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Compressibility Factor of Gas with High Content of CO_2 in Changshen Gas Reservoir

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Abstract— *The natural gas in Changshen gas reservoir is high content of CO_2. There are no conventional methods to calculate the compressibility factor of natural gas. In view of this particularity, the compressibility factor is determined and analyzed by PVT laboratory experiments. Experimental studies show that the compressibility factor has great difference between hydrocarbon gas and non-hydrocarbon gas under the same conditions and the compressibility factor of CO_2 has very strong temperature and pressure sensitivity. And for the natural gas with high content of CO_2, the lower the temperature is, the lower the inflexion pressure of compressibility factor curve is. Under the same temperature and the same pressure conditions, the compressibility factors of different gas systems are strongly sensitive to CO_2 component. And at 140 ℃, the inflexion pressure of compressibility factor curve increases with the increase of CO_2 content. Under the condition of 20 ℃, the calculation of Wichert and Aziz's formula will cause great error when the natural gas has high content of CO_2 (more than 80%). It suggests adopting laboratory experiment to measure the compressibility factor in order to provide theoretical reference for the reasonable development of gas reservoir.*

Keywords- Changshen gas reservoir; gas with CO_2; compressibility factor; temperature; pressure; component

I. INTRODUCTION

Compressibility factor is one of the most important property parameters of natural gas [1-3]. Now, the methods that ascertain the compressibility factor mainly are experiment measurement, formula calculation and chart method.

Changshen gas reservoir is a fracture-pore volcanic reservoir in which CO_2 content varies largely (5% - 98%) according to the data of test wells [4-5]. At present, this kind of gas reservoir was found for the first time in China and it is neither hydrocarbon gas reservoir, nor pure CO_2 gas reservoir.

The compressibility factors of CO_2 and conventional natural gas are extraordinarily different. At present, for the calculation of compressibility factor of natural gas, the correction methods of non-hydrocarbon are limited to the situation that the content of non-hydrocarbon is much little. But for the gas with high content of CO_2, there is no ready-made method for the calculation of compressibility factor [6-8]. So the compressibility factor of natural gas with different contents of CO_2 is very important in the form of experiment [9].

II. EXPERIMENT

A. Instrument and Materials

The main experimental apparatus is RUSKA mercury-free PVT device (model 2730, made in America). And the ancillary equipments include volume meter, vacuum pump, chromatography, high-pressure viscometer, interfacial tension meter, etc.

The formation pressure of Changshen gas reservoir is 42MPa and the formation temperature is 140℃. Table 1 shows the natural gas components of Changshen gas reservoir. The experimental temperatures are 20℃, 40℃, 60℃, 80℃, 120℃, 140℃. And the experimental pressures are 5MPa, 10MP, 20MPa, 30MPa, 35MPa, 42MPa and 45MPa.

Table 1. The data of natural gas components.

gas sample number	gas components (mol %)				
	CH_4	C_2H_6	C_3H_8	N_2	CO_2
sample 1	0.8674	0.0174	0.0016	0.0637	0.0500
sample 2	0.6893	0.0128	0.0012	0.0469	0.2498
sample 3	0.6426	0.0121	0.0011	0.0442	0.3000
sample 4	0.4625	0.0077	0.0007	0.0281	0.5010
sample 5	0.2678	0.0062	0.0006	0.0226	0.7029
sample 6	0.0900	0.0014	0.0001	0.0051	0.9034
sample 7	0.0216	0.0004	0.00004	0.0016	0.9763

B. Experimental Methods

1) Experimental preparation

a) Pressure test: fill the high-pressure gas into the PVT device (the pressure is greater than the maximum operating pressure for 3MPa), and make sure the gas is not leak.

b) Device calibrate: use CH_4 and CO_2 to test, the fractional error between testing result and chart method is less than 5%.

c) Vacuum the PVT device, close the valve 4, open the valves 1, 2 and 3 to switch the gas into the pipeline, shift the prepared gas into the PVT device, close the valves 1, 2 and 3, start the experiment at a constant temperature.

