Experimental study of the density of octafluorocyclobutane in the liquid and supercritical area of states

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Abstract. This work is a continuation of the cycle of studies of the ppT-surface of octafluorocyclobutane in the range of parameters of the state of operation of power plants. The new data of the following series of measurements of the density of octafluorocyclobutane, obtained by the method of a constant-volume cell, are presented. The measurements were carried out on 5 isotherms in the liquid and supercritical regions in the range of temperature from 25°C to 143°C and pressures from 1.6 to 10.9 MPa. The density uncertainty was estimated by the authors at no more than 0.2%. The resulting thermal surface is described by a polynomial with 20 coefficients. The mean square deviation of the experimental points from the calculated ones was 0.026%.

1. Introduction

The high thermodynamic efficiency of using fluorocarbon composition (octafluoropropane C3F8, octafluorocyclobutane c-C4F8, decafluorobutane C4F10) as working fluids of power plants was first noted in the works of Gokhshtein [1] back in the 60s of the last century. However, calculations of cycles on these substances with acceptable accuracy can only be performed based on the results of work performed at the Department of Theoretical Foundations of Thermal Engineering of National Research University "Moscow Power Engineering Institute" in the last 12 years. Experimental data on the thermophysical properties of octafluorocyclobutane (RC-318, c-C4F8) and computational models (equations of state), previously published in the available sources, covered only the range of operating parameters of refrigeration and heat pump units. At high temperature range, no reliable data were available.

This work is a continuation of the series of studies of the ppT-surface of working substances of fluorocarbon composition in the range of operation parameters of modern power plants. Somewhat earlier, new experimental data were obtained on the density of octafluorocyclobutane in the temperature range of 180÷450°C and pressures up to 11 MPa using a constant-volume piezometer. The error of the experimental measurements was estimated to be no more than 0.2% [2]. The beginning of the sample substance polymerization was also recorded at a temperature of 470°C and a pressure of 10 MPa, i.e. the boundaries for the use of RC-318 as a working substance of heat-power cycles were established in practical terms [3].

2. Experimental results
This paper presents data of the series of measurements of octafluorocyclobutane density, also obtained by the constant-volume cell method. The measurements were carried out on 5 isotherms in the liquid and supercritical areas of state. The range of obtained parameters of state of the new series is presented in figure 1 and figure 2, its boundaries being 25°C – 143°C, and the pressure values being 1.6 – 10.9 MPa. The error of density determination was estimated at no more than 0.2%.

![Figure 1.](image1.png)  ![Figure 2.](image2.png)

**Figure 1.** The range of experimental values of density of c-C₄F₈ in p-t diagram.

**Figure 2.** The range of experimental values of density of c-C₄F₈ in p-v diagram.

This paper presents a new series of measurements of octafluorocyclobutane density from 32 experimental points. Experimental data on octafluorocyclobutane density as a function of temperature and pressure are given in table 1. Thus, the total number of measurements of octafluorocyclobutane density in the operating range of power plants performed at the plant by the constant volume cell method was 112.

| №  | t, °C   | p, MPa | ρ, kg/m³ | №  | t, °C   | p, MPa | ρ, kg/m³ |
|----|---------|--------|----------|----|---------|--------|----------|
| 1  | 24.59   | 10.902 | 1557.9   | 17 | 76.69   | 2.363  | 1283.4   |
| 2  | 24.56   | 10.170 | 1554.5   | 18 | 104.48  | 10.085 | 1282.6   |
| 3  | 24.54   | 8.873  | 1548.1   | 19 | 104.50  | 8.256  | 1252.9   |
| 4  | 24.53   | 7.037  | 1538.6   | 20 | 104.53  | 6.941  | 1227.1   |
| 5  | 24.51   | 5.182  | 1528.1   | 21 | 104.46  | 5.417  | 1190.5   |
| 6  | 24.51   | 3.429  | 1517.4   | 22 | 104.51  | 4.224  | 1151.6   |
| 7  | 24.50   | 2.268  | 1509.8   | 23 | 104.49  | 3.191  | 1103.6   |
| 8  | 55.85   | 10.315 | 1457.3   | 24 | 142.81  | 10.009 | 1105.7   |
| 9  | 55.88   | 8.505  | 1443.1   | 25 | 142.81  | 8.174  | 1044.6   |
| 10 | 56.07   | 6.452  | 1425.7   | 26 | 142.82  | 6.281  | 941.02   |
| 11 | 56.30   | 4.431  | 1409.4   | 27 | 142.86  | 5.153  | 820.53   |
| 12 | 56.29   | 2.261  | 1385.2   | 28 | 142.84  | 4.662  | 724.97   |
| 13 | 76.46   | 9.767  | 1388.0   | 29 | 142.86  | 4.087  | 548.74   |
| 14 | 76.63   | 8.357  | 1372.4   | 30 | 142.89  | 3.569  | 392.78   |
| 15 | 76.61   | 6.455  | 1349.8   | 31 | 142.89  | 2.739  | 237.67   |
| 16 | 76.56   | 4.357  | 1320.5   | 32 | 142.90  | 1.687  | 120.59   |
3. Data comparison

