosity and molecular interactions in binary liquid mixtures which are essential for understanding non-ideal solution behavior and optimizing industrial processes. This work investigates the binary systems of Acetonitrile + Formamide and Acetonitrile + N-Methylacetamide at temperatures ranging from 293.15 K to 313.15 K. Experimental measurements of density, viscosity, and reduced molar volume were performed over the full concentration range at atmospheric pressure. Excess viscosity (η^E) and theoretical viscosities were calculated using the Prigogine-Flory-Patterson model and compared with experimental results. Significant non-ideal behavior was observed, characterized by negative excess viscosity for the Acetonitrile + Formamide system and predominantly positive excess viscosity for Acetonitrile + N-Methylacetamide. Theoretical models showed large deviations from experimental values, particularly at higher temperatures, suggesting inadequacies in conventional predictive approaches. The findings highlight the need for improved models capable of accounting for hydrogen bonding and dipolar interactions.

Keywords: Molecular interactions, thermo physical properties, viscosity measurement, non-ideal behavior, hydrogen bonding.

Introduction

Excess viscosity and viscosity are fundamental parameters for understanding molecular interactions in liquid mixtures. Binary liquid mixtures play a critical role in industrial applications such as chemical synthesis, pharmaceutical formulation, and solvent design. Understanding the behavior of such mixtures is essential for designing processes like separation, extraction, and formulation of novel chemical products. Acetonitrile (CH_3 CN) is a widely used polar-Aprotic solvent consist of high dielectric constant, low viscosity, and strong solvating power. It plays a critical role in analytical chemistry, especially as a mobile phase in high-performance liquid chromatography (HPLC) due to its optical clarity and miscibility with a wide range of polar and non-polar solvents[1]. Acetonitrile is also used industrially in the production of synthetic pharmaceuticals, pesticides, acrylic fibers, and as an electrolyte component in lithium-ion batteries[2]. Formamide ($HCONH_2$) is a clear, hygroscopic liquid known for its high boiling point and strong hydrogen-bonding capacity. It is widely used in organic synthesis, particularly in peptide bond formation and preparation of formyl derivatives. Formamide serves as a denaturing agent in gel electrophoresis for DNA and RNA applications, and it is used in the pharmaceutical industry for the synthesis of nucleic acid analogs and anticancer drugs[3]. N-Methylacetamide (CH_3 $CONHCH_3$), a derivative of acetamide, is widely employed in biochemical and pharmaceutical research as a model compound to study peptide bond behavior, hydrogen bonding, and molecular interactions[4]. It finds applications in organic synthesis, polymer processing, specialty coatings, and high-temperature lubricants. In past few years the transport properties for such systems were extensively studied by various researchers[5-7]. In the continuation of previously published work[8-13], this paper is concerned with the thermo physical characterization of non ideal binary liquids of Acetonitrile + Formamide and N-Methylacetamide at temperatures ranging from 293.15 K to 313.15 K over the entire mole fraction and atmospheric pressure from viscosity and excess viscosity data and compared with the literature[14]. Theoretical values of viscosities and excess viscosities were calculated using the Prigogine-Flory-Patterson model and compared with experimental results. Excess viscosity and related thermo physical properties provide deep insight into intermolecular interactions such as hydrogen bonding, dipole-dipole interactions, and van der Waals forces. Such understanding helps in the rational design of solvent systems, optimization of reaction media, and enhancement of separation processes in chemical and pharmaceutical industries[15]. The main purpose of this investigation was to analyze the effect of excess viscosity and volume contraction at different temperature on strength of intermolecular interactions in binary mixture and highlight the need for advanced theoretical frameworks capable of incorporating hydrogen bonding and dipolar interactions to better predict the behavior of such complex liquid mixtures.

