Estimation of recoverable reserves of shale gas by isothermal adsorption curve

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Abstract

Shale gas from the enrichment state can be divided into free gas and adsorbed gas, that exist in the calculation can be mining reserves time don't from that of conventional natural gas, for the reasonable use of the analytic method of shale gas in China Geological Exploration measured the shale gas content, that can match the recoverable resources, according to the Langmuir adsorption isotherm equation is used to calculate the adsorption gas recoverable reserves. In the practical application, the Langmuir isothermal adsorption curve measured in the laboratory is generally different from that of the formation temperature, which needs to be calculated for the isothermal adsorption curve at the formation temperature. The activation temperature of desorption, desorption temperature is more conducive to. The isothermal adsorption curve at the corresponding temperature is more realistic to reflect the actual block of shale gas recoverable reserves.

Keywords

shale gas, adsorption curve, recoverable reserves; adsorbed gas; free gas.

1. Introduction

Increased global demand for oil gas and improvement of exploitation technology have led to increased presence of non-conventional gas projects in foreign trade and production of oil gas [1-3]. Thereinto, shale gas, an unconventional natural gas hosted in shale and a new energy with high exploitability, accounts for an increasingly larger proportion. Shale gas' exploitable quantity refers to the proved (including excavated) and unproved exploitable total shale gas estimated during specific period under future foreseeable economic and technical conditions. It both serves as an important material basis to judge whether shale gas field has economic value and an important reference to formulate next-step development program and determine dimension of investment.

Therefore, it is very important to make reasonable estimate over exploitable quantity of shale gas. Thereinto, how to accurately calculate non-conventional gas reserves is much focused.[5-7].

The development prospect for shale gas is considerable across the world, with about 300 countries embarking on the exploratory development of shale gas at present. Mudstone and shale accounts for a proportion of about 60% in all sedimentary rocks and total reserves of shale gas in the world are about 456.324×10^{12} m^3,American surged ahead in commercialized production of shale oil gas, with over 35,000 shale gas production wells and annual output of over $200\times10^8 m^3$. Canada is hard on America's heels, while Australia has just started. In Asia, an upsurge of developing shale gas is under way in China, and revolution of shale gas has slipped into Europe[9-12].

Theoretically, many calculation methods for geological reserves of shale gas exist according to characteristics of the resources: for the newly explored area and initial development period, Monte-Carlo approach, abundance analogy method and volumetric method can be employed. For the region where real production has been carried out for a period of time, material balance method and single-well reserves successive subtraction method, etc. can be employed.

The paper calculates geological reserves of shale gas by numerical simulation application volumetric method, and calculates theoretical maximum recovery efficiency in shale gas exploitation using Langmuir Adsorption Isotherm to finally estimate the exploitable quantity of shale gas.

2. Calculate shale gas quantity using numerical simulation method

Petrel software is used to establish static model to estimate reserves of gas pool of shale gas in shale block I. During the modeling, GetData software is needed to process block relief map. The ground chorogram is digitized, and the digitized data stream is input into Petrel software to establish 3D-grid volume model(figure 1), density model(figure 2), free gas abundance model(figure 3)and adsorbing gas abundance model(figure 4)for the gas pool in shale:

