Optimization of calculation method for natural gas deviation coefficient of tight sandstone gas reservoir in Ordos Basin

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Abstract. The deviation coefficient of natural gas is an important parameter in the evaluation of gas reservoir geological reserves and the analysis of pipeline gathering and transportation capacity. For S blocks the status quo, no natural gas high pressure physical properties test data. In the current commonly used deviation based on the analysis of calculation method and the suitable condition, according to the S block formation temperature pressure condition and gas components, using different calculation methods for calculation, the gas deviation factor under different pressure and adjacent regions natural gas high pressure physical properties test results, S block gas deviation factor calculation method for optimization. The research shows that the calculated results of the beggs-Brill method are similar to the test results, and it is appropriate to use the Beggs-Brill method to calculate the natural gas deviation coefficient in Block S.

Keywords: Tight sandstone; Gas reservoir; Deviation coefficient.

1. Introduction
The deviation coefficient of natural gas refers to the ratio of the volume occupied by the real gas field to the volume occupied by the ideal gas with the same data under the same temperature and pressure, which reflects the degree of the actual gas deviating from the ideal gas state. Determining the deviation coefficient of natural gas correctly is crucial to the calculation of natural gas reserves and the formulation of development strategies [1]. Since Standing and Katz published the natural gas deviation coefficient chart in 1941, scholars at home and abroad have proposed various analytical calculation methods [2-10].

Block S is an upper Paleozoic gas reservoir in The Ordos Basin. It has not entered the stage of large-scale development yet, and the lack of high-pressure physical property data of natural gas brings great difficulties to the accurate evaluation of underground reserves. Therefore, it is necessary to optimize the calculation method of deviation coefficient for this area according to the reservoir characteristics.
2. Common calculation method of deviation coefficient

There are many methods to calculate the deviation coefficient of natural gas. At present, the commonly used methods mainly include Hall-Yarborough method, Dranchuk-abu-Kassem method and Beggs-Brill method.

(1) Hall-Yarborough method

Based on the Carnahan-Starling (1972) equation of state, the Hall-Yarborough method uses standing-Katz map data fitting parameters to obtain:

\[ Z = \frac{0.06125 P_{pr} t}{y} \exp[-1.2(1-t)^2] \]  
(1)

\[ F(y) = -0.06125 P_{pr} t \cdot \exp[-1.2(1-t)^2] + \frac{y^2 + y^3 - y^4}{(1-y)^3} \]
\[ - (14.76 t - 9.76 r^2 + 4.58 r^3) y^2 + (90.7 t - 242.2 r^2 + 42.4 r^3) y^{(1.18+2.82)} \]

\[ = 0 \]  
(2)

Where, \( t \) is the reciprocal of the quasi-comparative temperature, \( t = \frac{1}{T_{pr}} \); \( y \) is the "contrast density" specifically defined. After solving for \( y \) iteratively, the \( Z \) value can be calculated. Equation (2) is a nonlinear equation. Newton iteration method is needed to solve \( y \). Newton iteration format is as follows:

\[ y^{k+1} = y^k - \frac{F(y^k)}{F'(y^k)} \]  
(3)

Where, \( F'(y) \) can be derived from equation (3):

\[ F'(y) = -\frac{1+4y+4y^2-4y^3+4y^4}{(1-y)^4} - (29.52 t - 19.52 r^2 + 9.16 r^3) \]
\[ + (2.18 + 2.82 r)(90.7 t - 242.2 r^2 + 42.4 r^3) y^{(1.18+2.82)} \]  
(4)

This method is applicable to \( T_{pr} > 1.0 \).

(2) Dranchuk-abu-Kassem method

The theoretical basis of Dranchuk-Abu-Kassem equation is also the Benedict-Web-Rubin equation of state. Through fitting analysis of 1,500 data on the Standing-Katz chart, the state equation of 11 coefficients are obtained as follows, where the coefficients are shown in Table 1.

\[ Z = 1 + \left[ A_{1} + \frac{A_{2}}{T_{pr}} + \frac{A_{3}}{T_{pr}^2} + A_{4} \right] \rho_{pr} + A_{5} + \frac{A_{6}}{T_{pr}} + \frac{A_{7}}{T_{pr}^2} \rho_{pr}^2 \]
\[ - A_{8} \left[ \frac{A_{9}}{T_{pr}} + \frac{A_{10}}{T_{pr}^2} \right] \rho_{pr}^5 + A_{11}(1 + A_{11} \rho_{pr}^2) \frac{\rho_{pr}^2}{T_{pr}} \exp(1 - A_{11} \rho_{pr}^2) \]  
(5)

