Acta Technica 62 No. 2B/2017, 141–150

Production prediction model of coalbed methane wells at stable production stage

Jia Liu[1], Yinghong Liu[1], Ruyong Feng[1], Kailei Yang[1]

Abstract. To calculate the production capacity of coalbed methane wells at stable production stage, a seepage mathematical model suitable for coalbed methane wells at stable production stage is established based on the theory of seepage and the adsorption and desorption characteristics of coalbed methane to get the productivity equation of coalbed methane production so that the production capacity of coalbed methane wells can be predicted. The results show that the low critical desorption pressure leads to the lack of energy in the course of methane production. The weakness of gas expansion energy and the difficulty in pressure dropping will also seriously affect the gas production. The reduction of bottomhole flowing pressure can effectively improve the productivity of coalbed methane wells, and the increase in gas production is more prominent when the bottomhole flowing pressure is relatively high. It is advisable to install pump hanging tools in coalbed methane wells whose bottomhole flowing pressure is greater than 1.5 MPa

Key words. Coalbed methane, capacity prediction, critical desorption pressure, bottomhole flowing pressure, pump hanging tools.

1. Introduction

Since a vast majority of the coalbed methane adsorbed into the solid matrix of the coal, the main method of coalbed methane mining is depressurization. The coalbed methane is different from conventional natural gas in terms of hydrocarbon accumulation mechanism, occurrence state, distribution law and exploration and development mode [1–3]. During the period of 2011–2015, China has accelerated the construction of two industrial bases in the Qinshui Basin and the eastern Ordos. The new proven geological reserves in China are 350.41 billion m^3, and the accumulated proven geological reserves are 629.27 billion m^3. However, in terms of coalbed methane production, the production of a single well is still too low [4–5].

[1]CNOOC Research Institute, 100028, Beijing, China

Therefore, it is of great importance to predict the methane production capacity of coalbed wells since it is helpful for decision-makers in selecting wells and predicting the single production capacity of a single well when it is comes to new wells and to determine whether the current production is normal or whether the gas production has reached the peak in terms of old wells so that the data can be used to guide the work and adjust the work system. Thus, how to effectively predict coalbed methane production capacity and how to effectively determine the production possibility curve of coalbed methane wells becomes an important research topic in the development of coalbed methane.

Currently, there is no deep understanding on the prediction of coalbed methane production capacity. One approach to obtain the methane production capacity in coalbeds with artificial cracks and stress-sensitive coalbeds based on the seepage theory [6–7]. By calculating the production capacity of coalbed methane wells under different production pressures, they found that the extraction of coalbed methane needs to set up reasonable production pressures and strictly control the mining intensity. However, these models treat coalbed methane as a conventional reservoir, considering nothing about the adsorption and desorption properties of coalbed methane reservoirs. The coalbed methane production capacity could be predicted by he numerical method with taking desorption, diffusion and seepage processes of coal seam methane into consideration [8]. A neural network back propagation (BP) model was established for time series forecasting the dynamic production capacity of coalbed methane wells, with the modern artificial intelligence theory and mathematical statistics theory. The model could well fit the production history of coalbed methane wells and can make accurate quantified prediction [9–10]. Another method has established a type curve to analyze the correlation between the dimensionless production and time and established an equation to show the relationship between dimensionless production under different Langmuir pressures and practice and proposed some methods to use the type curve to predict the coalbed methane production [11]. However, the two above-mentioned formulas are established only on practice and do not take the seepage into consideration. This paper, based on the theory of seepage and the adsorption and desorption characteristics of coalbed methane, establishes a seepage mathematical model for coalbed gas wells at stable production stage. By introducing the pressure variable into the model and solve it, we can get an equation to predict the coalbed methane production, which is helpful to guide the efficient extraction of coalbed methane.

2. Analysis methods

Suppose in a mean circular strata whose temperature is in a constant state and of equal-thickness, a coalbed methane well located at the center of it is producing gas at a small time step with a fixed production. If the seepage flow is steady at this time, the differential equation can be expressed as

$$\frac{\mathrm{d}}{\mathrm{d}r}\left(r\frac{\mathrm{d}\tilde{P}}{\mathrm{d}r}\right) = 0\,. \tag{1}$$

Equation (1) is a second-order ordinary differential equation, whose general solution is

$$\tilde{P} = C_1 \ln r + C_2\,, \tag{2}$$

where r is the radius and $\tilde{P}$ is the pressure coefficient given by the relation

$$\tilde{P} = \int \rho\,\mathrm{d}P + C\,. \tag{3}$$

Here, P denotes the pressure. The pressure coefficient $\tilde{P}$ was created to make the calculation easier.