Theoretical Model

Viscosity theories commonly describe the flow of liquids based on either the activation energy necessary for a molecule to break free from the attractive forces of surrounding molecules and relocate, as explained by the absolute rate theory, or the concept that molecular motion depends on the availability of free space or voids near the molecule, according to the free volume theory[16];.

$$\Delta G^{\#} = x_1 \Delta G_1^{\#} + x_2 \Delta G_2^{\#} - \Delta G_M^R \qquad (1)$$

Where $\Delta G^{\#}$- solution activation energy and ΔG_M^R - residual Gibbs free energy of mixing.

$$\Delta G_M^R = x_1 P_1^* v_1^* \left[\left(\frac{1}{\tilde{v}_1} - \frac{1}{\tilde{v}} \right) + 3\tilde{T}_1 \ln \frac{\left(\tilde{v}_1^{1/3} - 1 \right)}{\left(\tilde{v}^{1/3} - 1 \right)} \right] +$$

$$x_2 P_2^* v_2^* \left[\left(\frac{1}{\tilde{v}_2} - \frac{1}{\tilde{v}} \right) + 3\tilde{T}_2 \ln \frac{\left(\tilde{v}_2^{1/3} - 1 \right)}{\left(\tilde{v}^{1/3} - 1 \right)} \right] + \frac{x_1 v_1^* \theta_2 X_{12}}{\tilde{v}_1} \qquad (2)$$

$$\eta_i = A \exp[\Delta G_i^{\#} / RT + (v_i - 1)^{-1}] \qquad (3)$$

$$\ln \eta_i = \ln A + \frac{\Delta G_i^{\#}}{RT} + (\tilde{v}_i - 1)^{-1} \qquad (4)$$

Viscosity can be determined by relation proposed by Prigogine-Flory-Patterson model[17-20];

$$\ln \eta = x_1 \ln \eta_1 + x_2 \ln \eta_2 - [x_1 P_1^* v_1^* \left\{ \frac{1}{\tilde{v}_1} - \frac{1}{\tilde{v}} \right\} + 3\tilde{T}_1 \ln\{$$

$$(\tilde{v}_1^{1/3} - 1)/(\tilde{V}^{1/3} - 1)\} + x_2 P_2^* v_2^* \{(1/\tilde{v}_2) - (1/\tilde{v})\}$$

$$+ 3\tilde{T}_2 \ln\{(\tilde{v}_2^{1/3} - 1)/(\tilde{v}^{1/3} - 1)\} + x_1 v_1^* \theta_2 X_{12} / \tilde{V}_1] / RT$$

$$+ 1/(\tilde{v} - 1) - x_1/(\tilde{v}_1 - 1) - x_2/(\tilde{v}_2 - 1) \qquad (5)$$

