



## Measurements of gaseous *PVT* properties of ethyl fluoride at temperatures 371.21 to 413.29 K\*

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**Abstract:** Gaseous pressure-volume-temperature (*PVT*) properties were measured at temperatures from 371.21 to 413.29 K and corresponding pressures from 1.2445 to 4.9718 MPa. An isochoric cell apparatus was used in the present measurements with uncertainties estimated to be  $\pm 1.5$  kPa for pressure and  $\pm 6$  mK for temperature. Comparison of the measured *PVT* data with the reported virial-type equation of state showed satisfactory agreement within  $\pm 0.28\%$  in pressure and within  $\pm 0.33\%$  in density. The purity of the HFC-161 sample used in this work was 99.74 mass %.

**Key words:** *PVT* properties, Equation of state, HFC-161

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### INTRODUCTION

A hydrofluorocarbon, ethyl fluoride (HFC-161), is chlorine-free and has low global warming potential. It has not been applied to engineering practice due to its flammability, but the expected improvement in performance of a refrigeration system using this refrigerant makes it attractive for replacing R502 (Xuan and Chen, 2005).

Information on the thermodynamic properties of ethyl fluoride (HFC-161) is essential for its application as a working fluid in refrigeration system. Limited data on gaseous *PVT* properties of HFC-161 are published in the literature. Chen *et al.* (2005a) measured 161 *PVT* data in the gaseous phase with an isochoric cell apparatus at temperatures from 300.16 to 370.15 K. Gas phase *PVT<sub>x</sub>* properties of binary HFC-32/125 systems are available in (Chen *et al.*, 2006a). Vapor pressure measurements from 236.69 to 372.14 K were made on ethyl fluoride (Chen *et al.*, 2005b). In this work, a total of 42 pieces of gaseous *PVT* data for HFC-161 were measured using the

isochoric method at temperatures from 371.21 to 413.29 K.

### EXPERIMENTAL DETAILS

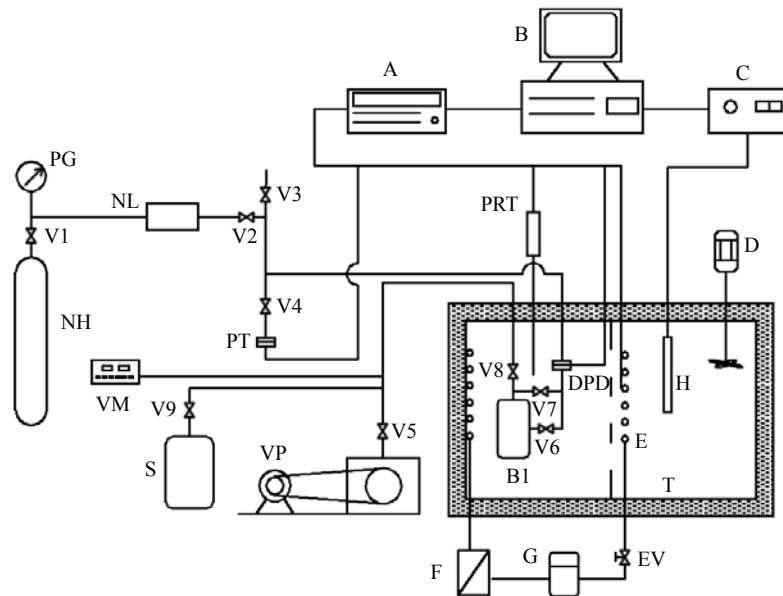
The ethyl fluoride (HFC-161) sample, provided by Zhejiang Chemical Industry Research Institute, had purity of 99.74 mass % with the principal impurities being ethylene and isobutane. It was used without further purification.

A schematic diagram of the apparatus used in this work is given in Fig. 1. It includes a sample cell, a high-accuracy thermostatic bath, a pressure measurement system, a temperature measurement system, and a vacuum system. This apparatus is the same as the one described previously (Chen *et al.*, 2006b), and it is only briefly described here.

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 temperature range. Its temperature fluctuations were determined to be less than  $\pm 3$  mK in 30 min. Temperature measurements are made with a four-lead 25- $\Omega$  platinum resistance thermometer and a Keithley

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**Fig.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 vessel; T: thermostatic bath; VM: vacuum gauge; VP: vacuum pump; V1 to V9: valves

2010 data acquisition/switch unit. The overall temperature uncertainty is  $\pm 6$  mK.

The pressure measurement system includes a pressure transducer, a diaphragm differential pressure detector, an oil-piston type dead-weight pressure gauge, and an atmospheric pressure gauge. The whole pressure measurement system has an uncertainty of  $\pm 1.5$  kPa in the pressure range from 0.1 to 6.0 MPa.

The sample cell was a heavy-walled isochoric metal vessel (about  $140.5$  cm<sup>3</sup> in 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  $1 \times 10^{-2}$  Pa.

For the isochoric method, the vessel was filled with a known sample mass using a precision chemical balance with accuracy  $\pm 0.5$  mg, and maximum allowable mass 1.5 kg. The uncertainty in density values was estimated to be within  $\pm 0.15\%$  in the present work.

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 measured and recorded in the computer.

## RESULTS AND DISCUSSION

In this study, 42 *PVT* data for ethyl fluoride were measured at temperatures from 371.21 to 413.29 K. Results of the isochoric measurements are given in Table 1. Because the volume of the sample cell underwent a small change at different temperatures, a temperature correction to the densities was made to compensate for the thermal expansion of the sample cell (Zhang and Zhao, 1987).

