The Density, Dynamic Viscosity and Kinematic Viscosity of Protic Polar Solvents (Pure and Mixed Systems) Studies: A Theoretical Insight of Thermophysical Properties

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ABSTRACT

The densities (ρ) and viscosities (η) have been studied for pure and mixed systems of protic polar solvents water, methanol, ethanol and propan-1-ol for entire composition range at temperature from 293 K to 343 K in 5 K intervals at atmospheric pressure. With increase in temperature the density values as well as the dynamic viscosity values were decrease. The obtained values are used to calculate the excess properties such as excess molar free volume (V^E), thermal expansion coefficient (α), excess thermal expansion coefficient (α^E), viscosity deviation (Δη) and excess Gibb's free energy (ΔG^{*E}) for the activation of viscous flow for mixed systems. The calculated excess properties of binary mixtures were correlated with Redlich-Kister type polynomial equation by least square regression method and fitting parameters were found for all binary systems. The temperature dependence of viscosities for mixed systems have been explained using Arrhenius type equation of Newtonian classic solvents and Eyring transition state equation. The thermodynamic parameters were also evaluated for mixed systems which show the thermal stability of system.

Keyword: Density, Dynamic viscosity, Protic polar solvent, Excess properties, Eyring transition, Thermodynamics.

1. INTRODUCTION

From experimental and theoretical point of view to understand molecular interaction of the mixed system, density and viscosity are the important physical properties.[1] Viscosity is the transport property of the fluids serves as quantitative data to design mass transfer, heat transfer and fluid flow mechanism.[2-5] and each fluid has specific transport properties which gives an unparalleled application. Solvent mixtures with various composition ranges have greater interest in industrial applications because of its unique transport properties.[6, 7] At present, transport properties of individual polar solvent is well known and many researchers were also done multiple works on binary and ternary mixture.[8-10] However, many works have been done on polar mixture system; temperature dependence of experimental data on solvent mixture with wide temperature range is still scanty which is necessitate to do further work to grip extreme knowledge on thermophysical properties of mixed solvent system.[11-14]

The mixed system of protic polar solvent has multiple application like antifreezing agent, pharmaceutical preparation, separation process, etc.,[15-18] Interest in studying the mixed system of protic polar solvents is due to greater solubilization and ionization power. The properties of mixture continuously vary based on simple change in composition of pure components. In addition, equilibrium constant, rate constant and activation energy of many reaction strongly depends on nonlinear way in the ratio of mixed solvent systems.[19, 20]

In this paper, thermodynamic and thermophysical property have been studied for water, methanol, ethanol and propan-1-ol and their mixed systems. Bulk property like density, viscosity, etc., are measured for pure: water, methanol, ethanol and propan-1-ol and binary systems: water (1) + methanol (2), water (1) + ethanol (2), water (1) + propan-1-ol (2), methanol (1) + ethanol (2), methanol (1) + propan-1-ol (2) and ethanol (1) + propan-1-ol (2) at temperature range from 293 K to 343 K with interval of 5 K. The data obtained is used to evaluate excess properties[21] excess molar volume (V^E), thermal expansion coefficient (α), excess thermal expansion coefficient (α^E), viscosity deviation ($\Delta\eta$), and excess gibbs energy (ΔG^{*E}) for activation of viscous flow. These excess properties are correlated with Redlich-Kister polynomial equation.[22-24] In addition, the change of enthalpy and entropy for activation of viscous flow and Gibb's free energy are calculated by modifying Eyring transition state equation,[25-27] and temperature dependence of viscosity for mixed system is represented by using Arrhenius type equation for Newtonian classic solvents [28-31].

The aim of this research is to find fundamental density and viscosity for pure and mixed system of protic polar solvents at various temperature in atmospheric pressure. And to understand the molecular interaction and molecular packing through evaluating excess properties from experimental data. Thermodynamic parameters have been derived to predict the thermal stability of mixed systems.

2. Materials and Methods

2.1. Materials

The extra pure methanol (CAS No. 67-56-1) of purity 99.5% were purchased from Loba Chemie, ethanol (CAS No. 64-17-5) of analytical grade purity 99.9% obtained from SD fine chem limited, propan-1-ol (CAS No. 71-28-8) LR grade of purity 99.5% purchased from Rankem

chemicals and water were used throughout experiment from Milli-Q water (specific conductivity 1–2 μS cm^{-1} at 298.15 K). The experimental data were also well agreed with literature [14, 32-34] values having standard error of 1 x 10^{-3} and this errors are due to impurity in chemicals and uncertainty in experiment.

2.2. Methods

2.2.1. Density Measurements

Densities (ρ) of protic solvents were measured by using the U-tube digital density meter (Laboratory Density Meter (model no: DMA 5000 M), Anton Paar GmbH) with a repeatability of 1×10^{-5} g/cm^3 and 0.01 K, at atmospheric pressure. For all (the densities of pure water, methanol, ethanol and propan-1-ol and their binary mixture) systems. The measurements were investigated at the temperature range of 293 to 343 K with a temperature interval of 5 K at atmospheric pressure. The measuring range of temperature (from 293 to 343 K) was controlled by a built-in Peltier thermostat (PT-100) with an accuracy of ±0.01 K. A standard deviation of 1.4×10^{-6} g/cm^3 was used to measure the density.

2.2.2. Viscosity Measurements

The viscosity of pure and their liquid mixture was measured at a temperature range from 293.15 to 343.15 K with a temperature interval of 5 K by using the Microviscometer (model no.: LOVIS 2000 ME) Microviscometer Module, Anton Paar GmbH. The measuring temperature (from 293.15 to 343.15 K) was controlled by a built-in Peltier thermostat with an accuracy of ± 0.01 K. It can measure the viscosity in the range of 0.3 mPa·s to 10000 mPa·s and the viscosity accuracy is 0.5%. The nominal uncertainty of the measured was estimated to be better than ± 0.5 % and reproducibility 0.1 %. The quantity of liquid required (approximately 1 ml) was transferred to the apparatus by a syringe; special care was taken not to introduce bubbles in the tube to prevent errors

in the measurements. In this range of viscosity values the diameter of the capillary was 1.59 mm, and the error for this capillary was < 0.01 %.

3. RESULTS AND DISCUSSION

In this work, the physical properties (*viz*., density, dynamic viscosity and kinematic viscosity) were experimentally determined for pure and mixed protic polar systems. Table 1 to 4 summarize the experimental values and calculated values of thermodynamic and thermophysical properties for the pure and their mixed systems.

3.1. Pure systems

Table 1 represents thermophysical properties of pure components, where density as well as viscosity values decrease with increase in temperature for all the pure systems. Water has highest density values due to compact packing of water molecules via multiple hydrogen bonding. Pure alcoholic solvent system has lower density values indicate less geometrical fitting due to presence of hydrophobic part.[35] Viscosity values increases as chain length of alcoholic molecule increases indicates that apart from hydrogen bonding, hydrophobic interaction plays major role in physical properties of pure system. Thermal expansion coefficient and Gibbs free energy for activation of viscous flow increases as increase of temperature. Methanol has higher thermal expansion coefficient and water has lower thermal expansion coefficient. Among the pure systems, water molecules show stronger intermolecular interaction and methanol shows fewer than other alcoholic systems due to lacking in dominant contribution of hydrophobic interaction and hydrogen bonding.[35]

3.2. Binary systems

3.2.1. Density

The densities of pure and mixed solvent systems are given as function of temperature in Table 1 to 2. Fig. 1 shows binary system of water (1) + methanol (2) and methanol (1) + ethanol (2). The represented Fig. 1(A) and (B) clearly shows that the densities deviation of water (1) + methanol (2) as function of mole fraction and temperature is exponentially decreasing as mole fraction of water increases. Trend of the deviation is similar for water with other protic polar solvents (see Supporting Information (SI), Fig. S1 A and B). Whereas the densities of methanol (1) + ethanol (2) shows in Fig. 1 (C) & (D) illustrate that the system deviation is almost ideal. The binary system of methanol (1) + propan-1-ol (2) shows nonlinear sigmoidal type deviation. And the system ethanol (1) + propan-1-ol (2) have linear deviation where density values decrease as mole fraction of ethanol increase (see SI, Fig. S1 C and D). With increase in temperature density values of mixture decrease where alcohol + alcohol mixtures have steepest decrease compared to water + alcohol mixture systems (see SI, Fig. S2 A to D). Fig. 2 (A) and (B) show densities of all binary mixture system as function of mole fraction at 298.15 K. For methanol (1) + ethanol (2), methanol (1) + propan-1-ol (2) have nonlinear deviation and linear deviation with convex trend for water (1) + methanol (2), water (1) + ethanol (2) and water (1) + propan-1-ol (2). In case of ethanol (1) + propan-1-ol (2) it is concave curve which strongly indicates interaction between water + alcohol mixture has more specific interaction than alcohol + alcohol mixture. As increase of temperature density values for mixtures tend to behave as ideal (see SI, Fig. S3).

The measured density values have been used to calculate excess molar volumes (V^E) by the following equation:

$$V^E = \frac{\sum_{i=0}^{n} x_i M_i}{\rho} - \sum_{i=1}^{n} \frac{x_i M_i}{\rho_i} \qquad (1)$$

where x_i is the mole fraction of the pure component, M_i is the molar mass of the pure component, ρ is the density of the mixture, ρ_i is the density of respective pure component and n is the number of component present in the system, respectively. The calculated excess molar free volumes from eq. (1) are recorded in Table 2. Fig. 3 shows excess molar volume of binary mixture for protic polar solvents at 298.15 K. The whole composition range for water + alcohol systems are found negative which indicates intermolecular dipolar interactions and geometrical fitting between components are more. Whereas, methanol (1) + ethanol (2) behaves almost ideal, no much deviation from other mixture. Through the whole composition for ethanol (1) + propan-1-ol (2) have positive values indicate hydrogen bond rupture and dispersion force between unlike molecules.[36-38] But methanol (1) + propan-1-ol (2) unlike other mixture systems shows unique sigmoidal type deviation. And up to mole fraction of methanol (0.5) have positive values, become negative at higher mole fraction indicate methanol have strong interaction with propan-1-ol at higher mole fraction. The excess molar volumes trend is similar for all fixed temperature as function of mole fraction for binary mixture systems (see SI, Fig. S4).

The thermal expansion coefficients (α) have been determined based on temperature dependence of density at constant atmospheric pressure can be expressed as:

$$\alpha = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P \qquad (2)$$

From eq. (2), α were calculated for pure and mixed systems and represented in Table 1 to 2. For the ideal condition, the thermal expansion coefficient is constant for measured atmospheric pressure [39, 40]. The deviation of thermal expansion coefficient from ideality can be calculated by using eq. (3):

$$\alpha_E = \alpha_m - \sum_{i=0}^{n} \phi_i \alpha_i \quad (3)$$

where $\phi_i = \sum_{j=0}^{n} \phi_j$ and $\phi_j = \frac{x_j V_j}{\sum_{i=1}^{n} x_i V_i}$; α_m is coefficient of thermal expansion of mixture, α_i coefficient of thermal expansion of pure component and ϕ_i is the volume fraction of the mixed system. Excess thermal expansion coefficient (α_E) is maximum negative for binary mixture of water + alcohol and least negative values observed for alcohol + alcohol. The mixed system ethanol (1) + propan-1-ol (2) shows maximum positive deviation indicates very weaker interaction between the unlike molecules of ethanol and propan-1-ol. The presence of water in binary system shows negative values indicate the system is stable comparing with other systems.

3.2.2. Viscosity

Dynamic and Kinematic viscosities were plotted as function of temperature and mole fraction for binary systems shown in Fig. 4 to 7. Fig. 4 (A) and (B) shows dynamic viscosities of water (1) + methanol (2) and indicates that mixture have higher viscosities value than pure. This give knowledge about mixture that have strong intermolecular and geometrical fitting between unlike molecule and that via hydrogen bond from hydroxy group of methanol. Whereas methanol (1) + ethanol (2) viscosity values represent ideal behavior (Fig. 4 (C) and (D)) and viscosity values of mixture is less than pure components. The viscosity values of mixture water (1) + ethanol (2) and water (1) + propan-1-ol (2) have higher value than pure components (see SI, Fig. S5 A and B). The mixture of methanol (1) + propan-1-ol (2) and ethanol (1) + propan-1-ol (2) have concave trend with less viscosity values for mixture than pure components (see SI, Fig. S5 C and D). The dynamic viscosities decrease concavely as increase of temperature for all binary mixtures (see SI, Fig. S6 A to D). Fig. 5 represents dynamic viscosity of all binary mixture systems at 298.15 K and

viscosities of mixture decreases as temperature increases but for different temperature has no much variation in viscosity trend for all binary mixture (see SI, Fig. S7).

Fig. 6 (A to D) illustrates the kinematic viscosities of water (1) + methanol (2) and methanol (1) + ethanol (2). The kinematic viscosities of water (1) + methanol (2) having mole fraction 0.00 and 0.25 of water intersect at temperature around 323.15 K represented in Fig. 6 (A and B) as function of mole fraction and temperature. The binary mixed system methanol (1) + ethanol (2) shows almost similar trend as dynamic viscosity shown in Fig. 6 (C and D) as well as other mixtures water (1) + ethanol (2), water (1) + propan-1-ol (2), methanol (1) + propan-1-ol (2) and ethanol (1) + propan-1-ol (2) follows similar trend as dynamic viscosity (see SI, Fig. S8 A to D). The increase in temperature decreases the kinematic viscosity values (see SI, Fig. S9 A to D). Kinematic viscosities of all binary mixtures at 298.15 K are represented in Fig. 7 and trend follows similar way as dynamic viscosity follows. Similar trend is observed for all fixed temperature of binary mixture systems (see SI, Fig. S10).

The deviation in viscosity of mixture ($\Delta\eta$) were calculated using the following equation:

$$\Delta\eta = \eta - \sum_{i=1}^{n} x_i \eta_i \qquad (4)$$

where η, η_i, x_i, n are viscosity of mixture, viscosity of pure component, mole fraction and number of component present in the system, respectively. Fig. 8 shows the viscosity deviation as a function of mole fraction at 298.15 K for all binary system. Deviation of viscosities for mixture explained by two factors, negative deviation indicates loss of dipolar association due to the variable molecular size and geometry of the molecules and specific interaction between unlike molecules like hydrogen bond and charge transfer identified by positive deviation.[41] Viscosity deviations were observed positive for entire composition of water + alcohol mixture illustrates strong interaction.

Whereas values are negative for alcohol + alcohol mixture, shows weaker interaction, but methanol (1) + ethanol (2) have almost ideal behavior from others shows sigmoidal deviation at ideal axis. The increase of temperature has significant change in viscosity deviation where reducing to behave almost ideal as function of mole fraction (see SI, Fig. S11).

Excess Gibbs free energy for activation of viscous flow (ΔG^{*E}) of binary and mixed system can be calculated using experimental viscosity data from eq. (5):

$$\Delta G^{*E} = RT\left[ln\eta V - \sum_{i=0}^{n} \eta_i V_i\right] \quad (5)$$

Where R, T, η, η_i, V, V_i are gas constant, absolute temperature, viscosity of mixture and pure component, molar volume of mixture and pure component, respectively. Fig. 9 illustrates the values of excess Gibbs energy for activation of viscous flow against mole fraction for all binary mixtures. The values are positive for water mixture with alcohols and the values for alcohol + alcohol mixture shows sigmoidal type pattern. The mixtures methanol (1) + ethanol (2) and ethanol (1) + propan-1-ol (2) have positive values up to mole fraction (x_1=0.5) and further have negative values, but methanol (1) + propan-1-ol (2) have negative value at lower mole fraction of methanol and positive for higher values. The excess Gibbs free energy can be used to correlate with Gibbs-Duhem equation to find activity coefficient of mixing.[42] The increase in temperature decreases the excess Gibbs free energy to the mixture as function of mole fraction (see SI, Fig. S12).

The excess properties (*viz*., excess molar volume, viscosity deviation, excess Gibbs free energy) were fitted to Redlich-Kister type polynomial equation:

$$Y = x_1 x_2 \sum_{j=0}^{n} A_j (x_1 - x_2)^j \quad (6)$$

where Y is either V^E or $\Delta\eta$ or G^E, x_1 and x_2 are mole fraction, A_j is interaction parameter. The fitting parameters were obtained by fitting the equation to non-linear least square regression method and shown in Fig. 7 to 9. The obtained values were correlated to find standard deviation from experimental data using eq. (7):

$$\sigma(Y) = \left[\frac{\Sigma(Y_{expt} - Y_{calc})^2}{N - n}\right]^{\frac{1}{2}} \tag{7}$$

where N is the number of data points and n is the number of fitting parameters. The calculated values were represented in Table 3.

3.3. Theoretical correlation of temperature dependence of viscosity

The change of enthalpy, entropy and Gibb's free energy for activation of viscous flow for pure and their mixtures were calculated by using modified equation based on the Eyring transition state theory:

$$\eta = \frac{hN_A}{V} exp\left(\frac{\Delta G^*}{RT}\right)_P \tag{8}$$

where
$$\left(\frac{\Delta G^*}{RT}\right)_P = ln\left(\frac{\eta V}{hN_A}\right) \tag{9}$$

and η is the experimental dynamic viscosity, V is the molar volume, h is the Planck's constant and N_A is the Avogadro number. By plotting $\ln(\eta V/hN_A)$ against 1/T, straight light was observed.

$$\Delta G^* = \Delta H^* - T\Delta S^* \tag{10}$$

$$ln\left(\frac{\eta V}{hN_A}\right) = \frac{\Delta H^*}{RT} - \frac{\Delta S^*}{R} = \frac{\Delta G^*}{RT} \tag{11}$$

From plotted graph, the change of enthalpy and entropy for viscous flow were found as slope and intercept. Table 4 shows calculated values for binary mixture of protic polar solvent. The

contributions of enthalpy and entropy changes to Gibb's free energy were calculated for studied temperature represented in Table 1 and 2. The free energy values increase as increase of temperature.

The temperature dependence of dynamic viscosity can be correlated with Arrhenius type equation for Newtonian classic solvents by modifying to logarithmic form:

$$ln(\eta) = ln(A_s) + \frac{E_a}{R}[1/T] \tag{12}$$

$$T^* = \frac{E_a}{R} \tag{13}$$

The temperature dependence of viscosities shows linear Arrhenius behavior by fitting to the Andrade equation. Where A_s is pre-exponential entropic factor related to viscosity at infinite temperature, E_a is activation energy for transition state, R is gas constant and T is absolute temperature. Using linear least square regression method, the equation is fitted with experimental data which gives slope is equal to E_a/R and intercept of dependent variable viscosity is $\ln(A_s)$. In addition, activation temperature (T^*) were determined from linear Arrhenius equation.

$$T_A = \frac{-E_a}{Rln(A_s)} \tag{14}$$

The Arrhenius temperature (T_A) were ascertained from the intercept with abscissa axis[43] to modify the equation to the form:

$$ln(\eta) = \frac{E_a}{RT}\left(\frac{1}{T} - \frac{1}{T_A}\right) \tag{15}$$

Where pure and mixture systems have linear Arrhenius behavior having activation energy for viscous flow of range ($11 < E_a < 23$ kJ.mol^{-1}) and preexponential factor of range ($-5 < \ln(A_s) < -8$ mPa.s) reported in Table 4. The binary mixed systems have the activation energy in the order

(water (1) + ethanol (2)) > (water (1) + propan-1-ol (2)) > (water (1) + methanol (2)) > (ethanol (1) + propan-1-ol (2)) > (methanol (1) + propan-1-ol (2)) > (methanol (1) + ethanol (2)). The presence of water in the mixed system increase the activation energy and make system more stable.

4. CONCLUSIONS

This paper demonstrates the pure and their mixing behavior of protic polar solvents for mixed systems of water, methanol, ethanol and propan-1-ol. Density, dynamic viscosity and kinematic viscosity decreases as increase in temperature for pure and mixed systems. The values for pure system is linear decrease for density and exponential decrease for viscosities. Excess molar volumes, thermal expansion coefficient, viscosity deviation, excess Gibb's free energy were calculated from experimental density and viscosity values. The excess properties were fitted to Redlich-Kister polynomial equation through least square regression method. Viscosity deviation is positive for mixture of water with alcoholic molecules having hydroxy group which indicates strong interaction between unlike molecules, like hydration through multiple hydrogen bonds. The mixtures of alcoholic molecules have unspecific weaker interaction like dispersion force observed by negative viscosity deviation. By observation of all experimental and calculated outcomes, water and ethanol have very stronger interaction than other mixtures whereas methanol and propan-1-ol mixture have weaker interaction. The temperature dependence of viscosities were studied by using semiemprical relationship of Eyring state transition equation and Arrhenius type equation for Newtonian classic solvents.

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REFERENCES

[1] B. Long, Z. Wang, H. Yang, Y. Ding, Intermolecular interactions of 1, 2-diethoxyethane with toluene: An insight from surface and volumetric properties at different temperatures, Journal of Molecular Liquids, DOI (2017).