2) Experimental procedure

In order to obtain the compressibility factor and volume factor at formation conditions, the single expansion experiment was taken that it depressurizes the natural gas from formation conditions to atmospheric conditions directly. The specific methods are as follows.

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a) Regulate the natural gas of the PVT device under the formation pressure P_i=42MPa and the formation temperature T_i=140℃.

b) Open the valves 1, 2 and 3 to liberate some gas into the pipeline, make the pipeline with a certain pressure.

c) Close the valves 1, 2 and 3 and read the PVT container's volume V_1 under the formation condition at this time.

d) Open the gas releasing valves, release 10~20ml gas into the gas-meter at the model of constant pressure, record the PVT device's volumeV_2, and use the gas-meter to record the releasing volume V_{gsc}.

e) Obey steps (1-4) to operate parallel testing for three times, and it is qualified that the error of volume ratios is less than 0.6%.

According to the reading volume, it calculates the compressibility factor Z_i and volume factor B_{gi} under the formation pressure.

$$z_{\mathrm{i}} = \frac{p_i(v_1 - v_2)T_{sc}}{p_{sc}v_{gsc}T_i} \tag{1}$$

$$B_{gi} = z_{\mathrm{i}} \times \frac{p_{sc}T_i}{p_i T_{sc}}$$

In the equation: T_{sc}-standard temperature, 273.15K; P_{sc}-standard pressure, 0.1MPa.

III. EXPERIMENTAL RESUITS AND DISCUSSION

A. CO_2 and CH_4

Figure 1 shows the comparison of compressibility factors of CO_2 and CH_4. It can be seen from Figure 1 that the change of the compressibility factor of CO_2 is obvious on the condition of different temperatures at low pressure. That is to say the compressibility factor shows different compressive properties at different temperatures. And the growth of the compressibility factor of CO_2 is minor with the increase of temperature at high pressure. But for CH_4, the change of compressibility factor is not obvious with the increases of temperature and pressure. The reason is the physicochemical properties of different gas which lead to the differences of compressibility factor curves eventually.

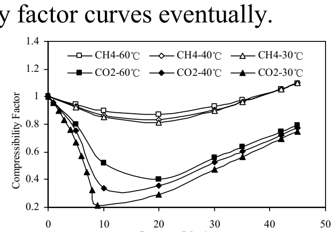

Figure 1. The comparison of compressibility factors between CO_2 and CH_4.

Under the same temperature and the same pressure conditions, the compressibility factor of CO_2 is less than that of CH_4. That is to say the disparity between the compressibility factor of CO_2 and the value of 1.0 is bigger than that of CH_4. That is because the CO_2 is a kind of highly compressible gas and deviates greatly from the ideal gas. It also can be seen from Figure 1 that, with the decrease of temperature, the compressibility factor of CO_2 decreases firstly and then increases with the increase of pressure. And there is an obvious inflexion that the lower the temperature is, the lower the pressure to the inflexion is which is because that the CO_2 is much easily to be compressed under the condition of low temperature.

B. Temperature

In Figure 2(left), there are the compressibility factor's correlation curves of natural gas with 25% content of CO_2 at different temperatures. It shows that the compressibility factor curves of natural gas with CO_2 and pure hydrocarbon natural gas are basically the same that they both show the tendency of compressibility factor about reducing first and then raising with the increase of pressure.

For the same gas and the same pressure, compressibility factor increases with the increase of temperature. And the higher the temperature is, the smaller the rangeability of compressibility factor is. The contrast of compressibility factor is minor at different temperatures on the conditions of low or high pressure. It indicates that for the same gas system, the higher the pressure is, the lower the sensitivity of compressibility factor to temperature is; the higher the temperature is, the lower the sensitivity of compressibility factor to pressure is.