Substituting the following boundary conditions

$$\text{borehole wall} : r = r_{\mathrm{w}} \qquad \tilde{P} = \tilde{P}_{\mathrm{w}}\,, \tag{4}$$

$$\text{external boundary} : r = r_{\mathrm{e}} \qquad \tilde{P} = \tilde{P}_{\mathrm{e}}\,. \tag{5}$$

As the coalbed methane is adsorbed gas, only when the pressure is lower than the critical desorption pressure the coalbed methane can desorb from surfaces, diffuse through the coal matrix and become free gas. However, the strata not in the range of desorption sees no gas flow. Therefore, in equation (5), $\tilde{P}_{\mathrm{e}}$ is the critical desorption pressure, r_{e} is the desorption radius, $\tilde{P}_{\mathrm{w}}$ is the bottomhole flowing pressure, and r_{w} is the radius of the wellbore.

Then we obtain:

$$C_1 = \frac{\tilde{P}_{\mathrm{e}} - \tilde{P}_{\mathrm{w}}}{\ln \frac{r_{\mathrm{e}}}{r_{\mathrm{w}}}} \quad C_2 = \tilde{P}_{\mathrm{w}} - \frac{\tilde{P}_{\mathrm{e}} - \tilde{P}_{\mathrm{w}}}{\ln \frac{r_{\mathrm{e}}}{r_{\mathrm{w}}}} \ln r_{\mathrm{w}}\,. \tag{6}$$

Substituting C_1 and C_2 into (2) we can obtain the equation for the pressure function in the form

$$\tilde{P} = \tilde{P}_{\mathrm{e}} - \frac{\tilde{P}_{\mathrm{e}} - \tilde{P}_{\mathrm{w}}}{\ln \frac{r_{\mathrm{e}}}{r_{\mathrm{w}}}} \ln \frac{r_{\mathrm{e}}}{r}\,. \tag{7}$$

In order to obtain the production Q, Darcy's law is used. Usually the volume of gas will change with the pressure. However when seepage flow is stable, the mass flow rate is a constant which can be obtained by multiplying area of the cross-section and mass flow rate.

$$M = \frac{2\pi K h(\tilde{P}_{\mathrm{e}} - \tilde{P}_{\mathrm{w}})}{\mu \ln \frac{r_{\mathrm{e}}}{r_{\mathrm{w}}}}\,. \tag{8}$$

In the above equation, h is the formation thickness, K is the cleavage permeability, Q is the gas production in standard conditions and μ is the gas viscosity.

The volume flow rate of the planar radial flow well under the standard condition is then

$$Q = \frac{\pi K h}{\mu} \frac{T_{\mathrm{a}}}{P_{\mathrm{a}} \bar{z} T_{\mathrm{f}}} \frac{P_{\mathrm{e}}^2 - P_{\mathrm{w}}^2}{\ln \frac{r_{\mathrm{e}}}{r_{\mathrm{w}}}} . \tag{9}$$

Here, T_{a} is the temperature under standard conditions, T_{f} is the formation temperature, P_{a} is pressure under standard conditions and $\bar{z}$ is the compression factor.

3. Analysis and discussion

In order to verify the applicability of this model, this paper chooses the real block to carry on the contrast simulation. Since the southeastern part of the Shizhuang South Block has been recovered for a relatively long time and its control system is relatively stable, this paper will take this block as the example to test the veracity of this model by comparing the prediction results of this model separately with the data in numerical simulation and actual mining process.

First, the result difference between the capacity prediction model and the commercial numerical simulation software is compared. By analyzing the geological parameters of the existing mining wells, among which, the thickness, porosity and initial pressure etc. are measured values while permeability, gas content, and critical desorption pressure etc. are calculated values based on the production data. Then, a typical coalbed methane geological model suitable for the target block is established on the average of the above-mentioned parameters. The parameters used in the model are shown in Table 1. Based on these parameters, capacity prediction model and numerical simulation software will be used separately to predict the gas production of coalbed methane wells.