[2] K. Soliman, E. Marschall, Viscosity of selected binary, ternary, and quaternary liquid mixtures, Journal of chemical and engineering data, 35 (1990) 375-381.

[3] P.S. Nikam, L.N. Shirsat, M. Hasan, Density and viscosity studies of binary mixtures of acetonitrile with methanol, ethanol, propan-1-ol, propan-2-ol, butan-1-ol, 2-methylpropan-1-ol, and 2-methylpropan-2-ol at (298.15, 303.15, 308.15, and 313.15) K, Journal of Chemical & Engineering Data, 43 (1998) 732-737.

[4] R. Gardas, S. Oswal, Volumetric and transport properties of ternary mixtures containing 1-butanol or 1-pentanol, triethylamine and cyclohexane at 303.15 K: Experimental data, correlation and prediction by the ERAS model, Journal of Solution Chemistry, 37 (2008) 1449-1470.

[5] W. Cao, A. Fredenslund, P. Rasmussen, Statistical thermodynamic model for viscosity of pure liquids and liquid mixtures, Industrial & engineering chemistry research, 31 (1992) 2603-2619.

[6] S. Song, C. Peng, Viscosities of binary and ternary mixtures of water, alcohol, acetone, and hexane, Journal of Dispersion Science and Technology, 29 (2008) 1367-1372.

[7] R.E. Leitão, F. Martins, M.C. Ventura, N. Nunes, Structural characterization of the ternary solvent mixture methanol–acetonitrile–1-propanol, Journal of physical organic chemistry, 15 (2002) 623-630.

[8] I.S. Khattab, F. Bandarkar, M.A.A. Fakhree, A. Jouyban, Density, viscosity, and surface tension of water+ ethanol mixtures from 293 to 323K, Korean Journal of Chemical Engineering, 29 (2012) 812-817.

[9] A.J. Parker, Protic-dipolar aprotic solvent effects on rates of bimolecular reactions, Chemical Reviews, 69 (1969) 1-32.

[10] S. Mashimo, S. Kuwabara, S. Yagihara, K. Higasi, The dielectric relaxation of mixtures of water and primary alcohol, The Journal of Chemical Physics, 90 (1989) 3292-3294.

[11] H. Kubota, Y. Tanaka, T. Makita, Volumetric behavior of pure alcohols and their water mixtures under high pressure, International journal of thermophysics, 8 (1987) 47-70.

[12] P. Kaur, G.P. Dubey, Thermo physical and FT-IR study on binary mixtures of 2-isopropoxy ethanol and alcohols at different temperatures, Journal of Molecular Liquids, 233 (2017) 479-486.

[13] Y. Tanaka, Y. Matsuda, H. Fujiwara, H. Kubota, T. Makita, Viscosity of (water+ alcohol) mixtures under high pressure, International journal of thermophysics, 8 (1987) 147-163.

[14] H.A. Zarei, F. Jalili, S. Assadi, Temperature dependence of the volumetric properties of binary and ternary mixtures of water (1)+ methanol (2)+ ethanol (3) at ambient pressure (81.5 kPa), Journal of Chemical & Engineering Data, 52 (2007) 2517-2526.

[15] V. Jouyban-Gharamaleki, K. Jouyban-Gharamaleki, J. Soleymani, W.E. Acree Jr, A. Jouyban, Solubility of tris (hydroxymethyl) aminomethane in water+ 1-propanol mixtures at various temperatures, Journal of Chemical & Engineering Data, 59 (2014) 3723-3727.

[16] D. Van Baelen, A. Reyniers, B. Van der Bruggen, C. Vandecasteele, J. Degrève, Pervaporation of binary and ternary mixtures of water with methanol and/or ethanol, Separation science and technology, 39 (2005) 563-580.

[17] L. Woolf, Insights into solute-solute-solvent interactions from transport property measurements with particular reference to methanol-water mixtures and their constituents, Pure and applied chemistry, 57 (1985) 1083-1090.

[18] Y. Marcus, Solvent mixtures: properties and selective solvation, CRC Press2002.

[19] S. Par, G. Guevara-Carrion, H. Hasse, J. Vrabec, Mutual diffusion in the ternary mixture of water+ methanol+ ethanol and its binary subsystems, Physical Chemistry Chemical Physics, 15 (2013) 3985-4001.

[20] R.V. Godbole, F. Khabaz, R. Khare, R.C. Hedden, Swelling of Random Copolymer Networks in Pure and Mixed Solvents: Multi-Component Flory-Rehner Theory, The Journal of Physical Chemistry B, DOI 10.1021/acs.jpcb.7b02194(2017).

[21] F. Zhang, X. Liu, X. Yang, L. Liu, Density, viscosity and spectroscopic studies for the binary system of dipropylene glycol+ 1, 2-ethylenediamine at T=(293.15, 298.15, 303.15, 308.15, 313.15, and 318.15) K, Journal of Molecular Liquids, 223 (2016) 192-201.

[22] O. Redlich, A. Kister, Algebraic representation of thermodynamic properties and the classification of solutions, Industrial & Engineering Chemistry, 40 (1948) 345-348.

[23] G.P. Dubey, K. Kumar, Density, Speed of Sound, Viscosity, Excess Properties, and Prigogine–Flory–Patterson (PFP) Theory of Binary Mixtures of Amine and Alcohols, Journal of Chemical & Engineering Data, 61 (2016) 1967-1980.

[24] G.P. Dubey, K. Kumar, Studies of thermodynamic, thermophysical and partial molar properties of liquid mixtures of diethylenetriamine with alcohols at 293.15 to 313.15 K, Journal of Molecular Liquids, 180 (2013) 164-171.

[25] M.M. Haring, The Theory of Rate Processes (Glasstone, Samuel; Laidler, Keith J.; Eyring, Henry), ACS Publications, 1942.

[26] D.J. Luning Prak, P.J. Luning Prak, J.S. Cowart, P.C. Trulove, Densities and Viscosities at 293.15–373.15 K, Speeds of Sound and Bulk Moduli at 293.15–333.15 K, Surface Tensions, and Flash Points of Binary Mixtures of n-Hexadecane and Alkylbenzenes at 0.1 MPa, Journal of Chemical & Engineering Data, 62 (2017) 1673-1688.

[27] H. Eyring, Viscosity, plasticity, and diffusion as examples of absolute reaction rates, The Journal of chemical physics, 4 (1936) 283-291.

[28] A. Messaâdi, N. Dhouibi, H. Hamda, F.B.M. Belgacem, Y.H. Adbelkader, N. Ouerfelli, A.H. Hamzaoui, A new equation relating the viscosity Arrhenius temperature and the activation energy for some Newtonian classical solvents, Journal of Chemistry, 2015 (2015).

[29] M. Hichri, D. Das, A. Messaâdi, E.B.H. Hmida, N. Ouerfelli, I. Khattech, Viscosity Arrhenius activation energy and derived partial molar properties in of N, N-dimethylacetamide+ 2-ethoxyethanol binary mixtures at temperatures from 298.15 K to 318.15 K, Physics and Chemistry of Liquids, 51 (2013) 721-730.

[30] K.J. Laidler, The development of the Arrhenius equation, J. Chem. Educ, 61 (1984) 494.

[31] G.W. Scherer, Use of the Adam-Gibbs Equation in the Analysis of Structural Relaxation, Journal of the American Ceramic Society, 67 (1984) 504-511.

[32] B. González, A. Domínguez, J. Tojo, Dynamic viscosities, densities, and speed of sound and derived properties of the binary systems acetic acid with water, methanol, ethanol, ethyl acetate and methyl acetate at T=(293.15, 298.15, and 303.15) K at atmospheric pressure, Journal of Chemical & Engineering Data, 49 (2004) 1590-1596.

[33] B. González, N. Calvar, E. Gómez, Á. Domínguez, Density, dynamic viscosity, and derived properties of binary mixtures of methanol or ethanol with water, ethyl acetate, and methyl

acetate at T=(293.15, 298.15, and 303.15) K, The Journal of Chemical Thermodynamics, 39 (2007) 1578-1588.

[34] P.S. Nikam, B.S. Jagdale, A.B. Sawant, M. Hasan, Densities and viscosities of binary mixtures of toluene with methanol, ethanol, propan-1-ol, butan-1-ol, pentan-1-ol, and 2-methylpropan-2-ol at (303.15, 308.15, 313.15) K, Journal of Chemical & Engineering Data, 45 (2000) 559-563.

[35] G. Vazquez, E. Alvarez, J.M. Navaza, Surface tension of alcohol water+ water from 20 to 50. degree. C, Journal of chemical and engineering data, 40 (1995) 611-614.

[36] Y. Wang, W. Yan, Excess molar volumes of 1, 3-diethyl propanedioate with methanol, ethanol, propan-1-ol, propan-2-ol, butan-2-ol, 2-methyl-propan-1-ol, and pentan-1-ol at T=(288.15, 298.15, 313.15, and 328.15) K, Journal of Chemical & Engineering Data, 55 (2010) 4029-4032.

[37] D.J. Luning Prak, J.S. Cowart, A.M. McDaniel, P.C. Trulove, Density, viscosity, speed of sound, bulk modulus, surface tension, and flash point of binary mixtures of n-hexadecane+ ethylbenzene or+ toluene at (293.15 to 373.15) K and 0.1 MPa, Journal of Chemical & Engineering Data, 59 (2014) 3571-3585.

[38] P.S. Nikam, T.R. Mahale, M. Hasan, Density and viscosity of binary mixtures of ethyl acetate with methanol, ethanol, propan-1-ol, propan-2-ol, butan-1-ol, 2-methylpropan-1-ol, and 2-methylpropan-2-ol at (298.15, 303.15, and 308.15) K, Journal of Chemical & Engineering Data, 41 (1996) 1055-1058.

[39] C.M. Neves, K.A. Kurnia, J.o.A. Coutinho, I.M. Marrucho, J.N.C. Lopes, M.G. Freire, L.P.N. Rebelo, Systematic study of the thermophysical properties of imidazolium-based

ionic liquids with cyano-functionalized anions, The Journal of Physical Chemistry B, 117 (2013) 10271-10283.

[40] H. Guerrero, P. Cea, I. Gascón, F.l.M. Royo, C. Lafuente, Volumetric study of the mixtures n-hexane+ isomeric chlorobutane: experimental characterization and volume translated Peng–Robinson predictions, The Journal of Physical Chemistry B, 117 (2013) 10284-10292.

[41] A.G. Oskoei, N. Safaei, J. Ghasemi, Densities and viscosities for binary and ternary mixtures of 1, 4-dioxane+ 1-hexanol+ N, N-dimethylaniline from T=(283.15 to 343.15) K, Journal of Chemical & Engineering Data, 53 (2008) 343-349.

[42] J.R. Liley, R.K. Thomas, J. Penfold, I.M. Tucker, J.T. Petkov, P. Stevenson, J.R. Webster, Surface Adsorption in Ternary Surfactant Mixtures above the Critical Micelle Concentration: Effects of Asymmetry on the Composition Dependence of the Excess Free Energy, The Journal of Physical Chemistry B, 121 (2017) 2825-2838.

[43] M.S. Alam, A.M. Siddiq, Density, dynamic viscosity, and kinematic viscosity studies of aqueous solution of a cationic gemini surfactant, hexanediyl-1, 6-bis (dimethylcetylammonium bromide (16-6-16): Influence of electrolytes and temperature, Journal of Molecular Liquids, 242 (2017) 1075-1084.

Figure Captions:

Fig. 1. Density (ρ) of Water (1) + Methanol (2) as a function of mole fraction (A) and temperature (B) and Density (ρ) of Methanol (1) + Ethanol (2) as a function of mole fraction (C) and temperature (D).

Fig. 2. Density (ρ) of binary mixture of Water (1) + Methanol (2), Water (1) + Ethanol (2) and Water (1) + Propan-1-ol (2) at 298.15 K (A) and Density (ρ) of Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K (B).

Fig. 3. Excess molar volume (V^E) and Redlich-Kister fitting of binary system of Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K.

Fig. 4. Dynamic viscosity (η) of Water (1) + Methanol (2) as a function of mole fraction (A) and temperature (B) and Dynamic viscosity (η) of Methanol (1) + Ethanol (2) as a function of mole fraction (C) and temperature (D).

Fig. 5. Dynamic viscosity (η) of binary system Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K.

Fig. 6. Kinematic viscosity (υ) of Water (1) + Methanol (2) as a function of mole fraction (A) and temperature (B) and Kinematic viscosity (υ) of Methanol (1) + Ethanol (2) as a function of mole fraction (C) and temperature (D).

Fig. 7. Kinematic viscosity (υ) of binary system Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K.

Fig. 8. Viscosity deviation (Δη) and Redlich-Kister fitting of binary system of Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K.

Fig. 9. Excess Gibbs free energy (ΔG^E) and Redlich-Kister fitting of binary system of Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K.

Figure(s)

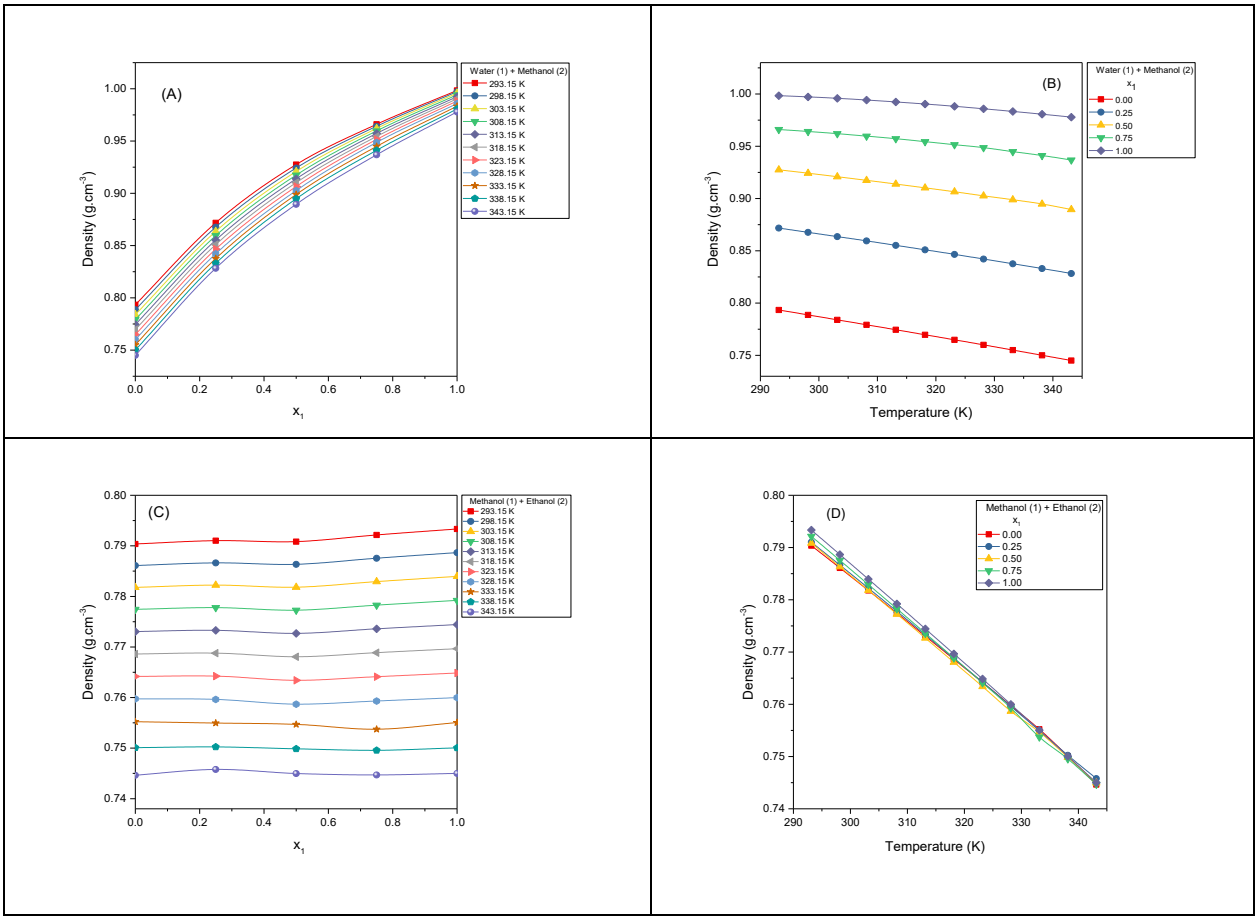


Fig. 1. Density (ρ) of Water (1) + Methanol (2) as a function of mole fraction (A) and temperature (B) and Density (ρ) of Methanol (1) + Ethanol (2) as a function of mole fraction (C) and temperature (D).

Figure(s)

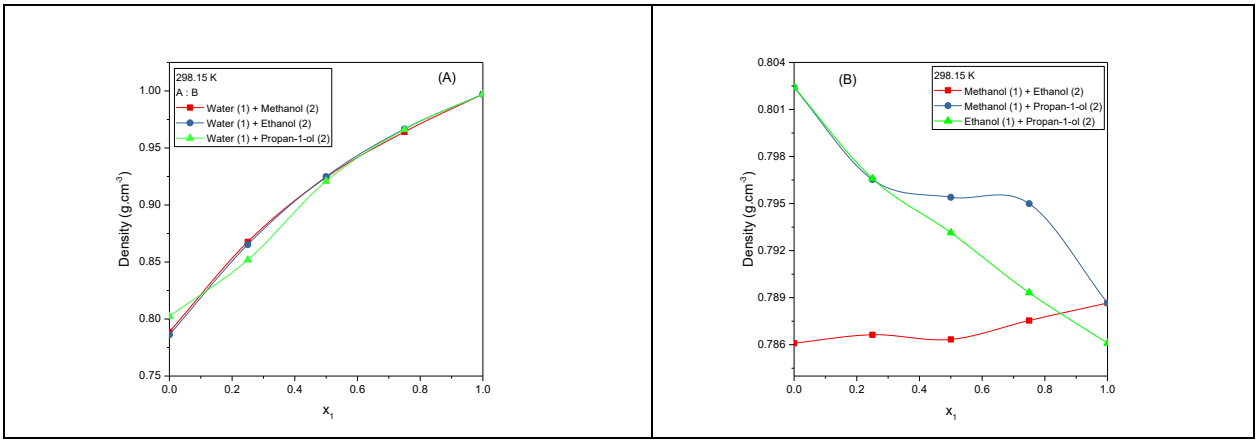
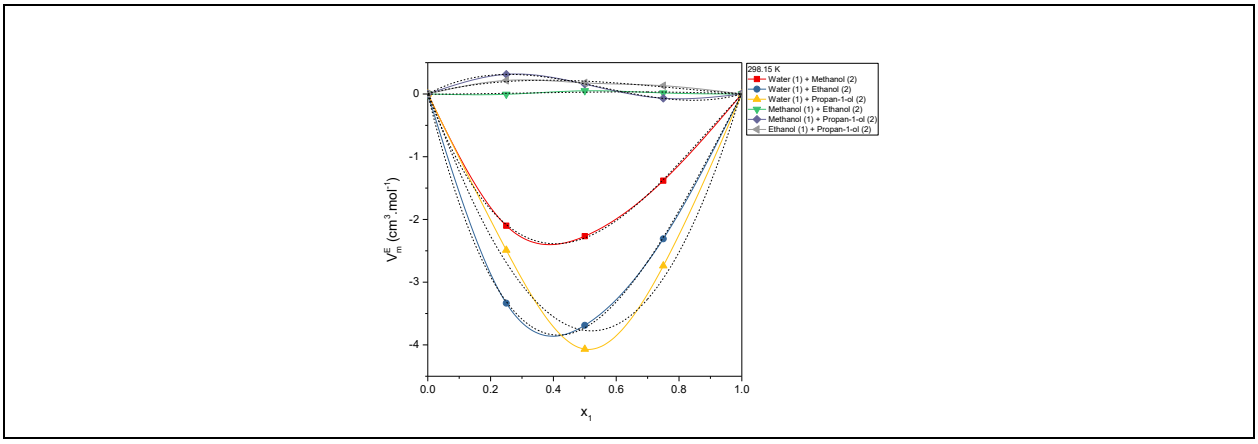


Fig. 2. Density (ρ) of binary mixture of Water (1) + Methanol (2), Water (1) + Ethanol (2) and Water (1) + Propan-1-ol (2) at 298.15 K (A) and Density (ρ) of Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K (B).

