Study and application of a new method for predicting the production of low rank CBM wells

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Abstract. Due to many factors affecting the production of low rank coalbed methane (CBM), it is difficult to predict the productivity. The difference of production ramp-up period is large, the fitting of peak production and peak date is difficult, and the efficiency of existing production prediction methods is limited. Based on the characteristics of typical curves of CBM, a new method is established in this paper. Based on the previous accurate history match of reservoir simulation and analysis of the characteristics of typical curves of production index, water gas ratio, pressure and cumulative water production of typical wells, a rate-cumulative water-method (RCM) mathematical model is established by using non-linear fitting method. The mathematical model is determined by historical fitting. The model parameters can predict the output of CBM quickly and accurately, and provide the production prediction data for the scheme formulation and field decision-making. Compared with other prediction methods, RCM improves the history fitting through correlation analysis, improves the reliability of prediction results. It can predict gas well production in both production ramp-up and declining periods. It does not need to update the reservoir model and is less time-consuming. So it is particularly suitable for predicting the production for a large number of wells in a short time. By comparing the production history of CBM wells in “A” block, the accuracy of RCM prediction result is verified.

1. Introduction
There are many factors influencing the production of low rank CBM, including burial depth, thickness, gas content, permeability, moisture, ash content, Langmuir volume and Langmuir pressure [1]. Combining these various factors, the production performance of single well differs greatly, and the main control-factors of productivity are not clear, which makes the production prediction difficult. In addition, the production ramp-up period of CBM wells is quite different. The ramp-up period of the earlier production gas wells is longer. The subsequent new production wells are affected by dewatering and gas production of old wells. The ramp-up period is shorter after the reservoir pressure decrease. It is difficult to fit peak gas production and peak date, and the existing production prediction methods are limited.

The existing production prediction methods mainly include Decline Curve Analysis Method (DCA) [1-2], Pseudo Steady State method (PSS)\cite{3}, numerical simulation [4-5], statistical model [6-11], data processing\cite{12}, etc. [13-15], among which numerical simulation, statistical method and decline curve method are the main three methods. The numerical simulation method based on percolation theory or adsorption desorption theory is based on the geological parameters and development dynamic parameters, and is fitted with the existing actual production data to obtain accurate reservoir and coalbed methane gas parameters. On the basis of successful fitting, the production of coalbed methane can be predicted. Although it can be repeated and relatively accurate, it is time-consuming and laborious, and is
affected by the geological model the accuracy of input reservoir parameters and data, the experience of simulation personnel and other factors. Production decline curve method DCA is to predict reserves by studying production characteristics of coalbed methane, such as gas production law, production, pressure, liquid level, etc., analysing production characteristics and historical data of gas wells. Generally, after coalbed methane has experienced peak gas production and started stable production or production decline, it uses the slope of production decline curve to estimate future production. This method is only applicable to the production with the gas wells with long decline stage cannot be used in the early and middle stage of drainage production, and its theoretical basis is not consistent with the drainage and pressure reduction process in the early stage of coalbed methane production. Single time series prediction method, such as Weng’s model, is only suitable for predicting short-term production of specific gas production stage, and does not consider geological, drilling and completion, fracturing and production factors closely related to coalbed methane production.

At present, in the process of using numerical simulation method, the workload of historical fitting and parameter adjustment is large, and the flexibility is low. How to predict the output quickly and accurately to meet the rapid change of market output demand and the decision-making are the difficulties in the current CBM output prediction. This paper aims to find a new method to determine the main control factors affecting the productivity through the correlation analysis of grey correlation method, combined with numerical simulation and statistics The advantage of regression method is to use the research of typical wells to establish a mathematical model that can predict the output of coalbed methane quickly and accurately, and to determine the parameters of the mathematical model through historical fitting, so as to predict the output of coalbed methane rapidly and accurately, and to provide the output prediction data for the scheme formulation and field decision-making.

2. New method for predicting the production of low rank CBM

2.1. Theoretical basis

With discrete data (Xi, Yi), 1 = 1, 2 …… n, the function f(x,y) is found. According to the least square method, the sum of the square deviation between the function value at point Xi and the observed data is minimized. So that y=f(x) at Xi is as close as possible to the value of given Yi, which is curve fitting. The steps to solve these problems are as follows: firstly, to make a scatter diagram to determine the curve function type of design fitting; secondly, to determine the initial value of the parameters according to the known characteristics, and then calculate the best parameters; thirdly, compare the fitting effect according to the determinable coefficient. If the function is exponential function, logarithmic function, power function, trigonometric function, hyperbolic function or S-shaped function (Logistic model, Gomperty model, Richards model, Weibull model, etc.), it is nonlinear fitting.

