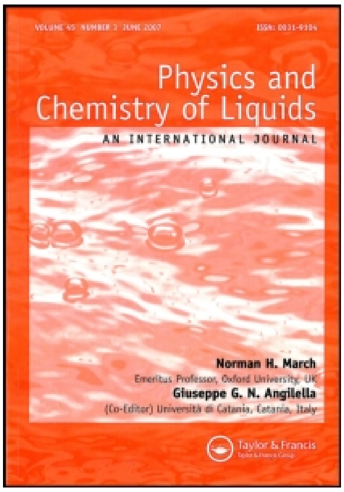

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EXCESS MOLAR VOLUMES AND VISCOSITIES FOR 1,1,1-TRICHLOROETHANE WITH ALCOHOLS AT 298.15 K

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Excess molar volumes (V^E), excess viscosities (η^E) and excess energies of activation for viscous flow (ΔG^{*E}) have been obtained for the 1,1,1-trichloroethane + alcohols systems at 298.15 K, over the whole concentration range. The Prigogine–Flory–Patterson model of solution thermodynamics has been used to predict the excess molar volumes. McAllister, Teja and Rice and Schrodt and Akel models have been used to predict viscosity coefficients and these were compared with experimental data, for the mixtures.

KEY WORDS: Excess molar volumes, excess viscosities, excess activation energies; 1,1,1-trichloroethane + (1-propanol,1-butanol,2-butanol and 3-methyl-1-butanol).

1 INTRODUCTION

Excess thermodynamic properties such as excess molar volume (V^E), excess viscosity (η^E) and excess energy of activation for viscous flow (ΔG^{*E}) have been obtained for the mixtures of 1,1,1-trichloroethane (TCE) with 1-propanol (1-PR), 1-butanol (1-BU), 2-butanol (2-BU) and 3-methyl-1-butanol or isoamyl alcohol (IAM) at 298.15 K, in order to investigate their possible interactions.

Densities and viscosities at different mole fractions were measured for these systems in which the alcohols are polar molecules with association in their pure state and TCE is a polar molecule. The excess volumes data were analyzed by the Prigogine–Flory–Patterson model in terms of three contributions: ΔV_{int} (interactional), ΔV_{P*} (internal pressure) and ΔV_F (free volume). Viscosities of the mixtures have been analyzed by means of the McAllister equations, Teja and Rice corresponding states method, and Schrodt and Akel estimation, based on Eyring's concept of dilute viscosity.

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2 EXPERIMENTAL SECTION

The methods used in our laboratory have been described previously[1,2]. Densities (ρ) were determined with a digital densimeter AP (model DMA 45) at 298.15 K. A thermostatically controlled bath (constant to ±0.01°C) was used. Calibration was carried out with air and doubly distilled water, with an error of $\pm 0.1\ \mathrm{kg\,m^{-3}}$. All weighings were made on a Mettler H315 balance. Temperatures were read from calibrated thermometers.

Viscosities of the pure components and of the mixtures were determined with a Cannon–Fenske viscosimeter calibrated with distilled water and benzene. Kinetic energy corrections were applied to viscosity data. The estimated error was ±0.005 mPa s.

The alcohols, Merck (puriss.) were distilled over calcium oxide and the middle fraction were collected. The 1,1,1-trichloroethane BDH (puriss.) was distilled and the middle fractions was also collected. Mixtures were prepared from weighed amounts of the pure liquids. Caution was taken to prevent evaporation.

3 RESULTS AND DISCUSSION

The experimental results for the pure liquids are reported in Table 1, together with literature values for comparison.

The excess molar volumes were calculated with the following equation:

$$V^E = x_1 M_1(\rho^{-1} - \rho_1^{-1}) + x_2 M_2(\rho^{-1} - \rho_2^{-1}) \tag{1}$$

where x_1 and x_2 are the mole fractions of the components, M_1 and M_2 are the molecular weights and ρ, ρ_1 and ρ_2 are the densities of the solutions and of the pure components.

Excess viscosities were obtained by the following equation:

$$\eta^E = \eta - \exp(x_1 \ln \eta_1 + x_2 \ln \eta_2) \tag{2}$$

where the additivity law in a logarithmic form is taken for the ideal mixtures.