Figure(s)



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Figure(s)

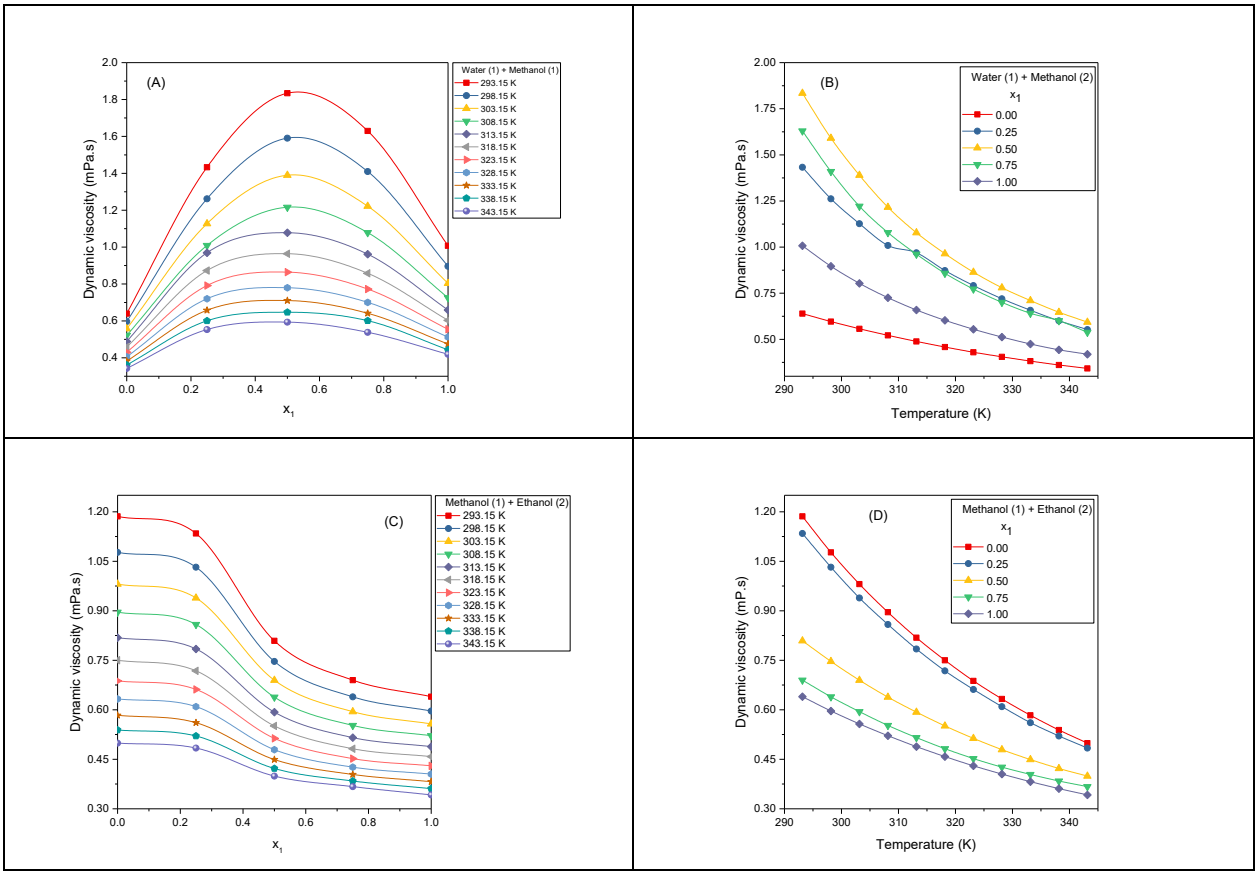


Fig. 4. Dynamic viscosity (η) of Water (1) + Methanol (2) as a function of mole fraction (A) and temperature (B) and Dynamic viscosity (η) of Methanol (1) + Ethanol (2) as a function of mole fraction (C) and temperature (D).

Figure(s)

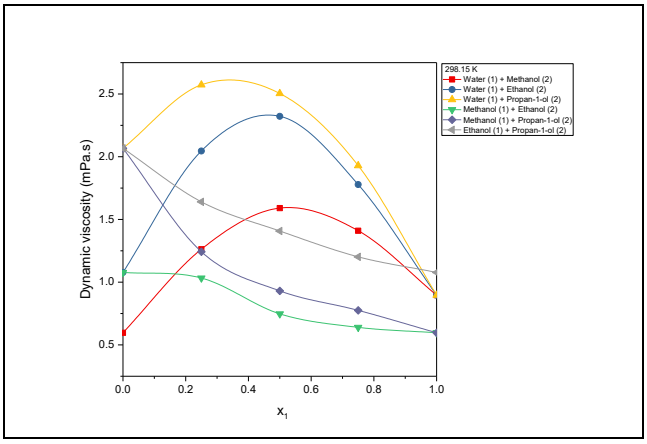


Fig. 5. Dynamic viscosity (η) of binary system Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K.

Figure(s)

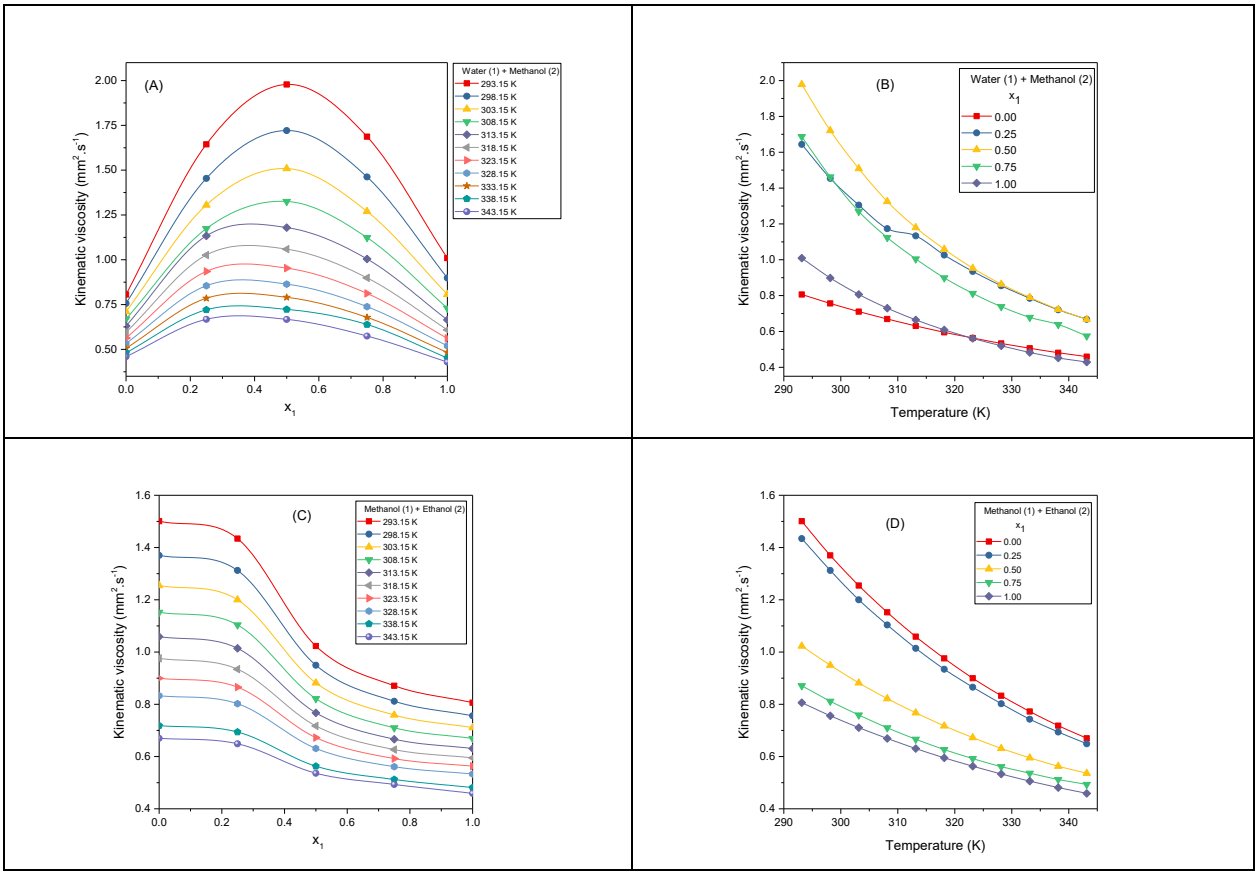


Fig. 6. Kinematic viscosity (υ) of Water (1) + Methanol (2) as a function of mole fraction (A) and temperature (B) and Kinematic viscosity (υ) of Methanol (1) + Ethanol (2) as a function of mole fraction (C) and temperature (D).

Figure(s)

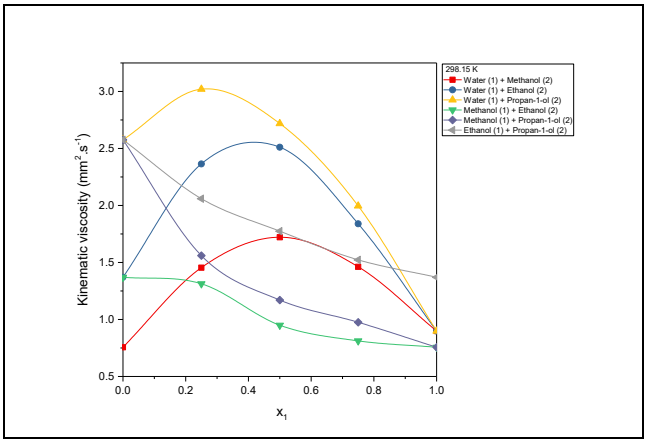
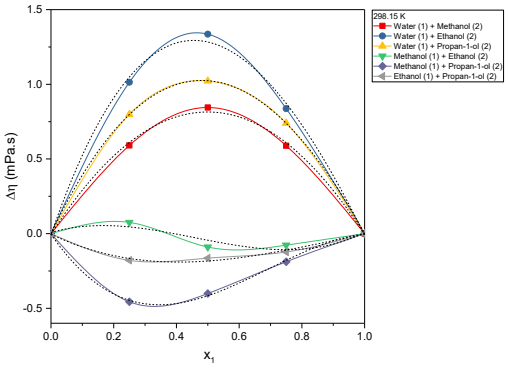


Fig. 7. Kinematic viscosity (υ) of binary system Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K.

Figure(s)



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Figure(s)

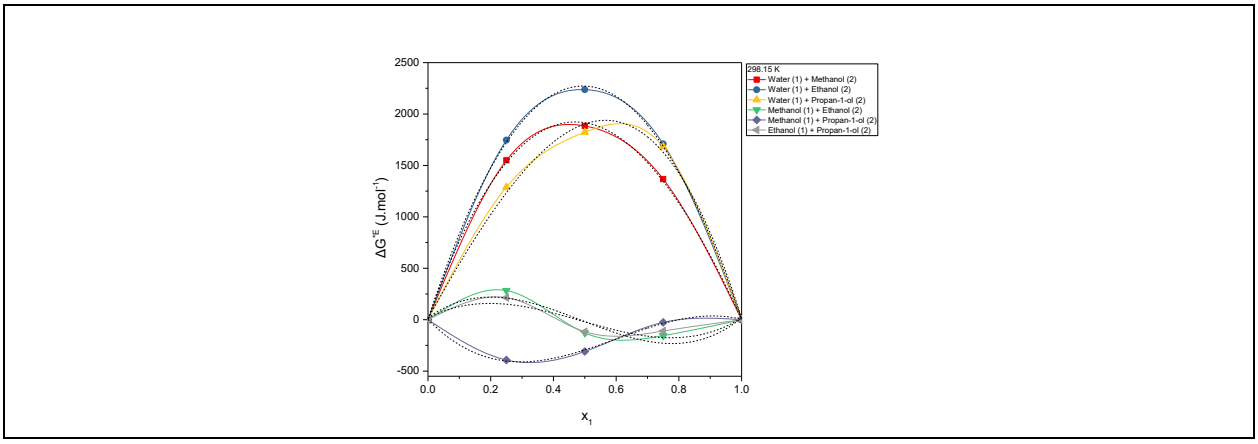

Fig. 9. Excess Gibbs free energy (ΔG^E) and Redlich-Kister fitting of binary system of Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) at 298.13 K.

Table 1

Experimental Density (ρ), Dynamic Viscosity (η), Kinematic Viscosity (υ), Thermal Expansion Coefficient (α) and Gibb's Free Energy of activation of viscous flow (ΔG^*) for pure Water, Methanol, Ethanol and Propan-1-ol.

T/ K	10^3 ρ / $Kg.m^{-3}$	η/ mPa.s	υ/ $mm^2.s^{-1}$	10^3 α/ K^{-1}	ΔG^*/ $kJ.mol^{-1}$
			Water		
293.15	0.99833	1.007	1.009	0.401	42.982
298.15	0.99718	0.896	0.899	0.401	43.427
303.15	0.99578	0.803	0.806	0.402	43.883
308.15	0.99416	0.726	0.730	0.402	44.352
313.15	0.99234	0.659	0.664	0.403	44.826
318.15	0.99034	0.603	0.609	0.404	45.311
323.15	0.98816	0.555	0.561	0.405	45.804
328.15	0.98581	0.512	0.520	0.406	46.302
333.15	0.98331	0.475	0.483	0.407	46.805
338.15	0.98066	0.443	0.452	0.408	47.32
343.15	0.97782	0.419	0.429	0.409	47.869
			Methanol		
293.15	0.79334	0.639	0.806	1.260	43.836
298.15	0.78865	0.596	0.756	1.268	44.426
303.15	0.78395	0.557	0.711	1.276	45.015
308.15	0.77921	0.521	0.669	1.283	45.602
313.15	0.77443	0.488	0.631	1.291	46.188
318.15	0.76966	0.458	0.595	1.299	46.774
323.15	0.76485	0.430	0.563	1.307	47.356
328.15	0.75997	0.405	0.533	1.316	47.943
333.15	0.75504	0.382	0.506	1.324	48.529
338.15	0.75004	0.361	0.481	1.333	49.117
343.15	0.74498	0.342	0.459	1.342	49.709
			Ethanol		
293.15	0.79037	1.186	1.501	1.139	46.238
298.15	0.78609	1.077	1.370	1.145	46.801
303.15	0.78178	0.981	1.255	1.151	47.364
308.15	0.77743	0.895	1.152	1.158	47.926
313.15	0.77304	0.819	1.059	1.164	48.484
318.15	0.76861	0.750	0.976	1.171	49.042
323.15	0.76417	0.688	0.900	1.178	49.595
328.15	0.75973	0.633	0.833	1.185	50.151
333.15	0.75522	0.583	0.773	1.192	50.708
338.15	0.75007	0.539	0.718	1.200	51.264
343.15	0.74463	0.499	0.670	1.209	51.824
			Propan-1-ol		
293.15	0.80644	2.369	2.937	1.116	48.522
298.15	0.80241	2.067	2.576	1.122	49.024
303.15	0.79834	1.816	2.275	1.127	49.533
308.15	0.79422	1.602	2.017	1.133	50.043
313.15	0.79006	1.421	1.799	1.139	50.556
318.15	0.78389	1.223	1.560	1.148	50.986
323.15	0.77966	1.101	1.412	1.154	51.519
328.15	0.77538	0.993	1.281	1.161	52.051
333.15	0.77103	0.900	1.167	1.167	52.586
338.15	0.76661	0.816	1.064	1.174	53.117
343.15	0.76211	0.742	0.974	1.181	53.650

Table 2

Experimental Density (ρ), Dynamic Viscosity (η), Kinematic Viscosity (υ), Excess Molar Volume (V^E), Viscosity Deviation (Δη), Thermal Expansion Coefficient (α), Excess Thermal Expansion Coefficient (α^E), Gibb's Free Energy (ΔG^*) and Excess Gibb's Free Energy of activation of viscous flow (ΔG^E) for Binary Mixture of Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2).

x_1	T/ K	10^3 ρ/ $Kg.m^{-3}$	η/ mPa.s	υ/ $mm^2.s^{-1}$	10^{-6} V^E/ $m3.mol^{-1}$	Δη/ mPa.s	10^3 α/ K^{-1}	10^3 α_E/ K^{-1}	ΔG^*/ $kJ.mol^{-1}$	ΔG^{*E}/ $kJ.mol^{-1}$
					Water (1) + Methanol (2)					
0.25	293.15	0.87170	1.433	1.644	-2.06736	0.702	1.032	-0.117	45.292	1.633
0.25	298.15	0.86767	1.262	1.454	-2.10045	0.591	1.037	-0.119	45.761	1.550
0.25	303.15	0.86357	1.127	1.305	-2.13395	0.508	1.042	-0.121	46.256	1.490
0.25	308.15	0.85942	1.009	1.174	-2.16775	0.436	1.047	-0.123	46.747	1.425
0.25	313.15	0.85518	0.969	1.133	-2.20205	0.438	1.052	-0.126	47.414	1.533
0.25	318.15	0.85088	0.873	1.026	-2.23489	0.379	1.058	-0.128	47.908	1.467
0.25	323.15	0.84651	0.791	0.935	-2.26775	0.330	1.063	-0.130	48.411	1.411
0.25	328.15	0.84212	0.720	0.855	-2.30470	0.288	1.069	-0.132	48.915	1.352
0.25	333.15	0.83758	0.658	0.785	-2.33970	0.252	1.075	-0.134	49.425	1.298
0.25	338.15	0.83297	0.600	0.721	-2.37517	0.219	1.080	-0.137	49.926	1.230
0.25	343.15	0.82825	0.553	0.668	-2.41112	0.192	1.087	-0.139	50.446	1.171
0.50	293.15	0.92746	1.834	1.978	-2.23056	1.011	0.755	-0.24	45.424	1.970
0.50	298.15	0.92420	1.590	1.721	-2.26603	0.844	0.757	-0.244	45.853	1.884
0.50	303.15	0.92086	1.389	1.509	-2.30234	0.709	0.760	-0.247	46.291	1.801
0.50	308.15	0.91741	1.216	1.325	-2.33900	0.592	0.763	-0.251	46.722	1.707
0.50	313.15	0.91385	1.078	1.179	-2.37625	0.504	0.766	-0.254	47.176	1.633
0.50	318.15	0.91020	0.964	1.059	-2.41286	0.433	0.769	-0.258	47.645	1.567
0.50	323.15	0.90643	0.864	0.953	-2.44957	0.372	0.772	-0.261	48.111	1.497
0.50	328.15	0.90257	0.780	0.864	-2.48752	0.321	0.776	-0.265	48.587	1.432
0.50	333.15	0.89879	0.710	0.790	-2.53216	0.282	0.779	-0.269	49.080	1.382
0.50	338.15	0.89472	0.647	0.723	-2.57148	0.245	0.782	-0.273	49.565	1.317
0.50	343.15	0.88942	0.593	0.667	-2.57642	0.213	0.787	-0.275	50.069	1.252
0.75	293.15	0.96604	1.630	1.687	-1.35261	0.714	0.621	-0.147	44.668	1.440
0.75	298.15	0.96405	1.410	1.462	-1.38231	0.589	0.622	-0.150	45.075	1.367
0.75	303.15	0.96197	1.221	1.270	-1.41409	0.480	0.624	-0.153	45.475	1.280
0.75	308.15	0.95967	1.078	1.124	-1.44446	0.404	0.625	-0.157	45.913	1.221
0.75	313.15	0.95719	0.961	1.004	-1.47475	0.345	0.627	-0.160	46.365	1.172
0.75	318.15	0.95436	0.858	0.899	-1.49980	0.291	0.629	-0.163	46.812	1.110
0.75	323.15	0.95147	0.773	0.812	-1.52681	0.249	0.631	-0.166	47.275	1.059
0.75	328.15	0.94862	0.700	0.738	-1.55852	0.215	0.633	-0.169	47.747	1.012
0.75	333.15	0.94482	0.641	0.679	-1.57121	0.190	0.635	-0.172	48.240	0.982
0.75	338.15	0.94106	0.601	0.638	-1.58796	0.178	0.638	-0.174	48.793	1.001
0.75	343.15	0.93683	0.538	0.574	-1.59730	0.138	0.640	-0.177	49.212	0.863
					Water (1) + Ethanol (2)					
0.25	293.15	0.86946	2.385	2.744	-3.30792	1.244	1.035	-0.035	47.306	1.840
0.25	298.15	0.86529	2.046	2.364	-3.33427	1.014	1.040	-0.035	47.744	1.747
0.25	303.15	0.86097	1.767	2.052	-3.35683	0.831	1.045	-0.036	48.188	1.657
0.25	308.15	0.85660	1.540	1.798	-3.37989	0.687	1.051	-0.037	48.643	1.575
0.25	313.15	0.85213	1.349	1.584	-3.40158	0.571	1.056	-0.038	49.102	1.499
0.25	318.15	0.84762	1.185	1.399	-3.42450	0.472	1.062	-0.039	49.558	1.416
0.25	323.15	0.84305	1.055	1.252	-3.44540	0.401	1.068	-0.039	50.038	1.360
0.25	328.15	0.83839	0.943	1.124	-3.46351	0.340	1.073	-0.040	50.520	1.301