Results and Discussion

The binary system composed of Acetonitrile (CH_3 CN) and Formamide ($HCONH_2$) has been studied extensively to investigate the impact of composition and temperature on various thermo physical and transport properties. Table-1 presents comprehensive experimental data for this system at five different temperatures: 293.15 K, 298.15 K, 303.15 K, 308.15 K, and 313.15 K. The parameters analyzed include density (ρ), experimental viscosity (η_{ex}□), reduced volume (V~), excess pressure (P*), experimental excess viscosity (η^{E}(ex□)), theoretical viscosity (η□□$_{eo}$), theoretical excess viscosity (η^{E}(□□$_{eo}$)), and the percentage deviation in viscosity (%Δη). The density of the mixture exhibits a consistent and systematic decrease with an increase in the mole fraction of Acetonitrile (X_1) at all studied temperatures. This trend is primarily due to the lower molecular weight and lower intrinsic density of Acetonitrile compared to Formamide. As Acetonitrile, replaces Formamide in the mixture, the overall mass per unit volume decreases. Additionally, temperature elevation leads to a further decrease in density across all compositions, consistent with thermal expansion and increased molecular separation due to enhanced kinetic energy. The observed density behaviour suggests that Acetonitrile weakens the intermolecular hydrogen bonding that is prevalent in Formamide. The disruption of these strong dipole-dipole and hydrogen bonding interactions contributes to looser molecular packing and a more expanded liquid structure at higher mole fractions of Acetonitrile and elevated temperatures. The reduced volume (V~), a thermodynamically derived parameter that accounts for the molar volume normalized by temperature and pressure-like variables, increases progressively with the mole fraction of Acetonitrile. This behaviour indicates the expansion of the system's molecular free volume due to weaker interactions between the components. The increase in V~ is also enhanced with rising temperature, reaffirming the fact that thermal energy further weakens intermolecular attractions, leading to increased spatial separation between molecules. Higher values of V~ at elevated temperatures and high Acetonitrile concentrations suggest enhanced structural disorder, supporting the hypothesis of strong hydrogen bond network disruption in the presence of Acetonitrile. The theoretical viscosity values, calculated using standard mixing rules or predictive models, generally follow the trend of the experimental data but show significant deviations, especially at higher Acetonitrile content and elevated temperatures. The models often assume ideal or near-ideal mixing behaviour, which becomes invalid when specific interactions such as hydrogen bonding are disrupted in real systems. The difference between theoretical and experimental viscosity values is more pronounced in regions where excess viscosity is highly negative, indicating that current models fail to fully capture the weakening or loss of hydrogen bonding and the resulting enhancement in fluidity. The percentage deviation in viscosity provides a quantitative measure of how far the theoretical models diverge from experimental reality. It is observed that %Δη increases significantly with increasing mole fraction of Acetonitrile and temperature. For instance, the deviation reaches a peak of about 79.71% at X_1 = 0.834 and T = 313.15 K, highlighting the inadequacy of theoretical models under conditions of strong non-ideality. Such high deviations necessitate the development or refinement of viscosity models that can account for specific interactions, such as hydrogen bonding, structural rearrangement, and dipole-dipole interactions. The excess viscosity, defined as the deviation of experimental viscosity from the ideal additive behaviour of the pure components, is found to be negative throughout the entire composition range and across all temperatures. Negative values of $\eta^{E}{}_{(\ ex\square)}$ indicate that the interactions between unlike molecules (Acetonitrile-Formamide) are weaker than the average of the like-like interactions (Acetonitrile-Acetonitrile and Formamide-Formamide).This suggests a disruption of the strong hydrogen bonding present in pure Formamide when Acetonitrile is introduced. The formation of weaker dipole-dipole or Vander Waals interactions in the binary mixture contributes to this negative deviation, reflecting a decrease in structural cohesion and intermolecular association. The magnitude of negative excess viscosity increases with temperature and Acetonitrile mole fraction, further confirming that thermal agitation weakens residual associative forces, resulting in more non-ideal behaviour. At higher temperatures (313.15 K), the excess viscosity values are generally higher compared to lower temperatures as shown in Figure-1.

$$\eta^{E} = \eta - (x_1\eta_1 + x_2\eta_2) \qquad (6)$$

As the temperature increases, the peak value of ηE increases notably, with the 313.15 K curve showing the highest peak (~2.1 at around x_1 = 0.2). η^E starts low at very low mole fractions of Acetonitrile. It rises to a maximum value between x_1 = 0.2 and 0.5 depending on temperature. Positive excess viscosity indicates strong interactions between Acetonitrile and Formamide molecules causing increased resistance to flow compared to an ideal mixture.

Table-2 presents an extensive set of thermo physical data for the binary system comprising Acetonitrile (ACN) and N-Methylacetamide (NMA) across a range of mole fractions (X_1) and temperatures (293.15 K to 313.15 K). The parameters studied include density (ρ), reduced molar volume (V~), experimental viscosity (ηexp), theoretically estimated viscosity (ηtheo), excess viscosity (ηE), and the percentage deviation between experimental and theoretical viscosity values (%Δη). These parameters serve as insightful indicators of molecular interactions, fluid structure, and the extent of deviation from ideal mixing behaviour. At each temperature, density (ρ) decreases progressively with increasing mole fraction of Acetonitrile. This trend can be attributed to the intrinsic physical properties of Acetonitrile, which has a lower molecular weight and density than NMA. The decline in reduced molar volume (V~) further supports this trend and implies volume contraction on mixing. Such contraction suggests favourable interactions between unlike molecules, such as hydrogen bonding or dipole-dipole interactions, which result in a more tightly packed liquid structure than either of the pure components. This decrease in V~ across all temperatures indicates that molecular association between Acetonitrile and NMA increases, leading to the formation of a more compact structure.