Table 1 Densities and viscosities of the pure components at 298.15 K.

Substance	$\rho \times 10^{-3}/\mathrm{kg\,m^{-3}}$		$\eta/\mathrm{mPa\,s}$	
1-Propanol	0.7994	0.7995[a]	1.914	1.943[b]
1-Butanol	0.8059	0.80575[b]	2.563	2.5710[b]
2-Butanol	0.8024	0.80241[b]	3.032	2.998[b]
3-Methyl-1-butanol	0.8080	0.8071[b]	3.888	3.738[b]
1,1,1-Trichloroethane	1.3293	1.3299[b]	0.786	0.795[b]

[a] Ref. (3), [b] Ref. (4).

Table 2 Densities and viscosities of the mixtures at 298.15 K

TCE(1) + 1-PR(2)			*TCE(1) + 1-BU(2)*		
x_1	$\rho \times 10^{-3}/kg\ m^{-3}$	$\eta/mPa\ s$	x_1	$\rho \times 10^{-3}/kg\ m^{-3}$	$\eta/mPa\ s$
0.0572	0.8395	1.789	0.1022	0.8639	2.187
0.1154	0.8787	1.667	0.2068	0.9221	1.072
0.1930	0.9285	1.506	0.3061	0.9762	1.611
0.3007	0.9935	1.318	0.4067	1.0330	1.372
0.3956	1.0472	1.165	0.5174	1.0880	1.164
0.4900	1.0976	1.045	0.6050	1.1330	1.042
0.6367	1.1706	0.909	0.6995	1.1804	0.936
0.7983	1.2442	0.824	0.7924	1.2260	0.855
0.8861	1.2816	0.799	0.9022	1.2796	0.811

The excess energies of activation for viscous flow were obtained by the following expression:

$$\Delta G^{*E} = RT(\ln \eta V - x_1 \ln \eta_1 V_1 - x_2 \ln \eta_2 V_2) \tag{3}$$

where V, V_1 and V_2 represent the molar volumes of the solutions and of the pure components.

Tables 2 and 3 show the experimental values of densities and viscosities of the four systems at 298.15 K.

Each set of results were fitted with a Redlich–Kister equation of the type:

$$X^E = x_1(1 - x_1) \sum_{j=1}^{n} a_j(1 - 2x_1)^{j-1} \tag{4}$$

where a_j are the polynomial parameters obtained by a linear least-squares fitting procedure. In each case the optimum number of coefficients was ascertained from an examination of the variation of the standard error of estimate with n (calculated with a VAX 11/780 computer):

$$\sigma = [\sum (X^E_{\text{obs}} - X^E_{\text{cal}})^2/(n_{\text{obs}} - n)]^{1/2} \tag{5}$$

Table 3 Densities and viscosities of the mixtures at 298.15 K

TCE(1) + 2-BU(2)			*TCE(1) + IAM(2)*		
x_1	$\rho \times 10^{-3}/kg\ m^{-3}$	$\eta/mPa\ s$	x_1	$\rho \times 10^{-3}/kg\ m^{-3}$	$\eta/mPa\ s$
0.0990	0.8567	2.210	0.1130	0.8619	3.084
0.2079	0.9160	1.726	0.1681	0.8887	2.720
0.2768	0.9531	1.460	0.3013	0.9540	2.010
0.3656	1.0002	1.225	0.3885	0.9975	1.663
0.5119	1.0768	1.008	0.5090	1.0589	1.339
0.5786	1.1111	0.940	0.5929	1.1025	1.169
0.6988	1.1729	0.850	0.6920	1.1553	1.035
0.7800	1.2144	0.808	0.7926	1.2100	0.913
0.8911	1.2712	0.781	0.8991	1.2696	0.817

Table 4 Coefficients A_j for Eq. (4) and standard deviation σ determined by the method of least squares.

