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Articles

Surface Tension of 2,2-Dimethylbutane from (233 to 378) K

Wanli Gao, Xiaoming Zhao,* and Zhigang Liu

State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China

The surface tension of 2,2-dimethylbutane was measured at temperatures from (233 to 378) K with a differential capillary rise method, together with the surface tension of heptane measured at temperatures from (303 to 358) K for verifying the experimental apparatus. The uncertainty of temperature is less than ± 10 mK. The uncertainty for surface tension was estimated to be within ± 0.2 $\text{mN}\cdot\text{m}^{-1}$. The surface tension results were correlated as a function of temperature with an average absolute deviation of 0.049 $\text{mN}\cdot\text{m}^{-1}$ for 2,2-dimethylbutane.

Introduction

2,2-Dimethylbutane ($(CH_3)_3CCH_2CH_3$) as a fuel additive can provide great improvement in aviation gasoline and motor gasoline combustion properties. It is regarded to be a good fuel additive and a potential alternative fuel in the future. It is also used for organic synthesis. For these applications, the thermophysical property data of 2,2-dimethylbutane is important. This article presents the surface tension of 2,2-dimethylbutane at temperatures ranging from (233 to 378) K along the saturation line.

To verify the reliability of the apparatus, the surface tension of heptane was measured at temperatures from (303 to 353) K.

Experimental Section

Materials. 2,2-Dimethylbutane was obtained from Alfa Aesar Company with a mole fraction purity of 99 %. Heptane was obtained from Xi'an FULI Chemical Company with a mass fraction purity of 99.9 %.

Apparatus and Procedure. The differential capillary rise method was used for the surface tension measurement. The experimental apparatus and procedure have been described in detail in previous work[1,2] and are only briefly described here. During the experiment, the capillary rise difference, Δh_0, was measured, and the surface tension can be calculated using the following expression

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

where σ is the surface tension; g is the local gravitational acceleration (this work, $g = 9.7965\ \text{m}\cdot\text{s}^{-2}$); and ρ_L and ρ_g are the densities of saturated liquid and vapor, respectively. Δh_0 is the height difference of the meniscus bottom of the two capillaries. r_1 and r_2 are the radii of two different capillaries used in the experiment. The capillary constant, a^2, is defined generally 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 inner radii of two capillaries used in this work are $r_1 = (0.2236 \pm 0.0012)$ mm and $r_2 = (0.3820 \pm 0.0.0011)$ mm. The capillaries were placed in a small pressure cell with observation windows, and the pressure cell was placed in a thermostat bath with the maximum temperature stability of the thermostat bath within ± 5 mK for 15 min. Alcohol and silicon oil were chosen to be the working medium depending on the temperature range.[1,3] The temperature measurement system consists of an ASL F18 thermometry bridge and two 25 Ω standard platinum resistance thermometers (Beijing Const Technology) and a 100 Ω reference resistance. One thermometer (no. 68033) was used from (83.8058 to 273.16) K, and another (no. 68115) was used from (273.15 to 933.473) K. The thermometers were calibrated at the National Institute of Metrology of China. The total standard uncertainty of temperature was better than ± 1.0 mK. The total uncertainty of temperature for surface tension measurement was less than ± 10 mK. The capillary rise difference was measured with a cathetometer with an uncertainty of ± 0.02 mm. In this work, the maximum uncertainty of surface tension was estimated to be within ± 0.2 $\text{mN}\cdot\text{m}^{-1}$.

Results and Discussion

Heptane. To check the apparatus, the surface tension of heptane was measured. Ten measurements of surface tension

Table 1. Experimental Surface Tension of Heptane

	ρ_l	ρ_g	Δh	a^2	σ
T/K	$\text{kg}\cdot\text{m}^{-3}$	$\text{kg}\cdot\text{m}^{-3}$	mm	mm^2	$\text{mN}\cdot\text{m}^{-1}$
303.489	670.72	0.1235	10.78	5.7841	19.46
313.132	661.36	0.1663	10.24	5.493	18.24
318.493	656.28	0.1962	10.21	5.0185	17.7
323.153	651.94	0.2265	9.78	5.4768	17.19
328.125	647.40	0.2640	9.70	5.0292	16.58
333.126	642.90	0.3081	9.36	5.2449	16.23
338.136	638.49	0.3596	9.38	4.7704	15.81
343.125	634.18	0.4194	8.90	5.2018	15.24
348.126	629.93	0.4894	8.93	4.7866	14.85
358.120	621.66	0.6659	8.53	4.5709	13.99

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* To whom correspondence should be addressed. E-mail: xmzhao@mail.xjtu.edu.cn. Tel: 86-29-82666875. Fax: 86-29-82668789.