0.25	333.15	0.83365	0.847	1.016	-3.48198	0.291	1.080	-0.041	51.010	1.250
0.25	338.15	0.82882	0.765	0.924	-3.53491	0.251	1.086	-0.042	51.506	1.201
0.25	343.15	0.82696	0.694	0.839	-3.77954	0.215	1.088	-0.048	51.993	1.132
0.50	293.15	0.92863	2.789	3.003	-3.66176	1.692	0.861	-0.103	47.044	2.380
0.50	298.15	0.92482	2.322	2.511	-3.68853	1.336	0.865	-0.105	47.402	2.238
0.50	303.15	0.92093	1.961	2.129	-3.71667	1.069	0.869	-0.106	47.781	2.110
0.50	308.15	0.91697	1.676	1.828	-3.74586	0.865	0.872	-0.108	48.178	1.995
0.50	313.15	0.91294	1.448	1.586	-3.77651	0.709	0.876	-0.110	48.590	1.893
0.50	318.15	0.90743	1.255	1.383	-3.75355	0.578	0.882	-0.111	49.004	1.787
0.50	323.15	0.90473	1.102	1.218	-3.84233	0.481	0.884	-0.114	49.434	1.697
0.50	328.15	0.90049	0.977	1.085	-3.87338	0.404	0.888	-0.116	49.882	1.619
0.50	333.15	0.89617	0.873	0.974	-3.90631	0.344	0.893	-0.118	50.345	1.554
0.50	338.15	0.89175	0.785	0.880	-3.96308	0.294	0.897	-0.120	50.816	1.490
0.50	343.15	0.88725	0.710	0.800	-4.03219	0.251	0.902	-0.124	51.295	1.416
0.75	293.15	0.96890	2.114	2.182	-2.27396	1.062	0.619	-0.164	45.663	1.826
0.75	298.15	0.96667	1.778	1.839	-2.30916	0.837	0.621	-0.167	46.019	1.709
0.75	303.15	0.96423	1.515	1.571	-2.34364	0.668	0.622	-0.170	46.393	1.604
0.75	308.15	0.96162	1.304	1.356	-2.37760	0.535	0.624	-0.172	46.780	1.501
0.75	313.15	0.95884	1.137	1.186	-2.41125	0.438	0.626	-0.175	47.191	1.418
0.75	318.15	0.95590	1.000	1.047	-2.44424	0.361	0.628	-0.178	47.614	1.340
0.75	323.15	0.95280	0.890	0.934	-2.47627	0.302	0.630	-0.180	48.056	1.275
0.75	328.15	0.94956	0.796	0.839	-2.50735	0.254	0.632	-0.183	48.506	1.214
0.75	333.15	0.94616	0.718	0.759	-2.53802	0.216	0.634	-0.186	48.967	1.161
0.75	338.15	0.94260	0.651	0.690	-2.57970	0.184	0.637	-0.189	49.437	1.105
0.75	343.15	0.93893	0.595	0.633	-2.62849	0.156	0.639	-0.192	49.922	1.040
				Water (1) + Propan-1-ol (2)						
0.25	293.15	0.86396	3.030	3.507	-3.01941	1.001	0.694	-0.368	48.485	1.318
0.25	298.15	0.85184	2.573	3.020	-2.48887	0.799	0.704	-0.364	48.942	1.288
0.25	303.15	0.84250	2.204	2.616	-2.13632	0.641	0.712	-0.361	49.401	1.252
0.25	308.15	0.85620	1.899	2.218	-3.37779	0.516	0.701	-0.378	49.793	1.147
0.25	313.15	0.85201	1.655	1.942	-3.40015	0.424	0.704	-0.381	50.255	1.106
0.25	318.15	0.84775	1.453	1.714	-3.56605	0.385	0.708	-0.386	50.726	1.133
0.25	323.15	0.84342	1.275	1.511	-3.58801	0.311	0.711	-0.388	51.186	1.071
0.25	328.15	0.83902	1.132	1.349	-3.60956	0.259	0.715	-0.391	51.667	1.030
0.25	333.15	0.83456	1.012	1.212	-3.63316	0.218	0.719	-0.393	52.159	0.996
0.25	338.15	0.83002	0.909	1.095	-3.65833	0.186	0.723	-0.396	52.656	0.967
0.25	343.15	0.82539	0.821	0.995	-3.68409	0.159	0.727	-0.398	53.160	0.934
0.50	293.15	0.92455	2.998	3.243	-4.03975	1.310	0.757	-0.219	47.713	1.918
0.50	298.15	0.92087	2.504	2.719	-4.06859	1.022	0.760	-0.221	48.090	1.823
0.50	303.15	0.91746	2.119	2.309	-4.11477	0.809	0.763	-0.224	48.485	1.738
0.50	308.15	0.91381	1.812	1.983	-4.15441	0.648	0.766	-0.226	48.895	1.660
0.50	313.15	0.91006	1.568	1.723	-4.19377	0.528	0.769	-0.228	49.323	1.596
0.50	318.15	0.90626	1.371	1.512	-4.33212	0.458	0.772	-0.233	49.764	1.580
0.50	323.15	0.90238	1.203	1.333	-4.37472	0.375	0.776	-0.235	50.208	1.512
0.50	328.15	0.89842	1.071	1.192	-4.41799	0.318	0.779	-0.238	50.678	1.469
0.50	333.15	0.89535	0.958	1.071	-4.51100	0.271	0.782	-0.241	51.154	1.426
0.50	338.15	0.89121	0.864	0.969	-4.55843	0.234	0.785	-0.243	51.641	1.392
0.50	343.15	0.88700	0.787	0.887	-4.60849	0.206	0.789	-0.246	52.154	1.363
0.75	293.15	0.96892	2.239	2.311	-2.71316	0.891	0.619	-0.196	46.122	1.717
0.75	298.15	0.96619	1.929	1.996	-2.73937	0.740	0.621	-0.198	46.546	1.682
0.75	303.15	0.96334	1.735	1.801	-2.76640	0.679	0.623	-0.201	47.068	1.733
0.75	308.15	0.96037	1.336	1.391	-2.79449	0.391	0.625	-0.203	47.182	1.376

0.75	313.15	0.95730	1.162	1.214	-2.82364	0.312	0.627	-0.205	47.592	1.304
0.75	318.15	0.95412	1.027	1.076	-2.90167	0.269	0.629	-0.210	48.035	1.276
0.75	323.15	0.95084	0.914	0.961	-2.93236	0.223	0.631	-0.212	48.487	1.226
0.75	328.15	0.94746	0.821	0.866	-2.96411	0.188	0.633	-0.215	48.952	1.185
0.75	333.15	0.94398	0.742	0.786	-2.99730	0.161	0.636	-0.217	49.429	1.153
0.75	338.15	0.94040	0.675	0.718	-3.03202	0.139	0.638	-0.22	49.915	1.120
0.75	343.15	0.93672	0.619	0.661	-3.06861	0.119	0.641	-0.222	50.416	1.078
				Methanol (1) + Ethanol (2)						
0.25	293.15	0.86396	3.030	3.507	-3.01941	1.001	1.138	-0.024	45.933	0.289
0.25	298.15	0.85184	2.573	3.020	-2.48887	0.799	1.144	-0.024	46.497	0.284
0.25	303.15	0.84250	2.204	2.616	-2.13632	0.641	1.151	-0.024	47.053	0.270
0.25	308.15	0.85620	1.899	2.218	-3.37779	0.516	1.157	-0.024	47.612	0.262
0.25	313.15	0.85201	1.655	1.942	-3.40015	0.424	1.164	-0.024	48.165	0.249
0.25	318.15	0.84775	1.453	1.714	-3.56605	0.385	1.171	-0.024	48.717	0.237
0.25	323.15	0.84342	1.275	1.511	-3.58801	0.311	1.178	-0.024	49.276	0.236
0.25	328.15	0.83902	1.132	1.349	-3.60956	0.259	1.185	-0.025	49.832	0.227
0.25	333.15	0.83456	1.012	1.212	-3.63316	0.218	1.192	-0.025	50.381	0.213
0.25	338.15	0.83002	0.909	1.095	-3.65833	0.186	1.200	-0.025	50.941	0.209
0.25	343.15	0.82539	0.821	0.995	-3.68409	0.159	1.207	-0.027	51.506	0.206
0.50	293.15	0.92455	2.998	3.243	-4.03975	1.310	1.138	-0.051	44.901	-0.133
0.50	298.15	0.92087	2.504	2.719	-4.06859	1.022	1.145	-0.051	45.482	-0.128
0.50	303.15	0.91746	2.119	2.309	-4.11477	0.809	1.151	-0.051	46.059	-0.128
0.50	308.15	0.91381	1.812	1.983	-4.15441	0.648	1.158	-0.051	46.636	-0.125
0.50	313.15	0.91006	1.568	1.723	-4.19377	0.528	1.165	-0.052	47.215	-0.118
0.50	318.15	0.90626	1.371	1.512	-4.33212	0.458	1.172	-0.052	47.791	-0.114
0.50	323.15	0.90238	1.203	1.333	-4.37472	0.375	1.179	-0.052	48.369	-0.104
0.50	328.15	0.89842	1.071	1.192	-4.41799	0.318	1.186	-0.052	48.945	-0.099
0.50	333.15	0.89535	0.958	1.071	-4.51100	0.271	1.193	-0.054	49.527	-0.090
0.50	338.15	0.89121	0.864	0.969	-4.55843	0.234	1.200	-0.054	50.114	-0.075
0.50	343.15	0.88700	0.787	0.887	-4.60849	0.206	1.208	-0.055	50.713	-0.052
0.75	293.15	0.96892	2.239	2.311	-2.71316	0.891	1.262	0.041	44.279	-0.154
0.75	298.15	0.96619	1.929	1.996	-2.73937	0.740	1.270	0.042	44.86	-0.156
0.75	303.15	0.96334	1.735	1.801	-2.76640	0.679	1.277	0.042	45.443	-0.156
0.75	308.15	0.96037	1.336	1.391	-2.79449	0.391	1.285	0.042	46.021	-0.158
0.75	313.15	0.95730	1.162	1.214	-2.82364	0.312	1.293	0.043	46.604	-0.155
0.75	318.15	0.95412	1.027	1.076	-2.90167	0.269	1.301	0.043	47.185	-0.152
0.75	323.15	0.95084	0.914	0.961	-2.93236	0.223	1.309	0.043	47.772	-0.141
0.75	328.15	0.94746	0.821	0.866	-2.96411	0.188	1.317	0.044	48.367	-0.126
0.75	333.15	0.94398	0.742	0.786	-2.99730	0.161	1.327	0.045	48.977	-0.095
0.75	338.15	0.94040	0.675	0.718	-3.03202	0.139	1.334	0.044	49.585	-0.068
0.75	343.15	0.93672	0.619	0.661	-3.06861	0.119	1.343	0.044	50.208	-0.029
				Methanol (1) + Propan-1-ol (2)						
0.25	293.15	0.80070	1.379	1.722	0.30764	-0.558	1.124	-0.014	46.918	-0.423
0.25	298.15	0.79653	1.243	1.560	0.31425	-0.456	1.130	-0.014	47.474	-0.392
0.25	303.15	0.79233	1.128	1.424	0.31976	-0.373	1.136	-0.014	48.040	-0.355
0.25	308.15	0.78810	1.028	1.304	0.32486	-0.304	1.142	-0.014	48.607	-0.319
0.25	313.15	0.78384	0.938	1.197	0.32899	-0.249	1.148	-0.014	49.173	-0.285
0.25	318.15	0.77953	0.859	1.102	0.19000	-0.173	1.155	-0.017	49.738	-0.191
0.25	323.15	0.77519	0.787	1.016	0.19405	-0.145	1.161	-0.017	50.302	-0.173
0.25	328.15	0.77079	0.724	0.939	0.19768	-0.122	1.168	-0.017	50.865	-0.155
0.25	333.15	0.76635	0.666	0.869	0.20065	-0.104	1.174	-0.017	51.427	-0.141
0.25	338.15	0.76183	0.614	0.806	0.20356	-0.088	1.181	-0.017	51.987	-0.127
0.25	343.15	0.75723	0.568	0.750	0.20685	-0.075	1.189	-0.017	52.548	-0.114

0.50	293.15	0.79972	1.015	1.269	0.15177	-0.489	1.125	-0.041	45.830	-0.342
0.50	298.15	0.79540	0.931	1.170	0.15772	-0.401	1.132	-0.042	46.409	-0.309
0.50	303.15	0.79105	0.856	1.082	0.16325	-0.331	1.138	-0.042	46.990	-0.278
0.50	308.15	0.78667	0.788	1.002	0.16805	-0.273	1.144	-0.042	47.569	-0.248
0.50	313.15	0.78226	0.728	0.930	0.17201	-0.227	1.151	-0.042	48.148	-0.219
0.50	318.15	0.77782	0.673	0.865	0.08057	-0.167	1.157	-0.044	48.725	-0.152
0.50	323.15	0.77335	0.623	0.806	0.08463	-0.142	1.164	-0.044	49.298	-0.137
0.50	328.15	0.76882	0.578	0.752	0.08806	-0.121	1.171	-0.045	49.874	-0.120
0.50	333.15	0.76424	0.537	0.703	0.09097	-0.104	1.178	-0.045	50.446	-0.110
0.50	338.15	0.75869	0.500	0.659	0.16542	-0.089	1.186	-0.044	51.021	-0.093
0.50	343.15	0.75393	0.467	0.619	0.17281	-0.075	1.194	-0.044	51.599	-0.078
0.75	293.15	0.79946	0.825	1.032	-0.06927	-0.246	1.126	-0.080	44.923	-0.082
0.75	298.15	0.79499	0.775	0.975	-0.06850	-0.188	1.132	-0.080	45.548	-0.026
0.75	303.15	0.79051	0.717	0.907	-0.06837	-0.155	1.139	-0.081	46.129	-0.015
0.75	308.15	0.78601	0.663	0.844	-0.06920	-0.128	1.145	-0.081	46.706	-0.006
0.75	313.15	0.78148	0.615	0.787	-0.07133	-0.106	1.152	-0.082	47.282	0.002
0.75	318.15	0.77693	0.571	0.735	-0.12035	-0.078	1.158	-0.083	47.855	0.028
0.75	323.15	0.77236	0.531	0.688	-0.12337	-0.066	1.165	-0.084	48.430	0.033
0.75	328.15	0.76778	0.495	0.645	-0.12983	-0.057	1.172	-0.085	49.004	0.033
0.75	333.15	0.76321	0.464	0.608	-0.14117	-0.047	1.179	-0.086	49.587	0.042
0.75	338.15	0.7573	0.437	0.577	-0.06638	-0.038	1.188	-0.084	50.184	0.065
0.75	343.15	0.75177	0.414	0.551	-0.02033	-0.028	1.197	-0.084	50.793	0.097
				Ethanol (1) + Propan-1-ol (2)						
0.25	293.15	0.80070	1.379	1.722	0.30764	-0.558	1.124	0.003	47.770	0.192
0.25	298.15	0.79653	1.243	1.560	0.31425	-0.456	1.130	0.003	48.321	0.214
0.25	303.15	0.79233	1.128	1.424	0.31976	-0.373	1.136	0.003	48.867	0.228
0.25	308.15	0.78810	1.028	1.304	0.32486	-0.304	1.142	0.003	49.399	0.227
0.25	313.15	0.78384	0.938	1.197	0.32899	-0.249	1.148	0.003	49.941	0.234
0.25	318.15	0.77953	0.859	1.102	0.19000	-0.173	1.154	0.001	50.485	0.304
0.25	323.15	0.77519	0.787	1.016	0.19405	-0.145	1.160	0.001	51.029	0.299
0.25	328.15	0.77079	0.724	0.939	0.19768	-0.122	1.167	0.001	51.565	0.287
0.25	333.15	0.76635	0.666	0.869	0.20065	-0.104	1.174	0.001	52.108	0.279
0.25	338.15	0.76183	0.614	0.806	0.20356	-0.088	1.180	0.001	52.648	0.270
0.25	343.15	0.75723	0.568	0.750	0.20685	-0.075	1.188	0.001	53.189	0.259
0.50	293.15	0.79972	1.015	1.269	0.15177	-0.489	1.129	0.003	47.236	-0.141
0.50	298.15	0.79540	0.931	1.170	0.15772	-0.401	1.135	0.003	47.793	-0.117
0.50	303.15	0.79105	0.856	1.082	0.16325	-0.331	1.141	0.003	48.329	-0.117
0.50	308.15	0.78667	0.788	1.002	0.16805	-0.273	1.147	0.003	48.881	-0.101
0.50	313.15	0.78226	0.728	0.930	0.17201	-0.227	1.153	0.003	49.432	-0.086
0.50	318.15	0.77782	0.673	0.865	0.08057	-0.167	1.159	0.001	49.982	-0.031
0.50	323.15	0.77335	0.623	0.806	0.08463	-0.142	1.166	0.001	50.530	-0.026
0.50	328.15	0.76882	0.578	0.752	0.08806	-0.121	1.173	0.001	51.078	-0.022
0.50	333.15	0.76424	0.537	0.703	0.09097	-0.104	1.180	0.002	51.627	-0.019
0.50	338.15	0.75869	0.500	0.659	0.16542	-0.089	1.187	0.001	52.177	-0.013
0.50	343.15	0.75393	0.467	0.619	0.17281	-0.075	1.194	0.001	52.722	-0.015
0.75	293.15	0.79946	0.825	1.032	-0.06927	-0.246	1.134	0.002	46.705	-0.102
0.75	298.15	0.79499	0.775	0.975	-0.06850	-0.188	1.140	0.002	47.244	-0.110
0.75	303.15	0.79051	0.717	0.907	-0.06837	-0.155	1.146	0.002	47.804	-0.100
0.75	308.15	0.78601	0.663	0.844	-0.06920	-0.128	1.153	0.002	48.360	-0.093
0.75	313.15	0.78148	0.615	0.787	-0.07133	-0.106	1.159	0.002	48.920	-0.081
0.75	318.15	0.77693	0.571	0.735	-0.12035	-0.078	1.166	0.002	49.473	-0.054
0.75	323.15	0.77236	0.531	0.688	-0.12337	-0.066	1.172	0.002	50.031	-0.044
0.75	328.15	0.76778	0.495	0.645	-0.12983	-0.057	1.179	0.002	50.581	-0.045

0.75	333.15	0.76321	0.464	0.608	-0.14117	-0.047	1.186	0.002	51.134	-0.042
0.75	338.15	0.7573	0.437	0.577	-0.06638	-0.038	1.194	0.001	51.693	-0.034
0.75	343.15	0.75177	0.414	0.551	-0.02033	-0.028	1.201	0.001	52.241	-0.038

Table 3

Fitting Parameters (A_j) and Standard Deviations (σ) of Excess Molar Volume (V^E), Viscosity Deviation ($\Delta\eta$) and Excess Gibb's Free Energy (ΔG^E) for Binary Mixture of Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2).