System		a_1	a_2	a_3	a_4	a_5	a_6	σ
TCE(1) + 1-PR(2)	V^E	−0.132	−0.466	−0.08	−0.45	0.88	−0.60	0.002
	η^E	−0.770	0.050	0.210	—	—	—	0.002
	ΔG^{*E}	−1590	920	380	−280	—	—	5
TCE(1) + 1-BU(2)	V^E	0.077	−0.366	0.722	−1.84	1.17	0.28	0.001
	η^E	−0.893	0.020	0.260	0.52	−0.36	−1.03	0.004
	ΔG^{*E}	−1677	940	420	1520	−79.8	2700	14
TCE(1) + 2-BU(2)	V^E	2.246	−0.74	0.38	−0.45	1.58	—	0.008
	η^E	−2.129	−2.130	−0.55	2.90	−1.50	−4.90	0.01
	ΔG^{*E}	4087	1462	531	5816	−1468	−7351	15
TCE(1) + IAM(2)	V^E	1.420	−0.696	−0.46	−0.57	1.67	—	0.005
	η^E	−1.575	−1.064	0.304	1.26	—	—	0.004
	ΔG^{*E}	−2371	1972	4665	−933.5	−7608	—	48

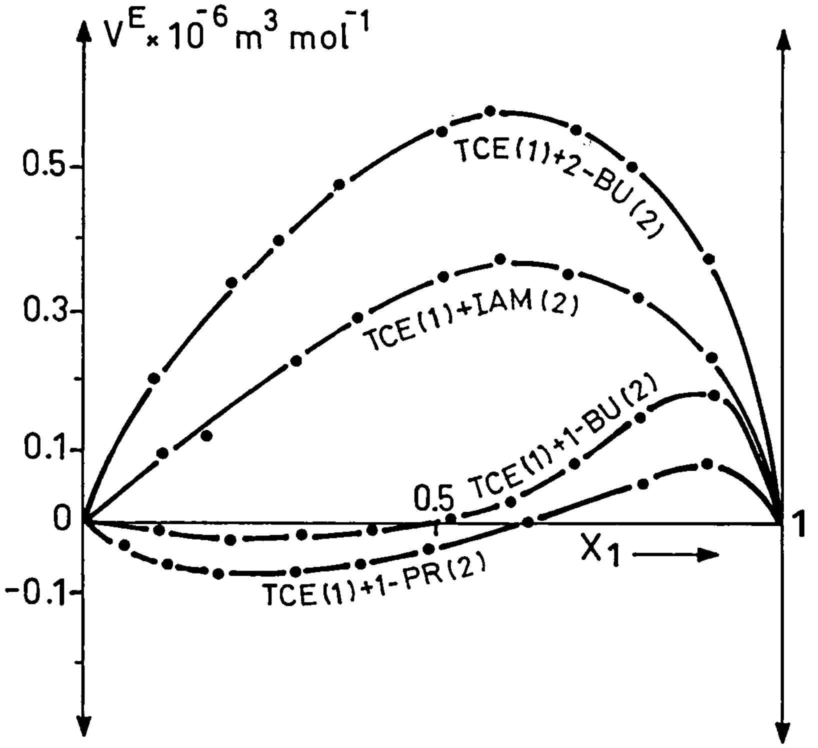

Figure 1 Excess molar volumes for the 1,1,1-trichloroethane(1) + 1-propanol(2), 1,1,1-trichloroethane(1) + 1-butanol(2), 1,1,1-trichloroethane(1) + 2-butanol(2), and 1,1,1-trichloroethane(1) + 3-methyl-1-butanol(2) systems at 298.15 K. Continuous curves were calculated from Eq. (4).

The values adopted for the coefficients a_j and the standard error of estimates associated with the use of Eq. (5) are summarized in Table 4.

Figures 1, 2 and 3 show the experimental values of V^E, η^E and ΔG^{*E} as a function of the mole fraction of component 1, for the four systems, at 298.15 K. The continuous curves were calculated from Eq. (4), using the adopted values for the coefficients.