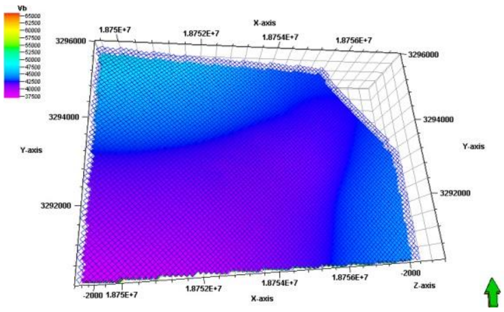

Fig. 1 volume model of 3D mesh

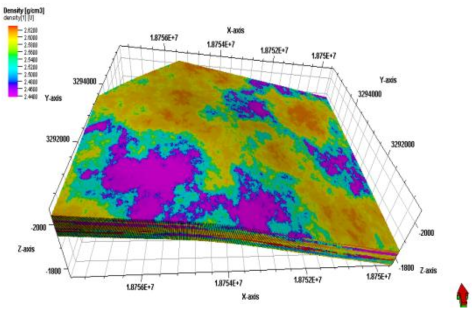

Fig. 2 density model

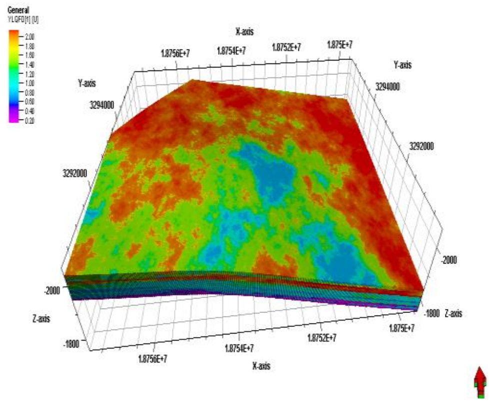

Fig. 3 free gas abundance

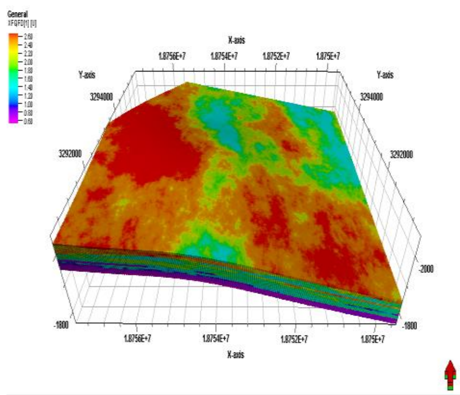

Fig. 4 adsorption gas abundance

When Petrel software is used to establish statistical geological model for calculation of reserves, the parameters used are not average value, instead, air content parameters in each grid in geological model are used for accumulative calculation. In Petrel software, each grid is assigned with a set of reserves parameter value and the grid-based calculation of reserves has much higher accuracy than other methods. After 3D-grid volume model and air content model are established, reserves can be calculated according to Petrel model by following way:

$$G = \text{grid volume x density of shale gas x gas content} \tag{1}$$

Model calculation result shows geological reserves of shale gas in gas pool field in shale block Ⅰ are about $2.46\times10^{10}m^3$. The geological reserves of shale gas obtained using volumetric method are $2.42\times10^{10}m^3$. The two calculation methods give similar result.

3. Research on calculation methods for exploitable reserves of shale gas

3.1 Calculation of exploitable reserves of adsorbing gas

Different from conventional reservoirs, in shale gas reservoir, the gas reserved in shale constituent is mainly concentrated in micropore of terrane and is in absorbed state under action of pressure. It can be desorbed to free form only when reservoir pressure declines to critical desorption pressure to seep to mineshaft through bedrock and fissure system. This absorption/desorption characteristics of shale basically conform to Langmuir isothermal adsorption equation. The adsorption isothermal curve can be expressed as [10]:

$$V = \frac{V_L P}{P_L + P} \quad (2)$$

Theoretical maximum recovery efficiency is:

$$\eta = 1 - P_{ad}(1 + bP_{cd}) / P_{cd}(1 + bP_{ad}) \quad (3)$$

Critical desorption pressure:

$$P_{cd} = V_{me} P_L / (V_L - V_{me}) \quad (4)$$

Exploitable quantity of resources is:

$$G_r = G\eta_i \quad (5)$$

Where: V——absorbed quantity of shale gas; P——reservoir pressure; P_L ——Langmuir pressure, reflecting capacity of inner surface of shale to absorb gas; V_L ——Langmuir volume, representing the maximum absorption capacity of shale; P_{cd} ——critical desorption pressure; P_{ad} ——abandonment pressure of shale gas well; V_{me} ——actually measured air content of shale; G——theoretical maximum recovery efficiency of absorbed gas; G_r ——Exploitable quantity of absorbed gas

Generally Langmuir isothermal adsorption curve is different from formation temperature in practical situation, and should be converted to isothermal adsorption curve at formation temperature through calculation. Temperature can activate desorption. The higher the temperature, the easier the desorption. When temperature rises, pressure constant b decreases, so does adsorptive capacity and adsorption quantity. Different temperature interval and coal samples lead to varying decrease degrees of absorbed quantity.

Langmuir isothermal adsorption curve changes with temperature fluctuation as follows:

$$V = \frac{V_L P}{P + P_L} \exp\left[n(t - t_0)\right] \quad (6)$$

Where: V_L ——Langmuir volume, P_L ——Langmuir volume; V—gas absorbed quantity under pressure P; t——experiment temperature; t_0 is reservoir temperature;

$$n = \frac{0.02}{0.993 + 0.7p} \quad (7)$$

Langmuir isothermal adsorption curve under corresponding formation temperature can be calculated by formula(2)and(6)

3.2 Calculation of exploitable reserves of free gas

The calculation formula is:

$$PV=NRT \quad (8)$$

Ratio of primary reserves to quantity of remaining reserves material

$$\frac{p_a}{P} = \frac{N_a}{N} \quad (9)$$

Theoretical maximum recovery efficiency:

$$\eta = 1 - \frac{N_a}{N} \quad (10)$$

Theoretical maximum output:

$$M_P = M\eta \quad (11)$$

Where, P—average pressure in primary reservoir; Pa— average pressure on formation (when flowing bottom-hole pressure reaches abandonment pressure); N—quantity of primary free gas material; Na—quantity of remaining free gas material;

