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Surface Tension of Dimethyl Ether from (213 to 368) K

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The surface tension of dimethyl ether has been measured with a differential capillary rise technique. Thirty-two experimental data points have been obtained in the temperature range from (213 to 368) K. The uncertainty of temperature is less than ±10 mK (ITS-90). The uncertainty of surface tension measurements was estimated to be less than ±0.2 $mN\cdot m^{-1}$. The results were correlated as a function of temperature.

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1. Introduction

As a chemical raw material, dimethyl ether plays an important role in the synthesis of many chemicals. At the same time, it is often used as a propellant gas, assistant solvent, fuel additive, and liquefied petroleum gas substitute.[1] Also, it can be used as a refrigerant and vesicant. Especially in recent research of clean alternative fuels,[2,3] it has been discovered that dimethyl ether and its mixtures are possible alternatives for diesel oil in the future. Hence, the thermophysical property data of dimethyl ether are important. In the research of the character of fuel spray and heat transfer through a heat-exchanging surface, the surface tension data are indispensable, but there are few data on the surface tension of dimethyl ether. This paper presents the surface tension data of dimethyl ether for temperatures ranging from (213 to 368) K along the saturation line.

2. Experimental Section

The surface tension is measured with the differential capillary rise method (DCRM), well-known as one of the most accurate methods. During the experiment, the capillary rise difference Δh_0 is measured, and the surface tension σ is determined by the following relation:

$$\sigma = \frac{(\rho_l - \rho_g)g}{2(1/r_1 - 1/r_2)}(\Delta h_0 + r_1/3 - r_2/3) \qquad (1)$$

where σ is the surface tension, ρ_l and ρ_g are the densities of saturated liquid and vapor, respectively, g is the local gravitational acceleration (this work, $g = 9.7965\ m\cdot s^{-2}$), Δh_0 is height difference of the meniscus bottom of the two capillaries,[4] and r_1 and r_2 are the radii of two different capillaries used in the experiment, respectively. Equation 1 is based on the assumption that the liquid−glass contact angle is zero. From direct observation, the capillary wall is completely wetted by the dimethyl ether, and the assumption is trustable. In general, the capillary constant a^2 is defined in order to learn the accuracy of the apparatus itself.

$$a^2 = \frac{\Delta h_0 + r_1/3 - r_2/3}{1/r_1 - 1/r_2} \qquad (2)$$

The bore radii of the two capillaries used in this work are $r_1 = (0.22697 \pm 0.0004)$ mm and $r_2 = (0.32920 \pm 0.0003)$ mm. Their radii were determined by partially filling the capillaries with plugs of mercury. The plugs were weighed, and their lengths were measured with a traveling microscope. The procedure was repeated at least six times for each capillary with different plugs of mercury.

The capillaries were placed in a small pressure cell with observation windows; the cell was filled with dimethyl ether and evacuated several times before the final filling; and the pressure cell was placed in a thermostat bath with the maximum temperature stability of the thermostat bath less than ±10 mK in 2 h. Alcohol and silicon oil were chosen as the working medium, which depends on the temperature range.[5,6] The temperature was measured with a standard platinum resistance thermometer and thermometry bridge F18 (ASL); the total uncertainty of temperature is less than ±1 mK. The total uncertainty of temperature for surface tension is less than ±10 mK on the ITS-90 scale. The capillary rise difference was measured with a cathetometer, and the uncertainty is ±0.02 mm. In this work, the maximum uncertainty of surface tension is less than ±0.2 $mN\cdot m^{-1}$.

Zhongshan Fine Chemical Co. Ltd provided the sample of dimethyl ether. Their analysis with gas chromatography indicated the mass purity of the dimethyl ether is better than 99.95%. So, no further purification was used in this experiment.

3. Result and Analysis

The surface tension of liquid dimethyl ether was measured along the saturation line from (213 to 368) K. The experimental data are listed in Table 1. The saturated liquid and gas densities of dimethyl ether were cited from ref 6. At each temperature, the capillary rise difference is measured at least three times.

The capillary constants a^2 were fitted to the functional form[7]

$$a^2 = a_0{}^2\tau^{0.935}(1 + a_1\tau) \qquad (3)$$

where τ is the reduced temperature $(T_c - T)/T_c$ and the

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Table 1. Measurements of Surface Tension of Dimethyl Ether

T/K	ρ_l/kg·m^{-3}	ρ_g/kg·m^{-3}	Δh_0/mm	a^2/mm^2	σ/mN·m^{-1}
213.118	781.331	0.513	8.81	6.4118	24.523
223.106	768.423	0.830	8.39	6.1048	22.953
228.187	761.774	1.046	8.21	5.9732	22.258
233.308	755.010	1.312	7.98	5.8076	21.440
238.152	748.549	1.613	7.79	5.6711	20.749
243.118	741.855	1.979	7.51	5.4665	19.811
248.120	735.037	2.415	7.39	5.3788	19.302
253.095	728.173	2.924	7.17	5.2180	18.537
258.110	721.163	3.522	6.93	5.0377	17.709
263.124	714.057	4.216	6.72	4.8867	16.991
268.081	706.928	5.003	6.51	4.7307	16.265
273.077	699.630	5.910	6.25	4.5407	15.429
278.058	692.232	6.935	5.99	4.3507	14.604
283.071	684.652	8.101	5.80	4.2142	13.966
288.042	676.992	9.399	5.54	4.0242	13.159
293.094	669.048	10.875	5.41	3.9268	12.659
298.085	661.028	12.501	5.09	3.6929	11.731
303.197	652.620	14.357	4.85	3.5175	10.997
308.123	644.315	16.343	4.58	3.3226	10.220
313.117	635.673	18.580	4.36	3.1618	9.557
318.180	626.658	21.106	4.23	3.0643	9.089
323.178	617.483	23.892	4.00	2.8986	8.428
328.142	608.068	26.993	3.71	2.6843	7.640
333.143	598.241	30.510	3.50	2.5332	7.045
338.091	588.140	34.445	3.25	2.3480	6.368
343.135	577.400	38.981	3.00	2.1677	5.717
348.069	566.401	43.952	2.79	2.0118	5.148
353.109	554.578	49.469	2.49	1.7926	4.435
358.106	542.166	55.004	2.29	1.6513	3.940
363.103	528.931	62.675	2.02	1.4515	3.315
368.041	514.861	70.285	1.78	1.2761	2.779

