



Experimental research on (vapor + liquid) equilibria for the {trifluoroiodomethane (CF₃I) + carbon dioxide (CO₂)} system from 243.150 to 273.150 K



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ABSTRACT

In this work, the (vapor + liquid) equilibria (VLE) data of the {trifluoroiodomethane (CF₃I) + carbon dioxide (CO₂)} system was measured at (243.150, 253.150, 263.150 and 273.150) K. The uncertainties of the temperature, pressure and composition were estimated to be less than ±5 mK, ±0.0013 MPa and ±0.005, respectively. PR–vdW model and PR–HV–NRTL model were used to correlate the experimental data. Both models can give satisfied results. This work will supply essential data for (CF₃I + CO₂) gas mixture using in the gas insulated switchgear (GIS) and gas insulated transmission line (GIL).

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1. Introduction

Sulfur hexafluoride (SF₆) was thought as a good insulated gas in electric power system for its outstanding characteristics on dielectric strength. Lots of electric equipment set SF₆ as the major insulated medium, especially in the gas insulated switchgear (GIS) and gas insulated transmission line (GIL). However, the severe greenhouse effect of SF₆ is inevitable. The global warming potential (GWP) of SF₆ is 23,900 and its residence time reaches up to 3200 years in the atmosphere. SF₆ was proposed as one of the six prime contributors to the greenhouse effect according to the Kyoto Protocol and the usage of SF₆ would be limited before 2020 [1–3]. Therefore, to find the substitute of SF₆ in GIS and GIL has become a research hotspot in the recent decades [3–11].

Trifluoroiodomethane (CF₃I) has been considered as a potential inerting agent to take the place of Halon and has a promising prospect as a new type of refrigerant in the refrigeration industry [12]. Both CF₃I and SF₆ have the same characteristics of incombustibility, odourlessness, achromaticity, wonderful dielectric strength and CF₃I has better environmental effect. Nevertheless, the liquefaction

characteristic of CF₃I is not that ideal for its high normal boiling point temperature. The normal operation temperature of GIS and GIL is between (243.15 and 323.15) K under the pressure of about 0.5 MPa [13]. Pure CF₃I gas would turn into liquid in these enclosing electric equipment in some low temperature environment which will lead to the failure of insulation. CO₂, an environmentally-friendly gas with lower normal boiling point and suitable dielectric strength, was proposed to be mixed with CF₃I gas to build a new potential insulated system in replacing SF₆ [8,10,11]. The factors (the GWP, the lifetime in atmosphere, dielectric strength relative to SF₆, normal boiling point) that need special attention for insulated gases in GIS and GIL are listed in Table 1. However, the research on liquefaction characteristic of (CF₃I + CO₂) gas mixture in the previous work was not precise and no experimental data was available. The calculation method was even simplified by isolating CF₃I and ignoring the influence of CO₂ [10,11].

In order to supply essential data for (CF₃I + CO₂) gas mixture using in GIS and GIL, the (vapor + liquid) equilibria (VLE) data of the (CF₃I + CO₂) system were measured in this paper. Peng–Robinson (PR) equation of state [14] with two mixing rules, the van der Waals (vdW) [15] mixing rule, the Huron Vidal (HV) mixing rule [16] applying the non-random two-liquid (NRTL) [17] activity coefficient model (PR–vdW model and PR–HV–NRTL model), were used to correlate the experimental data.

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Table 1
The global warming potential (GWP)^a, the lifetime in atmosphere (LIA)^a, the dielectric strength relative to SF₆ (DS)^a, the normal boiling point (NBP)^b, the mole fraction purity (MFP), critical parameters (T_c , p_c)^b, acentric factors (ω)^b of SF₆, CF₃I and CO₂.

Chemicals	CAS no.	GWP	LIA/year	DS	NBP/K	MFP	T_c /K	p_c /MPa	ω
SF ₆	2551-62-4	23,900	3200	1.00	204.9		318.72	3.755	0.21
CF ₃ I	2314-97-8	0	<1/365	1.23	251.3	0.995	396.44	3.953	0.176
CO ₂	124-38-9	1	50–200	0.30	194.686	0.99995	304.13	7.377	0.22394

^a Reference [9].

^b Reference [18].

2. Experiment

2.1. Chemicals and facility

CF₃I was provided by Nanjing Yuji Tuohao Co. Ltd with the declared mole fraction of 0.995. CO₂ was provided by Beijing AP BAIF Gases Industry Co. Ltd with the declared mole fraction of 0.99995.

