Vapor Pressure Measurements of Ethyl Fluoride

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The vapor pressures of ethyl fluoride (HFC-161) were measured at temperatures from (235.69 to 372.14) K and corresponding pressures from (0.1015 to 4.7139) MPa. The maximum uncertainties in the present work were estimated to be ± 1.5 kPa for pressure and ± 6 mK for temperature. The 110 experimental data points taken for the vapor pressure were fitted with a Wagner-type equation. The new vapor pressure equation of ethyl fluoride was also compared with available literature data. The purity of the HFC-161 sample used in the present measurements was 99.74 mass %.

Introduction

The Montreal Protocol establishes schedules for phasing out the manufacture of chlorine-containing refrigerants, chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC), which have been implicated in stratospheric ozone depletion. Ethyl fluoride (HFC-161), which is chlorine-free and a low global warming potential, could be considered as an alternative refrigerant. Xuan has proposed a new ternary mixture of HFC-161, HFC-125, and HFC-32 as a promising candidate to replace HCFC-22.[1]

Information about vapor pressure is important to qualify potential candidates as working fluids in refrigeration machinery. It is also very useful in calculating the thermodynamic properties necessary for the design of that machinery. The thermodynamic properties of ethyl fluoride (HFC-161) and its experimental data are scarce in the literature. Most of these results were obtained before the 1940s. Also, there is a large discrepancy between the vapor pressure of pure ethyl fluoride reported in various sources.[2−5] The basic thermodynamic properties of HFC-161 are given briefly in Table 1.

The present study aims to provide highly reliable vapor pressure of ethyl fluoride (HFC-161) at a wide range of temperature and pressure. A description of the apparatus and the comparison with earlier available data are also given in this paper.

Experimental Section

Chemicals. The sample of the ethyl fluoride (HFC-161), provided by Zhejiang Chemical Industry Research Institute, has a purity of 99.74 mass % with the principal impurities of ethylene and isobutane. It was used without further purification.

Apparatus and Procedure. The apparatus used in this work, shown schematically in Figure 1, includes a sample cell, a high-accuracy thermostatic bath, a pressure measurement system, a temperature measurement system, and a vacuum system.

The temperature in the thermostatic bath can be varied from (230.15 to 453.15) K. The bath fluid is alcohol, distilled water, or silicon oil depending on the temperature range. Its temperature fluctuations are less than ±3 mK in 2 h.

Table 1. Basic Thermodynamic Properties of HFC-161

formula	C_2H_5F
molecular weight	48.06
T_c/K	375.31[a]
P_c/MPa	5.02775[a]
T_{boil}/K	235.45[b]

[a] Booth and Swinehart.[2] [b] Grosse.[3]

The temperature measurements are made with a four-lead 25-Ω platinum resistance thermometer (Yunnan Instrument) with an uncertainty of ± 2 mK (ITS-90) and a Keithley 2010 data acquisition/switch unit with an uncertainty of less than ± 1 mK. The overall temperature uncertainty is ± 6 mK. We programmed temperature measurement control software on the basis of an incremental digital PID algorithm. The temperature of the thermostatic bath can be measured and controlled by a personal computer, which controls the heater's input power through a silicon-controlled on/off switch.

The pressure measurement system includes a pressure transducer (Davidson Measurement Pty Ltd., Druck PMP 4070), a diaphragm differential pressure detector (Xi'an Instrument, 1151DP), an oil-piston type dead-weight pressure gauge (Xi'an Instrument, YS-60), and an atmospheric pressure gauge (Ningbo Instrument, DYM-1). A sensitive differential pressure detector separates the sample from the N_2-filled system. The accuracy of the detector is 0.1 % within the range from (0 to 100) kPa. Its maximum uncertainty is 0.1 kPa. The accuracy of the oil-piston type dead-weight pressure gauge is less than 0.02 % within the range from (0.1 to 6.0) MPa, and its maximum uncertainty is 1.2 kPa. The accuracy of the pressure transducer is 0.04 %, and its maximum allowable pressure is 6.0 MPa, which was calibrated by the oil-piston type dead-weight pressure gauge before the experiments. The maximum uncertainty of the mercury atmosphere gauge is ± 50 Pa. The whole pressure measurement system has an uncertainty of ± 1.5 kPa.