Figure 1 shows V^E values over the whole concentration range. The systems TCE + 2-BU and TCE + IAM show excess positive volumes, and the other two mixtures, TCE + 1-PR and TCE + 1-BU show sigmoid curves. Several effects may contribute to the values of V^E, such as breaking of liquid order on mixing, unfavorable interaction between groups, differences in molecular volumes and differences in free volumes between liquids components[5]. The first two effects produce a positive excess volume. The alcohols are liquids associated by hydrogen bonds and this association diminishes with longer hydrocarbon chain. The addition of TCE, which is a polar but not-associated liquid, reduces the number of intermolecular hydrogen bonds between the 1-PR and 1-BU molecules, with the result that V^E is less than 0. On the other hand, the addition of 1-PR and 1-BU to TCE produces positive V^E, which can be explained, following Prigogine[6], by a dipole–dipole interaction with intermolecular complex formation. This kind of curves has been observed by other authors[7].

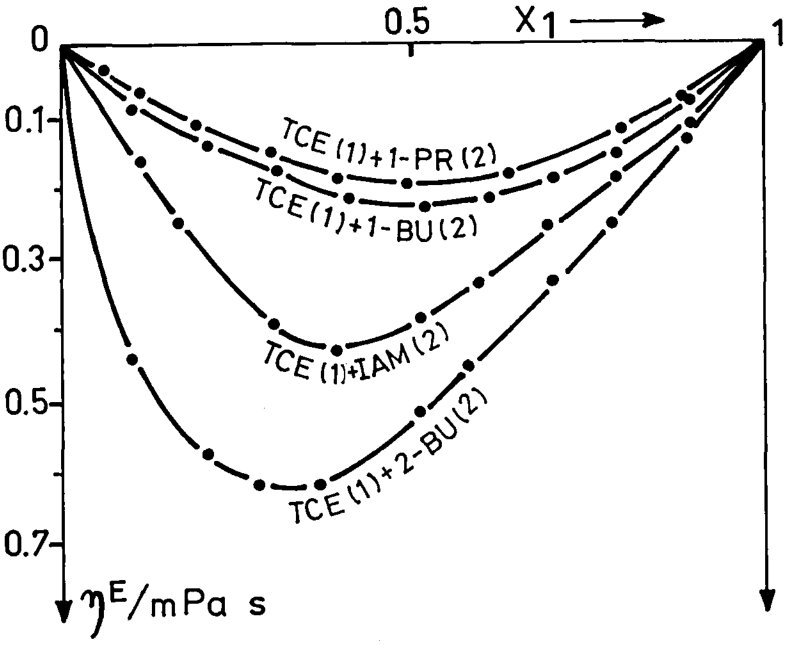

Figure 2 Excess viscosities for the 1,1,1-trichloroethane(1) + 1-propanol(2). 1,1,1-trichoroethane(1) + 1-butanol(2), 1,1,1-trichloroethane(1) + 2-butanol(2) and 1,1,1-trichloroethane(1) + 3-methyl-1-butanol(2) systems at 298.15 K. Continuous curves were calculated from Eq. (4).

