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# Densities, Viscosities, and Surface Tensions of the Trifluoroethanol + Quinoline System

**Ki-Sub Kim and Huen Lee***

Department of Chemical Engineering, Korea Advanced Institute of Science and Technology,
373-1 Kusung-dong, Yusung-gu, Taejon 305-701, South Korea

Densities, viscosities, and surface tensions of 2,2,2-trifluoroethanol (TFE) + quinoline were measured at various temperatures and concentrations. This system was chosen as it is a possible candidate for an organic working pair for an absorption heat pump. All results were correlated by a polynomial equation as a function of temperature and concentration, and the parameters of the regression equation were determined by a least-squares method. The average absolute deviations between the experimental and calculated values in the density, viscosity, and surface tension measurements were 0.12, 1.8, and 0.76%, respectively. The density values decreased with increasing temperature and quinoline mass fraction. As the temperature of the liquid mixture increased and the quinoline mass fraction decreased, the viscosity and surface tension values decreased.

## Introduction

Until now, $H_2O$ + LiBr and $NH_3$ + $H_2O$ have been the most widely used working pairs for absorption heat pump systems.[5] However, they still have some disadvantages, which are corrosion and solubility problems for $H_2O$ + LiBr and high working pressure and toxicity for $NH_3$ + $H_2O$.[1] The 2,2,2-trifluoroethanol and quinoline system was chosen as a new working pair to overcome the known problems of the $H_2O$ + LiBr and $NH_3$ + $H_2O$ systems.[5] 2,2,2-Trifluoroethanol acts as a refrigerant, and quinoline acts as an absorbent. The properties of 2,2,2-trifluoroethanol as one of fluoro alcohols are related to the hydrogen bonding properties of the alcohols. 2,2,2-Trifluoroethanol has the hydroxy group[5] available for interaction with a proton acceptor. Quinoline as the suitable absorbent is an electron donor that can achieve effective hydrogen bonds with a center of high electron density.[2] Therefore, 2,2,2-trifluoroethanol has good solubility in quinoline, and 2,2,2-trifluoroethanol can easily be separated from quinoline because of the considerable difference of boiling points (about 164 K) between 2,2,2-trifluoroethanol and quinoline.

To optimally design an absorption heat pump and decide whether the 2,2,2-trifluoroethanol + quinoline system is suitable as a new working pair for absorption heat transformers or not, several thermodynamic properties of the working fluid such as density, viscosity, surface tension, and vapor pressure are required. These properties were closely related to the performance of an absorption heat pump. In this study, the densities, viscosities, and surface tensions were measured over the temperature range (298.15 to 323.15) K and various mass fractions to provide the basic information for the potential use of the 2,2,2-trifluoroethanol + quinoline system. The measured values were correlated with simple polynomial equations.

## Experimental Section

***Materials.*** Quinoline (98%) and 2,2,2-trifluoroethanol (99+%) were supplied by Aldrich Chemical Co. and used without any further purification.

***Apparatus and Procedure. (i) Density Measurement.*** Two pycnometers were used for the density measurement. The equipment and procedure used for the density measurement were the same as those for our previous investigation.[7−9] The densities of the binary solution mixtures were calculated from the measured volume and mass values. To determine the volume of the pycnometers at various temperatures (298.15 to 323.15 K, at intervals of 5 K), calibration was carried out using triple-distilled water. The volumes of each pycnometer were reproducible within 0.2%. The solution temperature was controlled with an external bath circulator and measured with a thermometer within ±0.05 K.

***(ii) Viscosity Measurement.*** The viscosities of the binary mixture were measured with three appropriate Ubbelohde viscometers. The equipment and procedure used for the viscosity measurement were the same as those for our previous investigation.[7,9] A suitable viscometer was selected considering the viscosity values. The viscometer was put into a bath whose temperature was controlled with a bath circulator within ±0.05 K. The equilibrium time was about 15 min. The efflux time of the liquid solution through the capillary was measured manually with a stopwatch.

The dynamic viscosity values were calculated from

$$\eta = Kt\rho \tag{1}$$

where $\eta$ is the dynamic viscosity, $K$ the instrument constant, $t$ the efflux time, and $\rho$ the density of the sample.

***(iii) Surface Tension Measurement.*** The surface tensions of the binary system were measured by the plate (Wilhelmy) method using a dynamic contact angle analyzer (DCA) manufactured by Cahn Instruments. The plate was made of crystal clear−white glass with uniform surface quality, a precise squared edge, perfect flatness, and exact dimensions. Its size was 24 × 30 $mm^2$. The operation and analysis were automatically controlled by an external computer, which was connected to the DCA. To control the temperature of the sample within ±0.05 K, a bath circulator was used. The accuracy of the instrument is ±0.01 mN/m.

