Surface Tension of Difluoromethane

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The surface tension of difluoromethane has been measured using the differential capillary rise method over the temperature range of 267.95–334.27 K. The purity of the difluoromethane sample used in the experiment is 99.95 wt %. A surface tension correlation has also been proposed.

Introduction

To meet the restriction of the Montreal protocol, we must look for a hydrofluorocarbon (HFC) whose ozone depletion potential (ODP) value is zero to replace chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC). The binary and/or ternary mixtures using difluoromethane (HFC-32) as a component are thought to be the most promising alternatives for HCFC-22. Unfortunately reliable thermophysical property data for HFC-32 are limited. In particular, there are no published surface tension data for HFC-32.

Surface tension is an important thermophysical property of fluids, especially with respect to the heat transfer through a heat exchanging surface with bubbles or fluid drops on it. In this work, the surface tension data for HFC-32 were measured with a differential capillary rise method in the temperature range from 267.95 to 344.27 K. The results are compared with some predicted values. A van der Waals-type surface tension correlation for HFC-32 is proposed.

Experimental Apparatus

The apparatus used here has been described by Zhu et al. (*1*) and is shown in Figure 1.

The inner radii of the capillaries were determined by partially filling the capillaries with mercury slugs of different mass. For each mass, the slug was moved along the capillary tube. The length of the slug at different positions was measured by a traveling microscope with an accuracy of ±1 μm. The mass of the mercury slug was determined by a precision electrical balance accurate to ±0.1 mg. Combining the length and mass of the slug, we calculated the average radius at each position. From the results corresponding to different mercury slugs, a consistent set of values was developed for each capillary radius. The inner radii of the capillaries were represented as a function of distance in the longitudinal direction from one end of the capillary. The average bore radii of the capillaries in our apparatus are $r_1 = 0.499 \pm 0.002$ mm, $r_2 = 0.390 \pm 0.001$ mm, and $r_3 = 0.259 \pm 0.001$ mm. Before each measurement, the sample cell was carefully washed and the capillaries were sealed in the cell vertically. The temperature of the cell was controlled by a thermostated water bath in the range from 303.15 to 334.27 K and by a glycol fluid bath in the range of 293.15–267.95 K. The temperature uncertainty was ±0.02 K.

The capillary rise was observed through the crystal glass window on the sample cell by means of a telescope, with a cross hair, fixed on a movable coordinate frame. The differential capillary rise between two capillaries was sensed by a height transducer on the telescope and shown on a digital readout. The accuracy of the capillary rise measurement equipment was ±1 μm.

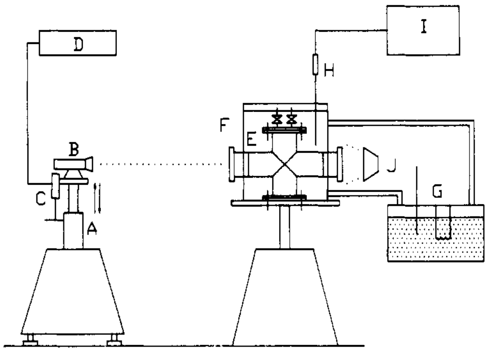

Figure 1. Surface tension experimental apparatus: (A) movable coordinate frame; (B) optical level instrument; (C) accurate displacement sensor; (D) digital readout; (E) experimental cell; (F) water bath; (G) temperature-controlled bath; (H) thermometer; (I) data accumulator; (J) light source.

Results

To eliminate the error for measuring the location of the bulk meniscus in the sample cell, the differential capillary rise method was used to deal with the experimental data. From Rayleigh et al. (*2*), the surface tension as a function of the capillary rise was determined as follows:

$$\sigma = \frac{(\rho_l - \rho_v)g}{2} r \left[h - h_0 + \frac{r}{3} - 0.1288\frac{r^2}{h - h_0} + 0.1312\frac{r^3}{(h - h_0)} \right] \quad (1)$$

Here, r is the radius of the capillary tube, $h - h_0$ is the capillary rise, ρ_l and ρ_v are densities of the liquid and vapor, respectively, and g is the acceleration due to gravity. In eq 1, ρ_l was calculated from the saturated liquid density correlation proposed by Widiatmo et al. (*3*), and ρ_v was calculated from the saturated vapor pressure correlation and the Martin–Hou equation of state proposed by Singh et al. (*4*). The equations are as follows:

$$\rho_l/\rho_c = 1 + B_1(1 - T/T_c)^{b_1} + B_2(1 - T/T_c)^{b_2} \quad (2)$$

Here, T is the temperature (K), $T_c = 351.28$ K is the critical temperature, $\rho_c = 424$ kg·m^{-3} is the critical density, and B_1, B_2, b_1, and b_2 are constants.

$$\ln(P) = A + B/T + CT + DT^2 \quad (3)$$

$$P = \frac{RT}{(v - b)} + \sum_{i=2}^{5} \frac{A_i + B_iT + C_i \exp(-KT_r)}{(v - b)^i} \quad (4)$$

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Table 1. Experimental Differential Capillary Rise and Surface Tension of HFC-32 with Predicted Data[a]