For the natural gas with 98% content of CO_2, it shows that the variation tendency of compressibility factor about natural gas and non-hydrocarbon gas are basically same in Figure 2(right). Compared with Figure 2(left), for the system of natural gas with high content of CO_2, the lower the temperature is, the smaller the inflexion pressure of compressibility factor curve is. That is because the majority of gas is CO_2 so that the variation of compressibility factor curve of natural gas with high content of CO_2 tends to the compressibility factor of pure CO_2 and the variation tendency of inflexion pressure of the curve is concordant.

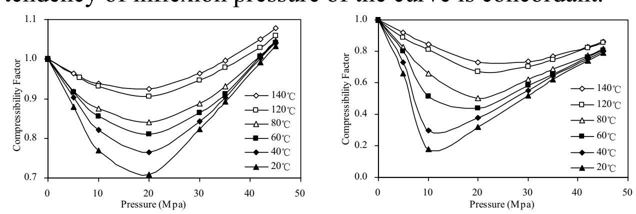

Figure 2. The relationship between pressure and compressibility factor of natural gas with 25% (left) / 98% (right) content of CO_2.

C. CO_2 content

The experiments have been finished that about compressibility factor of natural gas with different contents of CO_2 under the conditions of different temperatures and pressures. Figure 3(left) presents the compressibility factor of gas with different contents of CO_2 and pressures curve at 80℃. Under the same temperature and the same pressure, the compressibility factor of different gas systems change largely with different CO_2 contents and displays a certain rule. With the increase of CO_2 content, the compressibility factor shows a tendency to decline, and the higher the CO_2 content is, the sharper the decline is. That is to say the compressibility factor of natural gas with high content of CO_2 is less than that of natural gas with low content of CO_2. Because CO_2 is a highly compressible gas and the rate of deviation between CO_2 and ideal gas is a major factor.

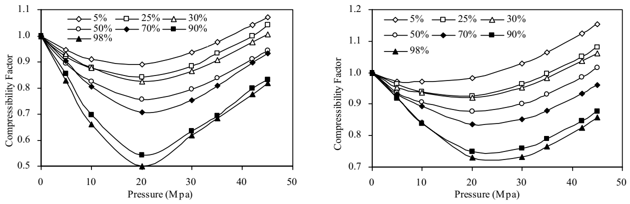

Figure 3. The relationship between pressure and compressibility factor of natural gas with different contents of CO_2 at 80℃(left) / 140℃ (right).

It also expresses that the pressures are 20MPa which the compressibility factor of natural gas with different contents of CO_2 turns downtrend into uptrend at 80℃. But Figure 3(right) reveals that the lower the content of CO_2 of natural gas is, the smaller the inflexion pressure is at 140℃. With the increase of CO_2 content, the inflexion pressure increases. It is also because the CO_2 content of natural gas that the major factor of natural gas is the hydrocarbon component which is leading to the advancing of inflexion pressure when the CO_2 content is small.

IV. METHODS COMPARISION

A. Empirical formula

To compare the data accuracy of compressibility factor obtained from the experiment, it is adopted the calculated value obtained from the relevant empirical formula of fitting Standing and Katz chart (1971) which are proposed by Beggs and Brill.

Fitting formula:

$$
\begin{aligned}
&Z = \mathrm{A} + (1-\mathrm{A})\mathrm{e}^{-\mathrm{B}} + \mathrm{C}p_{\mathrm{pr}}^{\mathrm{D}}\\
&\mathrm{A} = 1.39\left(T_{\mathrm{pr}} - 0.92\right)^{0.5} - 0.36T_{\mathrm{pr}} - 0.101\\
&B = \left(0.62 - 0.23T_{\mathrm{pr}}\right)p_{\mathrm{pr}} + \left(\frac{0.066}{T_{\mathrm{pr}} - 0.86} - 0.037\right)p_{\mathrm{pr}}^2 + \frac{0.32}{10^{9\left(T_{\mathrm{pr}}-1\right)}}p_{\mathrm{pr}}^6\\
&C = 0.132 - 0.32\lg T_{\mathrm{pr}}\\
&D = 10^{\left(0.3106 - 0.49T_{\mathrm{pr}} + 0.1824T_{\mathrm{pr}}^2\right)}\\
&T_{\mathrm{pr}} = \frac{T+273}{T_{\mathrm{pc}}+273}\\
&p_{\mathrm{pr}} = \frac{p}{p_{\mathrm{pc}}}
\end{aligned}
\tag{2}
$$

In the formula, T_{pc}-critical temperature, K; P_{pc}-critical pressure, MPa.