critical temperature $T_c = 400.378$ K was used in this work; a_0^2 and a_1 are the fitted parameters. The exponent 0.935 was taken from the theoretical analysis and is believed to be asymptotically correct near T_c. On the basis of the present results, the values of a_0^2 and a_1 have been determined. a_0^2 and a_1 are 13.564 18 mm^2 and -0.0761, respectively. The measured values of the capillary constant a_0^2 and the fitted curves are shown in Figure 1, and the deviations are shown in Figure 2. As can be seen in Figures 1 and 2, eq 3 fits the data within the precision of the measurements, and the maximum deviation is 1.67%.

The surface tension is normally correlated as a function of temperature by a van der Waals-type correlation

$$\sigma = \sigma_0\left(1 - \frac{T}{T_c}\right)^n \tag{4}$$

where σ_0 and n are fitted parameters. With the measurements of this work, σ_0 and n are determined and the values are 62.401 mN·m^{-1} and 1.223, respectively. The value of the constant n is very close to the theoretical value $^{11}/_9$, which is deduced from the $^1/_3$ principle of classic density theory. The average absolute and maximum deviations of eq 4 are 0.092 mN·m^{-1} and 0.19 mN·m^{-1}.

Also, the surface tension of dimethyl ether was correlated as the following equation[8]

$$\sigma = a(1 - T/T_c)^{5/4} + b(1 - T/T_c)^{9/4} + c(1 - T/T_c)^{13/4} \tag{5}$$

where a, b, and c are fitted parameters. In this work, the parameters a, b, and c were determined to be 65.380 mN·m^{-1}, 1.486 mN·m^{-1}, and -12.290 mN·m^{-1}, respectively. The average absolute deviation of eq 5 is 0.071 mN·m^{-1}.

We have learned from the critical review of surface tension data[9] that only Maass and Boomer[10] have measured the surface tension of pure dimethyl ether at temperatures from (231 to 263) K before 1972. Recently, ref 11 provides the surface tension of dimethyl ether from (131 to 139) K.

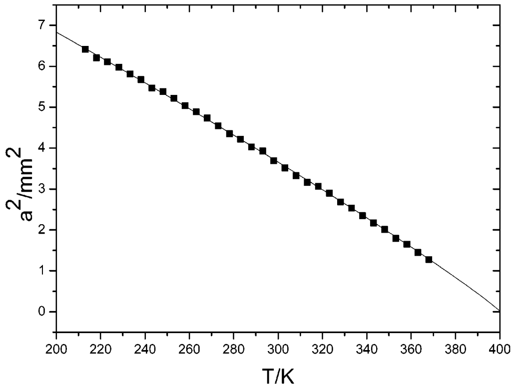

Figure 1. Relation between temperature and capillary constant.

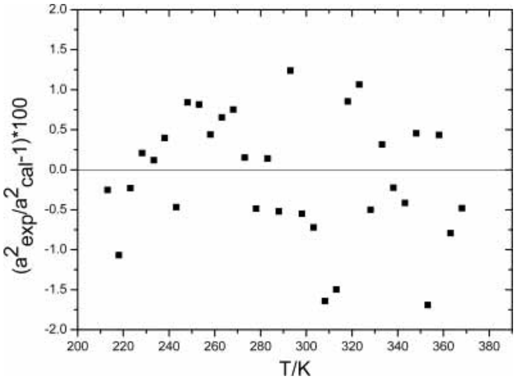

Figure 2. Deviation of capillary constant from the fit to eq 3.

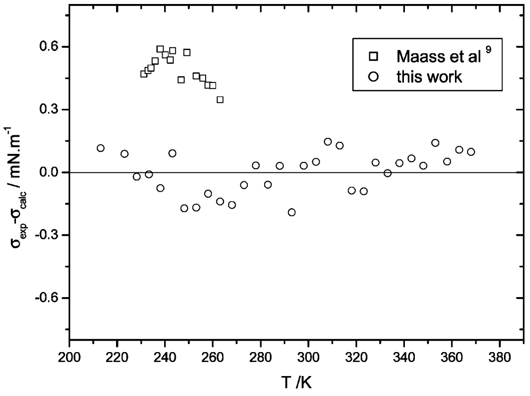

Figure 3. Comparison of the surface tension of dimethyl ether.

In this work, we have compared the deviations of these data. Compared to ref 10, with a temperature range from (231 to 263) K, the average absolute and maximum deviations of eq 4 are 0.490 mN·m^{-1} and 0.581 mN·m^{-1}. The details are shown in Figure 3. Compared to ref 11, with a temperature range from (131 to 139) K, the average absolute deviations of eqs 4 and 5 are 1.414 mN·m^{-1} and 0.144 mN·m^{-1}, respectively. So, eq 5 is much better than eq 4 in extrapolation.

4. Conclusion

The surface tension of dimethyl ether was measured over a wide temperature range from (213 to 368) K using the differential capillary rise method. The uncertainty of surface tension measurements is estimated to be within ±0.2 mN·m^{-1}. On the basis of the present results, a correlation of surface tension has been proposed. The capillary constant and its correlation were also presented.

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