The sample cell is a heavy-walled isochoric metal vessel (about 141 cm^3 in its inner volume), made of 1Cr18Ni9Ti stainless steel. Before the experiment, the sample cell was rinsed with acetone to remove any residue from the previous experiment and vacuum pumped to about 6.7 × 10^{-2} Pa.

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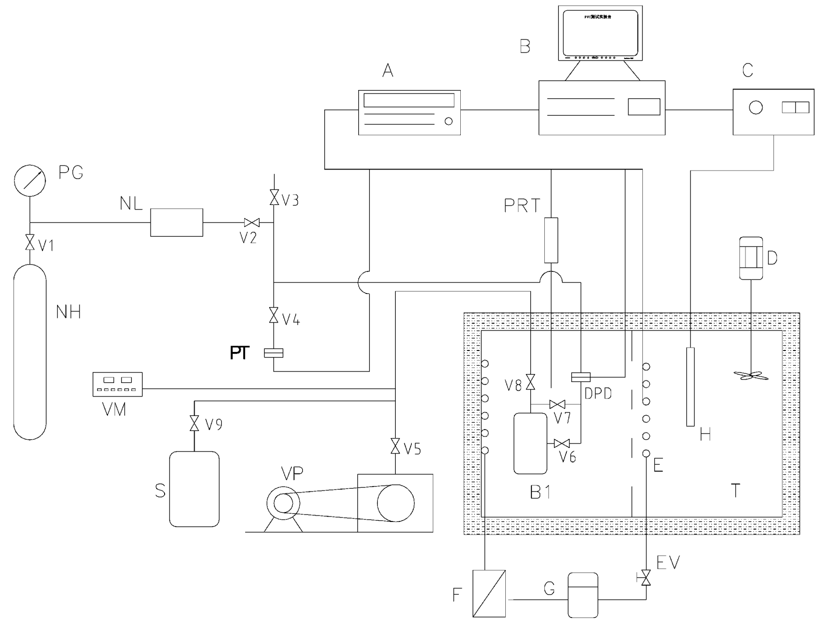

Figure 1. Experimental apparatus: A, Keithley 2010 data acquisition/switch unit; B, personal computer; B1, sample cell; C, silicon-controlled switch; D, stirrer; DPD, differential pressure detector; E, evaporator; EV, expansion valve; F, condenser; G, compressor; H, heater; NH, nitrogen gas; NL, pressure damper; PT, pressure transducer; PRT, platinum resistance thermometer; PG, pressure gage; S, sample bottle; T, thermostatic bath; VM, vacuum gauge; VP, vacuum pump; V1 to V9, valves.

Table 2. Experimental Vapor Pressures of HFC-161

T/K	P/MPa	T/K	P/MPa	T/K	P/MPa	T/K	P/MPa	T/K	P/MPa
235.69	0.1015	263.12	0.3095	287.13	0.6751	328.13	1.9389	352.15	3.2180
235.74	0.1017	264.11	0.3207	288.13	0.6952	330.15	2.0270	353.14	3.2820
235.79	0.1019	265.10	0.3324	290.14	0.7375	332.15	2.1193	354.15	3.3476
235.84	0.1022	266.12	0.3445	292.01	0.7779	333.15	2.1674	355.15	3.4142
235.89	0.1024	267.13	0.3566	294.03	0.8242	334.16	2.2151	356.15	3.4812
235.94	0.1026	268.13	0.3691	296.04	0.8718	335.15	2.2639	357.14	3.5495
236.00	0.1029	269.13	0.3820	298.07	0.9219	336.15	2.3132	358.14	3.6191
236.09	0.1034	270.13	0.3953	300.05	0.9729	337.15	2.3632	359.14	3.6891
237.11	0.1083	271.13	0.4088	302.00	1.0249	338.16	2.4145	360.15	3.7613
238.07	0.1133	272.15	0.4229	304.03	1.0814	339.15	2.4658	361.15	3.8340
240.11	0.1241	273.12	0.4367	306.12	1.1419	340.16	2.5185	362.16	3.9080
242.12	0.1354	274.11	0.4512	308.08	1.2009	341.15	2.5720	363.14	3.9822
244.10	0.1476	275.11	0.4660	310.32	1.2706	342.15	2.6263	364.14	4.0584
245.09	0.1538	276.14	0.4818	312.19	1.3305	343.15	2.6817	364.15	4.0602
247.09	0.1671	277.14	0.4975	314.18	1.3981	344.14	2.7374	365.14	4.1380
249.10	0.1815	278.17	0.5139	316.32	1.4728	345.15	2.7943	366.15	4.2168
251.07	0.1963	279.14	0.5299	316.33	1.4736	346.15	2.8522	367.15	4.2958
253.11	0.2127	280.13	0.5466	318.17	1.5398	347.15	2.9108	368.16	4.3768
255.11	0.2297	281.13	0.5639	320.14	1.6132	348.15	2.9707	369.14	4.4601
257.13	0.2478	282.16	0.5819	322.13	1.6902	349.15	3.0308	370.14	4.5435
259.11	0.2676	283.14	0.5996	324.12	1.7702	350.15	3.0922	371.14	4.6276
261.11	0.2880	285.18	0.6365	326.11	1.8522	351.15	3.1545	372.14	4.7139