The mentioned above is limited to the situation that the volume content of non-hydrocarbon component is less than 5% (N_2 content is less than 2%, CO_2 content is less than 1%) and the volume content of CH_4 is not less than 50%. Otherwise it will cause a greater error (more than 3%).

The CO_2 which is in the natural gas will affect its critical temperature and critical pressure that will make the increase of compressibility factor and cause other calculation errors. Therefore, it is very necessary to calibrate the critical parameters for acidic natural gas.

When the content of CO_2 is more than 1%, it uses the Wichert and Aziz's method to modify. First, it introduces a corrected value (ε) of the visual critical temperature (T_{pc}) which is based on the function of CO_2 and H_2S's concentration. Then it corrects the apparent critical pressure (P_{pc}). And it uses the corrected value T'_{pc} and P'_{pc} to calculate T_{pr} and P_{pr}.

Correction formula:

$$
\begin{aligned}
&T'_{pc} = T_{pc} - \varepsilon\\
&p'_{pc} = \frac{p_{pc}T'_{pc}}{T_{pc} + n(1-n)\varepsilon}\\
&\varepsilon = \frac{120\left(A^{0.9} - A^{1.6}\right) + 15\left(B^{0.5} - B^4\right)}{1.8}
\end{aligned}
\tag{3}
$$

In the formula, T_{pc}-the visual critical temperature of hydrocarbon mixture, K; T'_{pc}-the corrected critical temperature of hydrocarbon mixture, K; P_{pc}-the visual critical pressure of hydrocarbon mixture, MPa; P'_{pc}-the corrected apparent critical pressure of hydrocarbon mixture, MPa; n-the mole fraction of H_2S in the natural gas, %; ε-the correction fraction of visual critical temperature; A-the sum of the mole fraction of H_2S and CO_2 in the natural gas, %; B-the mole fraction of H_2S in the natural gas, %.

B. Comparison and analysis

On the basis of Table 2, it gives the comparison between measured value and calculated value about the compressibility factor of natural gas with different contents of CO_2. And there are some contrast between the measured data and the empirical formula data. The error range between measured value and calculated value is totally in ± 2% and the average relative error is 0.218% that the natural gas has 25% content of CO_2. However the error range between measured value and calculated value is great (the most is 150%) when the natural gas has 98% content of CO_2. Especially at the low temperature (20℃), the difference between measured value and calculated value is big.

It can be explained that the influence of CO_2 on the compressibility factor cannot be ignored when the primary component of natural gas is CO_2 (its content is more than 80%). It will produce a great error that using the non-hydrocarbon correction method which was proposed by Wichert and Aziz to calculate the compressibility factor of natural gas with high content of CO_2.

V. CONCLUSIONS

a) On the condition of same temperature and same pressure, the compressibility factors of CO_2 and CH_4 possess different variation characteristics. And the compressibility factor of CO_2 has strong temperature sensitivity and pressure sensitivity.

b) In the same system, the greater the pressure is, the weaker the temperature sensitivity of compressibility factor is, and the higher the temperature is, the weaker the pressure sensitivity of compressibility factor is. And for the natural gas with high content of CO_2, the lower the temperature is, the lower the inflexion pressure of compressibility factor curve is.