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* Corresponding author. E-mail: hlee@mail.kaist.ac.kr. Fax: 82-42-869-3910. Telephone: 82-42-869-3917.

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**Table 1. Measured Densities (ρ) for the 2,2,2-Trifluoroethanol (1 − *w*) + Quinoline (*w*) Mixtures**

| | $\rho$/kg·m$^{-3}$ at the following $T$/K | | | | | |
|---|---|---|---|---|---|---|
| $w$ | 298.15 | 303.15 | 308.15 | 313.15 | 318.15 | 323.15 |
| 0.00 | 1382 | 1374 | 1365 | 1357 | 1348 | 1338 |
| 0.10 | 1345 | 1337 | 1329 | 1321 | 1313 | 1305 |
| 0.20 | 1310 | 1303 | 1295 | 1288 | 1281 | 1273 |
| 0.30 | 1280 | 1274 | 1267 | 1260 | 1254 | 1246 |
| 0.40 | 1253 | 1247 | 1241 | 1234 | 1228 | 1222 |
| 0.50 | 1221 | 1215 | 1210 | 1204 | 1198 | 1193 |
| 0.60 | 1195 | 1190 | 1185 | 1180 | 1175 | 1169 |
| 0.70 | 1165 | 1159 | 1156 | 1151 | 1146 | 1141 |
| 0.80 | 1140 | 1136 | 1131 | 1127 | 1122 | 1118 |
| 0.90 | 1112 | 1108 | 1104 | 1099 | 1095 | 1091 |
| 1.00 | 1089 | 1085 | 1081 | 1077 | 1073 | 1070 |

**Table 2. Measured Viscosities (η) for the 2,2,2-Trifluoroethanol (1 − *w*) + Quinoline (*w*) Mixtures**

| | $\eta$/mPa·s at the following $T$/K | | | | | |
|---|---|---|---|---|---|---|
| $w$ | 298.15 | 303.15 | 308.15 | 313.15 | 318.15 | 323.15 |
| 0.00 | 1.73 | 1.53 | 1.35 | 1.21 | 1.09 | 0.98 |
| 0.20 | 2.34 | 2.05 | 1.84 | 1.62 | 1.46 | 1.32 |
| 0.40 | 2.91 | 2.57 | 2.27 | 2.04 | 1.83 | 1.65 |
| 0.60 | 3.14 | 2.79 | 2.46 | 2.21 | 2.00 | 1.82 |
| 0.80 | 3.17 | 2.80 | 2.49 | 2.25 | 2.05 | 1.87 |
| 1.00 | 3.36 | 3.01 | 2.68 | 2.43 | 2.21 | 2.03 |

***(iv) Experimental Verification.*** The experimental apparatus and procedure for the density and viscosity measurements were verified with pure water and 2,2,2-trifluoroethanol.

In the density measurement, the relative errors between the measured and literature values[4] of pure 2,2,2-trifluoroethanol were less than 0.06% in the temperature range from 298.15 K to 323.15 K. The reproducibility of the density measurements was within ±0.5%.

In the viscosity measurement, the relative errors were about 1.5% over the experimental temperature range from 298.15 K to 323.15 K. When two literature values[4,5] of pure 2,2,2-trifluoroethanol were compared, the difference was more than 3%. For a clear verification, the viscosities of water were measured from 298.15 K to 323.15 K. The experimental results were found to agree with the literature[3] within ±1%. The reproducibility of viscosity measurements was within ±1%.

For the surface tension measurement, the relative errors for pure water, ethanol, and methanol[3] were within 1% for temperatures from 298.15 K to 323.15 K. The reproducibility of surface tension measurements was within ±1%.

For each property measurement, the required accuracy of the experimental data was obtained for all the test experiments.

## Results and Discussion

***Density.*** Table 1 shows the density values of the binary liquid for temperatures from 298.15 K to 323.15 K and mass fractions of quinoline from 0 to 1. The density values decrease with increasing temperature and quinoline concentration.

All data were regressed by eq 2:

$$\rho/\mathrm{kg{\cdot}m^{-3}} = \left(\sum_{i=0}^{2}[(a_i + b_i T/\mathrm{K})w^i]\right) \times 1000 \qquad (2)$$

where $\rho$ is the density of the solution, $T$ is the absolute temperature, $a_i$ and $b_i$ are the regression parameters, and $w$ is the quinoline mass fraction. The regression parameters were determined by a least-squares method and listed in Table 4. The average absolute deviation (AAD) was 0.12% between the experimental and calculated values.