Table 1. Typical model parameters in the target block of four kinds of light sources

Well control area	300 m×300 m	Thickness	6 m
Permeability	10^{-3} μm^2	Porosity	5.82 %
Gas content	17.2 m^3/t	Initial pressure	6.0 MPa
Critical desorption pressure	2.2 MPa	Bottomhole pressure	0.2 MPa

Then, the commercial numerical simulation software is used to simulate the geological model. The dynamic fluid level will be declined at a speed of 3 m/d in the process of water-pumping and depressurization, that is, the descent speed of the bottomhole flowing pressure will be controlled at 0.03 MPa/d. After gas comes to the surface, slow the descent speed of the dynamic fluid level to 0.1 m/d. The simulation results are shown in the Fig. 1. This coalbed methane well enters the stable yield period after experiencing the water-pumping and depressurization period and the production-rising period, whose gas production remains at about 1350 m^3/d.

Then the capacity prediction model will be used to calculate the coalbed methane production under the same geological parameters. It can be seen from the formula (9) that the gas production in the coalbed methane wells is mainly related to the

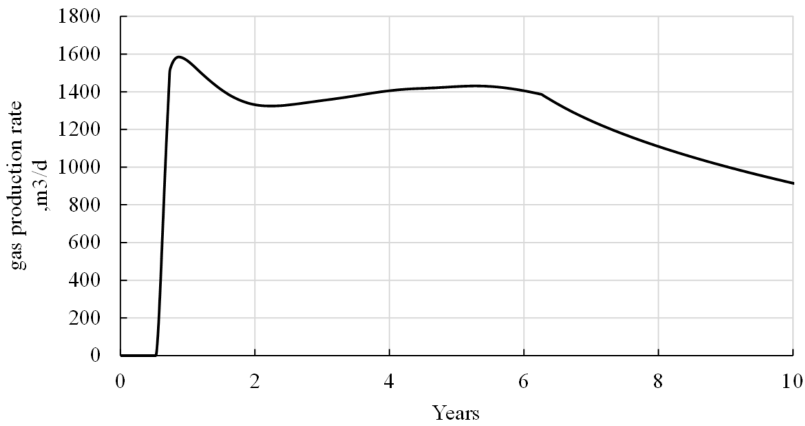

Fig. 1. Curve of numerical simulation results of gas production in target area

desorption radius. The larger the desorption radius is, the smaller the daily gas production is. This is because the larger the desorption radius is, the smaller the pressure drop of each grid can get from the same water production, and therefore the less the desorbed gas will be. However, it can be seen from the calculation result that the gas production is reduced at a small rate and basically maintains stable.

For the convenience of comparison, we will use the daily gas production data whose desorption radius is 70 m. The results show that the calculated gas production at stable stage is about 1400 m^3/d in the capacity prediction model (see Fig. 2), and the error between the results of the capacity prediction model and the numerical simulation is within the reasonable range. Therefore, it can be concluded that the capacity data derived from the prediction model and the numerical simulation are in good agreement.

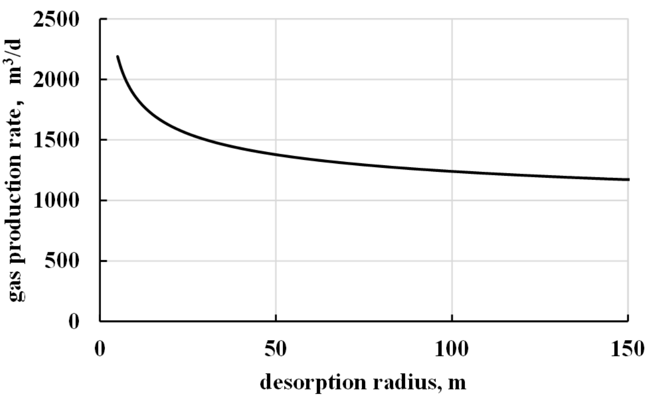

Fig. 2. Calculated results of gas production of a single well in target area

The production data of 32 single wells in Shizhuang South block that have produced gas and whose drainage system is stable and production rate per hour is high are selected in the calculation process. The calculation parameters are selected according to the actual well test data, among which, the viscosity is 0.013 mPa s and the well diameter is 0.1 m. The permeability is 0.25 mD–3.74 mD according to the coalbed well gas test. The thickness of the coal seam is based on the actual test data of each well, and the critical desorption pressure and the bottom hole pressure are taken from the actual production data. The critical desorption pressure is the bottomhole flowing pressure when the gas comes to the surface of the wells. The results are shown in Fig. 3.