	V^E x 10^6/m^3.mol^{-1}			$\Delta\eta$/ mPa.s			ΔG^E/ kJmol^{-1}		
T	A_0	A_1	σ	A_0	A_1	σ	A_0	A_1	σ
				Water (1) + Methanol (2)					
293.15	-9.0070	3.8120	0.020	3.9298	0.0664	0.028	8.0159	-1.0298	0.033
298.15	-9.1598	3.8301	0.023	3.2779	-0.0122	0.024	7.6413	-0.9741	0.025
303.15	-9.3174	3.8393	0.026	2.7509	-0.1527	0.021	7.2826	-1.1171	0.019
308.15	-9.4745	3.8576	0.028	2.3145	-0.1736	0.013	6.9249	-1.0886	0.024
313.15	-9.6335	3.8790	0.031	2.0474	-0.4989	0.008	6.8231	-1.9212	0.071
318.15	-9.7833	3.9205	0.032	1.7562	-0.4682	0.005	6.5275	-1.9051	0.062
323.15	-9.9357	3.9517	0.033	1.5119	-0.4315	0.006	6.2447	-1.8774	0.062
328.15	-10.1009	3.9796	0.036	1.3090	-0.3882	0.006	5.9748	-1.8156	0.060
333.15	-10.2574	4.0986	0.031	1.1492	-0.3351	0.005	5.7646	-1.6841	0.057
338.15	-10.4069	4.1985	0.029	1.0126	-0.2153	0.008	5.5594	-1.2233	0.071
343.15	-10.4700	4.3404	0.040	0.8629	-0.2852	0.003	5.1863	-1.6424	0.043
				Water (1) + Ethanol (2)					
293.15	-14.7490	5.5144	0.025	6.5021	-0.9720	0.064	9.6301	-0.0787	0.026
298.15	-14.8806	5.4673	3.844	4.0956	-0.3141	0.226	9.0654	-0.2004	0.027
303.15	-15.0101	5.4037	0.034	4.1547	-0.8693	0.029	8.5500	-0.2839	0.026
308.15	-15.1420	5.3455	0.038	3.3744	-0.8080	0.021	8.0749	-0.3976	0.023
313.15	-15.2753	5.2818	0.041	2.7726	-0.7070	0.015	7.6596	-0.4282	0.022
318.15	-15.2867	5.2281	0.066	2.2735	-0.5948	0.010	7.2340	-0.4089	0.021
323.15	-15.5501	5.1687	0.044	1.9035	-0.5273	0.005	6.8904	-0.4533	0.025
328.15	-15.6773	5.0995	0.044	1.6034	-0.4596	0.004	6.5748	-0.4686	0.024
333.15	-15.8087	5.0345	0.044	1.3660	-0.4005	0.003	6.3071	-0.4744	0.022
338.15	-16.0466	5.0945	0.047	1.1690	-0.3572	0.002	6.0420	-0.5112	0.020
343.15	-16.5399	6.1389	0.099	0.9970	-0.3148	0.002	5.7196	-0.4904	0.013
				Water (1) + Propan-1-ol (2)					
293.15	-15.7852	1.6333	0.090	5.1581	-0.5880	0.020	7.8534	2.1240	0.041
298.15	-15.2748	-1.3360	0.241	5.1678	-0.9437	0.222	7.5619	2.0996	0.065
303.15	-15.0083	-3.3600	0.350	3.3579	0.2022	0.029	7.3829	2.5690	0.104
308.15	-16.5498	3.1109	0.016	2.5179	-0.6672	0.018	6.6781	1.2235	0.009
313.15	-16.6987	3.0747	0.018	2.0488	-0.5980	0.016	6.4025	1.0555	0.005
318.15	-17.2937	3.5434	0.008	1.7934	-0.6174	0.009	6.3648	0.7645	0.011
323.15	-17.4512	3.4968	0.012	1.4684	-0.4671	0.008	6.0819	0.8250	0.008
328.15	-17.6110	3.4424	0.015	1.2378	-0.3770	0.008	5.8894	0.8268	0.003
333.15	-17.8885	3.3912	0.038	1.0538	-0.3047	0.008	5.7165	0.8399	0.003
338.15	-18.0654	3.3403	0.041	0.9068	-0.2548	0.007	5.5663	0.8170	0.000
343.15	-18.2511	3.2826	0.044	0.7895	-0.2155	0.009	5.4153	0.7660	1.139
				Methanol (1) + Ethanol (2)					
293.15	0.1156	0.1025	0.017	-0.2384	-0.9097	0.043	-0.1487	-2.3624	0.092
298.15	0.1304	0.1082	0.018	-0.2073	-0.8125	0.037	-0.1461	-2.3437	0.088
303.15	0.1447	0.1133	0.018	-0.1868	-0.7086	0.032	-0.1605	-2.2702	0.084
308.15	0.1572	0.1176	0.018	-0.1666	-0.6313	0.027	-0.1675	-2.2393	0.080
313.15	0.1673	0.1221	0.019	-0.1464	-0.5507	0.023	-0.1619	-2.1553	0.075
318.15	0.1838	0.1321	0.019	-0.1306	-0.4809	0.020	-0.1640	-2.0727	0.071
323.15	0.2041	0.1399	0.019	-0.1090	-0.4280	0.018	-0.1296	-2.0089	0.069
328.15	0.4186	0.1119	0.049	-0.0941	-0.3689	0.016	-0.1110	-1.8824	0.069
333.15	0.1897	0.3677	0.015	-0.0775	-0.3003	0.014	-0.0701	-1.6409	0.070

338.15	0.0546	0.2367	0.001	-0.0588	-0.2514	0.013	-0.0103	-1.4758	0.070
343.15	-0.1120	0.5053	0.014	-0.0378	-0.2049	0.012	0.0838	-1.2571	0.070
Methanol (1) + Propan-1-ol (2)									
293.15	0.6193	-2.0102	0.003	-2.0354	1.6620	0.019	-1.3587	1.8186	0.318
298.15	0.6414	-2.0414	0.003	-0.7202	0.2989	0.214	-1.1838	1.9507	0.012
303.15	0.6604	-2.0700	0.002	-0.5876	0.2022	0.178	-1.0584	1.8133	0.013
308.15	0.6763	-2.1017	0.001	-1.1187	0.9402	0.006	-0.9377	1.6655	0.013
313.15	0.6876	-2.1351	0.000	-0.9246	0.7641	0.004	-0.8238	1.5298	0.013
318.15	0.2638	-1.6552	0.014	-0.6691	0.5035	0.000	-0.5330	1.1638	0.018
323.15	0.2742	-1.6929	0.016	-0.5672	0.4222	0.001	-0.4721	1.0954	0.018
328.15	0.2788	-1.7467	0.018	-0.4803	0.3500	0.001	-0.4135	1.0062	0.016
333.15	0.2759	-1.8230	0.221	-0.4098	0.3014	0.001	-0.3635	0.9774	0.018
338.15	0.5349	-1.4397	0.031	-0.3459	0.2682	0.002	-0.2842	1.0268	0.022
343.15	0.6082	-1.2116	0.020	-0.2893	0.2482	0.003	-0.1978	1.1211	0.028
Ethanol (1) + Propan-1-ol (2)									
293.15	0.7951	-0.4613	0.023	-0.9225	0.5184	0.028	-0.2200	-1.5659	0.083
298.15	0.8027	-0.4573	0.023	-1.6528	1.4296	0.024	-0.1476	-1.7299	0.077
303.15	0.8081	-0.4524	0.023	-1.3587	1.1619	0.021	-0.1217	-1.7463	0.084
308.15	0.8121	-0.4490	0.023	-0.4732	0.1596	0.013	-0.0779	-1.7063	0.079
313.15	0.8141	-0.4419	0.023	-0.3764	0.1160	0.008	-0.0224	-1.6786	0.078
318.15	0.3813	0.0775	0.009	-0.2023	-0.0450	0.005	0.2140	-1.9067	0.082
323.15	0.3940	0.0879	0.010	-0.1660	-0.0382	0.006	0.2314	-1.8279	0.081
328.15	0.4186	0.1119	0.010	-0.1416	-0.0352	0.006	0.2263	-1.7698	0.076
333.15	0.4427	0.1360	0.010	-0.1199	-0.0340	0.005	0.2275	-1.7131	0.073
338.15	0.3648	0.0440	0.008	-0.0973	-0.0246	0.008	0.2403	-1.6188	0.071
343.15	0.2452	-0.1027	0.004	-0.0853	-0.0278	0.003	0.2179	-1.5864	0.067

Table 4

Activation Energy of Viscous Flow (E_a), Entropic Factor ($\ln(A_s)$), Activation Temperature (T^*), Arrhenius Temperature (T_A), Enthalpy change (ΔH^*) and Entropy change (ΔS^*) for Binary Mixture of Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2).

x_1	E_a/ J.mol^{-1}	$\ln(A_s)$/ mPa.s	T^*/ K	T_A/ K	ΔH^*/ kJ.mol^{-1}	ΔS^*/ J.mol^{-1}
			Water (1) + Methanol (2)			
0.25	15572.98	-6.0409	1873.0	310.05	14.72	-104.17
0.50	18872.16	-7.1578	2269.8	317.11	18.18	-92.71
0.75	18274.35	-7.0413	2197.9	312.14	17.77	-91.47
			Water (1) + Ethanol (2)			
0.25	20653.95	-7.6227	2484.1	325.88	19.78	-93.72
0.50	22831.51	-8.3790	2746.0	327.72	22.07	-84.87
0.75	21131.20	-7.9620	2541.5	319.20	20.61	-85.12
			Water (1) + Propan-1-ol (2)			
0.25	21847.91	-7.8755	2627.7	333.66	21.23	-92.85
0.50	22359.25	-8.1145	2689.2	331.41	21.67	-88.51
0.75	22000.06	-8.2445	2646.0	320.94	21.44	-83.99
			Methanol (1) + Ethanol (2)			
0.25	14319.16	-5.7447	1722.2	299.79	13.33	-111.23
0.50	11917.95	-5.1011	1433.4	281.00	10.92	-115.90
0.75	10682.42	-4.7609	1284.8	269.86	9.65	-118.07
			Methanol (1) + Propan-1-ol (2)			
0.25	14792.26	-5.7468	1779.1	309.58	13.86	-112.75
0.50	13005.48	-5.3160	1564.2	294.24	12.03	-115.33
0.75	11845.61	-5.0393	1424.7	282.72	10.84	-116.37
			Ethanol (1) + Propan-1-ol (2)			
0.25	15572.98	-6.3440	2038.9	321.41	16.04	-108.27
0.50	16005.34	-6.1170	1925.0	314.70	15.07	-109.73
0.75	15127.33	-5.9140	1819.4	307.62	14.17	-110.95

Graphical Abstract

The Density, Dynamic Viscosity and Kinematic Viscosity of Protic Polar Solvents (Pure and Mixed Systems) Studies: A Theoretical Insight of Thermophysical Properties

Md. Sayem Alam,[a,b,*] Ashokkumar Baskar,[a] and A. Mohammed Siddiq[a]

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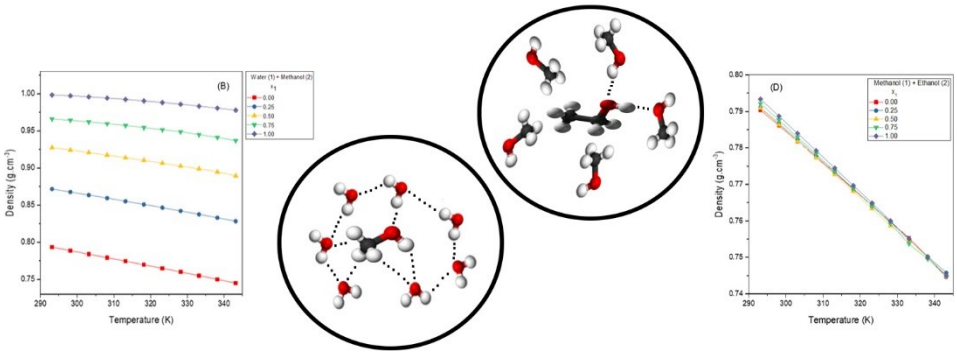

[Graphical Abstract]

The graphical representation of density (ρ) distribution for binary mixed systems: water (1) + methanol (2), methanol (1) + ethanol (2) as function of temperature.

Supporting Information

The Density, Dynamic Viscosity and Kinematic Viscosity of Protic Polar Solvents (Pure and Mixed Systems) Studies: A Theoretical Insight of Thermophysical Properties

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[a]*Council of Scientific and Industrial Research (CSIR) — Central Leather Research Institute (CLRI), Polymer Science and Technology Laboratory, Adyar, Chennai 600 020, India.*

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[*]*To whom correspondence may be addressed: Tel.: + 91-44-24437106. E-mail: sayemalam@gmail.com, sayem@clri.res.in.*

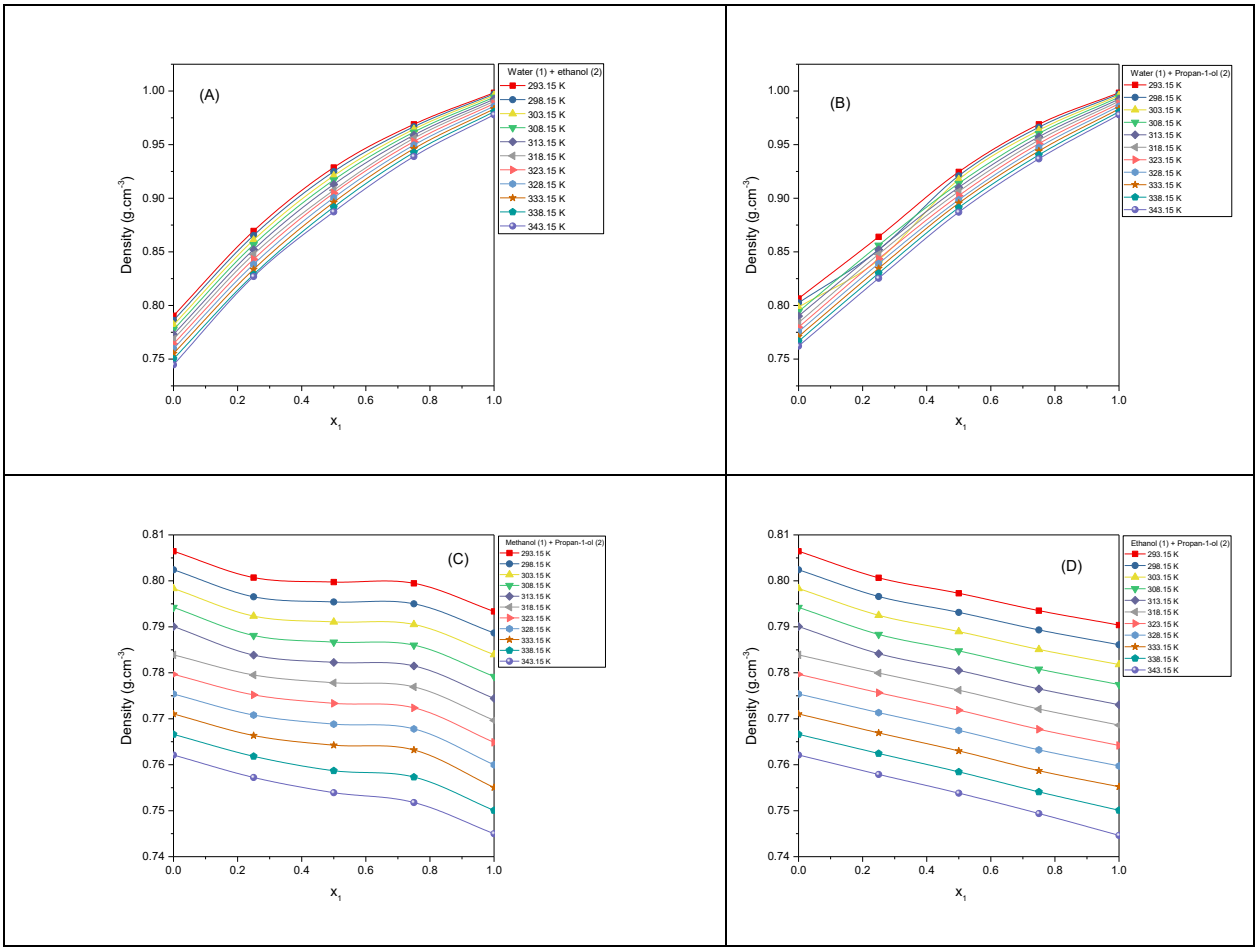


Fig. S1. Density (ρ) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction

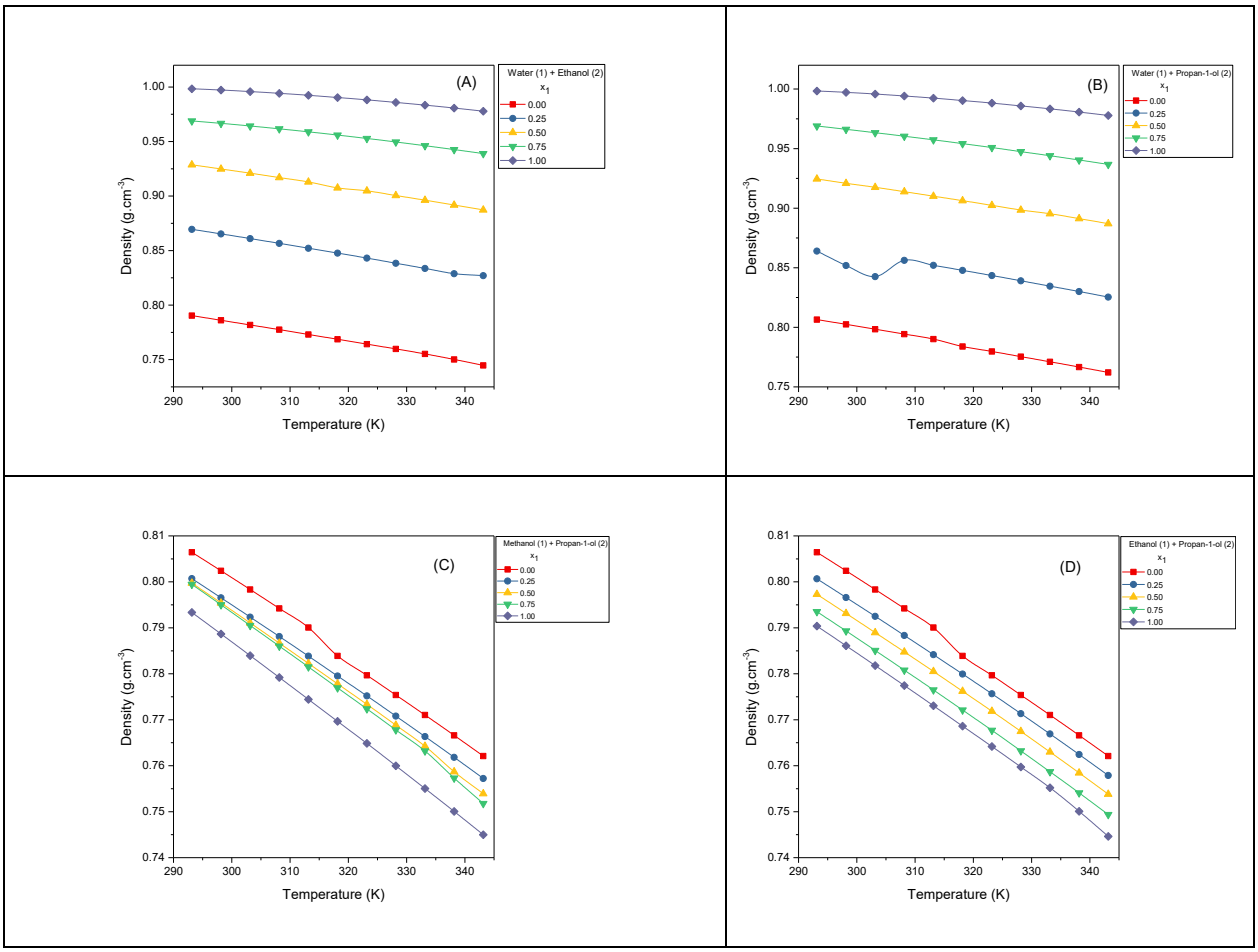
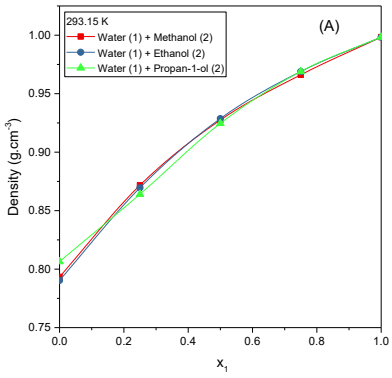
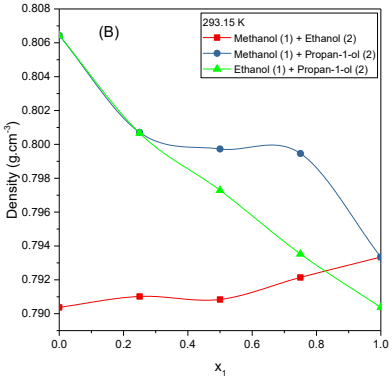
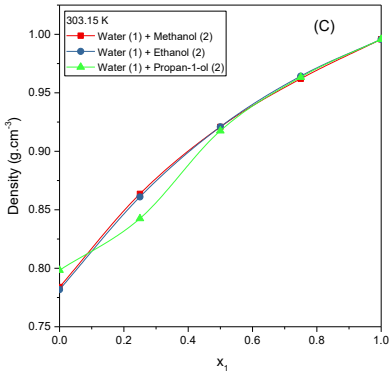
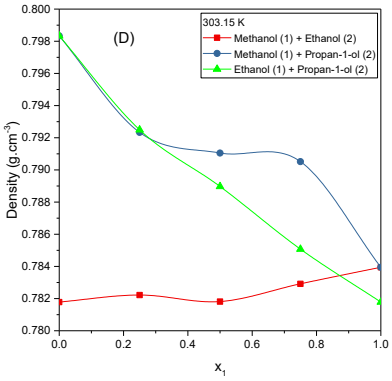


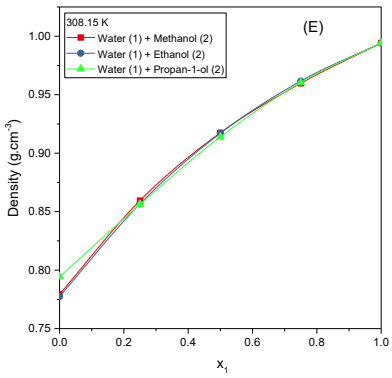
Fig. S2. Density (ρ) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of temperature