The mole fraction was testified by a Shimadzu GC2014 gas chromatograph with a thermal conductivity detector (TCD) and no impurities was obviously detected. Both the chemicals were used without further purification in the experiment. The mole fraction purity (MFP), critical parameters and acentric factors of CF₃I, CO₂ [18] are listed in Table 1.

The measurements were conducted based on a static-analytic method. The effectiveness and accuracy of the experimental facility have been verified in the previous work [12,19–22]. A 25 Ω platinum resistance thermometer, calibrated by the Cryogenic Metrology Station of the Chinese Academy of Sciences based on the 1990 International Temperature Scale (ITS 90), with the uncertainty less than ± 3 mK was used to get the inner temperature of the sample cell. The combined standard uncertainty of the temperature measurement is estimated to be less than ± 5 mK. The data of pressure was collected by a Mensor CPT6000 ($\pm 0.02\%$ FS) digital pressure transducer with two full scales of 3.0 and 6.0 MPa, and their uncertainty are ± 0.0006 MPa and ± 0.0012 MPa, respectively. In this work, the full scale of 6.0 MPa was used and the combined standard uncertainty of the pressure is estimated to be less than ± 0.0013 MPa. A gas chromatograph, calibrated by mixtures with compositions obtained gravimetrically, was used to acquire the mole fractions of the vapor and liquid phases. The uncertainty of the composition measurement is less than ± 0.005 .

2.2. Experimental measurements

The sample cell was firstly vacuumized before the experiment and then be purged by CF₃I for three times at first. Secondly, an amount of CF₃I was injected into the sample cell. When a required temperature was reached and maintained for about 1 h with a continuous work of the magnetic pump, and the fluctuations of the temperature and the pressure would stay less than ± 3 mK, ± 200 Pa, respectively, for more than 10 min in the sample cell, the saturated vapor pressure of CF₃I would be acquired. Then an estimated amount of CO₂ was injected into the sample cell. When the same equilibrium state was obtained, the mole fractions of the vapor and liquid phases of (CF₃I + CO₂) would be collected by the gas chromatograph. The data should be measured at least three times. When the deviations of the results were all less than ± 0.001 , the average value would be regarded as the data of VLE in this condition. As the temperature and the injected amount of CO₂ changed, the VLE data in various conditions would be acquired.

The saturated vapor pressures of pure CF₃I and CO₂ have been measured by this system. The experimental results were put into comparison with the data from REFPROP 9.0 [18] and the

differences between the experimental and database values are acceptable (see Table 2).

3. Calculation model

Both PR–vdW model and PR–HV–NRTL model were used to correlate the experimental data

PR EoS:

$$p = \frac{RT}{v-b} - \frac{a(T)}{v(v+b) + b(v-b)}, \quad (1)$$

where p represents pressure, R is the gas constant ($R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$), T is the temperature, v is the mole volume. $a(T)$ and b are expressed below:

$$a(T) = 0.457235 \frac{R^2 T_c^2 \alpha(T)}{p_c}, \quad (2)$$

$$b = 0.077796 \frac{RT_c}{p_c}, \quad (3)$$

with

$$\alpha(T) = \left[1 + (0.37464 + 1.54226\omega - 0.26992\omega^2) \left(1 - T_r^{0.5} \right) \right]^2, \quad (4)$$

$$T_r = \frac{T}{T_c}, \quad (5)$$

where ω is the acentric factor, T_c is the critical temperature and p_c is the critical pressure of pure fluid.

The vdW mixing rule:

$$a = \sum_i \sum_j x_i x_j a_{ij}, \quad (6)$$

$$b = \sum_i x_i b_i, \quad (7)$$

Table 2

Experimental and calculated vapor pressure from REFPROP 9.0 (p_{exp} and p_{ref}) of CF₃I and CO₂.^a

T /K	p_{exp} /MPa	p_{ref} /MPa	Δp^b /MPa	$\Delta p/p^c$
<i>CF₃I</i>				
243.150	0.0727	0.0719	0.0008	1.10
253.150	0.1101	0.1092	0.0009	0.82
263.150	0.1604	0.1602	0.0002	0.12
273.150	0.2284	0.2279	0.0005	0.22
<i>CO₂</i>				
243.150	1.4265	1.4278	−0.0013	−0.09
253.150	1.9684	1.9696	−0.0012	−0.06
263.150	2.6475	2.6486	−0.0012	−0.05
273.150	3.4838	3.4850	−0.0013	−0.04

^a Standard uncertainties u are $u(T) = 5$ mK and $u(p) = 0.0013$ MPa.

^b $\Delta p = p_{\text{exp}} - p_{\text{ref}}$.

^c $\Delta p/p = 100 \times (p_{\text{exp}} - p_{\text{ref}})/p_{\text{exp}}$.

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