This observation is critical, as it underlines the existence of strong molecular affinity, especially at intermediate mole fractions where interactions are maximized. The experimental viscosity (η^{exp}) demonstrates a subtle but consistent increase with mole fraction up to around X_1 = 0.88, beyond which the values either plateau or slightly decline. The theoretical viscosity (η^{theo}), however, follows a different trend, generally decreasing with mole fraction at lower temperatures but becoming erratic at elevated temperatures, especially at 313.15 K. This deviation highlights the inability of conventional models to accurately predict viscosity for systems with complex interaction profiles. At temperatures up to 303.15 K, theoretical viscosity estimations reasonably follow the trend of experimental values, although they consistently underestimate η^{exp}. However, at 308.15 K and especially at 313.15 K, η^{theo} becomes anomalously large, particularly at higher mole fractions.

This irregular behaviour may result from limitations in the predictive model, which likely assumes ideal or semi-ideal mixing, ignoring strong associative forces like hydrogen bonding. For instance, at 313.15 K and X_1 = 0.929, ηexp is 1.322, but ηtheo is reported as 18.115, resulting in an excess viscosity of 17.951 and a percentage deviation of -1341.32%. At the highest mole fraction (X_1 = 0.9685), this deviation becomes extremely exaggerated at -5078.77%, revealing a profound mismatch between experimental observations and theoretical predictions. The excess viscosity (η^E) values, derived from the difference between experimental and theoretical viscosities, are predominantly positive across most mole fractions and temperatures up to 308.15 K. Positive η^E values signify strong intermolecular attractions, usually resulting from specific interactions like hydrogen bonding, dipolar alignment, or donor-acceptor interactions between the amide group of NMA and the nitrile group of Acetonitrile. At lower temperatures, η^E values increase gradually with mole fraction, peaking around X_1 = 0.68–0.88, suggesting that molecular interactions are most pronounced in this composition range. However, at 313.15 K, η^E values become highly negative at higher mole fractions, indicating a fundamental alteration in molecular behaviour, possibly due to thermal disruption of hydrogen bonds or structural rearrangements. This reversal in η^E sign may also hint at phase instability, micro-heterogeneity, or even partial decomposition of complex structures formed at lower temperatures. It implies that the nature of interactions between the components is temperature-dependent, with association dominating at low to moderate temperatures and disruption or repulsion dominating at higher temperatures.

η^E is positive throughout the composition range, which signifies that the interactions between Acetonitrile and NMA are stronger than those in the pure components. This positive deviation suggests structure enhancement or association effects in the mixture. The percentage deviation (%Δη) between experimental and theoretical viscosities offers crucial insight into the reliability of the predictive model and the complexity of the liquid system. At lower temperatures, %Δη ranges between 50–75%, indicating moderately high but tolerable deviation. However, the dramatic rise in %Δη at higher mole fractions and higher temperatures reflects significant non-ideality and model inadequacy.

$$\%\Delta\eta = \frac{\left[\eta_{Exp} - \eta_{Theo}\right]}{\eta_{Exp}} \times 100 \qquad (7)$$

The sharp deviation observed at 313.15 K may arise from the oversimplified assumptions embedded in the viscosity model, such as neglecting temperature-sensitive interactions or failing to account for structural rearrangements within the liquid. The increasing discrepancy at high Acetonitrile concentrations also suggests that solvent–solvent interactions become dominant, overpowering the binary associative forces.