Table 2. The comparison between measured value and calculated value about the compressibility factor of natural gas with different contents of CO_2.

temperature（℃）	pressure（MPa）	25% content of CO_2 measured value	25% content of CO_2 empirical formula value	25% content of CO_2 fractional error (%)	98% content of CO_2 measured value	98% content of CO_2 empirical formula value	98% content of CO_2 fractional error (%)
20	45	1.0461	1.0481	-0.1937	0.7881	0.7346	7.2894
	42	1.0025	1.0036	-0.1123	0.7400	0.6766	9.3710
	35	0.8921	0.8993	-0.7968	0.6207	0.5415	14.6131
	30	0.8243	0.8243	0.0000	0.5212	0.4453	17.0369
	20	0.7092	0.7095	-0.0493	0.3167	0.2536	24.9055
	10	0.7682	0.7730	-0.6231	0.1760	0.0704	150.1002
	5	0.8796	0.8809	-0.1485	0.6586	0.6000	9.7747
40	45	1.0426	1.0416	0.0989	0.7981	0.7833	1.8875
	42	1.0037	1.0009	0.2749	0.7500	0.7320	2.4541
	35	0.9078	0.9064	0.1583	0.6407	0.6123	4.6419
	30	0.8371	0.8433	-0.7352	0.5512	0.5266	4.6590
	20	0.7642	0.7648	-0.0766	0.3767	0.3552	6.0625
	10	0.8207	0.8206	0.0104	0.2960	0.3149	-6.0027
	5	0.9037	0.9063	-0.2799	0.7286	0.7425	-1.8678
60	45	1.0325	1.0398	-0.7064	0.8065	0.8054	0.1407
	42	1.0022	1.0025	-0.0348	0.7595	0.7596	-0.0144
	35	0.9120	0.9189	-0.7432	0.6548	0.6523	0.3821
	30	0.8652	0.8663	-0.1216	0.5811	0.5754	0.9951
	20	0.8096	0.8067	0.3593	0.4370	0.4208	3.8299
	10	0.8566	0.8576	-0.1113	0.5159	0.5475	-5.7861
	5	0.9171	0.9258	-0.9373	0.8005	0.8097	-1.1444
80	45	1.0412	1.0427	-0.1441	0.8176	0.8187	-0.1307
	42	0.9978	1.0083	-1.0426	0.7744	0.7773	-0.3720
	35	0.9318	0.9335	-0.1844	0.6841	0.6803	0.5591
	30	0.8830	0.8887	-0.6410	0.6190	0.6106	1.3736
	20	0.8403	0.8429	-0.3049	0.5012	0.4726	6.0434
	10	0.8755	0.8874	-1.3495	0.6591	0.6751	-2.3717
	5	0.9182	0.9411	-2.4359	0.8274	0.8500	-2.6647
120	45	1.0588	1.0588	0.0000	0.8525	0.8366	1.8974
	42	1.0293	1.0293	0.0000	0.8192	0.8020	2.1512
	35	0.9793	0.9685	1.1165	0.7443	0.7206	3.2907
	30	0.9470	0.9350	1.2858	0.7004	0.6643	5.4383
	20	0.9062	0.9048	0.1572	0.6704	0.6460	3.7790
	10	0.9310	0.9322	-0.1329	0.8090	0.7916	2.1981
	5	0.9528	0.9632	-1.0810	0.8843	0.8986	-1.5975
140	45	1.0812	1.0714	0.9172	0.8575	0.8444	1.5533
	42	1.0501	1.0439	0.5992	0.8253	0.8123	1.6102
	35	0.9963	0.9885	0.7918	0.7649	0.7404	3.2987
	30	0.9634	0.9588	0.4892	0.7335	0.7036	4.2533
	20	0.9253	0.9312	-0.6336	0.7291	0.7089	2.8486
	10	0.9387	0.9489	-1.0836	0.8425	0.8259	2.0151
	5	0.9641	0.9711	-0.7239	0.9197	0.9149	0.5185

c) Under the same temperature and the same pressure, the compressibility factors of different gas systems are strongly sensitive to CO_2 component. At 140 ℃ , the inflexion pressure of compressibility factor curve increases with the increase of CO_2 content.

d) At the low temperature (20℃), it suggests to adopt laboratory experiment to measure the compressibility factors, and it will produce a great error if using the non-hydrocarbon correction method to calculate the compressibility factor of natural gas with high content of CO_2.

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