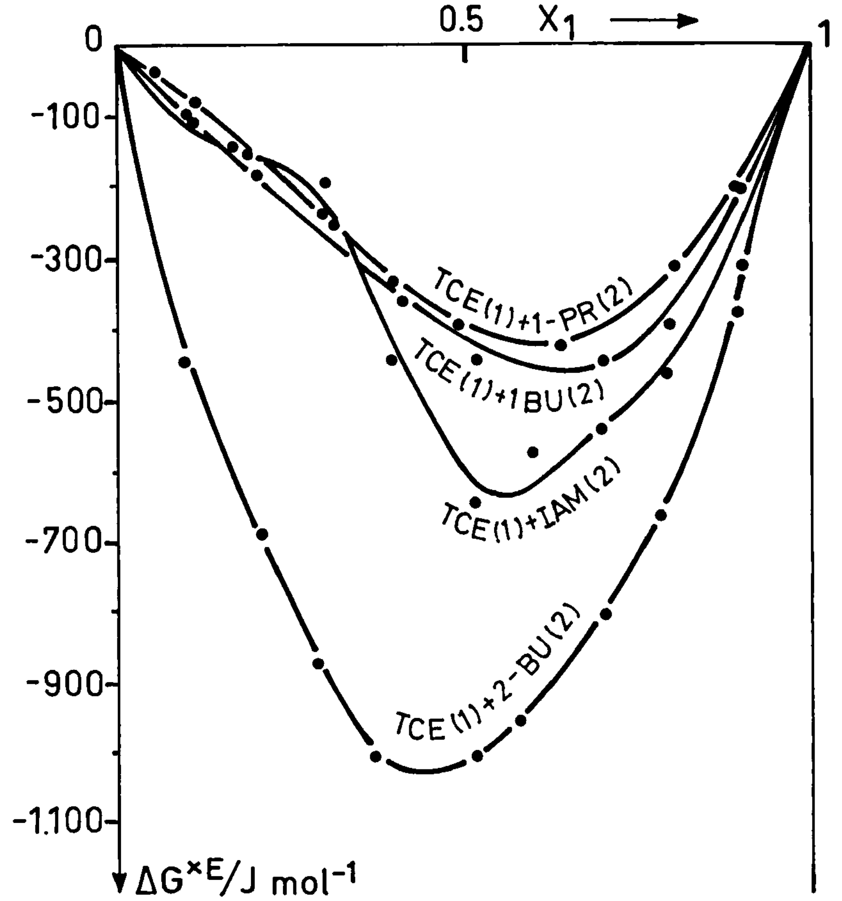

Figure 3. Excess molar energies of activation for viscous flow for the 1,1,1-trichloroethane(1) + 1-propanol(2), 1,1,1-trichloroethane(1) + 1-butanol(2), 1,1,1-trichloroethane(1) + 2-butanol(2) and 1,1,1-trichlorethane(1) + 3-methyl-1-butanol(2) systems at 298.15 K. Continuous curves were calculated from Eq. (4).

The excess positive V^E is greater for 2-BU than for IAM. The volume contraction with 1-PR and 1-BU implies specific interactions, and at approximately $x_1 = 0.630$ for TCE + 1-PR and at $x_1 = 0.500$ for TCE + 1-BU an inversion of sign is produced. We conclude that the primary contribution to the interaction effects for the last two systems reported here is a breakdown of the alcohol structure and consequently dispersion forces are dominant. In the other two systems with primary alcohols, an association by hydrogen bond of the type O—H···Cl is produced.

Ortega *et al.*[8] showed that V^E values are greater when alkanes are mixed with secondary or tertiary alcohols than when mixed with primary alcohols, as in this case.

Generally, positive V^E corresponds to negative η^E, as in this case, which means that dispersion forces are dominant, more negative at longer carbon chain. The effect is minor with secondary alcohols. Excess viscosities are smaller in the mixtures with 1-PR and 1-BU, as corroborated by the volume contraction.

According to Reed and Taylor[9] and Meyers *et al.*[10], the ΔG^{*E} parameter may be considered a reliable measure to detect the presence of interaction between molecules. Positive values of ΔG^{*E} can be observed in binary systems where specific interactions between molecules take place[11]. In our systems, ΔG^{*E} are negative, but for the TCE + 1-PR it is less negative than for the others; then, we conclude again that dispersion forces are dominant and little association occurs between TCE and 1-PR and 1-BU molecules.

Molar excess volumes can be calculated from the Prigogine–Flory–Patterson (PFP) theory[12]. The original PFP theory[15,16] includes three contributions in order to explain the thermodynamic behavior of liquid structure: an interactional contribution (ΔV_{int}) to V^E which is proportional to the interactional parameter X_{12}; the free volume contribution which arises from the dependence of the reduced volume upon the reduced temperature as a result of the difference between the degree of expansion for the two components (ΔV_F), and the internal pressure (ΔV_{P*}) which depends both on the difference of characteristic pressures and of the reduced volumes of the components. Some new effects not treated in this theory have been discussed for the case of mixtures of molecules of different shapes. The equation is:

$$\frac{V^E}{x_1 V_1^* + x_2 V_2^*} = \frac{(\tilde{V}^{1/3} - 1)\tilde{V}^{2/3}}{(4/3)\tilde{V}^{1/3} - 1}\psi_1\theta_2\frac{X_{12}}{P_1^*} - \frac{(\tilde{V}_1 - \tilde{V}_2)^2(\frac{14}{9}\tilde{V}^{-1/3} - 1)}{[(4/3)\tilde{V}^{-1/3} - 1]\tilde{V}}\psi_1\psi_2$$
$$+ \frac{(\tilde{V}_1 - \tilde{V}_2)(P_1^* - P_2^*)}{P_2^*\psi_1 + P_1^*\psi_2}\psi_1\psi_2 = \Delta V_{\text{int}} + \Delta V_F + \Delta V_{P*} \tag{6}$$