After filling the sample cell, the thermostat bath temperature was controlled to the experimental temperature. Once thermal equilibrium between the sample and the heat transfer fluid in the bath was established and the pressure remained constant, the temperature and the pressure of the sample were recorded.

The vapor pressures of chlorodifluoromethane (HCFC-22) with a purity of 99.99 mass % have been measured at temperatures from (243.15 to 363.15) K. The maximum and average absolute pressure deviations of our experimental data from data calculated from REFPROP[6] are 0.339 % and 0.137 %, respectively.

Results and Discussion

In this study, vapor pressures of ethyl fluoride (HFC-161) were measured at temperatures from (235.69 to 372.14) K to obtain the 110 data points listed in Table 2. On the basis of the present vapor pressure measurements, a Wagner-type vapor equation[7] of ethyl fluoride was fitted:

$$\ln(P/P_c) = (A_1\tau + A_2\tau^{1.25} + A_3\tau^3 + A_4\tau^7)T_c/T \qquad (1)$$

where $\tau = 1 - T/T_c$, $T_c = 375.31$ K is the critical temperature, and $P_c = 5.02775$ MPa is the critical pressure of ethyl fluoride. The parameters A_1, A_2, A_3, and A_4 in eq1 are −7.771716, 1.988635, −2.634753, and −1.646982, respectively.

The equation fits our experimental data to within an average absolute pressure deviation of 0.066 % and a maximum deviation of 0.343 %. Figures 2 and 3 show the deviations of the available literature data from eq 1. The maximum and average absolute pressure deviations of eq 1 from Vidaurri[4] are 1.146 % and 0.368 %, respectively, and 4.816 % and 1.114 % for the results of Booth and Swinehart.[2] Our reported vapor pressure equation closely reproduces the present vapor pressures from (0.1013 to

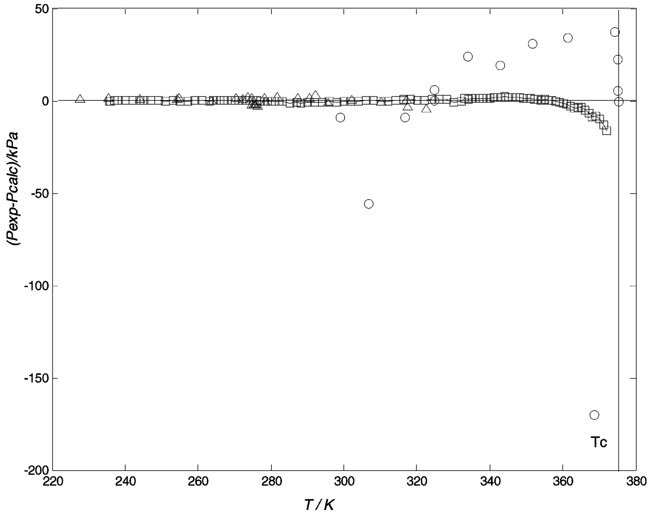

Figure 2. Absolute deviation of the vapor pressure for HFC-161 from eq 1: □, this work; △, Vidaurri;[4] ○, Booth and Swinehart.[2]