**Table 3. Measured Surface Tensions (σ) for the 2,2,2-Trifluoroethanol (1 − *w*) + Quinoline (*w*) Mixtures**

| | $\sigma$/mN·m$^{-1}$ at the following $T$/K | | | |
|---|---|---|---|---|
| $w$ | 293.15 | 303.15 | 313.15 | 323.15 |
| 0.00 | 21.11 | 20.31 | 19.44 | 18.58 |
| 0.20 | 24.78 | 23.07 | 21.87 | 20.86 |
| 0.40 | 28.62 | 26.98 | 25.84 | 25.00 |
| 0.60 | 32.57 | 31.53 | 30.56 | 29.34 |
| 0.80 | 37.23 | 36.02 | 35.07 | 33.77 |
| 1.00 | 43.27 | 42.10 | 41.05 | 39.84 |

**Table 4. Parameters for the Correlation of Eqs 2−4**

| | $a_i$ | $b_i$ | $c_i$ |
|---|---|---|---|
| | Density, Eq 2 | | |
| $i = 0$ | 1.902 | $-1.751 \times 10^{-3}$ | |
| $i = 1$ | $-7.931 \times 10^{-1}$ | $1.510 \times 10^{-3}$ | |
| $i = 2$ | $2.126 \times 10^{-1}$ | $-5.381 \times 10^{-4}$ | |
| AAD (%) | | 0.12 | |
| | Viscosity, Eq 3 | | |
| $i = 0$ | $5.804 \times 10^{1}$ | $-3.363 \times 10^{-1}$ | $4.941 \times 10^{-4}$ |
| $i = 1$ | $1.139 \times 10^{2}$ | $-6.325 \times 10^{-1}$ | $8.890 \times 10^{-4}$ |
| $i = 2$ | $-1.698 \times 10^{1}$ | $-3.132 \times 10^{-3}$ | $1.525 \times 10^{-4}$ |
| $i = 3$ | $-4.699 \times 10^{1}$ | $3.458 \times 10^{-1}$ | $-6.126 \times 10^{-4}$ |
| AAD (%) | | 1.8 | |
| | Surface Tension, Eq 4 | | |
| $i = 0$ | $4.940 \times 10^{1}$ | $-9.603 \times 10^{-2}$ | |
| $i = 1$ | $3.877 \times 10^{1}$ | $-8.238 \times 10^{-2}$ | |
| $i = 2$ | $-1.355 \times 10^{1}$ | $7.078 \times 10^{-2}$ | |
| AAD (%) | | 0.76 | |

***Viscosity.*** Table 2 shows the experimental and calculated viscosity values for temperatures from 298.15 K to 323.15 K and mass fractions of quinoline from 0 to 1. The viscosity values decrease as the temperature increases and the quinoline concentration decreases.

All data were regressed by eq 3. The regression parameters were listed in Table 4.

$$\eta/\mathrm{mPa{\cdot}s} = \sum_{i=0}^{3}[(a_i + b_i T/\mathrm{K} + c_i(T/\mathrm{K})^2)w^i] \qquad (3)$$

where $\eta$ is the viscosity of the solution, $T$ is the absolute temperature, $a_i$, $b_i$, and $c_i$ are the regression parameters, and $w$ is the quinoline concentration in mass fraction. The deviation between the experimental and calculated values was 1.8% in AAD%.

***Surface Tension.*** The experimental and calculated data of the 2,2,2-trifluoroethanol + quinoline system were presented in Table 3 for temperatures from 293.15 K to 323.15 K and mass fractions of quinoline from 0 to 1. The surface tension values decrease as the temperature increases and the quinoline concentration decreases.

A polynomial correlation for the surface tension of 2,2,2-trifluoroethanol + quinoline as a function of quinoline mass fraction ($w$) and temperature ($T$) was fitted to all data:

$$\sigma/\mathrm{mN{\cdot}m^{-1}} = \sum_{i=0}^{2}[(a_i + b_i T/\mathrm{K})w^i] \qquad (4)$$

where $\sigma$ is the surface tension of the binary mixture, $T$ is the absolute temperature, and $a_i$ and $b_i$ are the parameters given in Table 4. The deviation between the experimental and calculated values was 0.76% in AAD%.

## Conclusions

Densities, viscosities, and surface tensions of the 2,2,2-trifluoroethanol (refrigerant) + quinoline (absorbent) system were measured as basic physical properties to test the suitability of the working fluid for use in an absorption chiller. The experimental data were satisfactorily correlated with the simple polynomial functions of temperature and mass fraction. The average absolute deviations for the density, viscosity, and surface tension were 0.12%, 1.8%, and 0.76%, respectively. The density, viscosity, and surface tension measurements together with the vapor pressure and VLE data of the working fluid are essential to design an absorption heat pump.

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