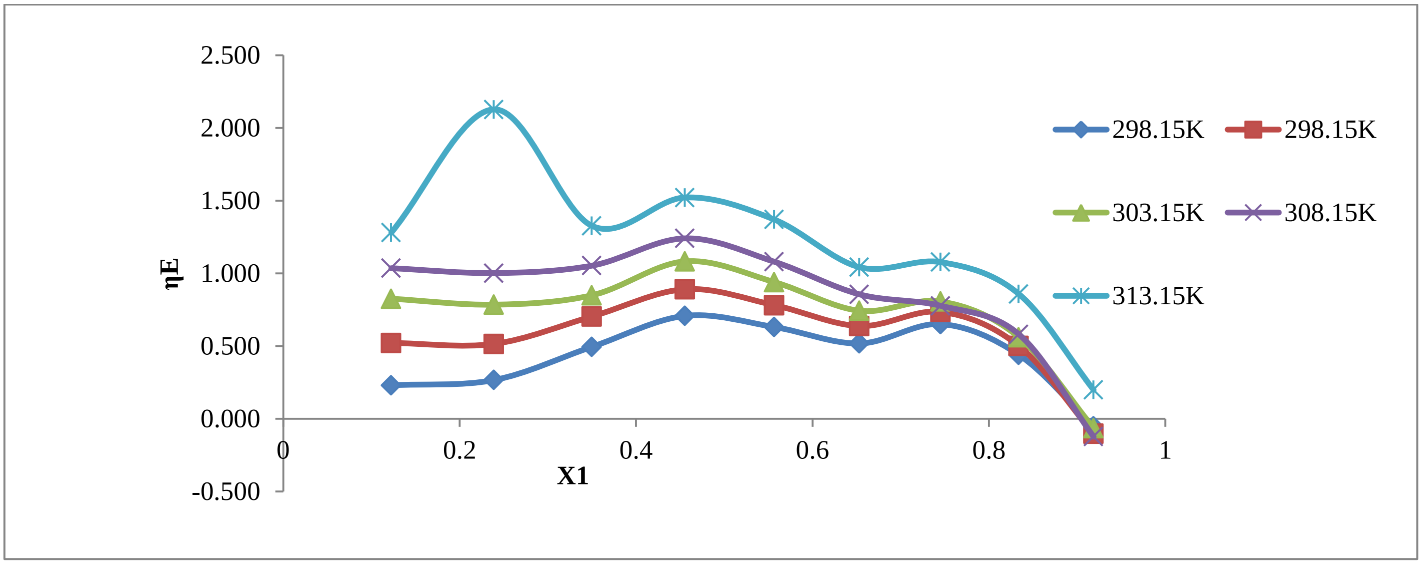

Figure-1: Plot of η^E with x_1 of Acetonitrile + Formamide at different temperatures.