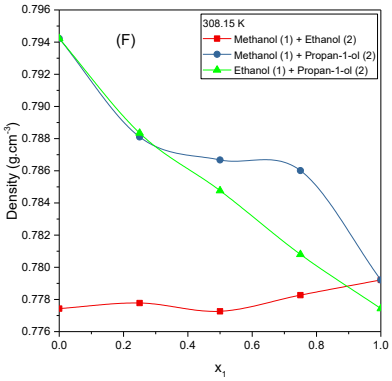

293.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(A)
Density (g.cm-3)
x1

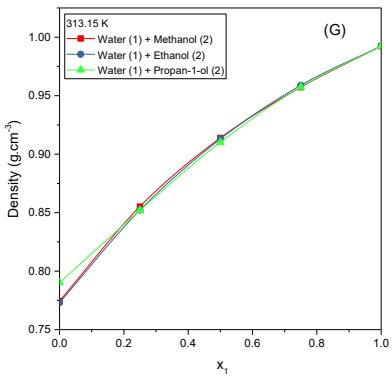

293.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(B)
Density (g.cm-3)
x1

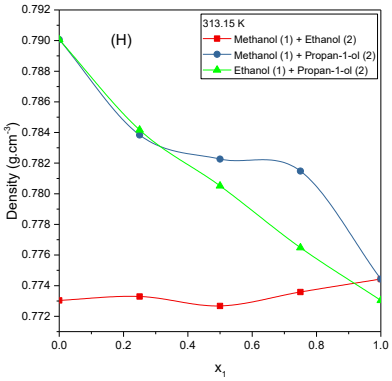

303.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(C)
Density (g.cm-3)
x1

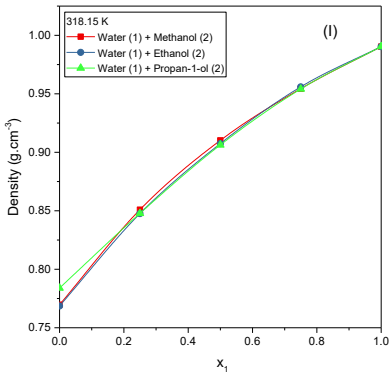

303.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(D)
Density (g.cm-3)
x1

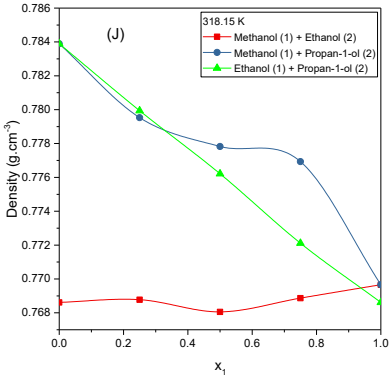

308.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(E)
Density (g.cm-3)
x1

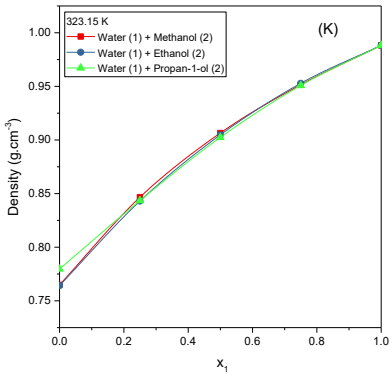

308.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(F)
Density (g.cm-3)
x1

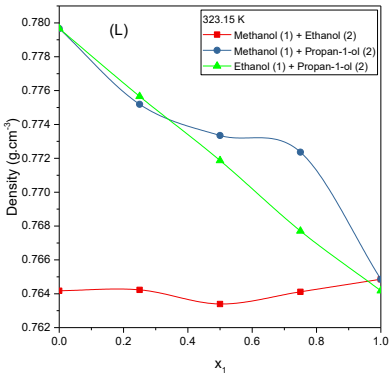

313.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(G)
Density (g.cm-3)
x1

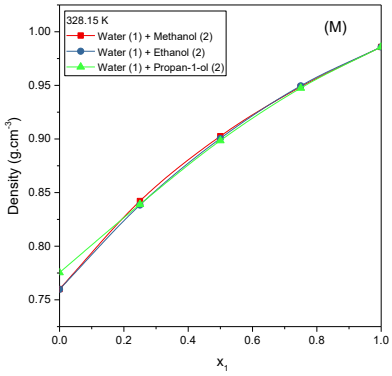

313.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(H)
Density (g.cm-3)
x1

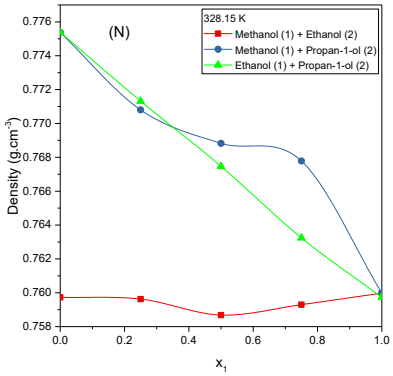

318.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(I)
Density (g.cm-3)
x1

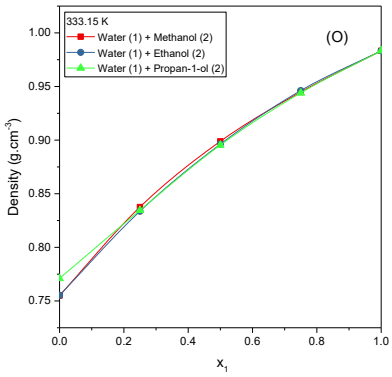

318.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(J)
Density (g.cm-3)
x1

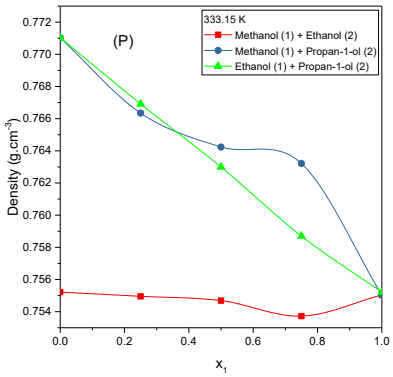

323.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(K)
Density (g.cm-3)
x1

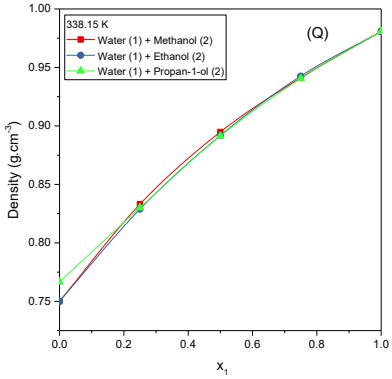

323.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(L)
Density (g.cm-3)
x1

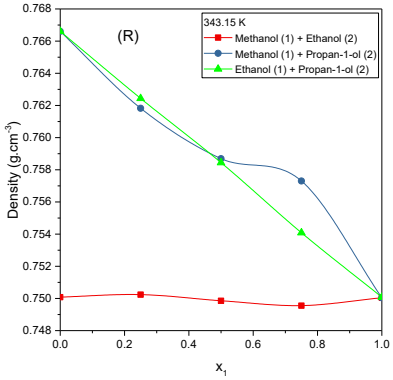

328.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(M)
Density (g.cm-3)
x1


328.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(N)
Density (g.cm-3)
x1


333.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(O)
Density (g.cm-3)
x1


333.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(P)
Density (g.cm-3)
x1


338.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
(Q)
Density (g.cm-3)
x1


343.15 K
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(R)
Density (g.cm-3)
x1

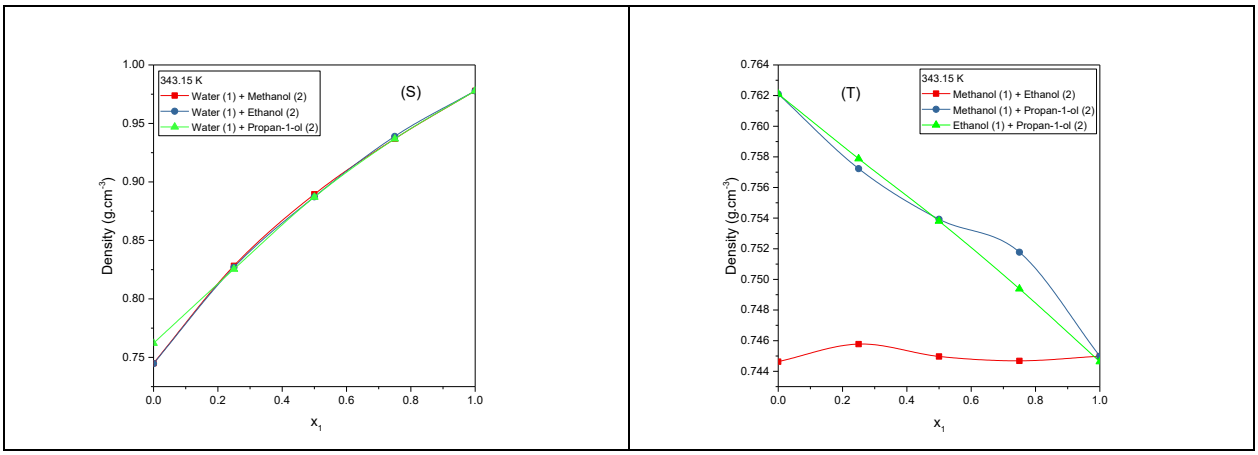
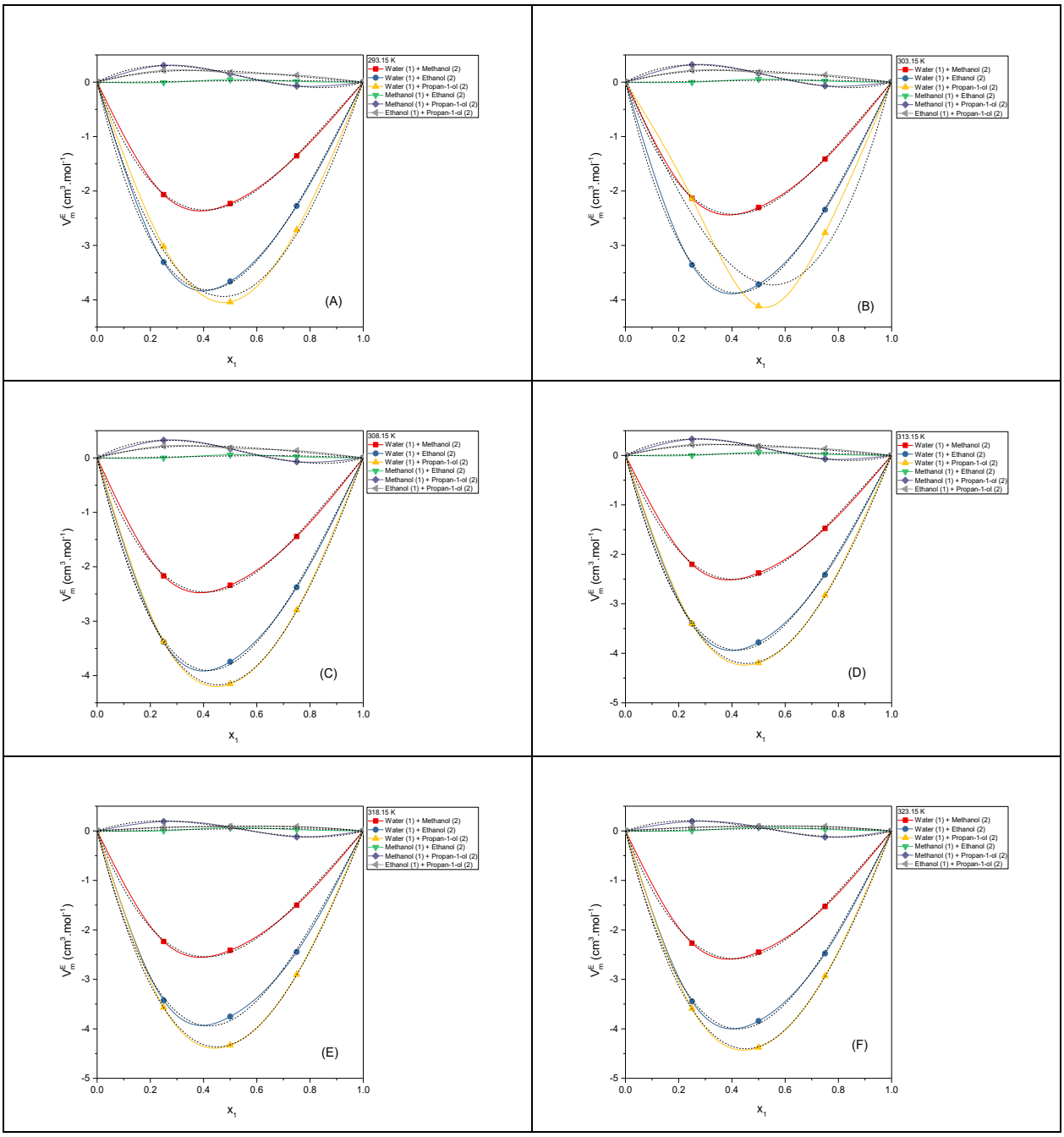


Fig. S3. Density (ρ) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction from 293.15 K to 343.15 K


293.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
(A)
303.15 K
(B)
308.15 K
(C)
313.15 K
(D)
318.15 K
(E)
323.15 K
(F)
V_m^E (cm^3.mol^{-1})
x_1

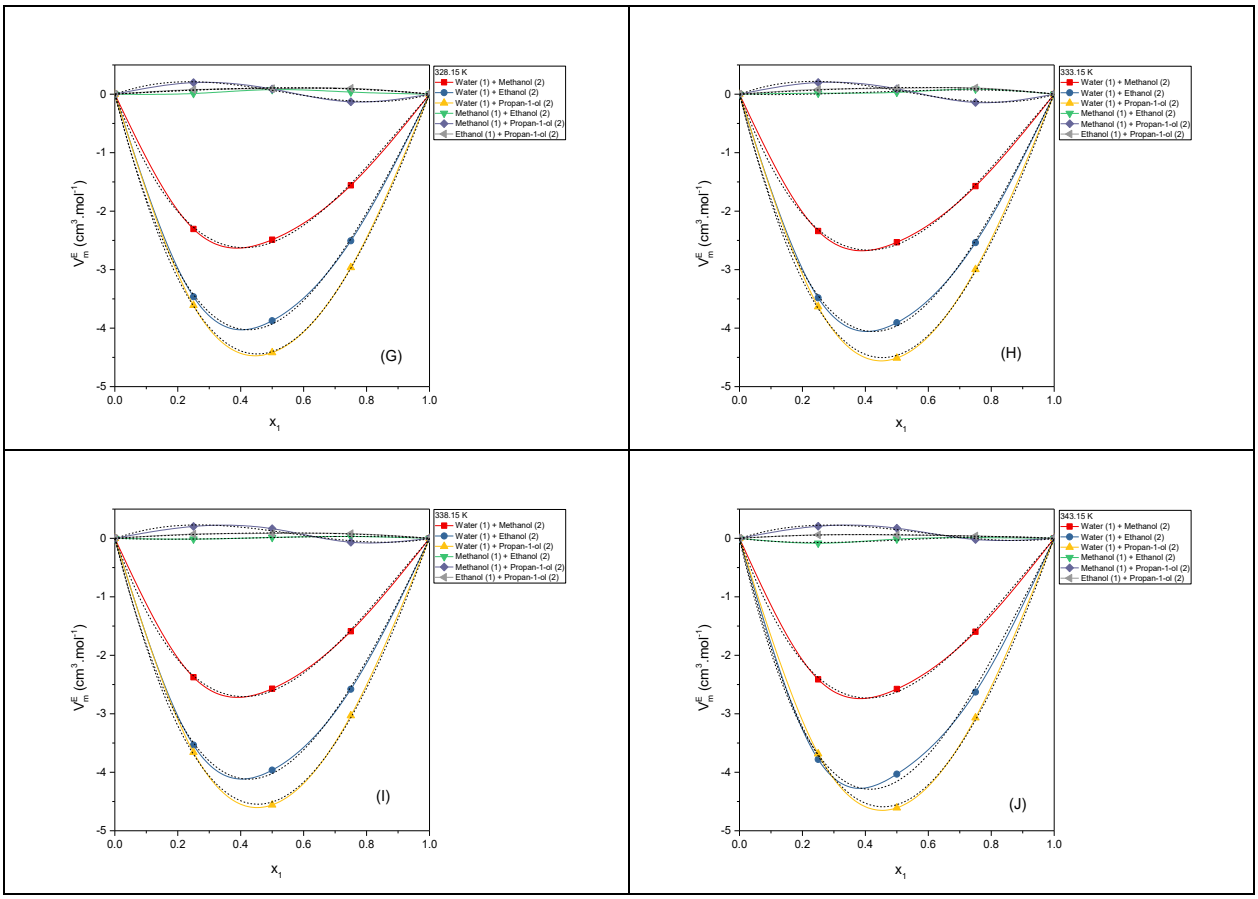


Fig. S4. Excess Molar Volume (V^E) of binary mixtures Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction from 293.15 K to 343.15 K

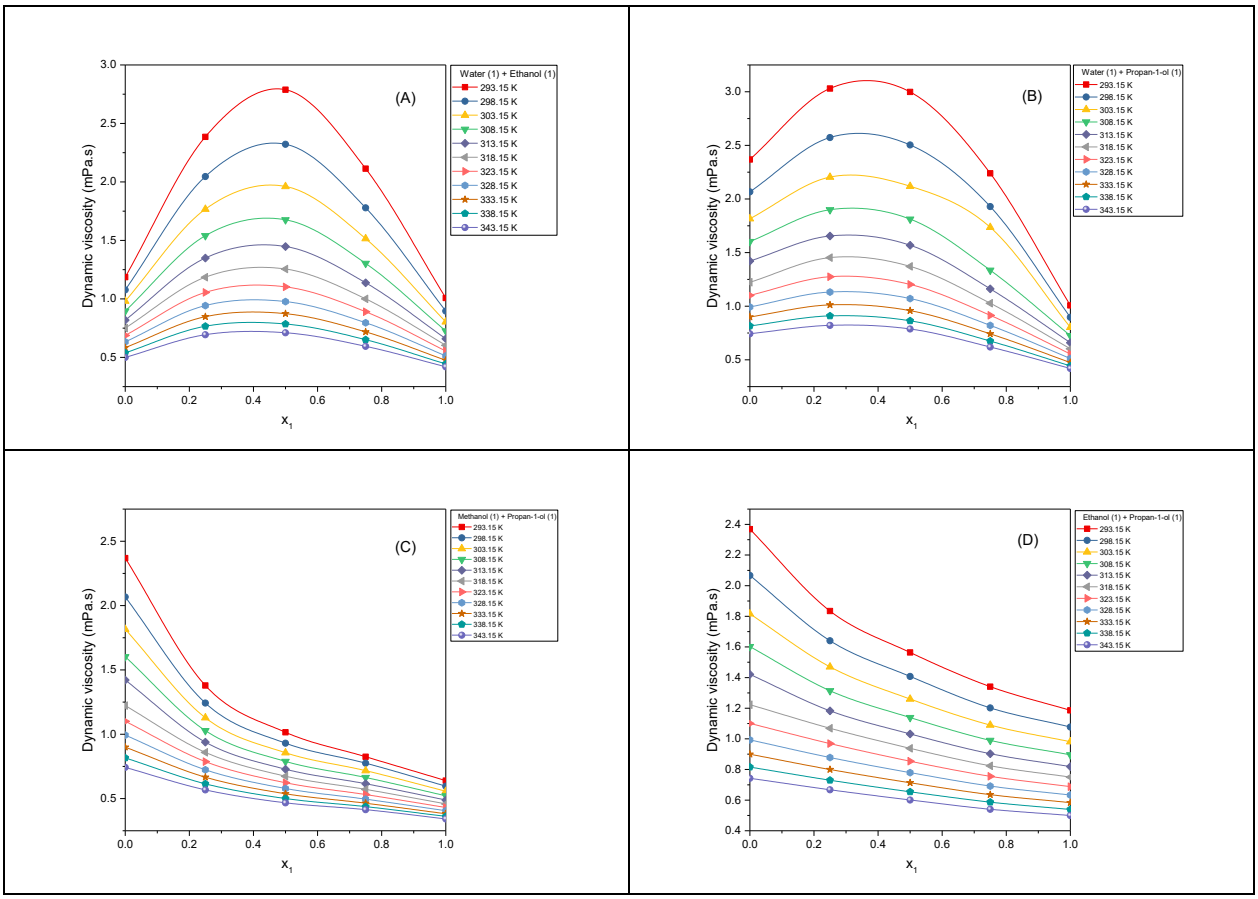


Fig. S5. Dynamic Viscosity (η) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction

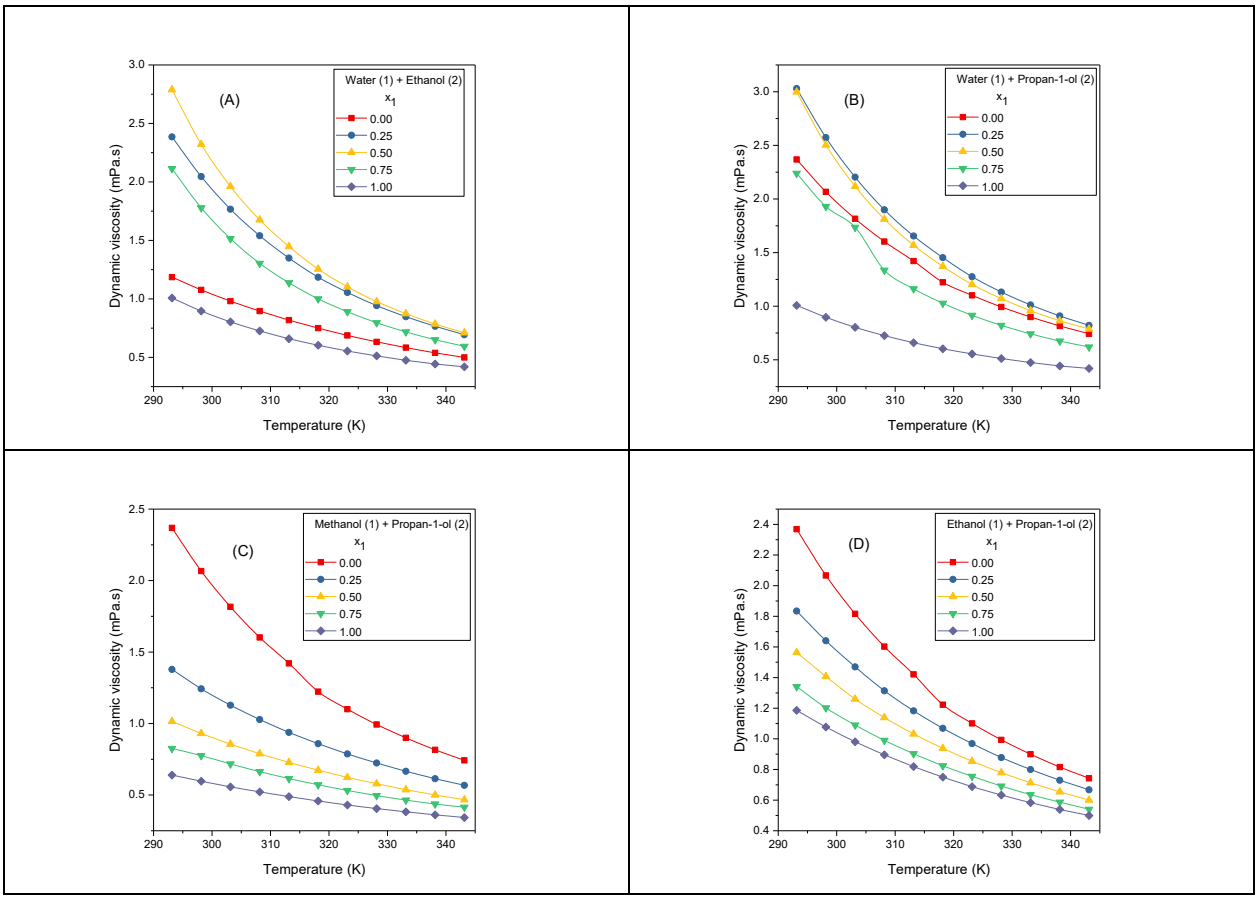
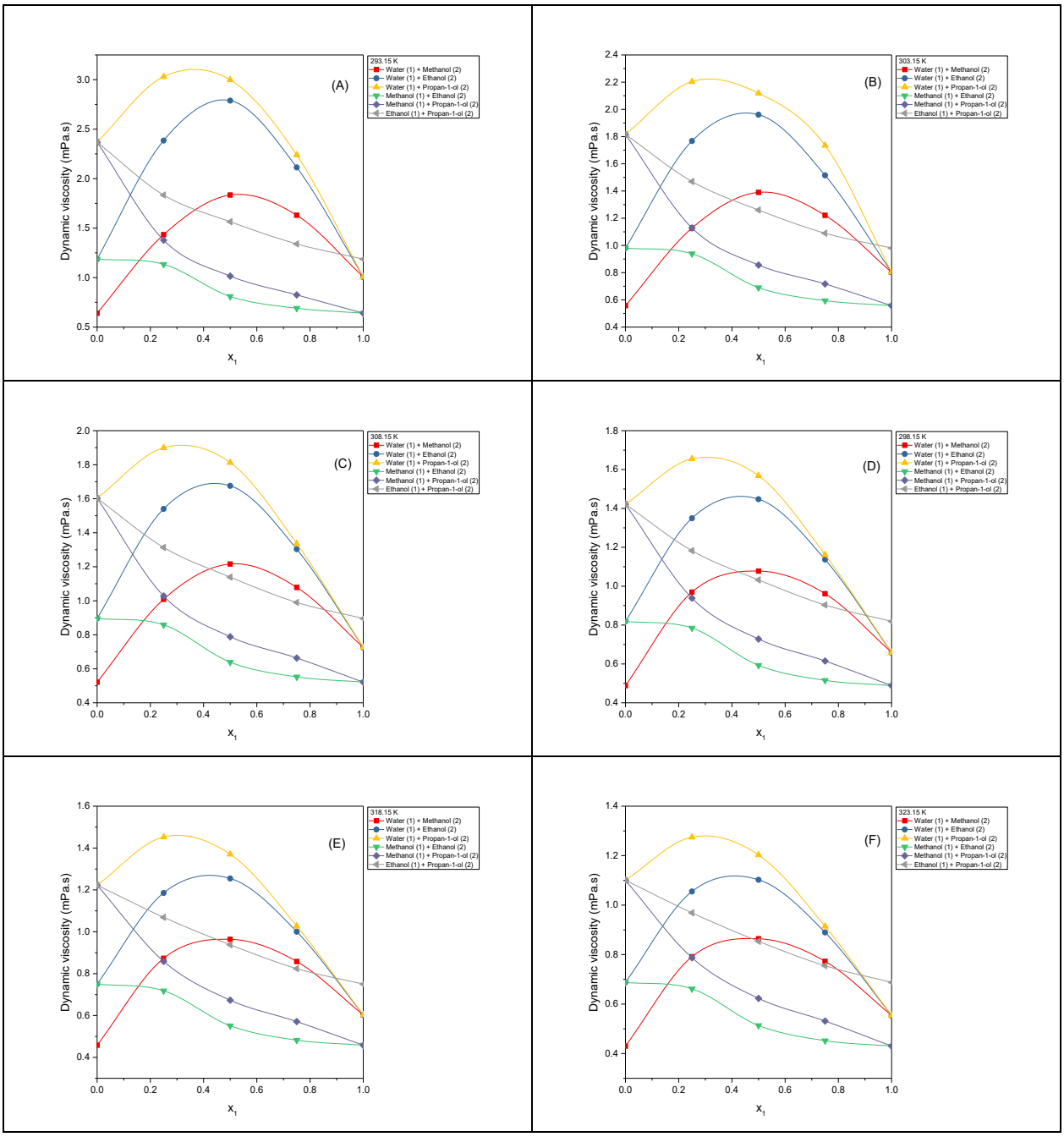


Fig. S6. Dynamic Viscosity (η) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of temperature


(A)
293.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
Dynamic viscosity (mPa.s)
x1
(B)
303.15 K
(C)
308.15 K
(D)
298.15 K
(E)
318.15 K
(F)
323.15 K

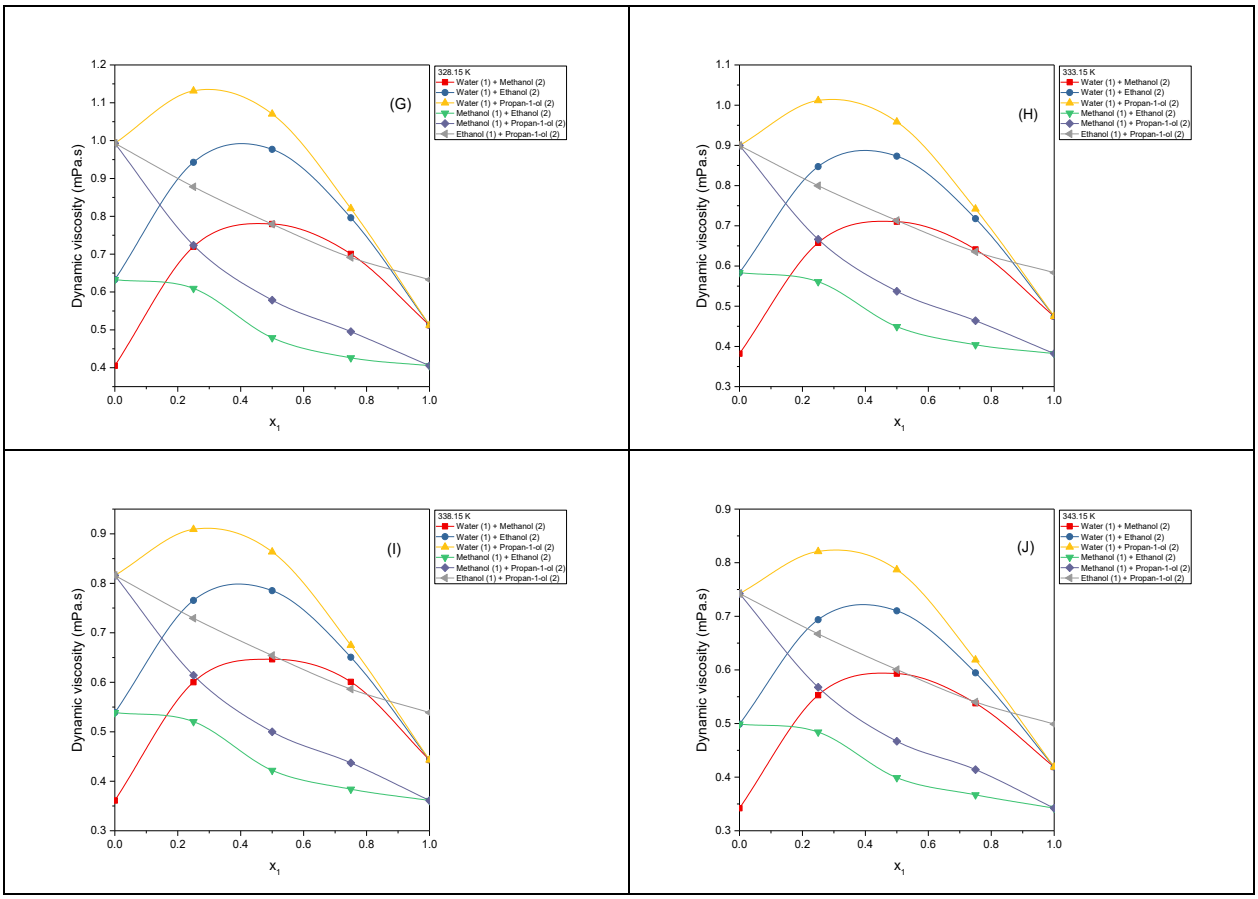


Fig. S7. Dynamic Viscosity (η) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction from 293.15 K to 343.15 K

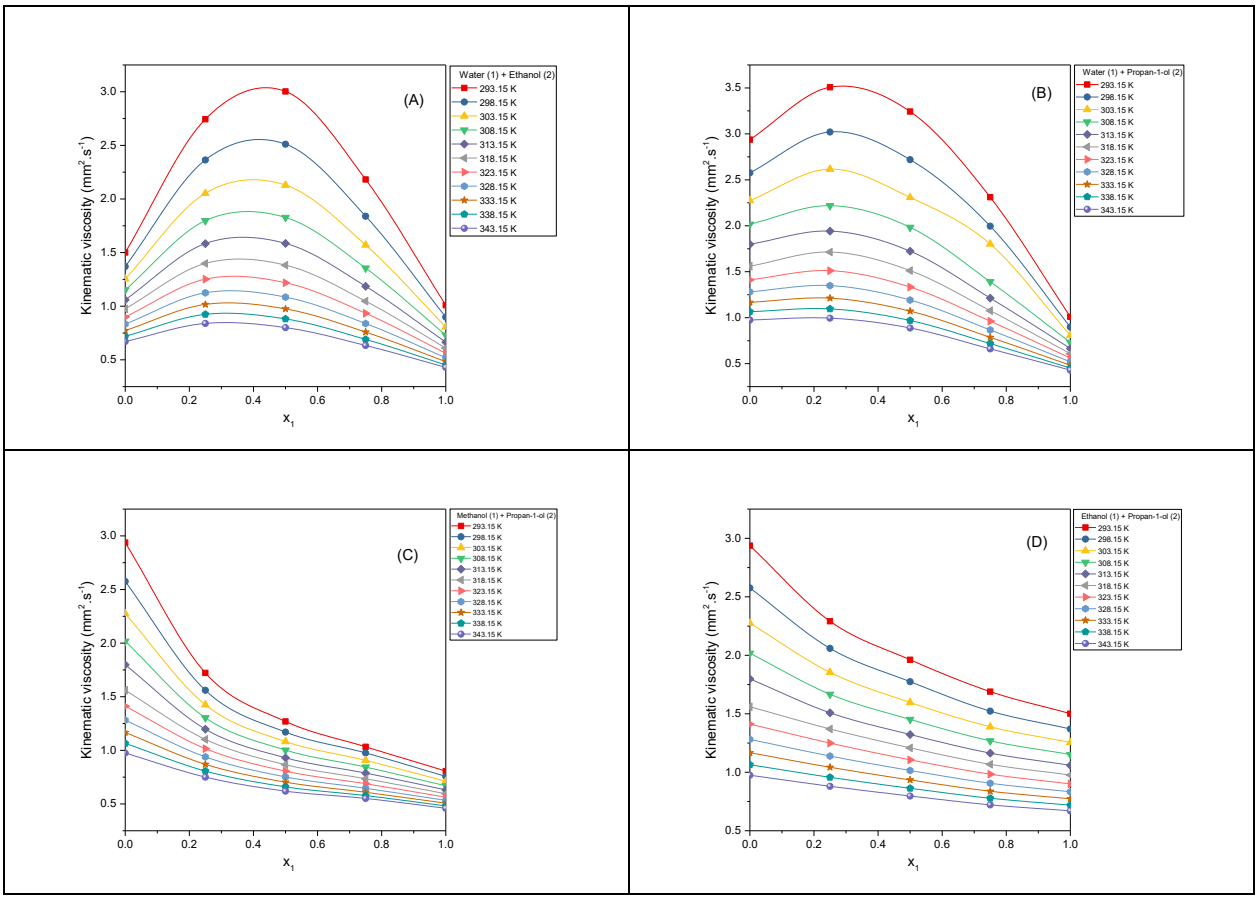


Fig. S8. Kinematic Viscosity (v) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction

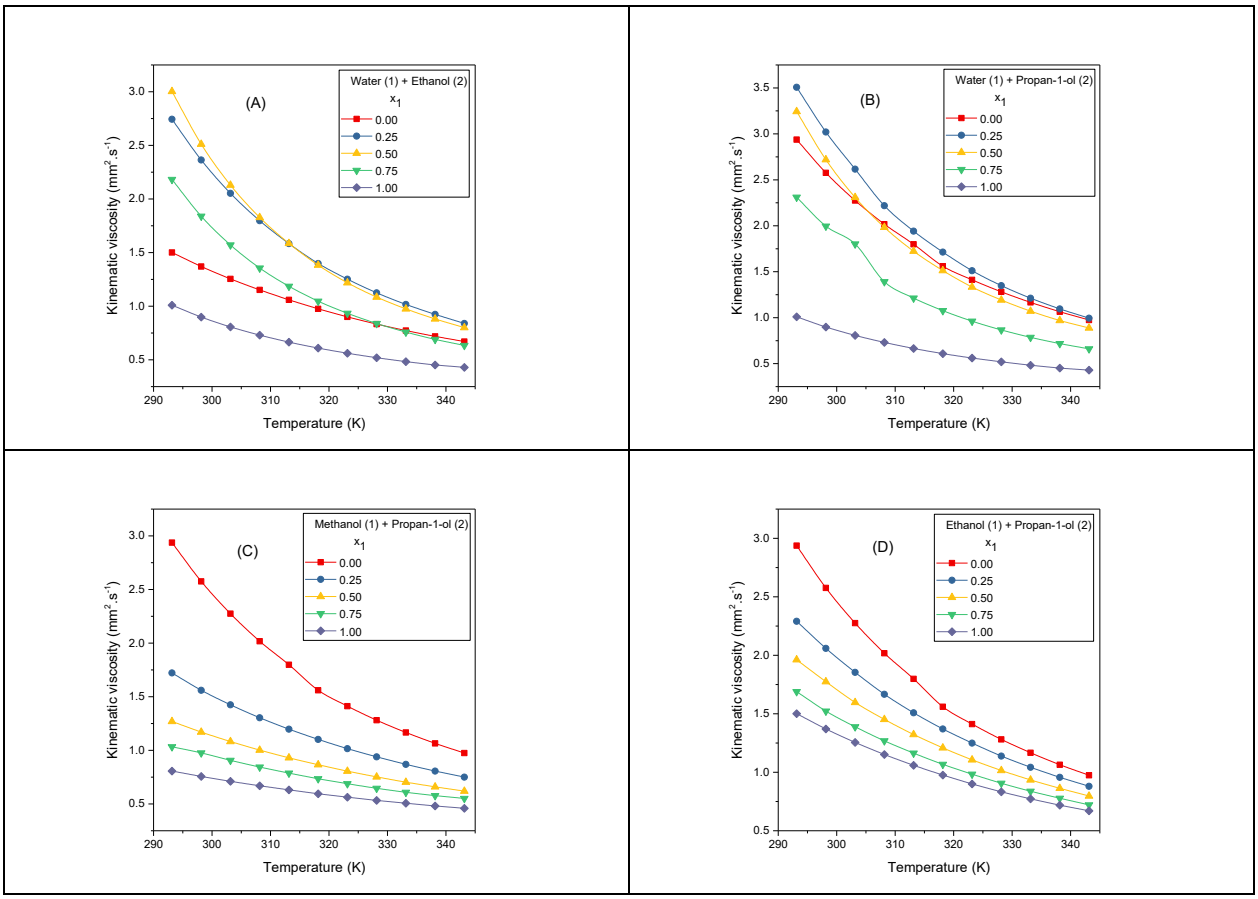
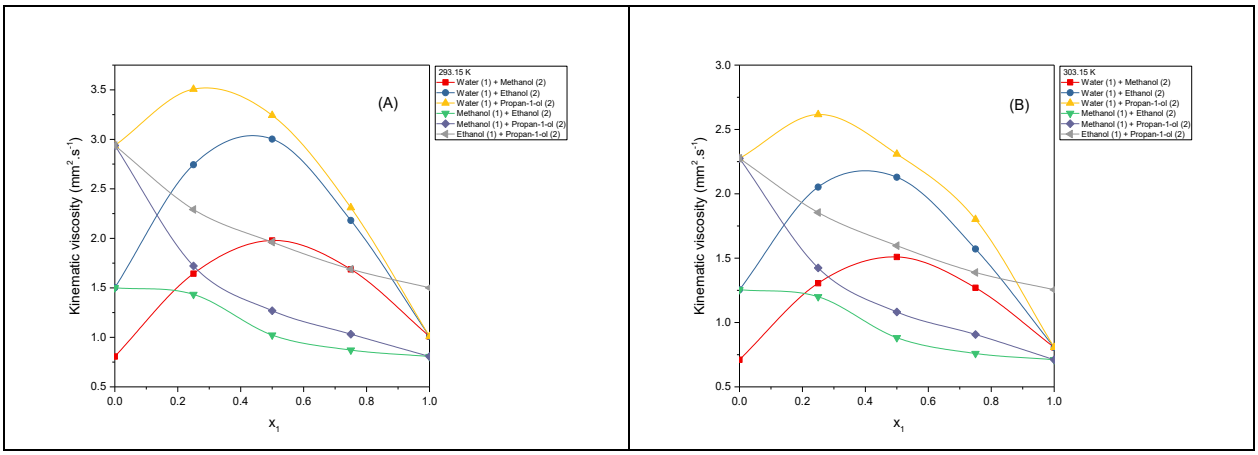
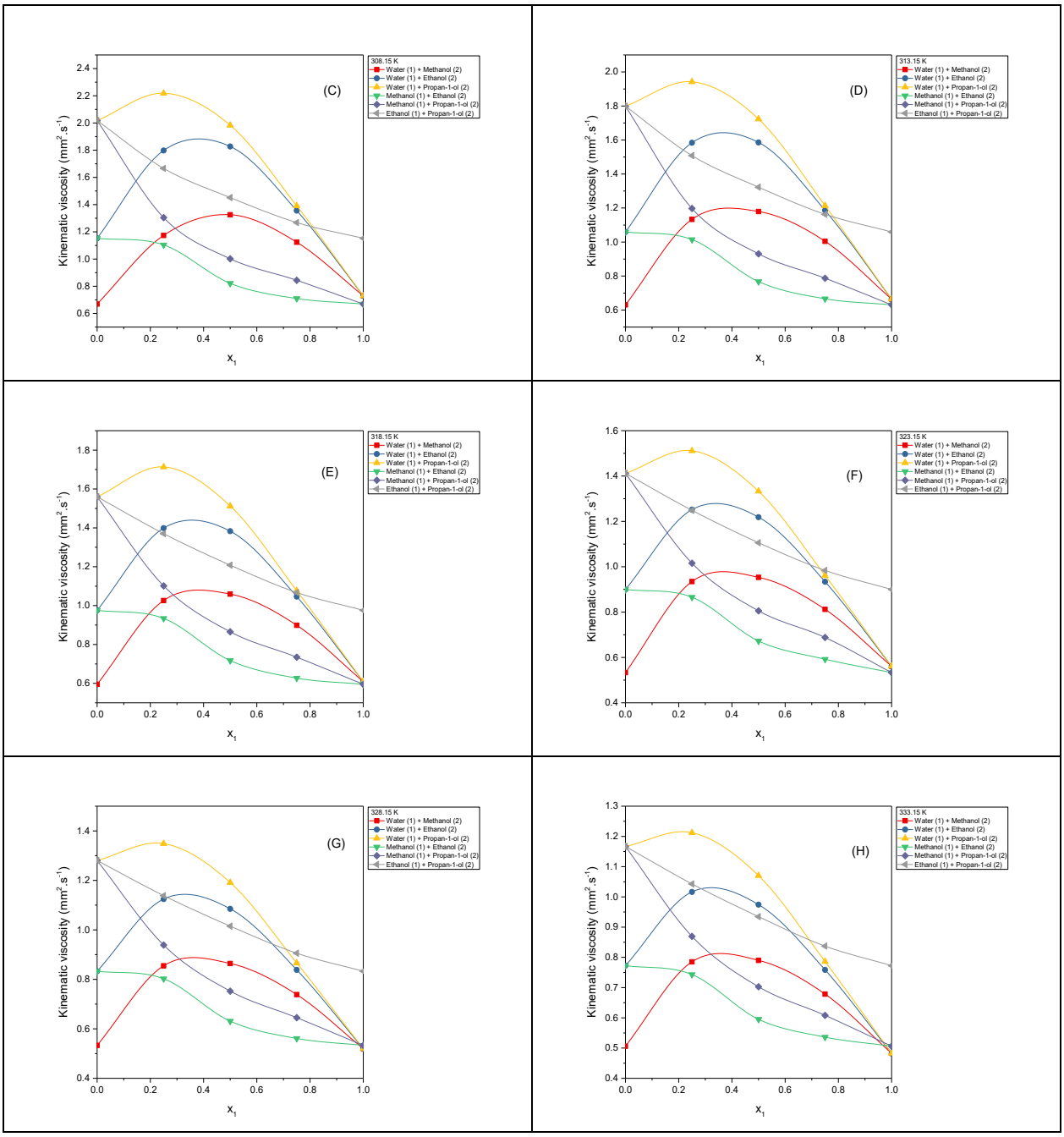


Fig. S9. Kinematic Viscosity (v) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of temperature.




