Viscometric behavior of binary mixtures of butan-2-one with benzene at $T = (303.15, 313.15, \text{ and } 323.15) \text{ K}$

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Abstract

Viscosities of binary liquid mixtures of butan-2-one with benzene were measured at a number of mole fractions at $T = (303.15, 313.15, \text{ and } 323.15)$ K and atmospheric pressure. The viscometric behavior is discussed on the basis of structural and geometrical effects between the components. In addition, kinematic viscosities were calculated by UNIFAC-VISCO model. The kinematic viscosities predicted are in good agreement with the experimental ones.

Keywords

Binary liquid mixture; Butan-2-one; Benzene; Viscosity; Atmospheric pressure; Kinematic viscosity; UNIFAC-VISCO model

1 Introduction

2 The nature of the interaction among polar and non-polar liquid mixtures is important to understand
3 their behavior in the analytical applications e.g. conductometric, potentiometric, and electroanalytical
4 techniques which work in mixed solvents, chromatographic applications, etc.¹⁻⁴ These data are also
5 useful in process engineering design applications and other related areas, and has drawn considerable
6 attention from many investigators.⁵⁻²⁰ In this work, which is a part of our research²¹⁻²⁶ on the
7 accumulation of the binary physical property data of organic liquid mixtures, we present here the data of
8 viscosity for the binary mixtures of butan-2-one with benzene at $T = (303.15, 313.15 \text{ and } 323.15) \text{ K}$.
9 The density data for the same system was reported earlier.²³

10 The aprotic and protophilic liquid butan-2-one (dipole moment, $\mu_1 = 2.8 \text{ D}$, relative permittivity at
11 20°C , $\epsilon^{20^\circ\text{C}} = 18.5$),²⁷ herein have been considered as the solute while apolar, aprotic, and nonprotophilic
12 liquid benzene ($\mu_1 = 0 \text{ D}$, $\epsilon^{20^\circ\text{C}} = 2.28$)²⁷ have been considered as the solvent. Both the liquids are widely
13 used as solvents in scientific studies and industrial applications. The experimental data have been
14 interpreted using some previous observations for the binary systems. In addition, kinematic viscosities
15 predicted by UNIFAC-VISCO model^{28, 29} are compared with the experimental ones.

16 In the literature, there are reports on the viscometric behavior of the binary systems of butan-2-one
17 with benzene at different temperatures other than those reported in this work³⁰⁻³⁶ except that from
18 Jayalakshmi and Reddy³⁷ at $T = 303.15 \text{ K}$. However, no experimental viscosity data are available at the
19 comparable conditions for butan-2-one with benzene at $T = (313.15 \text{ and } 323.15) \text{ K}$.

21 Experimental

22 Butan-2-one (E. Merck, 0.98 mass fraction purity) and benzene (BDH, 0.99 mass fraction purity)
23 were used without further treatment. The solvent purity was ascertained by comparing the densities and
24 viscosities of the liquids with the available literature data (Table 1).

25 All binary mixtures were prepared by mass on an analytical balance (B 204-S, Mettler Toledo,

Switzerland) with uncertainty of ± 0.0001 g and operating in a dry box. Mixtures were made just before use, and were completely miscible over the whole composition range. Caution was taken to prevent evaporation of the samples after preparation. The uncertainty of the mole fraction was estimated to be less than $\pm 1 \times 10^{-4}$. The densities of liquids were measured using a 25 mL specific gravity bottle, previously calibrated with redistilled water with an average uncertainty of $0.0002 \text{ g} \cdot \text{cm}^{-3}$. The uncertainties in viscosities were of the order of $\pm 0.005 \text{ mPa} \cdot \text{s}$. A-type Ostwald viscometer previously calibrated with redistilled water was used to measure viscosities. An electronic digital stopwatch with an uncertainty of $\pm 0.01 \text{ s}$ was used for flow time measurements. A transparent glass-walled thermostatic water bath was used, and the uncertainty in the temperature during the measurements was $\pm 0.05 \text{ K}$. For all mixture compositions and pure solvents, triplicate measurements were performed, and the average of these values was considered in all calculations.

Results and Discussion

The binary compositions and the experimental viscosities (η_{exp}) at all the investigated temperatures are summarized in Table 2. Viscosities, η_{exp} of the binary mixtures of butan-2-one and benzene as a function of the mole fraction of butan-2-one (x_1) at $T = (303.15, 313.15, \text{ and } 323.15) \text{ K}$ are shown in Figure 1. It can be observed that with the addition of butan-2-one to benzene the viscosity decreases slowly up to a substantial concentration of ketone. The viscosity of a mixture strongly depends on liquids structure and bond enthalpy, and consequently with molecular interactions between the components of the mixture.³⁸ The positive values of η_{exp} can be attributed to the dispersion type interaction between butan-2-one and benzene.³⁹ Butan-2-one, like all other linear ketones, has a stiff propanone skeleton and less inflexible than the other linear organic solvents.¹⁰ However, butan-2-one molecule has a light molecular structure compared to the other linear ketones. Therefore, at the low concentration region, butan-2-one molecule may be able to orient itself into a less flow-resistant arrangement due to the dispersion force created from the apolar organic solvent benzene resulting in

decreasing the viscosity. The inflexible nature of the butan-2-one becomes the major influencing force at the high concentration region. It is revealed from the viscosity values that the magnitude of positive η_{exp} decreases with the increase of temperature i.e., $(d\eta_{\text{exp}}/dT)_p$ are negative.