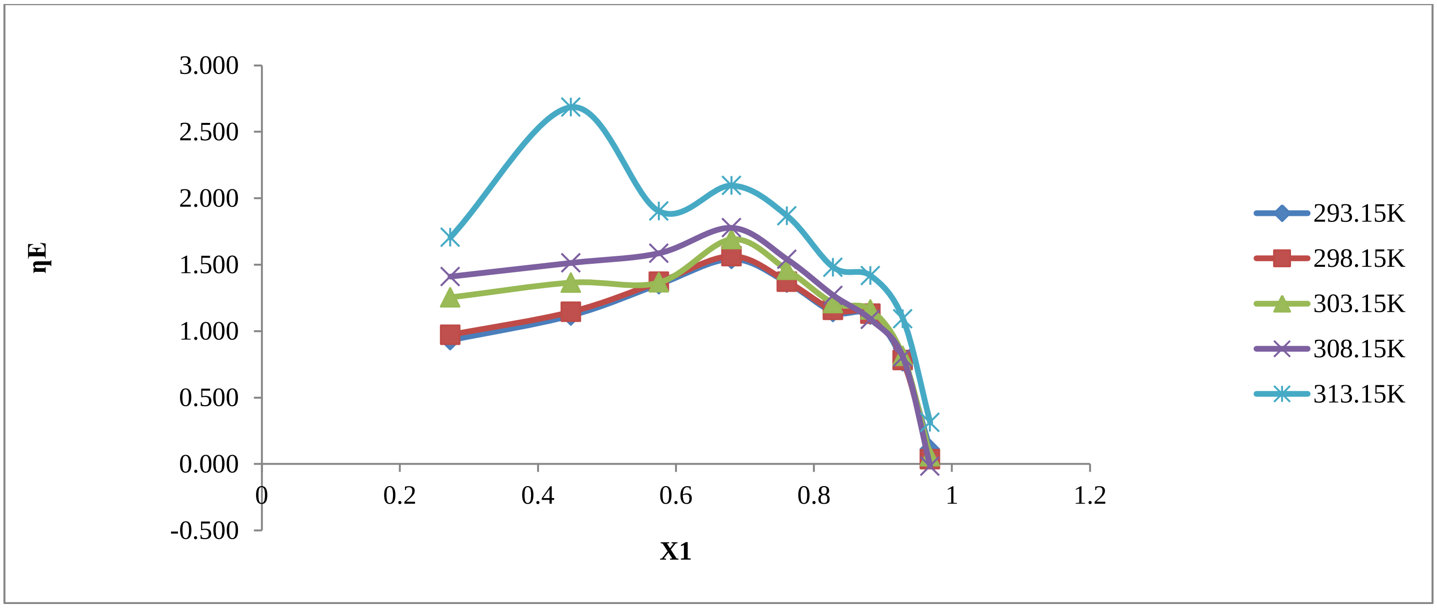

Figure-2: Plot of η^E with x_1 of Acetonitrile + NMA at different temperatures.

Table-1: Viscosity and excess viscosity of Acetonitrile + Formamide from 293.15-313.15K.

X_1	ρ	P*	V~	η^{exp}	$\eta^{(Theo)}$	$\eta^{E}_{(Exp)}$	$\eta^{E}_{(Theo)}$	%Δη
T=293.15K								
0.1225	1.1258	8.968	1.240	3.482	3.307	0.055	0.231	5.05
0.239	1.0992	8.442	1.247	3.136	2.863	-0.006	0.267	8.69
0.3499	1.0835	7.977	1.254	3.000	2.392	-0.113	0.495	20.25
0.4557	1.0405	7.561	1.261	2.865	1.940	-0.217	0.708	32.29
0.5567	1.0102	7.188	1.267	2.457	1.535	-0.291	0.631	37.52
0.6533	0.9705	6.852	1.274	2.027	1.189	-0.319	0.518	41.31
0.7456	0.9403	6.548	1.280	1.856	0.906	-0.300	0.651	51.21
0.834	0.9015	6.272	1.286	1.355	0.680	-0.235	0.440	49.82
0.9187	0.8503	6.020	1.292	0.585	0.504	-0.133	-0.052	13.87
T=298.15K								
0.1225	1.1015	9.019	1.245	3.481	3.047	0.087	0.522	12.47
0.239	1.0825	8.480	1.253	3.130	2.668	0.054	0.515	14.75
0.3499	1.0657	8.003	1.260	2.990	2.205	-0.082	0.704	26.27
0.4557	1.0345	7.580	1.267	2.864	1.841	-0.133	0.891	35.74
0.5567	0.9985	7.201	1.274	2.456	1.467	-0.208	0.782	40.28
0.6533	0.9624	6.860	1.280	2.026	1.144	-0.245	0.638	43.57
0.7456	0.9351	6.553	1.287	1.851	0.876	-0.240	0.735	52.67
0.834	0.8792	6.274	1.293	1.354	0.661	-0.193	0.500	51.21
0.9187	0.8492	6.021	1.299	0.500	0.492	-0.111	-0.103	1.66
T=303.15K								
0.1225	1.0998	9.113	1.250	3.472	2.785	0.139	0.826	19.78
0.239	1.0735	8.552	1.258	3.126	2.484	0.143	0.785	20.53
0.3499	1.0538	8.058	1.265	2.900	1.835	-0.216	0.849	36.72