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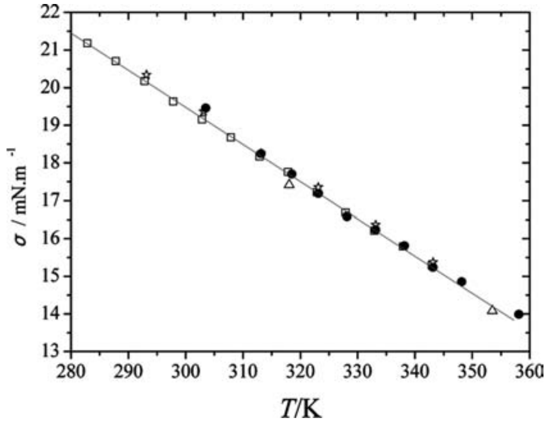

Figure 1. Surface tension of heptane: ●, this work (solid line, linear fit of eq 3); □, Kahl;[8] △, Grigoryev;[9] ☆, Aguila-Hernández.[10]

Table 2. Experimental Surface Tension of 2,2-Dimethylbutane

T/K	ρ_l / kg·m^{-3}	ρ_g / kg·m^{-3}	Δh / mm	a^2 / mm^2	σ / mN·m^{-1}
233.085	701.36	0.003	12.18	6.539	22.46
238.102	697.22	0.006	12.02	6.453	22.04
243.135	693.02	0.009	11.75	6.307	21.41
248.108	688.84	0.014	11.58	6.216	20.97
253.116	684.60	0.022	11.30	6.065	20.34
258.125	680.31	0.031	11.06	5.935	19.78
263.127	675.99	0.043	10.87	5.833	19.31
268.102	671.65	0.059	10.63	5.703	18.76
273.099	667.25	0.078	10.45	5.606	18.32
278.081	662.82	0.102	10.22	5.482	17.80
283.090	658.32	0.132	9.95	5.337	17.21
288.173	653.71	0.169	9.72	5.213	16.69
293.124	649.16	0.213	9.52	5.105	16.23
298.095	644.54	0.268	9.28	4.975	15.70
303.174	639.77	0.336	9.01	4.830	15.13
308.126	635.06	0.417	8.70	4.663	14.49
313.125	630.25	0.518	8.53	4.571	14.10
318.126	625.37	0.643	8.29	4.442	13.59
323.135	620.42	0.796	8.12	4.350	13.20
328.125	647.40	0.264	9.70	5.202	16.58
328.125	615.42	0.985	7.82	4.188	12.61
333.126	642.90	0.308	9.40	5.019	16.23
333.130	610.33	1.218	7.60	4.070	12.14
338.132	605.18	1.506	7.42	3.972	11.75
343.132	599.94	1.862	7.18	3.843	11.26
348.126	594.63	2.301	6.88	3.681	10.68
353.126	589.22	2.844	6.68	3.573	10.26
358.124	583.71	3.514	6.44	3.444	9.79
363.128	578.11	4.341	6.17	3.298	9.27
368.124	572.40	5.360	5.98	3.196	8.88
373.128	566.57	6.617	5.81	3.104	8.51
378.234	560.50	8.203	5.54	2.959	8.00

were made in the temperature range from (303 to 353) K. The values are listed in Table 1. The saturated liquid densities of heptane are from refs 4 and 5. The gas densities were calculated from the RKS equation of state, where the critical temperature T_c, the critical pressure p_c, and the Pitzer acentric factor, ω, were 540.26 K, 2736 kPa, and 0.351, respectively.[6] The ten experimental values of surface tension were compared with available reference values in Figure 1. The solid line in Figure 1 shows the linear fit of surface tension versus temperature according to eq 3.[7] More sophisticated models that include the critical temperature were not applied because our experimentally covered temperature range is far below the critical range. The linear equation is the following