Here, the thermal expansion coefficient α_i is used to compute the reduced volume:

$$\tilde{V}_i = \left(\frac{1 + \frac{4}{3}\alpha_i T}{1 + \alpha_i T}\right)^3 \tag{7}$$

The characteristic volume $V_i^* = V_i/\tilde{V}_i$ and the characteristic pressure is:

$$P_i^* = T\tilde{V}_i^2\alpha_i/\kappa_i \tag{8}$$

where κ_i is the isothermal compressibility. The contact energy fraction is given by:

$$\psi_1 = 1 - \psi_2 = \frac{\phi_1 P_1^*}{\phi_1 P_1^* + \phi_2 P_2^*} \tag{9}$$

with the hard core volume fraction defined by:

$$\phi_1 = 1 - \phi_2 = \frac{x_1 V_1^*}{x_1 V_1^* + x_2 V_2^*} \tag{10}$$

The surface or site fraction is:

$$\theta_2 = 1 - \theta_1 = \frac{s_2\phi_2}{s_1\phi_1 + s_2\phi_2} \tag{11}$$

Table 5 Parameters for the pure liquids at 298.15 K.

Substance	$\alpha \times 10^4$ (K^{-1})	$\kappa \times 10^7$ (kPa^{-1})	$V \times 10^6$	$V^* \times 10^6$ $(m^3\ mol^{-1})$	$P^* \times 10^6$ $(J\ m^{-3})$	T^* (K)	$\tilde{V}$	$\tilde{T}$
1-PR	10.04[a]	10.76[b]	75.17	60.21	434	5220	1.2485	0.0571
1-BU	9.48[a]	9.42[a]	91.97	74.36	460	5390	1.2369	0.0553
2-BU	10.24[a]	9.96[c]	92.38	73.75	481	5167	1.2526	0.0577
IAM	9.2[a]	9.75[c]	109.10	88.62	426	5481	1.2311	0.0544
TCE	12.54[d]	11.08[c]	100.36	77.34	568	4651	1.2976	0.0641

[a] Ref. (4); [b] Ref. (13); [c] Ref. (14); [d] Calculated with density values.

where s_i is the molecular surface/volume ratio for the components:

$$s_1/s_2 = (V_2^*/V_1^*)^{1/3} \tag{12}$$

To solve Eq. (6), it is necessary to obtain values for the interaction parameter X_{12}, which is usually done using experimental values from excess enthalpy. For these systems, values of H^E are not available; thus, values of X_{12} were derived by fitting the theory to experimental values of V^E for each one of the four systems. The various parameters involved in Eq. (6) for the pure components (with subscript) and the mixture (without subscript) were obtained through the Flory theory[17], as showed in Table 5.

Table 6 gives the calculated equimolecular values of the three contributions to V^E according to Eq. (6), together with X_{12} values and the experimental and calculated V^E values.

An analysis of each of the three contributions to V^E shows that interactional contribution is negative for the first two systems and increases from TCE + 1-PR to TCE + IAM. In the first system, the free volume contributions ΔV_F are positive and smaller than in the other systems and the internal pressure ΔV_{P^*} contribution is positive in all cases and with the same values approximately. The total theoretical V^E values for $x_1 = 0.5$ are found to be in agreement with the experimental ones in the last two systems, but the PFP theory does not take into account the possible interaction which gives different values from the observed behavior and cannot explain the sigmoid curves.

There exist in the literature different equations that predict mixtures viscosities, like McAllister's equations, Teja and Rice method and Schrodt and Akel model.

Table 6 Experimental and theoretical molar excess volumes at 298.15 K.