In Figure 2, kinematic viscosities predicted by UNIFAC-VISCO model are compared with the experimental ones. Experimental kinematic viscosities, ν_{exp} were calculated from experimental viscosities, η_{exp} (Table 2) and densities, ρ_{exp} that was obtained in our previous study²³, by the following equation:

$$\nu_{\text{exp}} (\text{m}^2 \cdot \text{s}^{-1}) = \frac{\eta_{\text{exp}} (\text{Pa} \cdot \text{s})}{\rho_{\text{exp}} (\text{kg} \cdot \text{m}^{-3})} \quad (1)$$

Note that the unit for the viscosities is changed in the calculations. As can be seen from the figure, the kinematic viscosities obtained by UNIFAC-VISCO model are in good agreement with the experimental ones. The relative errors, $E_{v,i}$ and the absolute average differences, AAD, are expressed by the following equations, and shown in Table 3:

$$E_{v,i} = \frac{\nu_{\text{exp},i} - \nu_{\text{cal},i}}{\nu_{\text{exp},i}} \times 100 \quad (2)$$

$$\text{AAD} = \frac{1}{N_p} \sum_i^{N_p} |E_{v,i}| \quad (3)$$

where i denotes the i -th experimental data and N_p is the number of the experimental data at each temperature. For all temperatures studied, the maximum errors are observed around 0.2 mole fraction of butan-2-one, but they are only about 2.0%. Therefore, the UNIFAC-VISCO model seems to have a sufficient predictability for the system at the temperature range studied.

Conclusions

Viscosities for the binary systems of butan-2-one with benzene were measured at several temperatures and for the whole composition range. A systematic change with the increasing temperature is observed

for η_{exp} . Interactions between the components in binary mixtures is used to interpret the observed viscometric behavior. Furthermore, the kinematic viscosities predicted by UNIFAC-VISCO model are in good agreement with the experimental ones.

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1 Table 1. Comparison of experimental densities, ρ_{exp} and viscosities, η_{exp} of pure liquids with literature
2 values at $T = 303.15$ K

Liquid (s)	$\rho_{\text{exp}} / \text{g}\cdot\text{cm}^{-3}$			$\eta_{\text{exp}} / \text{mPa}\cdot\text{s}$		
	Exp.	Lit.	Ref.	Exp.	Lit.	Ref.
Butan-2-one	0.7946	0.7946	⁴⁰	0.367	0.366	⁴⁰
		0.7948	⁴¹		0.372	⁴²
Benzene	0.8681	0.8683	⁴¹	0.564	0.562	⁴⁰
		0.8684	⁴³		0.560	⁴³

1 Table 2. Composition and experimental viscosities, η_{exp} for the binary mixtures of butan-2-one (1) with
2 benzene (2) at $T = (303.15, 313.15, \text{ and } 323.15) \text{ K}$

x_1	$T/\text{K} = 303.15$	$T/\text{K} = 313.15$	$T/\text{K} = 323.15$
	$\eta_{\text{exp}}/\text{mPa}\cdot\text{s}$	$\eta_{\text{exp}}/\text{mPa}\cdot\text{s}$	$\eta_{\text{exp}}/\text{mPa}\cdot\text{s}$
0	0.564	0.498	0.442
0.1010	0.534	0.473	0.422
0.1999	0.508	0.448	0.403
0.2988	0.478	0.427	0.384
0.3969	0.452	0.409	0.369
0.4996	0.432	0.393	0.354
0.5988	0.417	0.378	0.343
0.6993	0.401	0.367	0.333
0.7931	0.389	0.355	0.324
0.8961	0.376	0.345	0.316
1	0.367	0.334	0.306

1 Table 3. Comparison of the predicted kinematic viscosities by UNIFAC-VISCO model with the
2 experimental values

T/K	AAD/%	$ E_{v,i} _{\max}/\%$
303.15	1.21	2.4
313.15	0.64	1.7
323.15	0.70	2.1

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Figure 1. Experimental viscosities for the system butan-2-one (1) + benzene (2) at $T = (303.15, 313.15$ and $323.15)$ K

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2 Figure 2. Kinematic viscosities for the system butan-2-one (1) + benzene (2) at $T = (303.15, 313.15$ and
 3 $323.15)$ K

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