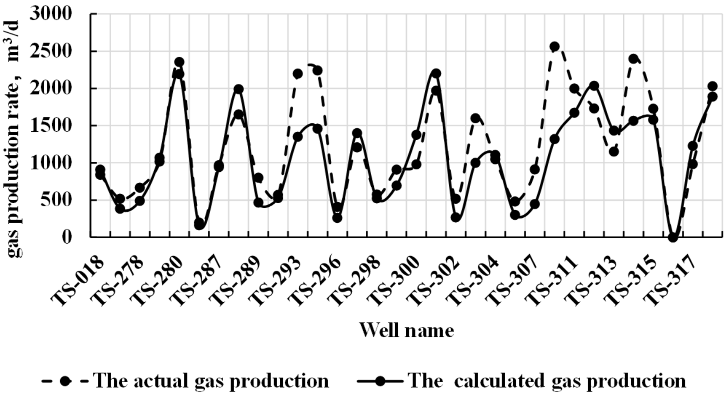

Fig. 3. Comparison between the theoretical gas production and the actual gas production in target area

The results show that 85 % of the predicted results are in good agreement with the actual mining data, with an average error of 10 % and a minimum error of less than 3 %. Therefore, it can be concluded that this model can be used to predict coalbed gas production. Some of the wells (15 %) have poor prediction of gas production. There are two main reasons accounting for this poor prediction. First, the permeability of coal seam is unclear, and the underground permeability cannot be truly reflected. Second, there is some error in the measurement of bottomhole flowing pressure.

Based on the capacity prediction model, the influencing factors of coal seam permeability, coal seam thickness, critical desorption pressure and bottomhole flowing pressure are analyzed respectively.

The results show that the gas production of coalbed methane wells increases with the increase of coal seam permeability, thickness and critical desorption pressure and there is a linear relationship between the permeability, coal thickness and gas production.

The critical desorption pressure is proportional to the gas production in terms of power function, i.e., with the increase of the critical desorption pressure, the daily production is increased.

However, the above-mentioned three parameters (permeability, coalbed thickness, critical desorption pressure) all are the attributes of coal seam itself, so it is difficult to increase the production through the existing technology. Although the artificial fracturing technology can increase the permeability to a certain extent, its function is only limited to the range around the coalbed methane wells, and the secondary fracturing will not only increase the cost but also bring higher risk, so it is unlikely to adjust the coal seam permeability after the production. Therefore, the bottomhole flowing pressure becomes one of the important parameters to control the production of coalbed methane wells. Reducing the bottomhole flowing pressure can improve the gas production of coalbed methane wells and the bottomhole flowing pressure can be further reduced in the well site by the installation of pump hanging tools.

The calculation results show that the gas production of coalbed methane increases with the pressure drop of the bottom hole, and the increase rate is getting smaller and smaller. So, when the bottom hole pressure is high, reducing the bottomhole flowing pressure can get a larger increase in gas production.

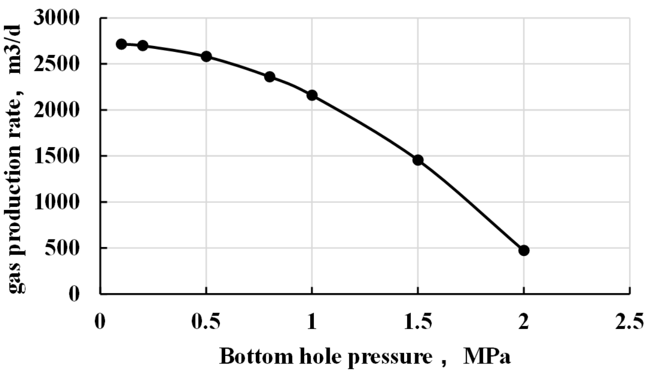

Fig. 4. Curve of coalbed methane production and bottomhole flowing pressure

Presently, there are some wells in the southeastern part of the Shizhuang South Block have installed pump hanging tools in their operation and the daily gas production has increased to a certain extent. The following figure shows the relationship between the bottomhole flowing pressure before the operation and the increase of gas production after installing the pump hanging tools. The results show that the larger the bottomhole flowing pressure is, the larger the growth rate is, which is in agreement with the theoretical results of this study. In order to obtain a better yield effect, it is suggested to select the coalbed methane wells with the bottomhole flowing pressure greater than 1.5 MPa t before installing the pump hanging tools.