System	$X_{12} \times 10^6$ $(J\ m^{-3})$	ΔV_{int}	ΔV_F	ΔV_{P^*}	$V^E_{exp} \times 10^6$ $(x_1 = 0.5;\ m^3\ mol^{-1})$	$V^E_{cal} \times 10^6$
TCE(1) + 1-PR(2)	−12.95	-2.68×10^{-3}	8.88×10^{-4}	3.30×10^{-3}	−0.022	−0.036
TCE(1) + 1-BU(2)	−3.66	-2.46×10^{-3}	1.31×10^{-3}	3.16×10^{-3}	−0.046	0.007
TCE(1) + 2-BU(2)	35.14	8.49×10^{-3}	1.89×10^{-3}	2.98×10^{-3}	0.724	0.556
TCE(1) + IAM(2)	6.78	1.31×10^{-3}	1.63×10^{-3}	4.77×10^{-3}	0.369	0.352

The McAllister correlation[18] is treated on a model proposed by Eyring, which considers that interaction occurs between three bodies:

$$\begin{aligned}\ln \nu = {} & x_1^3 \ln \nu_1 + x_2^3 \ln \nu_2 + 3x_1^3 \ln M_1 + x_2^3 \ln M_2 - \ln(x_1 M_1 + x_2 M_2) \\ & + 3x_1^2 x_2 \ln\left(2M_1 + \frac{M_2}{3}\right) + 3x_1 x_2^2 \ln\left(M_1 + \frac{2M_2}{3}\right) \\ & + 3x_1^2 x_2 x_2 \ln \nu_{12} + 3x_1 x_2^2 \ln \nu_{21} \qquad (13)\end{aligned}$$

where ν represents the kinematic viscosity (η/ρ) and ν_{12} and ν_{21} are two interaction parameters obtained by a computation program. Table 8 gives these values at 298.15 K with the percent error.

Teja and Rice[19] applied corresponding states theory to calculate mixtures viscosities. These authors proposed the relation:

$$\ln(\eta\xi) = \ln(\eta\xi)^{(r_1)} + \frac{\omega - \omega^{(r_1)}}{\omega^{(r_2)} - \omega^{(r_1)}} [\ln(\eta\xi)^{(r_2)} = \ln(\eta\xi)^{(r_1)}] \qquad (14)$$

where r_1 and r_2 refer to the properties of two reference fluids (in this case, the pure components) and ω is the acentric factor. For mixtures, the pseudo properties T_{cm}, V_{cm} and ω_m of an hypothetical substance replacing the pure fluids are defined as

$$T_{cm} V_{cm} = \sum_i \sum_j x_i x_j T_{cij} V_{cij} \qquad (15)$$

$$V_{cm} = \sum_i \sum_j x_i x_j V_{cij} \qquad (16)$$

$$\omega_m = \sum_i x_i \omega_i \qquad (17)$$

$$M_m = \sum_i x_i M_i \qquad (18)$$

$$T_{cij} V_{cij} = \psi_{ij} (T_{cii} V_{cii} T_{cjj} V_{cjj})^{1/2} \qquad (19)$$

$$V_{cij} = (V_{cii}^{1/3} + V_{cjj}^{1/3})^3/8 \qquad (20)$$

where ψ_{ij} is a binary interaction coefficient which must be evaluated from experimental data. The values of ξ from Eq. (14) is obtained as:

$$\ln(\eta\xi) = V_c^{2/3}/(T_c M) \qquad (21)$$

The two reference fluids contribution should be at the same reduced temperature of the mixtures. Using values of η from literature and our own values we calculate constants A and B from the equation:

$$\ln(\eta\xi) = A + B/T_R \qquad (22)$$

Next, values of $\ln(\eta\xi)^{(r_1)}$ and $\ln(\eta\xi)^{(r_2)}$ at the same T_R of the mixtures were calculated. Values of ψ are shown in Table 8 together with the average deviation in %.

Table 7 gives the parameters used to calculate viscosities.

Table 7 Parameters for the pure components at 298.15 K.