$$\sigma = (49.06330 - 0.0986)T/\text{mN}\cdot\text{m}^{-1} \tag{3}$$

Table 3. Surface Tension, σ, of 2,2-Dimethylbutane at 298.15 K

T/K	σ / mN·m^{-1}	ref
298.095	15.70	this work
298.15	15.81	Riddick, J. A.[12]
298.15	16.06	Kozlowska, M. K.[13]

The results from eq 3 were compared with literature data. The average deviation and maximum deviation are 0.083 mN·m^{-1} and 0.28 mN·m^{-1} or 0.47 % and 1.62 %, respectively.

2,2-Dimethylbutane. The surface tension of liquid 2,2-dimethylbutane was measured along the saturation line from (233 to 378) K. The experimental values are listed in Table 2. The saturated liquid densities of 2,2-dimethylbutane were calculated according to the function from ref 6. The gas densities were calculated from the RKS equation of state, where the critical temperature, T_c, the critical pressure, p_c, the critical density, ρ_c, and the acentric factor, ω, were 488.78 K, 3081 kPa, 2787.2 mol·m^{-3}, and 0.234, respectively.[6] Every value of the surface tension, the temperature, and the capillary rise difference were measured thrice.

The capillary constant a^2 was fitted to the functional form[11]

$$a^2 = a_0^2\tau^{0.935}(1 + a_1\tau) \tag{4}$$

where τ is the reduced temperature $(T_c - T)/T_c$. The exponent 0.935 was taken from the theoretical analysis[11] and was believed to be asymptotically correct near T_c. On the basis of the present results, $a_0{}^2$ and a_1 were fitted to give the values 11.76467 mm^2 for $a_0{}^2$ and 0.04265 for a_1.

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

$$\sigma = \sigma_0\left(1 - \frac{T}{T_c}\right)^n \tag{5}$$

where σ_0 and n are the fitted parameters. From the measurements reported, σ_0 and n are determined to be 50.44231 mN·m^{-1} and 1.24303, respectively. The average and relative maximum deviations of eq 5 from experimental values are 0.34 % and 0.98 %.

There were only two published values of surface tension of liquid 2,2-dimethylbutane in previous literature, as shown in Table 3. The deviations of eq 5 from refs 12 and 13 at 298.15 K are −0.16 mN·m^{-1} and −0.41 mN·m^{-1}.

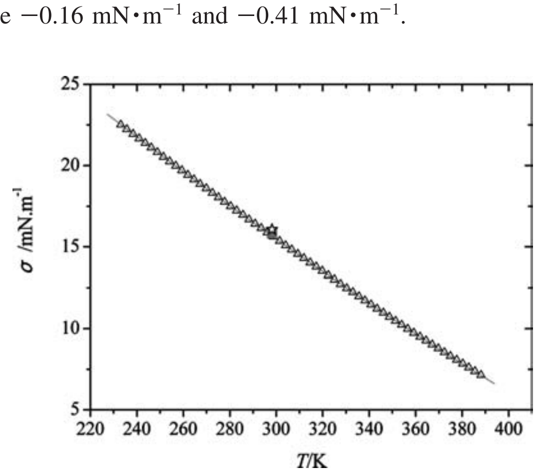

Figure 2. Surface tension of 2,2-dimethylbutane: △, this work (solid line, linear fit of eq 5); ■, Riddick;[12] ☆, Kozlowska.[13]

Conclusions

The surface tension of 2,2-dimethylbutane was measured over a temperature range from (233 to 378) K. For heptane, measurements were made from (303 to 358) K using the differential capillary rise method. The uncertainty of the surface tension measurements was estimated to be within ± 0.2 $\mathrm{mN \cdot m^{-1}}$. On the basis of the present results, the equations for the surface tension for 2,2-dimethylbutane as a function of temperature have been proposed. The capillary constant and its correlation were also presented.

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