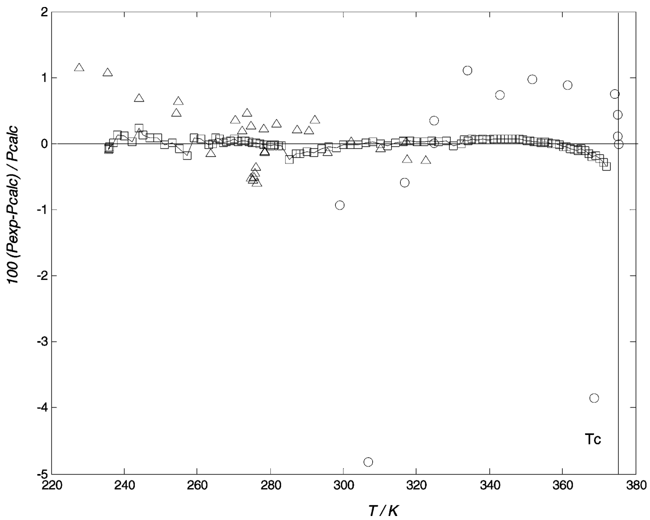

Figure 3. Relative deviation of the vapor pressure for HFC-161 from eq 1: □, this work; △, Vidaurri;[4] ○, Booth and Swinehart.[2]

5.0277) MPa. The applicable range of temperature is from 235.65 K up to the critical temperature. In agreement well with the result of Booth and Swinehart,[2] this equation predicts the critical pressure P_c of ethyl fluoride (HFC-161) to be 5.0277 MPa. The normal boiling point is also calculated to be 235.65 K with an absolute temperature deviation of 0.20 K from the result of Grosse.[3]

The acentric factor of Pitzer[8] is one of the important properties used in corresponding states calculations of pure compounds and mixtures. The definition of the acentric factor characterizes the nonsphericity of the molecular interactions:[8]

$$\omega = -1 - \log_{10}(P_r)_{T_r=0.7} \qquad (2)$$

where $P_r = P/P_c$ and $T_r = T/T_c$. P_r is calculated from eq 1 at the reduced temperature of $T_r = 0.7$. The acentric factor ω of ethyl fluoride (HFC-161) is calculated from eq 2 to be 0.2169.

Conclusion

In total, 110 vapor pressures of ethyl fluoride (HFC-161) were measured at temperatures from (235.69 to 372.14) K and corresponding pressures from (0.1015 to 4.7139) MPa. The uncertainties of the measurements were estimated to be ± 6 mK for temperature and ± 1.5 kPa for pressure, respectively. The results were fitted with a Wagner-type vapor pressure equation and compared with the available literature data. The applicable range of this equation was at temperatures from 235.65 K to the critical temperature and at pressures from 0.1013 MPa to the critical pressure. The critical pressure was calculated with the developed vapor pressure equation at the critical temperature, the normal boiling point and the acentric factor were also calculated.

Acknowledgment

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Literature Cited

(1) Xuan, Y. M. Theoretical and experimental study on new alternative refrigerants. Ph.D. Thesis, Zhejiang University, China, 2004.
(2) Booth, H. S.; Swinehart, C. F. Critical constants and vapor pressure of some gaseous fluorides of group IV. *J. Am. Chem. Soc.* **1935**, *57*, 1337−1342.
(3) Grosse, A. V. Refractive indices at low temperatures. *J. Am. Chem. Soc.* **1937**, *59,* 2739−2741.
(4) Vidaurri, F. C. Ethyl fluoride vapor pressure. *J. Chem. Eng. Data* **1975**, *20*, 349−350.
(5) Grosse, A. V.; Wackher, R. C.; Linn, C. B. Physical properties of the alkyl fluorides and a comparison of the alkyl fluorides with the other alkyl halides and with the alkyls of the elements of period II. *Phys. Chem.* **44**, *1940,* 275−296.
(6) McLinden, M. O.; Klein, S. A.; Lemmon, E. W.; Peskin, A. P. *Thermodynamic and Transport Properties of Pure Refrigerants and Refrigerant Mixtures* (*REFPROP*), Version 6.01; NIST: Boulder CO, 1998.
(7) Wagner, W. New vapor pressure measurements for argon and nitrogen and a new method for establishing rational vapor pressure equation. *Cryogenics* **1973**, *13*, 470−482.
(8) Pitzer, K. S. The volumetric and thermodynamic properties of fluid, I: Theoretical basis and virial coefficients. *J. Am. Chem. Soc.* **1955**, *77*, 107−113.

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