The typical production curves and IPR (Inflow Performance Relationship) curves of CBM wells as the Figure 1 below show that the formation pressure, water-gas-ratio, production index and cumulative water production have certain correlation, showing typical curve characteristics. Based on the nonlinear fitting, a mathematical model (RCM) suitable for the correlation (rate-cumulative water) of CBM can be established by using the research of typical wells.
2.2. Establishment of mathematical model of RCM

2.2.1. An example data selection. In order to obtain the mathematical model and standardized work flow of RCM, based on the results of eclipse numerical simulation, well “D” with relatively continuous production and relatively good historical match as the Figure 2 below is selected as a typical well. The relevant parameters of WPI (Water Production Index, PI_water), WGR (Water Gas Ratio), WBP9 (Well Bottom Hole Pressure) and WWPT (Well’s Water Production in Total, CumWater) are extracted from the existing historical matching numerical model.

2.2.2. Fitting model. The water production index PI_water, water gas ratio WGR, formation pressure and cumulative water were regressed and fitted respectively. It can be seen from the regression curve as the Figure 3 below that the regression fitting effect of PI_water, WGR, pressure and cumulative water is good because of the good numerical simulation matching effect of the well.
Select the appropriate function type, and adjust the parameters, finally get the relevant fitting equation as follows:

**PI\textsubscript{water} & CumWater:**
\[ PI\textsubscript{w} = e^{1.888-0.00211W\textsubscript{p}-6W\textsubscript{p}^2} \]

**WGR & CumWater:**
\[ WGR = 2999.1W\textsubscript{p}^{-1.5455} \]

**Pressure & CumWater:**
\[ P\textsubscript{r}(i) = \left(1 + e^{-0.00512(W\textsubscript{p}-477.31)}\right)^{-407} \]

The curve of water production, gas production and formation pressure calculated by the above equation is as the Figure 4 below. Through comparison with historical data, it can be seen that it is in good agreement with the actual curve data.

**Figure 3.** Rate-CumWater curve fitting.

2.2.3. **Model prediction.** Given different bottom-hole-pressures (35psia, 50psia, 65psia, 80psia), the fitting equations are used for prediction as the Figure 5 below. It can be seen that the correlation formula can be used for the history matching and production prediction of CBM well.

**Figure 4.** Comparison between RCM fitting results and actual data.

**Figure 5.** Production prediction under different bottom-hole-pressures for well “D”.

2.2.4. General model. Finally, the general mathematical model for CBM is determined.

PI_water &CumWater model:  
\[ PI_w = e^{a + b W_p + c W_p^2} \]

WGR &CumWater model:  
\[ WGR = d W_p^e \]

Pressure &CumWater model:  
\[ P_r = \frac{m}{1 + e^{n(W_p+1)}} \]

2.3. RCM method fitting and prediction process

Using the mathematical model established by the RCM method, the specific process of historical fitting and production prediction for CBM production in Figure 6 mainly includes four parts, namely data preparation, initial correlation equation generation, historical fitting and production prediction.

**Figure 6.** RCM method history fitting and production forecast flow chart.

3. Comparison of different prediction methods

The differences between RCM, DCA and PSS in history matching and production prediction are compared by example wells.

3.1. Prediction and comparison of dewatering period and gas ramp-up period

From the example well “A” in Figure 7, we can see that the actual data is higher than the DCA prediction data. It shows that it is difficult to accurately predict the gas rate of CBM reservoir by using DCA decline curve analysis in the dewatering period and gas ramp-up period of CBM reservoir. The prediction of PSS model is generated during the peak period of gas rate, which is more optimistic, because the prediction shows that the gas production is much higher than the actual value before the decline of gas rate. The quality of RCM historical fitting is good for both early and the later period.

3.2. Prediction and comparison of decline period

As the example well “B” in Figure 8, for the wells that have entered the decline period, the DCA parameters can be directly derived by reference to the historical decline rate. The DCA method used in the prediction process shows a high prediction value and a sharp decline trend. The PSS method provides a pessimistic forecast compared with the reality. The RCM method has a good history fitting, the prediction results are consistent with DCA, and the decline range is small, similar to PSS method, the RCM method's history fitting results are better than PSS model.
Figure 7. Comparison of gas production. prediction curve of example well "A"

Figure 8. Comparison of gas production. prediction curve of example well "B"

Generally speaking, RCM improves the reliability of prediction results by improving the historical fitting through correlation analysis on the basis of previous reservoir numerical simulation. RCM can predict in each production stage of gas well. It is suitable for a large number of wells in a short time. Characteristics of different production prediction methods is as Table 1. Compared with DCA and PSS models, RCM provides faster prediction time on the basis of previous reservoir numerical simulation. It is very efficient for short-term and medium-term prediction without updating the reservoir numerical simulation model.