(C)
308.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
Kinematic viscosity (mm².s⁻¹)
x1
(D)
313.15 K
(E)
318.15 K
(F)
323.15 K
(G)
328.15 K
(H)
333.15 K

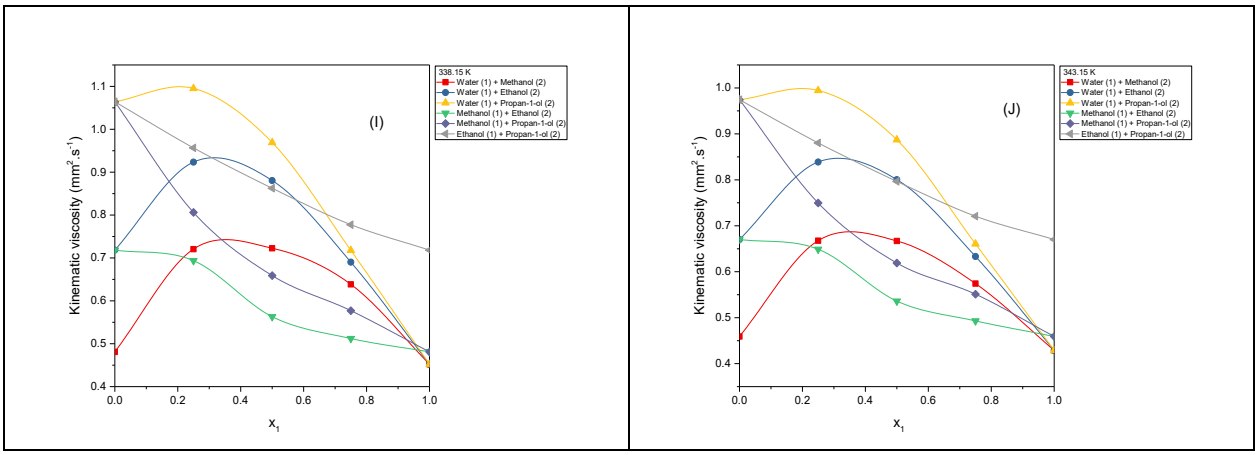
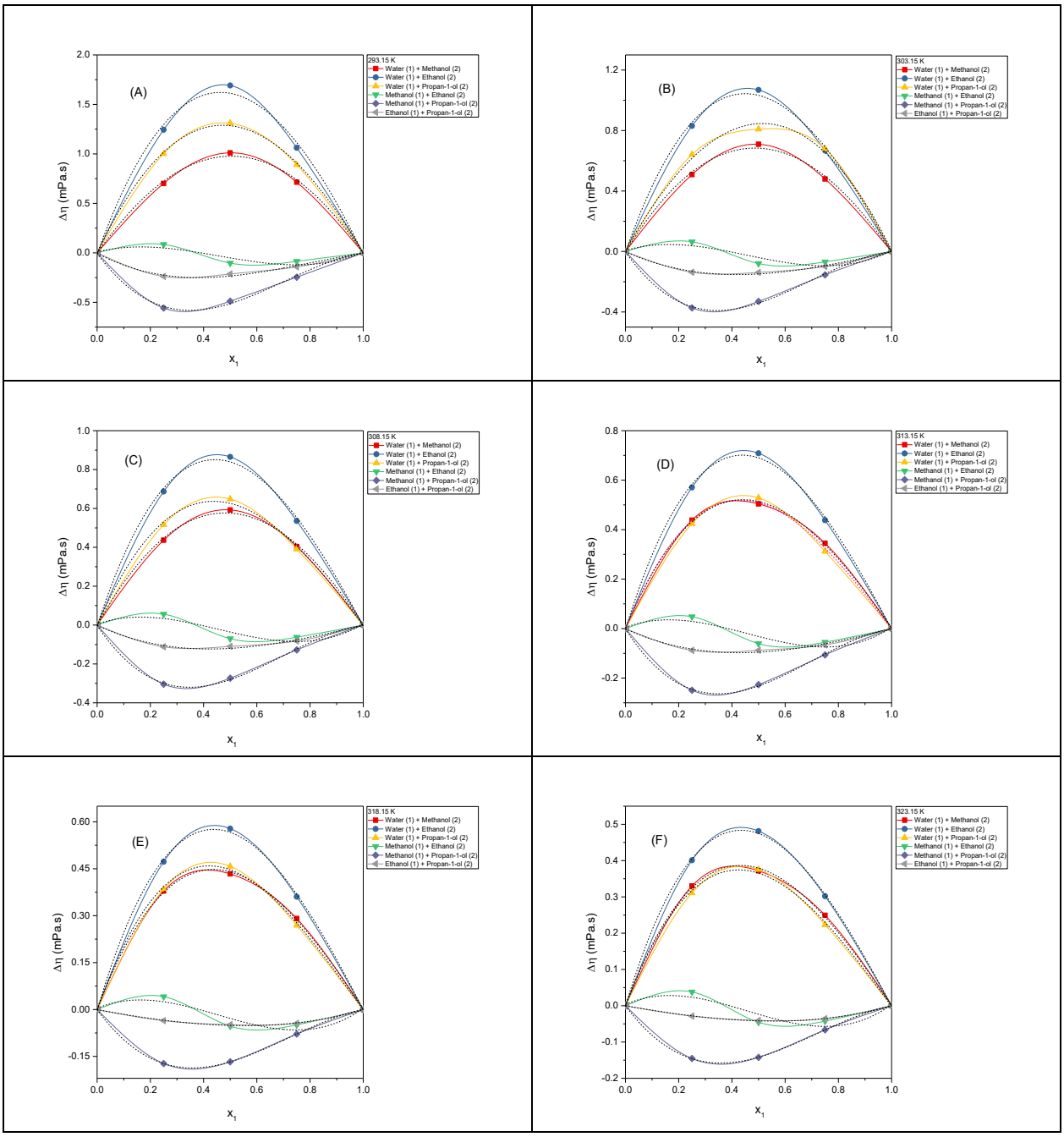


Fig. S10. Kinematic Viscosity (v) of binary mixtures Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction from 293.15 K to 343.15 K


(A)
293.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
Δη (mPa.s)
x1
(B)
303.15 K
(C)
308.15 K
(D)
313.15 K
(E)
318.15 K
(F)
323.15 K

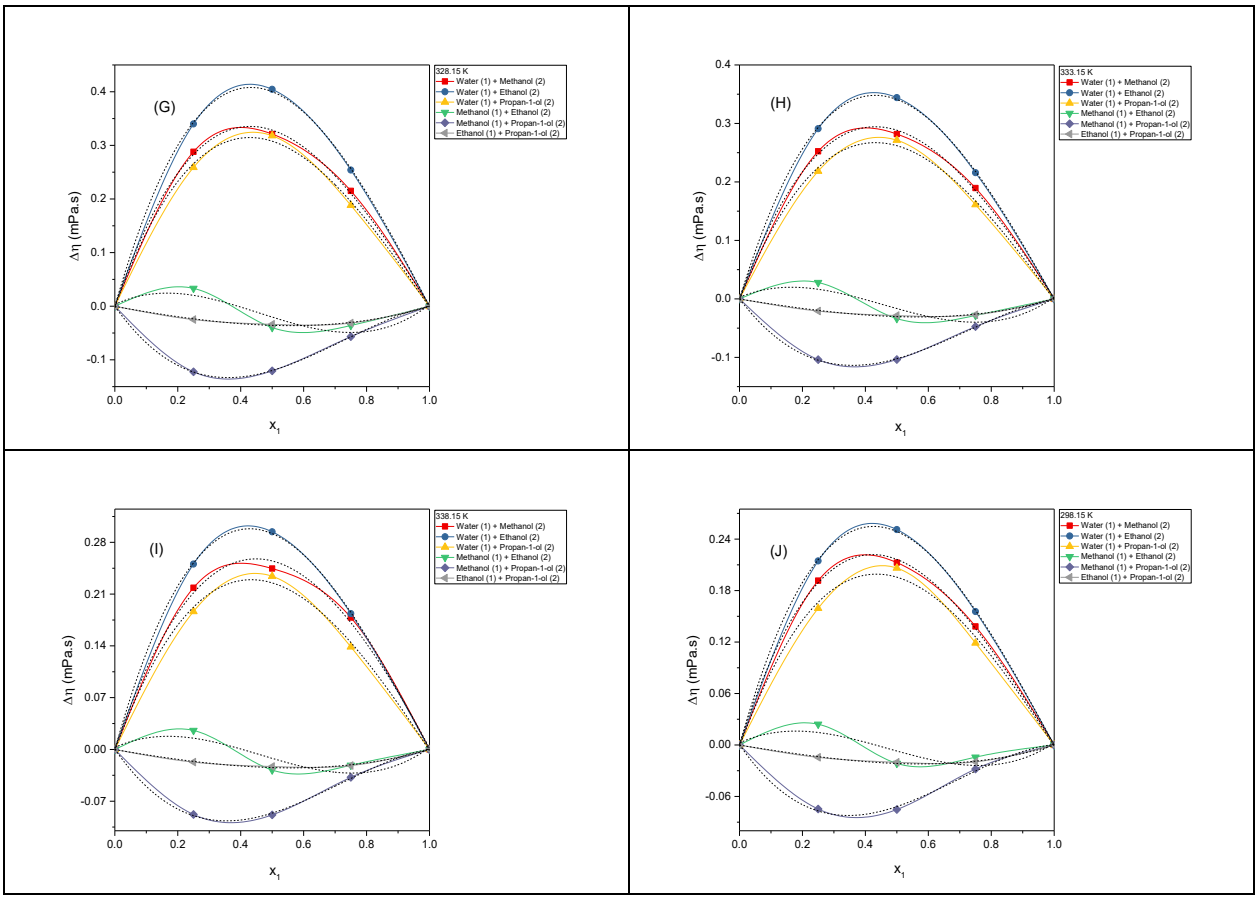
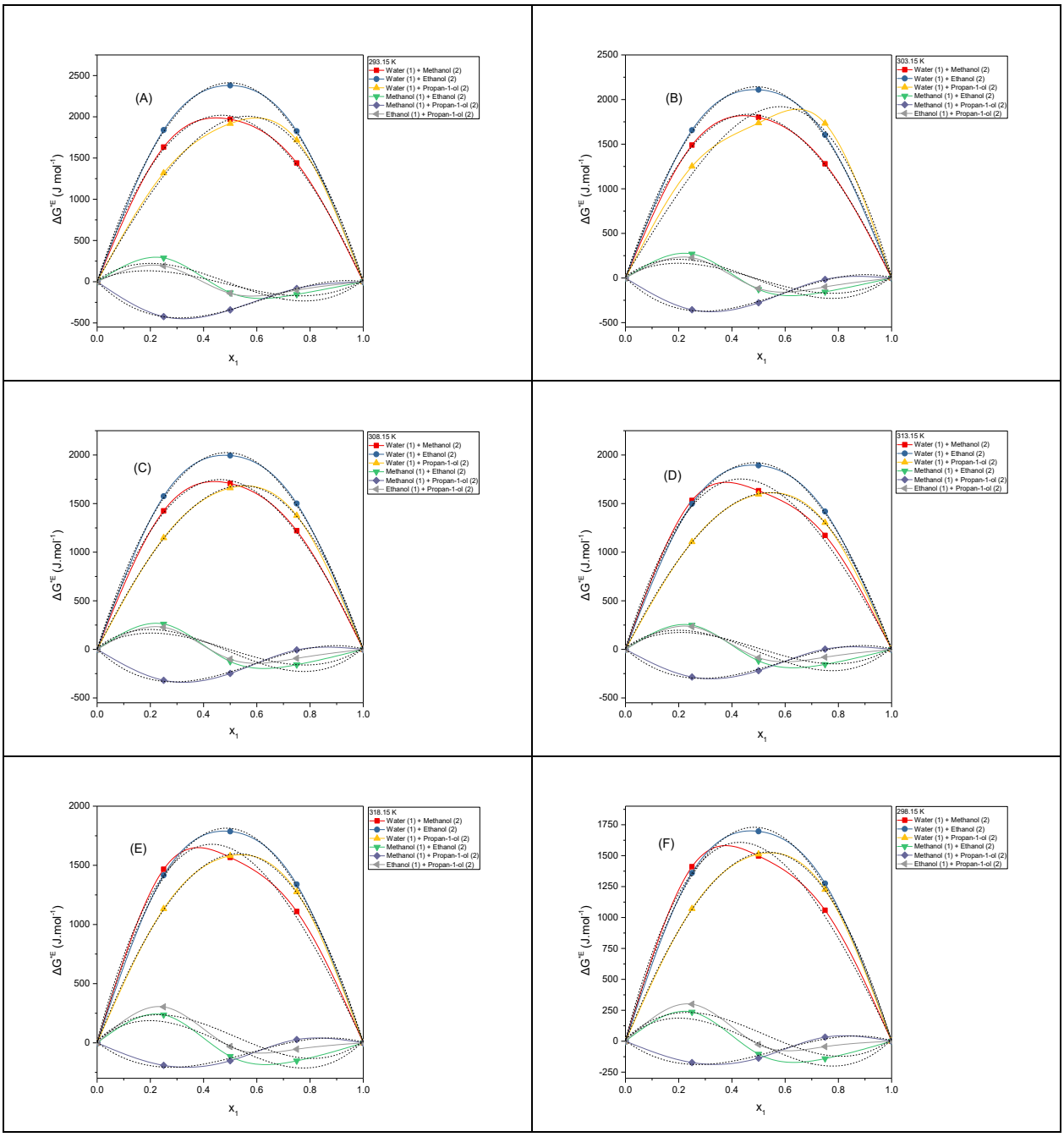


Fig. S11. Viscosity Deviation (Δη) of binary mixtures Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction from 293.15 K to 343.15 K


(A)
293.15 K
Water (1) + Methanol (2)
Water (1) + Ethanol (2)
Water (1) + Propan-1-ol (2)
Methanol (1) + Ethanol (2)
Methanol (1) + Propan-1-ol (2)
Ethanol (1) + Propan-1-ol (2)
ΔG^E (J.mol^-1)
x1
(B)
303.15 K
(C)
308.15 K
(D)
313.15 K
(E)
318.15 K
(F)
298.15 K

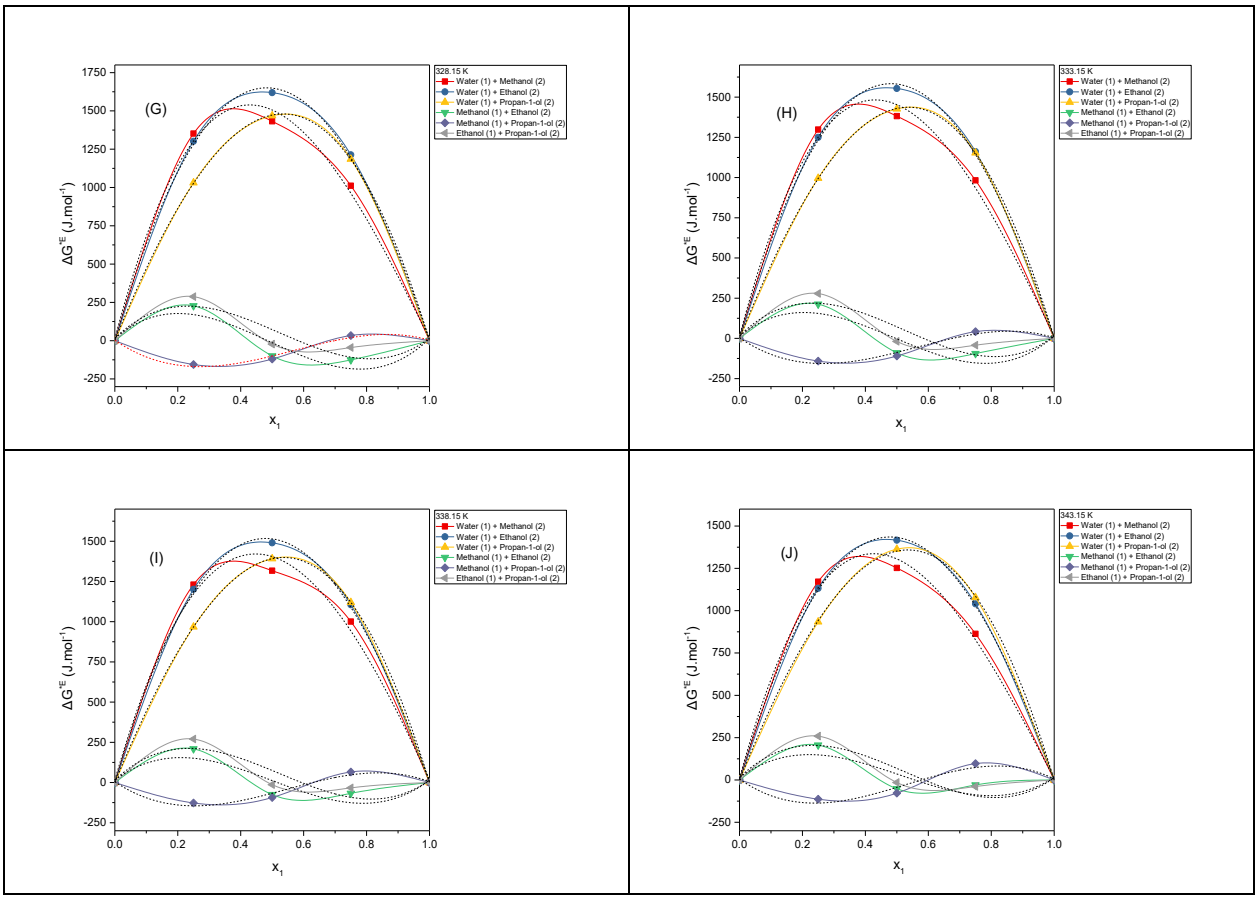


Fig. S12. Excess Gibb's Free Energy (ΔG^E) for Activation of Viscous flow of binary mixtures Water (1) + Methanol (2), Water (1) + Ethanol (2), Water (1) + Propan-1-ol (2), Methanol (1) + Ethanol (2), Methanol (1) + Propan-1-ol (2) and Ethanol (1) + Propan-1-ol (2) as function of mole fraction from 293.15 K to 343.15 K