



Density, viscosity, surface tension and spectroscopic studies for the liquid mixture of tetraethylene glycol + *N,N*-dimethylformamide at six temperatures

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ABSTRACT

Density (ρ), viscosity (η) and surface tension (γ) are always significant physicochemical properties for liquid mixtures. In this work, the ρ , η and γ data for the liquid mixture of tetraethylene glycol (T₄EG) + *N,N*-dimethylformamide (DMF) were systemically measured from 293.15 to 318.15 K with a step of 5 K and $p = 0.1$ MPa. From these physicochemical properties, viscosity deviation ($\Delta\eta$), excess molar volume (V_m^E), and surface tension deviation ($\Delta\gamma$) were calculated. Meanwhile, V_m^E , $\Delta\eta$ and $\Delta\gamma$ of activation functions were fitted with Redlich-Kister (R-K) equation to evaluate the coefficients and standard deviations. The η values of the liquid mixtures were fitted with Grunberg and Nissan equation and three-body McAllister expression. UV-vis and FTIR spectra were measured to discuss the intermolecular interaction of T₄EG with DMF, which indicated that there was hydrogen bonds interaction between hydroxyl hydrogen atoms in T₄EG and oxygen atoms in DMF.

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1. Introduction

Industrial plants have emitted a large number of sulfur dioxide (SO₂), which is a considerable source of atmospheric pollution and a menace of human health [1–3]. To eliminate the negative effect, the control or removal of SO₂ are necessary before SO₂ emission, and it has been compulsively put into practice in many countries [4]. Over the past decades, many works about SO₂ removal have been carried out, such as ammonia scrubbing, sodium citrate alkaline limestone and sodium humate scrubbing solution. However, these conventional procedures have the intrinsic drawbacks of secondary pollution and high complexity in industrial operation [2,5]. In recent years, alcohol and water liquid mixture showed not only strong desorption and absorption properties for SO₂, but also the perfect recyclable feature of solvents [6–11].

In the previous work [12], DMF showed a strong performance to dissolve SO₂ with 47.2 mol/m³ pure DMF at $\phi_{\text{SO}_2} = 5 \times 10^{-4}$. Additionally, ethylene glycol (EG) and diethylene glycol (DEG) were mixed with DMF and presented an attractive effect on the dissolving SO₂ [12,13]. Here, an

increasing polymerization degree of T₄EG was added into DMF to confirm the structure and interactions of ethylene glycol derivative (EGs) + DMF mixtures.

In this work, the ρ , η and γ data of DMF + T₄EG liquid mixture were measured over the whole concentration range at six temperatures from 293.15 to 318.15 K with the step of 5 K. The corresponding $\Delta\eta$, V_m^E and $\Delta\gamma$ values of liquid mixture were calculated. Moreover, the V_m^E , $\Delta\eta$ and $\Delta\gamma$ values of liquid mixture were fitted to the R-K equation to evaluate the coefficients and the standard deviations. Furthermore, Grunberg and Nissan and McAllister three body equations were fitted with the viscosities. Finally, FTIR and UV spectroscopic techniques were used to investigate the intermolecular interaction of T₄EG with DMF.

2. Experimental section

2.1. Materials

Analytical grade T₄EG (CAS No. 112-60-7) and DMF (CAS No. 68-12-2) were purchased from Shang Hai Aladdin Industrial Corporation (Aladdin) and Tianjin Beilian Reagent (TBR), respectively. Before measurements, these pure component reagents were kept over 0.4 nm molecular sieves. The HPLC grade ethanol was purchased from TBR. The specific gravity bottle and Ubbelohde type were calibrate by double

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Table 1
Specification of chemical samples.

Chemicals name	Origin ^b	Mass fraction purity	Molecular formula	Isolation method
Tetraethylene glycol	Aladdin industrial corporation., Co., Ltd., China	≥99.0%	C ₈ H ₁₈ O ₅	Desiccation ^c and degasification ^d
N,N-dimethylformamide	Tianjin Beilian Reagent Co., Ltd., China	≥99.5%	C ₃ H ₇ NO	Desiccation ^c and degasification ^d
Ethanol ^a	Tianjin guangfu Technology Development Co. Ltd., China	≥99.8%	C ₂ H ₆ O	Degasification ^d

^a Chromatographic grade.
^b Declared by the supplier.
^c Molecular sieve type 4A.
^d Ultrasound.

Table 2
Comparison of experimental and literature density and viscosity values of T₄EG and DMF at six temperatures.