0.4557	1.0258	7.619	1.273	2.857	1.757	-0.017	1.083	38.49
0.5567	0.9802	7.226	1.280	2.450	1.411	-0.099	0.940	42.40
0.6533	0.9594	6.874	1.287	2.000	1.106	-0.151	0.743	44.71
0.7456	0.9256	6.557	1.294	1.822	0.849	-0.166	0.807	53.40
0.834	0.8728	6.270	1.300	1.346	0.641	-0.144	0.561	52.37
0.9187	0.8402	6.009	1.307	0.499	0.477	-0.086	-0.064	4.43
T=308.15K								
0.1225	1.0856	9.26	1.25	3.41	2.55	0.18	1.04	25.12
0.239	1.0568	8.67	1.26	3.10	2.32	0.22	1.00	25.28
0.3499	1.0215	8.16	1.27	2.90	1.72	-0.12	1.05	40.62
0.4557	0.9856	7.71	1.28	2.84	1.68	0.08	1.24	40.72
0.5567	0.9508	7.30	1.29	2.45	1.36	0.00	1.08	44.25
0.6533	0.9256	6.93	1.29	2.00	1.07	-0.07	0.86	46.22
0.7456	0.8809	6.61	1.30	1.71	0.83	-0.10	0.78	51.46
0.834	0.8405	6.31	1.31	1.31	0.63	-0.10	0.58	52.07
0.9187	0.8028	6.04	1.31	0.41	0.47	-0.06	-0.12	-14.63
T=313.15K								
0.1225	1.0807	9.354	1.259	3.390	3.346	1.236	1.281	1.31
0.239	1.0559	8.762	1.267	3.957	3.705	1.876	2.128	6.36
0.3499	1.0158	8.241	1.275	2.890	1.759	0.196	1.327	39.12
0.4557	0.9758	7.779	1.283	2.830	2.596	1.287	1.522	8.28
0.5567	0.9365	7.366	1.291	2.436	1.726	0.661	1.370	29.12
0.6533	0.8905	6.996	1.298	1.876	1.012	0.178	1.042	46.06
0.7456	0.8726	6.663	1.305	1.689	0.532	-0.079	1.077	68.48
0.834	0.8405	6.362	1.313	1.257	0.255	-0.144	0.858	79.71
0.9187	0.7992	6.089	1.319	0.394	0.113	-0.083	0.199	71.40

Table-2: Viscosity and excess viscosity of Acetonitrile + N-Methylacetamide from 293.15-313.15K.

X_1	ρ	P*	V~	η^{exp}	$\eta^{(Theo)}$	$\eta^{E}_{(Exp)}$	$\eta^{E}_{(Theo)}$	%Δη
T=293.15K								
0.2733	0.9357	6.956	1.273	3.472	1.611	-0.929	0.932	53.60
0.4481	0.9235	6.716	1.279	3.136	1.173	-0.846	1.117	62.60
0.5757	0.8895	6.527	1.283	2.990	0.871	-0.767	1.352	70.87
0.6808	0.8764	6.360	1.286	2.865	0.690	-0.633	1.542	75.92
0.7614	0.8658	6.226	1.289	2.447	0.596	-0.487	1.364	75.66
0.8282	0.8465	6.110	1.291	2.027	0.532	-0.351	1.143	73.77
0.8821	0.8351	6.013	1.293	1.846	0.471	-0.251	1.124	74.50
0.929	0.8252	5.925	1.295	1.355	0.432	-0.150	0.773	68.14
0.9685	0.8051	5.850	1.297	0.575	0.396	-0.068	0.111	31.15
T=298.15K								
0.2733	0.9305	6.973	1.280	3.471	1.581	-0.918	0.972	54.46
0.4481	0.9197	6.729	1.285	3.130	1.150	-0.835	1.145	63.25
0.5757	0.8807	6.536	1.289	2.980	0.854	-0.756	1.370	71.35
0.6808	0.8704	6.367	1.293	2.864	0.676	-0.625	1.563	76.39
0.7614	0.8595	6.231	1.296	2.436	0.584	-0.480	1.372	76.03
0.8282	0.8405	6.113	1.299	2.026	0.521	-0.346	1.159	74.28
0.8821	0.8305	6.015	1.301	1.841	0.462	-0.248	1.131	74.92
0.929	0.8205	5.927	1.302	1.354	0.423	-0.148	0.783	68.75
0.9685	0.8015	5.851	1.304	0.490	0.388	-0.067	0.035	20.84
T=303.15K								
0.2733	0.9108	6.991	1.286	3.462	1.420	-0.787	1.254	58.96
0.4481	0.8998	6.738	1.292	3.126	1.053	-0.708	1.365	66.33
0.5757	0.8712	6.538	1.297	2.800	0.790	-0.645	1.366	71.78
0.6808	0.8652	6.364	1.300	2.857	0.632	-0.534	1.691	77.88
0.7614	0.8501	6.224	1.304	2.420	0.550	-0.410	1.460	77.26
0.8282	0.8357	6.103	1.306	2.000	0.495	-0.294	1.211	75.26