Substance	T_c/K	$V_c \times 10^6/m^3$	M	ω	T_R
1-PR	836.7[a]	218.5[a]	60.096[b]	0.624[a]	0.5555
1-BU	562.9[a]	274[a]	74.219[b]	0.590[a]	0.5297
2-BU	536[a]	268[a]	74.122[b]	0.578[a]	0.5563
IAM	579.5[a]	329[a]	88.149[b]	0.580[a]	0.5145
TCE	545[a]	283[a]	133.405[b]	0.216[a]	0.5471

[a] Ref. (21); [b] Ref. (4).

Following Schrodt and Akel[20] model, which is based upon Eyring's concept of fluid viscosity, for a pure component:

$$\eta = \frac{hN_A}{V} \exp(\Delta G^*/RT) \tag{23}$$

where h is Planck's constant, N_A is Avogadro's number, V is the molar volume and ΔG^* is the free energy of activation for viscous flow. For mixtures:

$$\eta_m = \frac{hN_A}{V_M} \exp\left[\left(\sum x_i \Delta G_i^*\right) + \frac{\Delta G^{*E}}{A} \Big/ RT\right] \tag{24}$$

where $V_m = (x_1 M_1 + x_2 M_2)/\rho$ is the molar volume of the solution and ΔG^{*E} is the excess free energy of activation and A an empirical factor (in this case = 1).

Note that for an ideal system:

$$\frac{x_i \Delta G_i^*}{RT} = \frac{x_1 \Delta G_1^* + x_2 \Delta G_2^*}{RT} = x_1 \ln \frac{\eta_1 V_1}{hN_A} + x_2 \ln \frac{\eta_2 V_2}{hN_A} = \sum x_i \ln \eta_i^0 \tag{25}$$

where:

$$\eta_i^0 = \frac{\eta_i V_i}{hN_A} \tag{26}$$

which is the dimensionless viscosity. The excess free energy of activation can be expressed in a similar form with the free energy of Gibbs in vapor–liquid equilibrium, by the following equation:

$$\frac{\Delta G^{*E}}{RT} = \sum x_i \ln \gamma_i^v \tag{27}$$

where γ_i^v is the viscosity activity coefficient to be distinguished from the activity coefficient of VLE. Then, expression (24) will be:

$$\ln \eta_m = \ln \frac{hN_A}{V_m} + \sum x_i \ln \eta_i^0 + \sum x_i \ln \gamma_i^v \tag{28}$$

With a set of binary viscosity data we find ΔG^{*E} values, and the viscosity activity coefficients are determined in this case from predictive equations like NRTL and related to $\Delta G^{*E}/RT$ as shown in Eq. (27). These viscosity coefficients in a binary solution should obey the Gibbs–Buhem relation, i.e., Eq. (29):

$$\frac{d\ln\gamma_i^v}{d\ln x_1} = \frac{d\ln\gamma_2^v}{d\ln x_2} \tag{29}$$

The parameters of NRTL equation are also given in Table 8. Next, we applied Eq. (28) to obtain mixtures viscosities and the average deviation in all cases (or percentual error) is defined by:

$$AD = \left[\frac{\sum \eta_{\exp} - \eta_{\mathrm{cal}})^2}{n}\right]^{1/2} \times 100 \tag{30}$$

and are shown in Table 8.

Table 8 Parameters from Eq. (13), (14) and (28). Average deviations and NRTL method constants.

System	*Eq. (13)*			*Eq. (14)*		*Eq. (28); $\alpha = 0.30$*		
	ν_{12}	ν_{21}	$\sigma\%$	ψ	$\sigma\%$	τ_{12}	τ_{21}	$\sigma\%$
TCE(1) + 1-PR-(2)	0.6291	0.2410	0.6	0.940	4.2	1.0478	−1.2584	2.1
TCE(1) + 1-BU(2)	0.2784	0.8025	1.0	0.950	5.3	1.1162	−1.3510	2.9
TCE(1) + 2-BU(2)	0.5045	0.2789	2.2	0.740	12.8	−1.1961	−0.2174	1.5
TCE(1) + IAM(2)	1.1024	0.2822	2.7	0.975	10.5	1.1991	−1.5654	3.8

An analysis of each of the three contributions to viscosity to our mixtures shows that McAllister's equations have the best agreement with experimental data.

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