4. Application example

For the Langmuir isothermal adsorption curve at 30℃ in this paper, following data are presented, and exploitable reserves of absorbed gas at 85℃ are calculated. The average value for air content of shale is 1.97m^3/t,

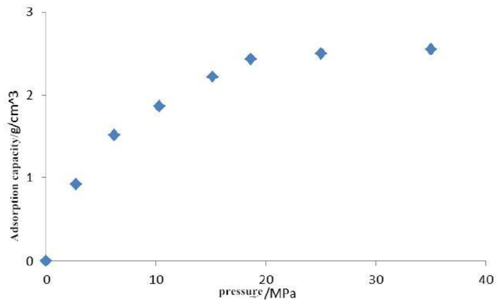

Figure 5 Adsorption test data measured at 30℃

Langmuir volume and Langmuir pressure can be obtained after fitting using First Option software

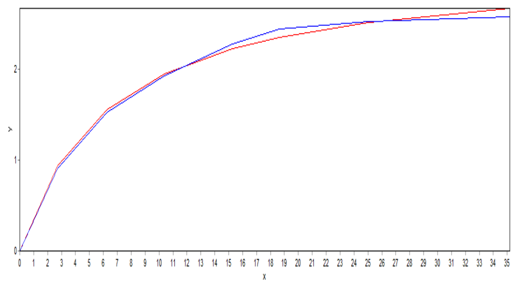

Figure 6 Langmuir curve diagram after fitting

Model formula:

$$y = a \times x/(b+x) \tag{12}$$

$$y = \frac{3.1519x}{(6.4426+x)} \tag{13}$$

Langmuir pressure is 6.44MPa and Langmuir volume is 3.15 cm^3/g

Langmuir isothermal adsorption curve is obtained under formation condition by bringing formation temperature of 85℃ into formula(6)and(7).Then the pressure and absorbed quantity at 85℃ can be calculated.

Table 1 Adsorption quantity corresponding to 85 °

pressure	30℃Adsorption capacity	85℃Adsorption capacity
0	0	0
2.70042	0.906401	0.63557
6.24473	1.51872	1.263556
10.3797	1.92	1.702007
15.2743	2.27	2.01737
18.6498	2.43922	2.16586
25.0633	2.54	2.362546
35.1899	2.56843	2.551807

Again First Option software is used to simulate to get Langmuir pressure and Langmuir volume at formation temperature.

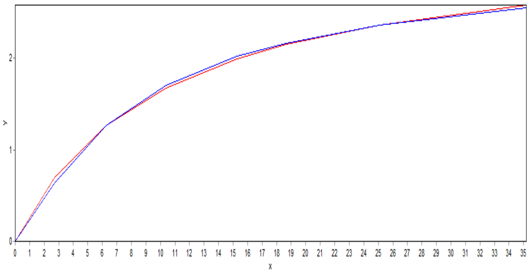

Figure 7 Langmuir isothermal adsorption curve diagram at formation temperature

Model formula:

$$V = V_L P / (P_L + P) \tag{14}$$

$$y = \frac{3.3302x}{(10.2285 + x)} \tag{15}$$

Langmuir pressure is 10.22MPa, and Langmuir volume is 3.33 cm^3/g .

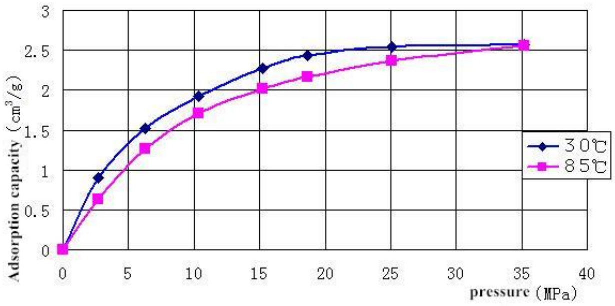

Figure 8 Comparison of Langmuir isothermal adsorption curves at experimental temperature and formation condition

Table 2 Calculation table of exploitable quantity of shale gas in researched area

	reserves (108m3)	Recoverable reserves (108m3)	recovery ratio (%)
Adsorbed gas	139	21.31	15.33
Free gas	105	71.02	67.64
Shale Gas	244	92.33	37.84

5. Conclusion

The concentration state of shale gas and particularity of development mode determine particularity in calculation method of exploitable reserves. However, the compact reservoir and diversified hosting modes of fluid, etc. significantly increase uncertainty in calculation of non-conventional gas reserves. The paper utilizes isothermal adsorption curve to calculate exploitable reserves of shale gas, and converts adsorption curve at experimental temperature to get adsorption curve at corresponding formation temperature to calculate exploitable reserves, which provides a good solution to exploitable potential of shale gas.

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