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Measurements of the surface tension for R290, R600a and R290/R600a mixture

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Abstract

The surface tensions of R290, R600a and R290/R600a mixture have been measured by the modified differential capillary-rise method. Twenty-two data points for R290 and 21 data points for R600a were obtained in the temperature range between 273 K and 354 K, and 43 data points for R290/R600a mixture on three isotherms of 278 K, 300 K and 320 K were obtained. The experimental uncertainties of temperature and surface tension are estimated to be within 20 mK and 0.2 mN m^{-1}, respectively. Surface tension correlations as a function of temperature for pure R290 and R600a were formulated in the temperature range between 253 K and critical temperature, and the correlation as a function of the composition for R290/R600a mixture was discussed at 278 K, 300 K and 320 K. It is found that the surface tension for R290/R600a mixture can be reproduced by the simple mixing rule by mole fraction with the correlations of both pure components.

Keywords: Refrigerant; Propane; R290; Isobutane; R600a; Binary mixture; Measurement; Surface tension

R290, R600A et un mélange de R290 et de R600a : mesures de la tension superficielle

Mots clés : Frigorigène ; Propane ; R290 ; Isobutane ; R600a ; Mélange binaire ; Mesure ; Tension superficielle

1. Introduction

Because of the low ozone-depletion potentials and low global-warming potentials, hydrocarbons and their mixture have been increasingly recognized as the working fluid in air-conditioning and heat-pump systems. Not only the pure substances of R290 (propane: C_3H_8) and R600a (isobutane: i-C_4H_{10}) but also their mixture have been expected as the alternative refrigerant of CFCs and HCFCs.

The surface tension, which is one of important thermophysical properties of fluids, is required for the heat transfer analyses with boiling and condensation states. Although the experimental data and the correlation of the surface tension are necessary to design the air-conditioning and heat-pump systems, their available data for R290 and R600a are very

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Nomenclature

a^2	capillary constant (m^2)
g	gravitational acceleration ($m\,s^{-2}$)
h	rise height in the capillary (m)
n	adjustable parameter
P	pressure (Pa)
r	inner radius of the capillary (m)
T	temperature (K)
T_c	critical temperature (K)
w	mass fraction ($kg\,kg^{-1}$)
x	mole fraction ($mol\,mol^{-1}$)
θ	contact angle (rad)
ρ	saturated density ($kg\,m^{-3}$)
σ	surface tension ($N\,m^{-1}$)
σ_0	adjustable parameter ($N\,m^{-1}$)

Subscripts

1	first capillary
2	second capillary
cal	calculation value
m	measurement value
R290	R290
R600a	R600a

Superscripts

$'$	liquid phase
$''$	vapor phase

restricted. Baidakov and Sulla [1] and Lin and Duan [2] measured the surface tension for R290 and R600a with a differential capillary-rise method. The data by Baidakov and Sulla exist in the temperature range from 273 K to 365 K for R290 and from 273 K to 404 K for R600a. Unfortunately, there is no description of the sample purity in their paper. The data by Lin and Duan exist in the temperature range from 253 K to 334 K for R290 and R600a. Their sample purity was reported better than 99.9% of mass fraction. However, there is no data for R290/R600a mixture. In the present study, the surface tension measurements for R290, R600a and R290/R600a mixture were conducted in the temperatures from 273 K to 354 K. And their correlations were also formulated by the simple mixing rule.

2. Apparatus

In our laboratory, the surface tension measurements had been made for the most of halogenated hydrocarbon refrigerants (CFCs, HCFCs, and HFCs) by the differential capillary-rise method [3–5]. In the present work, the apparatus is modified to measure the surface tension for mixtures as shown in Fig. 1. Two glass capillaries are placed vertically in a pressure vessel composed of a thick-walled Pyrex glass tube (17 mm in inner diameter and 25 mm in outer diameter). Four kinds of capillaries were prepared for the present measurement. Their inner radii of capillaries determined by means of a mercury thread are 0.4204 ± 0.0019 mm, 1.0141 ± 0.0013 mm, 0.2754 ± 0.0003 mm and 0.7526 ± 0.0009 mm. The traveling microscope is used to measure the location of the bottom of the meniscus in each capillary through the window of the thermostat. Measured values of the location of the meniscus were corrected by the Rayleigh's equation [6] as follows:

$$h = h_m + \frac{r}{3} - 0.1288\,\frac{r^2}{h_m} + 0.1312\,\frac{r^3}{h_m^2} \qquad (1)$$

The corrected values were used for the difference of rise heights in the capillaries. The surface tension is determined by the following relation:

$$\sigma = \frac{g(\rho' - \rho'')(h_1 - h_2)}{2(1/r_1 - 1/r_2)\cos\theta} \qquad (2)$$

where the local gravitational acceleration g at Iwaki, Japan is $9.8002\ m\,s^{-2}$. The contact angle θ is assumed to be zero since the inner walls of the capillary were carefully washed by ultrasonic cleaner. The capillary-rise height measurements were performed under the condition of a receding contact angle. The pressure vessel was installed in the thermostat whose temperature was kept constant to be within ±5 mK. Water was used as a heat transfer medium in this

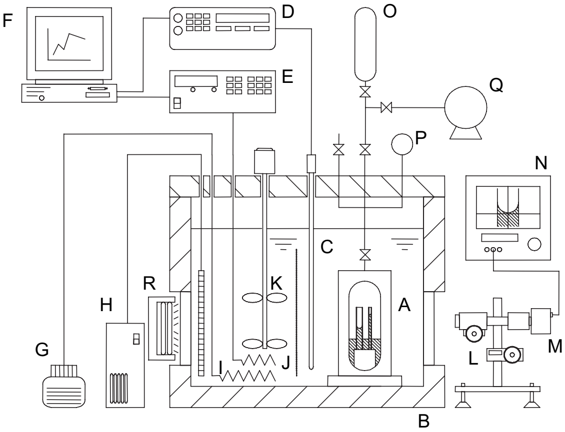

Fig. 1. Schematic diagram of the experimental apparatus: A, pressure vessel; B, thermostat; C, platinum resistance thermometer (100 Ω); D, precise thermometer bridge; E, power supply; F, computer; G, voltage transformer; H, cooler; I, main heater (1 kW); J, sub heater (500 W); K, stirrer; L, traveling microscope; M, CCD camera; N, monitor; O, sample bottle; P, pressure gauge; Q, vacuum pump; and R, illumination lamp.