The calculation method of this method is the same as the DPR method, and the required formula is as follows:
\[ F(\rho_{pr}) = \rho_{pr} - 0.27 \rho_{pr} / T_{pr} + (A_1 + A_2 / T_{pr} + A_3 / T_{pr}^2 + A_4 / T_{pr}^3) \]

\[ + A_5 / T_{pr}^5 \rho_{pr}^3 + (A_6 + A_7 / T_{pr} + A_8 / T_{pr}^2) \rho_{pr}^2 \]

\[ - A_9 (A_9 / T_{pr} + A_9 / T_{pr}^2) \rho_{pr} + (A_{10} / T_{pr}^3) \]

\[ \times (1 + A_{11} \rho_{pr}^3) \exp(-A_{12} \rho_{pr}^2) \]  

(6)\[ F'(\rho_{pr}) = 1 + (A_1 + A_2 / T_{pr} + A_3 / T_{pr}^2 + A_4 / T_{pr}^3 + A_5 / T_{pr}^4 + A_6 / T_{pr}^5) \]

\[ \times 2\rho_{pr} + (A_9 + A_9 / T_{pr} + A_9 / T_{pr}^2) \times 3 \rho_{pr}^2 \]

\[ - A_9 (A_9 / T_{pr} + A_9 / T_{pr}^2) \times 6 \rho_{pr}^5 + (A_{10} / T_{pr}^3) \]

\[ \times [3 \rho_{pr}^2 + A_{11} (3 \rho_{pr}^4 - 2 A_{11} \rho_{pr}^6) \] \exp(-A_{12} \rho_{pr}^2) \]  

(7)\[ This \ method \ is \ applicable \ to: \ 1.0 \leq T_{pr} \leq 3.0, \ 0.2 \leq p_{pr} \leq 3.0. \]

(3) Beggs-Brill method

\[ Z = A + \frac{1}{e^B + C p_{pr}^D} \]  

(8)\[ Among \ them \]

\[ A = 1.39 \left(T_{pr} - 0.92\right)^{0.5} - 0.36 T_{pr} - 0.101 \]  

(9)\[ B = \left(0.62 - 0.23 T_{pr}\right) p_{pr} + \left[ \frac{0.066}{T_{pr} - 0.86} - 0.037 \right] p_{pr}^3 + \frac{0.32}{10^9 \left(T_{pr} - 1\right)} p_{pr}^6 \]  

(10)\[ C = 0.132 - 0.32 \log T_{pr} \]  

(11)\[ D = 10^\left(0.3106 - 0.497 T_{pr} + 0.1824 T_{pr}^2\right) \]  

(12)\[ 3. \ Optimization \ of \ calculation \ method \ of \ deviation \ coefficient \ of \ block \ S \]

S block is located in the north of Yishan slope, the Ordos Basin carboniferous benxi formation, upper palaeozoic bottom-up development in the area, Permian taiyuan, shanxi group, under the stone box, upper stone box and shi qian feng group, which contains in Shanxi Province, the stone box group as the main reservoir, belongs to the sea and land transition phase - continental clastic sediment. Main production box 8 has an effective thickness of 6–9m, average porosity of 8.3% and average permeability of 0.809mD. The average formation pressure is 28.95mpa, the pressure coefficient is 0.82, the gas layer temperature is 102.39-118.6 ℃, and the geothermal gradient is 2.93℃/100m. In natural gas, the average CH4 content is 95.63%, CO2 content is 0.61%, H2S content is 0–9.9mg/m3, relative density is 0.5811, it is a typical dry gas reservoir with low porosity, low permeability and low abundance.

No material test data of high pressure in Block S. Considering that the gas composition of the upper ancient gas reservoirs in this area is similar to that of the adjacent area, therefore, the Hall-Yarborough, Dranchuk-abu-Kassem and Beggs-Brill methods are used to calculate the natural gas deviation coefficient under different pressures. Combined with the high-pressure physical properties test results of natural gas in the adjacent area, the calculation method of natural gas deviation coefficient in block S is optimized. The research shows that the calculated results of the beggs-Brill method are similar to the test results, so it is appropriate to use the Beggs-Brill method to calculate the natural gas deviation coefficient in Block S.
4. Conclusion and cognition

Different calculation methods are used to calculate the natural gas deviation coefficient in Block S of the Ordos Basin. Comparative analysis shows that the method of beggs-Brill is suitable for calculation of natural gas deviation coefficient in this area.

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