New experimental data allow estimating extrapolation possibilities of the computational model Refprop NIST USA [4], built on the similarity method. The deviations are shown in figure 3.

![Figure 3. Deviations of the obtained values of density of octafluorocyclobutane from those calculated in [4].](image)

The character of relative deviations is quite natural: with an increase in temperature their value increases from -0.25% to 2.1% being practically independent of pressure. On this basis, a recommendation can be formulated to adjust the computational model in this range of parameters of state of octafluorocyclobutane, since the deviations of the calculated calorific functions should be expected to be even greater.

4. The equation of thermal surface

To assess the internal consistency of the data of this series (in the liquid and supercritical region of states), the experimental data were described by a polynomial equation as follows:

\[ v = \sum_{i=0}^{3} \sum_{j=0}^{4} b_{ij} p^i \tau^{-j} \]  

(1)

where \( p \) is the pressure in MPa; \( \tau = T/100 \) is the reduced absolute temperature; \( b_{ij} \) are the numerical coefficients of the equation; and \( v \) is the specific volume, \( \text{m}^3/\text{kg} \).

The description of the obtained experimental data by the equation of the specified type and the calculation of absolute and relative deviations were carried out in [5]. A polynomial with 20 coefficients was used to describe the obtained thermal surface. The numerical values of the coefficients are given in table 2. The mean square deviation of the experimental points from the calculated ones was 0.026%. The shape of the surface of the obtained equations with applied experimental points is shown in figure 4. In the near-critical region, the thermal surface has a significant convexity, for the description of which the new experimental data are especially important.
Table 2. Coefficients of equation (1).

|   | b_{0,0} | 1.30570 | b_{2,0} | 0.029565 |
|---|---------|---------|---------|----------|
| b_{0,1} | -17.10651 | b_{2,1} | -0.374776 |
| b_{0,2} | 84.07013 | b_{2,2} | 1.77851 |
| b_{0,3} | -183.53521 | b_{2,3} | -3.74455 |
| b_{0,4} | 150.14108 | b_{2,4} | 2.95125 |
| b_{1,0} | -0.340597 | b_{3,0} | -0.000846 |
| b_{1,1} | 4.411468 | b_{3,1} | 0.010386 |
| b_{1,2} | -21.41154 | b_{3,2} | -0.047563 |
| b_{1,3} | 46.15061 | b_{3,3} | 0.096280 |
| b_{1,4} | -37.26926 | b_{3,4} | -0.072651 |

Figure 4. Graphic illustration of equation (1) with obtained experimental points of specific volume of octafluorocyclobutane plotted on the surface.

The comparison of deviations of new experimental data from the data of [4], as well as from the data of [6,7,8] allows concluding that the obtained data on thermal properties can be considered reliable and that the described method may be used in further calculations when creating algorithms for computer programs that provide a more reliable calculation of the thermodynamic properties of substances proposed for implementation as working fluids of power plants.

5. Conclusion
The new experimental data on the density of octafluorocyclobutane will be used by the authors of this work to construct a reliable equation of state of octafluorocyclobutane in a wide range of states corresponding to the operating parameters of modern combined heat and power plants.

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