Measurement and correlation of compressibility factor of high CO_2-content natural gas

Xiaoqiang Bian *, Zhimin Du, Yong Tang, Jianfen Du

The State Key Laboratory of Oil & Gas Reservoir Geology and Exploitation Engineering Southwest Petroleum University, Chengdu, Sichuan Province 610500, PR China

ABSTRACT

The JEFRI-PVT apparatus made in Canada by the Schlumberger company has been used to obtain accurate compressibility factor measurements on high CO_2-content natural gasses so as to study the effect of different CO_2 content on gas compressibility factor (range covered: temperature, 263.15 K to 313.15 K; pressure, 3 MPa to 15 MPa; CO_2 content, 9.84, 28.86 and 50.99 mol%). The results showed that gas compressibility factors reduce with increasing CO_2 content in natural gasses and increase with increasing temperature. In addition, a non-integral power polynomial correlation was proposed without an iterative procedure whose coefficients were determined by fitting experimental data. The mixing rules used include: Kay's mixing rule combined with Wichert-Aziz correlations (Kay) and Stewart-Burkhardt-Voo mixing rule with Wichert-Aziz (SBV). Comparison of the DAK-SBV, DAK-Kay, and proposed correlations showed that the presented model yielded the most accurate predictions with the lowest average absolute deviation (0.42%) among them.

Crown Copyright © 2012 Published by Elsevier B.V. All rights reserved.

1. Introduction

In recent years, more and more high CO_2-content gas reservoirs in the world have been discovered (Jokhio et al., 2001). Different CO_2 content leads to different gas compressibility factor which is involved in calculating gas properties such as formation volume factor, density, compressibility, and viscosity (Shokir, 2008).

Prediction of gas compressibility factor commonly contains three methods: experiment (Adisoemarta et al., 2004), equation of state (Li and Guo, 1991), and empirical formula (Heidaryan et al., 2010). Experimental measurement of gas compressibility factor is the most accurate among all methods. Several correlations fitting the Standing and Katz chart (Standing and Katz, 1942) can be used to calculate the gas compressibility factor (Dranchuk and Abou-Kasem, 1975; Dranchuk et al., 1974; Hall and Yaborough, 1973). But Dranchuk-Abou-Kassem (DAK) correlation is the most accurate. In addition, among the mixing rules (Bahadori et al., 2007; Elsharkawy and Elkamel, 2001; Sutton, 2007), Kay (1936) and Stewart et al. (1959) mixing rules are the most widely used. Kay's mixing rule is simple. SBV mixing rule provided the most satisfactory results (Satter and Campbell, 1963).

Since the presence of CO_2 gas, prediction of the compressibility factor is much more difficult than that of sweet gasses. Wichert and Aziz (1972) presented corrections for the presence of hydrogen sulfide (H_2S) and/or CO_2 for determining compressibility factor of sour gasses. Fortunately, in the present study, due to the absence of C_{7+} fraction, the critical properties of the C_{7+} fraction are not calculated from correlations (Pedersen et al., 1989).

This study has two objectives. The first objective is to measure gas compressibility factor for different CO_2-content natural gasses (CO_2 content is about 10%, 30% and 50%, respectively) by applying JEFRI-PVT experimental equipments which were made in Canada by the Schlumberger company. The second objective is to develop a non-iterative empirical correlation to estimate gas compressibility factor based on the experimental results, and to make a comparison among the proposed model, DAK-SBV and DAK-Kay correlation.

2. Experiment

2.1. Experimental material

CO_2 was purchased from Southwest Oil and Gas Field Company, Chengdu, China, with a purity of 99.99 mol%, and natural gas was directly taken from surface separator in Xusheng gas field, Daqing, China. All the samples were used without further purification.

Strictly speaking, this is a synthetic gas prepared in the lab. As a result, CO_2 and natural gas was mixed as follows:

Firstly, natural gas from surface separator was introduced into the equilibrium cell.
Secondly, CO_2 was added to the equilibrium cell.
Finally, stir the gas mixture well and control the cell to the desired temperature and pressure.

* Corresponding author. Tel./fax: +86 28 83032091.
  E-mail address: bxqiang3210_88@163.com (X. Bian).

2.2. Measured principles

For dry gasses, compressibility factor can be calculated using the following equation:

$$Z = \frac{P \cdot \Delta V \cdot T_s}{P_s \cdot V_s \cdot T} \tag{1}$$

In the above equation, it is of great significance to control the ambient temperature (T_s). For this experiment, the ambient temperature was about 20 °C ± 0.5 °C. When the gas was released from PVT cell, the released gas passed through a flash separator which was soaked in a constant temperature water bath whose temperature was controlled to 20 °C. During this period, we ensured that the gas flow rate was very slow so that the released gas temperature became the ambient temperature.

2.3. Experimental apparatus and procedure

In this study, mercury free DBR-PVT vessels were used to measure gas compressibility factors. A schematic diagram of the apparatus is shown in Fig. 1.