4. Conclusion

Currently, there is no deep understanding on the prediction of coalbed methane production capacity. This paper establishes capacity prediction model of coalbed methane wells at stable production stage based on the classic theory of seepage and the special mining rule of coalbed methane. Based on the geological parameters of

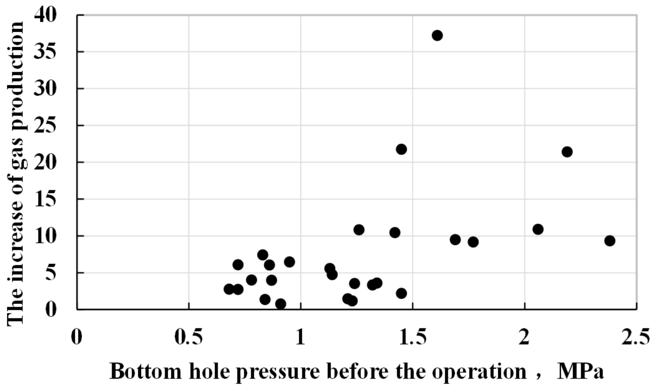

Fig. 5. Curve between the bottomhole flowing pressure and production increase with pump hanging tools of the coalbed methane wells in the target area

the southeastern part of the Shizhuang South Block, the gas production capacity of coalbed methane wells at stable production stage is calculated by the capacity prediction model, which is then compared with data produced by the numerical simulation and the data in the actual production. The results show that this model has good applicability. The influencing factors: permeability, coal seam thickness, critical desorption pressure and bottomhole flowing pressure, are analyzed separately by the capacity prediction model and the finding shows that the gas production of coalbed methane wells increases with the increase of coal seam permeability, thickness and critical desorption pressure, and decreases with the increase of bottomhole flowing pressure. The results of this paper provide a theoretical basis for the rational selection of wells and layers before the production and how to increase the coalbed methane production and keep it stable after production.

The results of this study are only suitable for the stable stage of coalbed methane wells, but the gradual decrease in coalbed methane production is also a relatively long stage in the coalbed methane development. So it is the future research direction to predict the production capacity of coalbed methane wells when the coalbed methane production is gradually decreasing.

References

[1] X. J. Shao, C. F. Wang, D. Z. Tang, Y. B. Sun, H. Xu: *Productivity mode and control factors of coalbed methane wells: A case from Hancheng region.* Journal of China Coal Society *38* (2013), No. 2, 271–276.

[2] S. A. Zhang, L. H. Cao, C. X. Du: *Study on CBM production mechanism and control theory of bottom-hole pressure and coal fines during CBM well production.* Journal of China Coal Society *39* (2014), No. 9, 1927–1931.

[3] D. M. Smith, F. L. Williams: *Diffusional effects in the recovery of methane from coalbeds.* Society of Petroleum Engineers *24* (1984), No. 5, 529–535.

[4] J. Q. Shi, S. Durucan: *Modelling laboratory horizontal stress and coal permeability*

data using S&D permeability model. International Journal of Coal Geology *131* (2014), 172–176.

[5] B. Yan, Y. Wang, J. E. Killough: *Beyond dual-porosity modeling for the simulation of complex flow mechanisms in shale reservoirs.* Computational Geosciences *20* (2016), No. 1, 69–91.

[6] Y. Fu, X. Guo, H. Long: *Productivity method of fractured horizontal wells in coalbed gas.* Journal of Southwest Petroleum University(Science & Technology Edition) *25* (2003), No. 3, 44–46.

[7] M. P. Yang, G. Wang, S. Y. Xu, C. Gao: *Steady flow productivity equation for stress sensitivity coal-bed methane gas well.* Natural Gas Geoscience (2011), No. 2, paper 023.

[8] A. Khanna, A. Keshavarz, K. Mobbs, M. Davis, P. Bedrikovetsky: *Stimulation of the natural fracture system by graded proppant injection.* Journal of Petroleum Science and Engineering *111* (2013), 71–77.

[9] X. D. Wu, G. Q. Wang, A. Li, X. Wang: *Productivity prediction of coal-bed gas wells.* Natural Gas Industry *24* (2004), No. 8, 82–84.

[10] Y. Deng, R. Huang, D. Guo, S. Zhang: *Affecting factors of coal-bed gas production and production prediction of unstable percolation.* Natural Gas Industry *25* (2005), No. 1, 117–119.

[11] B. X. Xu, X. F. Li, X. H. Hu, S. M. Hu: *Type curves for production prediction of coalbed methane wells.* Journal of China University of Mining & Technology *40* (2011), No. 5, 743–747.

Received September 12, 2017