Table 1. Characteristics of different production prediction methods.

| NO | Characteristic                        | DCA     | PSS     | Numerical Simulation | RCM     |
|----|---------------------------------------|---------|---------|----------------------|---------|
| 1  | Sufficient theoretical basis          | sufficient | sufficient | sufficient          | sufficient |
| 2  | Number of input parameters            | less    | more    | more                | less    |
| 3  | Consider reservoir parameters         | no      | yes     | yes                 | yes     |
| 4  | Interference between wells            | not considered | not considered | considered          | considered |
| 5  | Prediction in dewatering period       | bad     | good    | good                | good    |
| 6  | Prediction in decline period          | good    | good    | good                | very good |
| 7  | New well forecast                     | can’t   | can     | can                 | can     |
| 8  | Prediction of pressure                | can’t   | can     | can                 | can     |
| 9  | Time to generate forecast for each well | short | long    | long                | short   |
| 10 | Efficiency of processing large capacity data | low    | low     | high                | high    |
| 11 | Automatic prediction capability       | yes     | yes     | no                  | yes     |
| 12 | Numerical model dependence            | no      | no      | yes                 | yes     |
| 13 | Prediction sensitivity                | can     | can     | can                 | can     |
| 14 | Multilayer prediction                 | can’t   | can     | can                 | can     |
| 15 | Complexity                            | simple  | simple  | complex             | simple  |
| 16 | Applicable to horizontal well         | yes     | no      | yes                 | yes     |
| 17 | Subjectivity                          | more    | less    | less                | less    |
| 18 | Forecast uncertainty                  | more    | more    | less                | less    |

4. Application of RCM method in coalbed gas field of block A

Block A has been put into development since 2005. By adjusting the relevant parameters of the mathematical model, the production history of 443 wells in the gas field was fitted, with a fitting rate of 83.7%. Among them, 194 pump-on wells, 86.1% of the wells with peak gas production error less than 30%, 84.5% of the wells with accumulative gas production error less than 30% as the Figure 9 below, 75.3% of the wells with peak water production error less than 30%, 84.0% of the wells with accumulative water production error less than 30% .
5. Conclusions

On the basis of accurate reservoir numerical simulation, we analyze the correlation of production index, water gas ratio, pressure and cumulative water yield typical curve characteristics, and establish a regression mathematical model with nonlinear fitting method.

The advantages and disadvantages of DCA, PSS, numerical simulation and RCM are summarized through literature research and study on the production prediction of typical wells. RCM improves the reliability of prediction results by improving the historical fitting through correlation analysis; it can predict in each production stage of gas well, and is suitable for predicting a large number of wells in a short time, providing a faster prediction time without updating the reservoir numerical simulation model.

Using RCM to fit the production history of 443 CBM wells in “A” block, the fitting rate is 83.7%, including 194 pump-on wells, the peak gas production fitting rate is 86.1%, and the cumulative gas production fitting rate is 84.5%, which better verifies the accuracy of RCM fitting prediction.

Reference

[1] Wang J S and Zhang Y K 2018 [J]. Coal Technology 37(09) 70-72
[2] Liu H L and Wu S H 2015 [J]. Henan Science v.33; No. 203(10) 140-145
[3] Lai F P, Li Z P, Liu X Y et al. 2014 [J]. Journal of China Coal Society 39(9) 1820-1825
[4] Li S C 2016 Establishment and numerical simulation of productivity prediction model for coalbed methane [D]
[5] Wu Y 2015 Study on numerical simulation and prediction method of coalbed methane productivity [D]
[6] Li H, Li Z P, Zhang H R et al. 2013 [J]. Journal of Oil and Gas Technology (07) 8+110-113
[7] Liu G, Sun J B and Yin J T 2017 [J]. Special Oil and Gas Reservoirs 024(002) 145-148
[8] Lv M Y, Shi H F, Zheng N et al. 2012 [J]. China Coalbed Methane (06) 37-40
[9] Zhang H R, Li H et al. 2013 [J]. Lithologic Reservoirs 25(4) 116-118
[10] Kang Y S, Du F K, Zhang B et al. 2013 Dynamic statistical method for production prediction of coalbed methane [C]. Symposium on coalbed methane 2013
[11] Han Y 2018 [J]. Shanxi Chemical Industry 38(06) 122-124
[12] Li Y L 2017 Study on the main control factors and production prediction of single coalbed methane well based on machine learning method [D]
[13] Kong L X and Wang B 2014 [J]. Science and Technology Innovation Herald 2014(26) 68-68
[14] Mazumder S, Jiang J, Sharma V and Sugianto I 2013 Coalbed Methane Well Production Forecasting [J]. SPE-167076-MS, SPE Unconventional Resources Conference and Exhibition-Asia Pacific, 11-13 November, Brisbane, Australia
[15] Soot P M 1992 Coalbed Methane Well Production Forecasting [J]. SPE-24359-MS, SPE Rocky Regional Meeting