The experimental apparatus used consisted of PVT vessel of approximately 135 ml capacity, automatic pump, gas chromatography, dry gasometer, constant temperature air bath, flash separator and ground separator.

Experimental procedure:

(1) Clean PVT vessel and cells, then connect the PVT vessel to the cells and evacuate the cells;
(2) Control and maintain the desired temperature using the constant-temperature air bath;
(3) Introduce a test gas (about 100 ml) into PVT vessel at the specified temperature and pressures in the oven and keep 5 h, then hold up half an hour and measure the gas volumes of the PVT vessel;
(4) Slightly open the valve between the cells and bleed gas from the PVT vessel into the flash separators, at the same time, keep the pressures of the PVT vessel constant using automatic pump;
(5) Record the bled gas volumes and remaining gas volumes of PVT vessel;
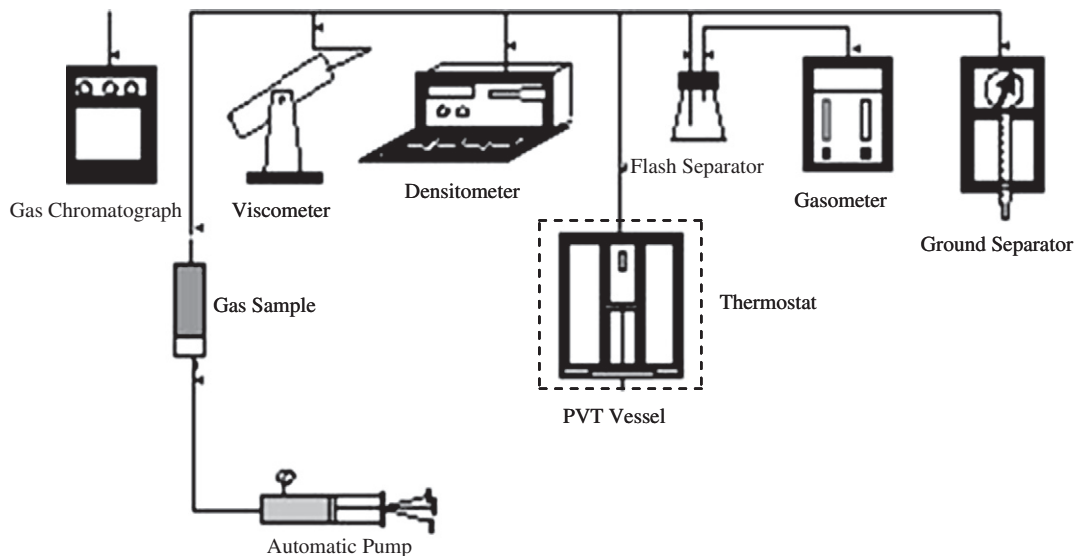(6) Use Eq. (1) to determine Z-factors;

Table 1
Composition of gas mixtures and critical properties of defined component.

Component	Sample 1	Sample 2	Sample 3	P_c/MPa	T_c/K	Mw/g·mol^{-1}
	Mole fraction					
CO_2	0.0984	0.2886	0.5099	7.38	304.1	44.01
N_2	0.0205	0.0124	0.0083	3.39	126.20	28.013
C_1	0.8602	0.6773	0.4654	4.60	190.4	16.043
C_2	0.0167	0.0159	0.0116	4.88	305.4	30.07
C_3	0.0031	0.0042	0.0033	4.25	369.8	44.094
iC_4	0.0004	0.0006	0.0005	3.65	408.2	58.124
nC_4	0.0005	0.0007	0.0006	3.80	425.2	58.124
iC_5	0.0001	0.0003	0.0002	3.39	460.4	72.151
nC_5	–	0.0001	0.0001	3.37	469.7	72.151
C_6	0.0001	–	–	3.01	507.5	86.178

Repeat procedures (4)–(6), and ensure that tested Z-factors are about the same at least three times. For more detailed descriptions see SY/T 6434-2000 and Varotsis and Pasadakis (1996)

2.4. Experimental results

The gas samples used were analyzed using a HP-6890 Gas Chromatograph. The results of analysis were shown in Table 1. The critical pressure and temperature for the pure components normally present in natural gasses are also provided in Table 1 (Reid et al., 1987).

Experimental compressibility factors for different CO_2-content natural gasses were listed in Table 2. Table 2 indicated that compressibility factors reduce with increasing CO_2 content in natural gasses and pressures, but increase with increasing temperature.

3. Methods

3.1. Existing methods

When gas composition is available, pseudo critical properties are calculated using a given mixing rule. In the present work, Kay and SBV mixing rules are considered. Kay's mixing rule, based on molar weighted average critical properties, has the following form:

$$P_{pc} = \sum_{i=1}^{n_c} y_i P_{ci} \tag{2}$$

Fig. 1. Schematic diagram of the experimental apparatus.