The data listed in Table 1 were compared with the truncated virial equation of state (Chen *et al.*, 2005a). The equation was based on the following functional form:

$$\frac{P}{\rho RT} = 1 + B\rho + C\rho^2 + D\rho^3, \quad (1)$$

where

$$B = B_0 + B_1 T_r^{-1} + B_2 T_r^{-2} + B_3 T_r^{-3} + B_4 T_r^{-6} + B_5 T_r^{-8},$$

$$C = C_0 T_r^{-5} + C_1 T_r^{-6},$$

$$D = D_0 + D_1 T_r,$$

$T_r = T/T_c$ ,  $T_c = 375.31$  K is the critical temperature (Booth and Swinehart, 1935),  $p$  is the pressure in Pa;  $T$  the temperature in K;  $\rho$  the density in  $\text{kg/m}^3$ ; the gas constant  $R = 173.2$  J/(K·kg), and the molar mass of HFC-161 is 48.06 g/mol.

Fig.2a represents the density deviations of the present  $PVT$  data from the virial equation of state in the gas phase. The maximum and average absolute density deviations from Eq.(1) are 0.33% and 0.14%, respectively. Fig.2b shows the pressure deviations of the measured  $PVT$  data from Eq.(1). The maximum and average absolute pressure deviations from Eq.(1) are 0.28% and 0.09%, respectively. The suitable range of Eq.(1) is from 0.6422 to 4.9718 MPa in pre-

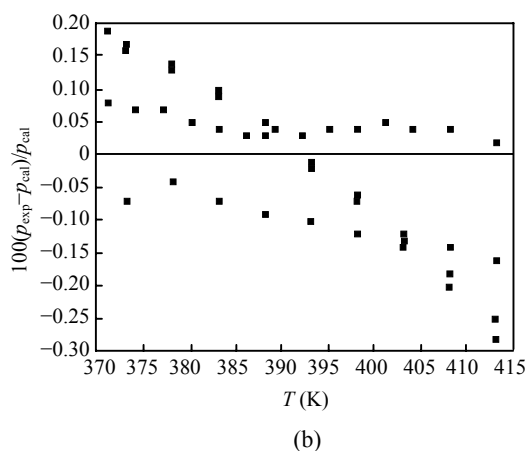
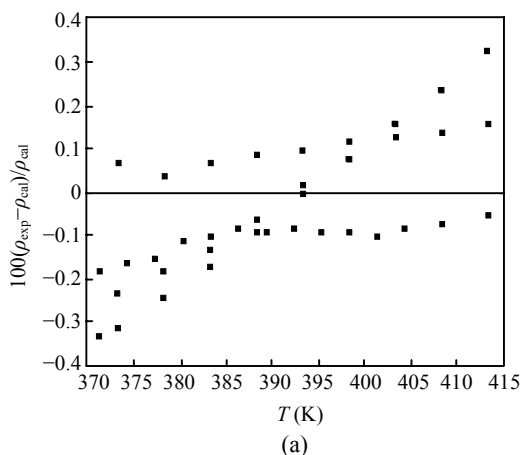
ssure, from 300.16 to 413.29 K in temperature and from 13.920 to 104.590  $\text{kg/m}^3$  in density.

## CONCLUSION

In this work, a total of 42 gaseous  $PVT$  data on ethyl fluoride (HFC-161) were measured at temperatures from 371.21 to 413.29 K and corresponding pressures from 1.2445 to 4.9718 MPa using the isochoric method. The maximum uncertainties were estimated to be within  $\pm 1.5$  kPa,  $\pm 6$  mK and  $\pm 0.15\%$  for pressure, temperature, and density, respectively. Comparison of the measured  $PVT$  data with the reported virial-type equation of state showed satisfactory agreement within  $\pm 0.28\%$  in pressure and within  $\pm 0.33\%$  in density.

**Table 1** Experimental  $PVT$  properties of HFC-161

$T$ (K)	$p$ (MPa)	$\rho$ ( $\text{kg/m}^3$ )	$T$ (K)	$p$ (MPa)	$\rho$ ( $\text{kg/m}^3$ )	$T$ (K)	$p$ (MPa)	$\rho$ ( $\text{kg/m}^3$ )
373.28	1.2445	21.280	398.21	2.9663	53.114	371.26	3.8976	99.470
378.26	1.2656	21.275	403.19	3.0243	53.101	374.22	3.9771	99.455
383.24	1.2859	21.269	408.18	3.0823	53.087	377.20	4.0564	99.441
388.25	1.3065	21.264	413.21	3.1406	53.074	380.30	4.1375	99.425
393.20	1.3269	21.259	371.21	3.4552	79.510	383.26	4.2146	99.411
398.22	1.3475	21.254	373.18	3.4951	79.502	386.25	4.2917	99.396
403.30	1.3682	21.248	378.15	3.5950	79.483	389.31	4.3707	99.381
408.28	1.3887	21.243	383.18	3.6945	79.463	392.28	4.4462	99.366
413.28	1.4091	21.238	388.25	3.7934	79.443	395.23	4.5212	99.351
373.17	2.6675	53.180	393.24	3.8897	79.423	398.28	4.5984	99.336
378.16	2.7282	53.167	398.22	3.9851	79.403	401.29	4.6743	99.321
383.17	2.7885	53.154	403.21	4.0798	79.383	404.26	4.7480	99.307
388.24	2.8487	53.140	408.25	4.1752	79.364	408.30	4.8485	99.287
393.23	2.9076	53.127	413.17	4.2677	79.344	413.29	4.9718	99.262



**Fig.2** Density (a) and pressure (b) deviations of measured  $PVT$  data from values calculated from Eq.(1)

## ACKNOWLEDGEMENTS

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