T/K	DMF				T ₄ EG			
	$\rho/(\text{g}\cdot\text{cm}^{-3})$		$\eta/(\text{mPa}\cdot\text{s})$		$\rho/(\text{g}\cdot\text{cm}^{-3})$		$\eta/(\text{mPa}\cdot\text{s})$	
	Exp.	Lit.	Exp.	Lit.	Exp.	Lit.	Exp.	Lit.
293.15	0.9491	0.9481	0.855		1.1235	1.1239 [23] 1.1241 [26]	59.456	59.678 [26]
298.15	0.9445	0.9442 [14] 0.9439 [15]	0.820	0.8136 [19] 0.8135 [18]	1.1198	1.1211 [25] 1.1201 [26]	44.642	44.63 [23] 44.451 [25]
303.15	0.9399	0.9394 [16] 0.9395 [15]	0.768	0.7675 [19] 0.765 [20]	1.1163	1.1166 [24] 1.1161 [26]	35.476	35.923 [26] 34.97 [23]
308.15	0.9351	0.9344 [14] 0.9347 [16]	0.729	0.7217 [19] 0.711 [15]	1.1121	1.1126 [24] 1.1122 [25]	28.783	27.89 [24] 28.464 [26]
313.15	0.9302	0.9295 [17] 0.9292 [14]	0.687	0.673 [21] 0.679 [11]	1.1084	1.1087 [24] 1.1082 [26]	22.006	22.48 [24] 23.158 [26]
318.15	0.9251	0.9246 [17] 0.9248 [11]	0.652	0.635 [22] 0.636 [11]	1.1042	1.1045 [22] 1.1043 [21]	19.139	19.080 [26]

Table 3
Comparison of experimental and literature surface tension values of T₄EG and DMF at six temperatures.

T/K	DMF					T ₄ EG
	Lit.	298.15	303.15	308.15	313.15	318.15
		Exp.	36.55	36.02	35.45	34.76
$\gamma/(\text{mN}\cdot\text{m}^{-1})$		35.20 [28] 36.98 [27]	34.10 [28]	33.00 [28]	32.00 [28]	44.72 [24]

distilled water (conductivity $\leq 0.1 \text{ Ms cm}^{-1}$ at 298.15 K) and HPLC grade ethanol at each experiment temperature. Table 1 presented the specifications of all chemical samples.

2.2. Equipment and procedure

The measurement of mass was weighed via an electronic balance (Sartorius BS224S) having precision of $\pm 0.0001 \text{ g}$. The uncertainty in the mass fraction was less than ± 0.0001 .

Densities of samples were measured via a 25 cm^3 pycnometer. All samples were immersed into a water bath (precision: $\pm 0.01 \text{ K}$) for 20 min to keep a desired temperature. A commercial Ubbelohde viscometer was used to perform the determination of kinematic viscosity (ν) values. The Ubbelohde viscometer with sample were immersed into the same water bath for 20 min to get a constant temperature. At every temperature, the Ubbelohde viscometer was calibrated via

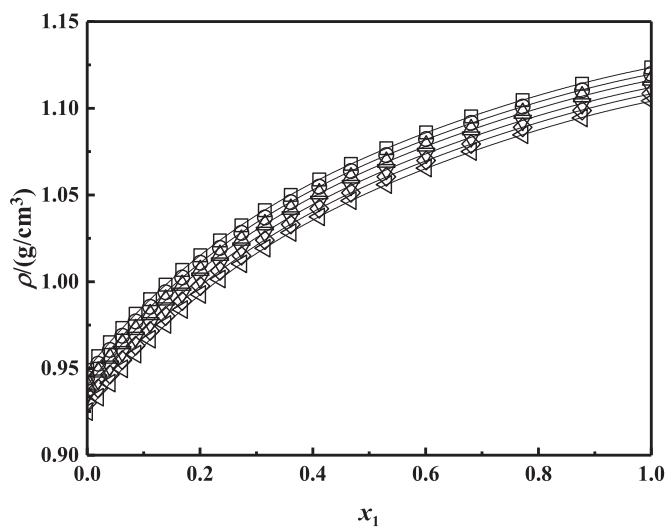


Fig. 1. Experimental density values with mole fraction for T₄EG (1) + DMF (2) liquid mixture at several temperatures: \square , 293.15 K; \circ , 298.15 K; \triangle , 303.15 K; ∇ , 308.15 K; \diamond , 313.15 K; and \triangleleft , 318.15 K. Solid line fitted by R-K equation.

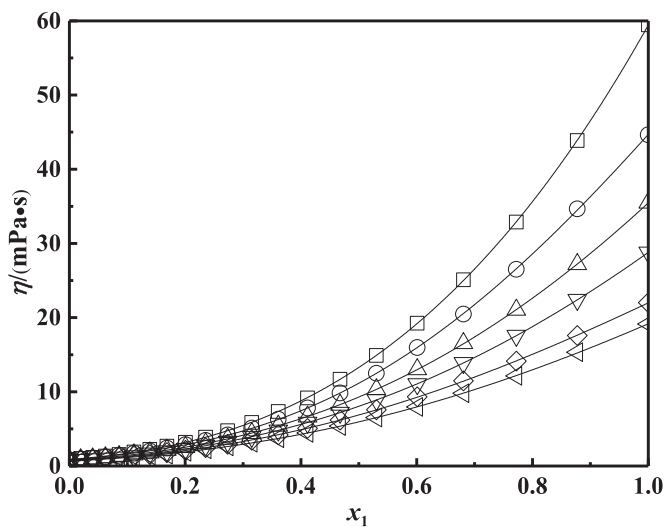


Fig. 2. Experimental viscosity values with mole fraction for T₄EG (1) + DMF (2) liquid mixture at several temperatures: \square , 293.15 K; \circ , 298.15 K; \triangle , 303.15 K; ∇ , 308.15 K; \diamond , 313.15 K; and \triangleleft , 318.15 K. Solid line fitted by R-K equation.

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