			$\sigma/(\mathrm{mN{\cdot}m^{-1}})$			
	$(h - h)$/mm		measured			
T/K	caps. 3, 2	caps. 3, 1	caps. 3, 2	caps. 3, 1	av	predicted
267.95	2.994	4.246	11.828	11.653	11.741	11.399
273.85	2.751	3.920	10.610	10.501	10.555	10.542
278.85	2.598	3.714	9.804	9.733	9.769	9.818
283.65	2.525	3.560	9.320	9.123	9.222	9.126
288.35	2.299	3.253	8.282	8.133	8.207	8.452
295.50	2.122	2.976	7.344	7.144	7.244	7.433
300.34	1.874	2.669	6.283	6.206	6.244	6.748
305.07	1.755	2.392	5.692	5.372	5.532	6.082
310.27		2.168		4.669	4.669	5.356
314.95	1.408	2.051	4.197	4.236	4.216	4.707
320.10	1.258	1.845	3.552	3.608	3.580	4.000
325.05	1.007	1.425	2.664	2.602	2.633	3.327
334.27	0.822	1.176	1.862	1.834	1.848	2.097

[a] Caps. = capillaries.

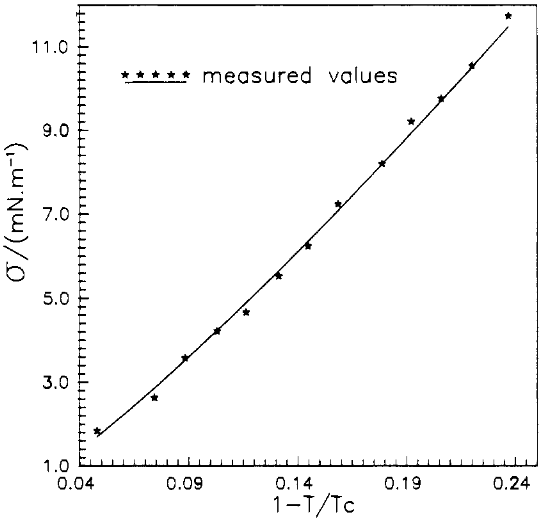

Figure 2. Temperature and surface tension relation of HFC-32.

The coefficients and units of the parameters, in eqs 3 and 4, are reported in ref 4.

Using the differential capillary rise method, the height of the bulk meniscus, h_0, is eliminated numerically by combining the calculated surface tension from eq 1 corresponding to two different capillaries. Therefore, using three capillaries, two sets of HFC-32 surface tension results are obtained, as reported in Table 1. The predicted surface tension values using a corresponding state correlation proposed by Hakim et al. (*5*) are also listed in Table 1. Table 1 shows that the two sets of experiments are consistent with each other, and agree satisfactorily with the predicted values.

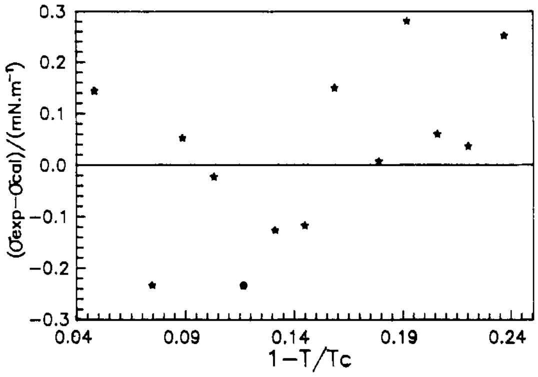

Figure 3. Absolute deviation of the experimental data from eq 5.

A van der Waals-type surface tension correlation

$$\sigma = \sigma_0(1 - T/T_c)^n \qquad (5)$$

was used to correlate the experimental data. In eq 5, σ_0 and n are constant and T_c is the critical temperature. From our data, $\sigma_0 = 64.6837\ \mathrm{mN{\cdot}m^{-1}}$ and $n = 1.20109$.

Figure 2 illustrates the relation between the reduced temperature and the surface tension. Figure 3 shows the absolute deviation of experimental data from eq 5.

Conclusion

The surface tension of HFC-32 was measured in the temperature range from 267.95 to 334.27 K. The results and a surface tension correlation are presented. Most of the measured data fit the correlation with relative deviations of less than 3%. The measured data and predicted data are consistent.

Acknowledgment

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Literature Cited

(1) Zhu, M. S.; Han, L. Z.; Lu, C. X. *Fluid Phase Equilib.* **1993**, *86*, 363–367.
(2) Rayleigh, O. M. *Proc. R. Soc. London, Ser. A* **1916**, *92*, 184.
(3) Widiatmo, J. V.; Sato, H.; Watanabe, K. *Proc. 3rd Asian Thermophys. Prop. Conf.* **1992**, 364–369.
(4) Singh, R. R.; Lund, E. A. E.; Shankland, I. R. *Proc. Int. CFC Halon Alternatives Conf.* **1991**, 451–459.
(5) Hakim, D. I.; Steinberg, D.; Stiel, L. I. *Ind. Eng. Chem. Fundam.* **1971**, *10*, 174.

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