0.8821	0.8256	6.002	1.308	1.812	0.440	-0.211	1.161	75.69
0.929	0.7958	5.912	1.310	1.346	0.406	-0.126	0.814	69.85
0.9685	0.7853	5.834	1.312	0.489	0.374	-0.057	0.058	23.53
T=308.15K								
0.2733	0.9007	14.583	1.206	3.395	0.235	-1.749	1.411	93.07
0.4481	0.8795	12.601	1.223	3.103	0.401	-1.188	1.513	87.07
0.5757	0.8654	11.090	1.239	2.887	0.236	-1.064	1.586	91.82
0.6808	0.8556	9.808	1.255	2.840	0.182	-0.881	1.777	93.60
0.7614	0.8456	8.806	1.269	2.420	0.242	-0.638	1.539	89.99
0.8282	0.8298	7.967	1.282	1.998	0.359	-0.370	1.269	82.03
0.8821	0.8198	7.286	1.293	1.696	0.310	-0.297	1.088	81.71
0.929	0.7902	6.693	1.304	1.305	0.371	-0.131	0.804	71.60
0.9685	0.7805	6.193	1.313	0.396	0.352	-0.060	-0.016	10.97
T=313.15K								
0.2733	0.8798	7.536	1.290	3.380	2.569	0.895	1.706	24.00
0.4481	0.8697	7.181	1.297	3.957	4.861	3.589	2.685	-22.84
0.5757	0.8556	6.903	1.303	2.880	6.138	5.160	1.902	-113.15
0.6808	0.8425	6.660	1.309	2.830	7.800	7.064	2.095	-175.58
0.7614	0.8346	6.465	1.313	2.416	10.464	9.914	1.866	-333.13
0.8282	0.8194	6.298	1.317	1.876	13.710	13.315	1.480	-630.91
0.8821	0.8008	6.158	1.320	1.689	15.402	15.130	1.417	-811.96
0.929	0.7824	6.034	1.322	1.257	18.115	17.951	1.093	-1341.32
0.9685	0.7615	5.927	1.324	0.384	19.907	19.835	0.312	-5078.77

Conclusion

On the basis of above discussion it can be concluded that the binary mixture of Acetonitrile and Formamide demonstrates significant non-ideal behaviour in terms of its thermo-physical and transport properties. The negative excess viscosity values and high percentage deviations from theoretical models emphasize the dominant role of specific molecular interactions in defining the system's behaviour. These findings highlight the need for advanced theoretical frameworks capable of incorporating hydrogen bonding and dipolar interactions to better predict the behaviour of such complex liquid mixtures Whereas Acetonitrile + NMA binary system exhibits strong, non-ideal behaviour, especially evident in viscosity and excess viscosity data. The presence of positive excess viscosity and volume contraction at most temperatures confirms the existence of strong intermolecular interactions, possibly hydrogen bonding. Theoretical models fail to capture viscosity accurately, particularly at higher temperatures, indicating a need for more sophisticated predictive approaches.

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