Research and exploration on production decline curve model of shale oil and gas

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Abstract. The inconsistency of shale oil and gas production decline prediction methods leads to the inconsistency of shale oil and gas production decline curve prediction. Aiming at this problem, this paper introduces five commonly used shale oil and gas production decline curve models: typical curve model based on ARPS model, modified hyperbolic decline model, power index model, mixed typical curve model and Duong model. The prediction methods of uncertainty typical curve model and certainty typical curve model are studied. The results show that the production history of multistage fractured horizontal wells is not long enough, and it is difficult to verify the production decline in the later stage, so it is suggested to use hyperbolic decline model or modified hyperbolic decline model. Aiming at the blocks with production data, a prediction method of uncertain shale oil and gas production decline based on production performance data is proposed. The results are in good agreement with the actual production data, and can be used in oilfield production allocation. Due to the characteristics of shale reservoir such as nanometer pore size, nadasi permeability, strong heterogeneity and high fracturing strength of long horizontal wells, the output of shale oil and gas wells varies greatly. The typical production decline curve obtained by deterministic method has certain risk.

Key words: Shale, Oil and Gas, Production, Decline, Curve, Model, Production allocation.

1. Introduction

As an unconventional reservoir, shale oil and gas reservoir is highly heterogeneous, with nanometer pore size and poor permeability. Therefore, its commercial development must rely on the volume transformation of shale reservoir. Multistage fracturing technology for long horizontal wells is one of the key technologies for commercial development of shale oil and gas. Volume modification further aggravates the heterogeneity of reservoir, which leads to great difference between shale oil and gas productivity evaluation technology and conventional natural gas [1].

Shale gas productivity evaluation methods can be generally divided into three categories: the first is the typical curve method based on production performance data; the second is the simplified analytical method based on the gas seepage mechanism of matrix and fracture combination; the third is the numerical simulation method considering the complex factors of reservoir and fluid and the mechanisms
of seepage and desorption. At present, the typical curve method is widely used in engineering practice. However, there are still a series of problems in the process of using typical curve to predict decline, such as the determination method of key parameters related to typical curve, the prediction process of typical curve, and how to carry out uncertain decline prediction [2, 3].

2. Typical production decline model of shale oil and gas
Five widely used models are introduced below. Although there are some other typical curve models, other models are not widely used as these five models, so they are not described here.

2.1. Typical curve model based on ARPS model
Physical property interlayer is a kind of stratum whose porosity and permeability become worse because of mud content and grain size change of sediments. It is mainly composed of siltstone and fine sandstone, and also includes fine conglomerate, argillaceous conglomerate and grain supported conglomerate with high argillaceous content. The physical property interlayer has certain porosity and permeability, but the physical property becomes worse due to the cementation of fine-grained and thin sandstone in the sand. ARPS can calculate the development speed, dimensionless development speed and recovery degree of decline development mode. The parameters have influence on the Arps decline development model. The smaller the decline index \( n \) is, the faster the decline rate is and the smaller the recovery degree is. The larger the decline rate \( D \) is, the faster the decline rate is. In the early stage of development, the Arps decline development model should be determined as early as possible for early development decision.

2.2. Modified hyperbolic decline model
In order to solve the problem that the decrease of instantaneous decline rate with time will lead to overestimation of ultimate recoverable reserves (EUR), the modified hyperbolic decline method introduced by Robertson et al. Is often used for shale oil and gas, but it brings new difficulties, that is, how to determine when the hyperbolic decline will be converted into exponential decline. At present, there is no recognized method.

2.3. Power exponent model
In order to solve the problem of optimistic prediction in the late stage of hyperbolic decline, ILK et al. Proposed the episodic exponential decline model as a modification of the traditional exponential decline method, but there are many parameters and the physical meaning of the parameters is not clear.

2.4. Mixed canonical curve model
Ambrose et al. Assumed that the fracture is infinite conductivity and constant bottom hole flow pressure. Based on this, the prediction method of mixed typical curve was proposed, that is, the mixed analysis method and empirical method. In the linear flow stage, the ratio of pseudo pressure difference and flow rate to the square root of time is linear on the logarithmic graph, and ARPS hyperbolic decline is used in the prediction boundary control flow stage.

2.5. Duong model
Duong model is based on the premise of microfracture development. It is believed that with the decrease of pressure in shale during production, due to the influence of stress, some previously closed microfractures and small faults will be activated, resulting in the increase of fracture permeability and flow capacity. In addition, there are some other typical curve models, but other models are not as widely used as the above models, and will not be described here.

Based on the verification of a large number of production wells in the sedimentary basin of western Canada, the steps of using Duong production decline method to predict recoverable reserves are obtained.

1) Before analyzing production, we should first understand the reservoir: collect reservoir and fluid property parameters, including \( K / \mu \) (mobility), \( h \), PI, TR and \( \gamma \) g, and analyze the percentage of gas components (H2S, CO2, N2, etc.). Reservoir parameters can be obtained from adjacent vertical wells
by pressure transient analysis (PTA), production instability analysis (RTA), static pressure gradient test and core analysis. Fluid properties can be obtained from the experimental analysis report.

2) Know well conditions: such as engineering well spacing (drainage area), horizontal well length, completion type (open hole or casing multi-stage fracturing), etc.

3) To understand the surface production conditions, it is necessary to determine the bottom hole flowing pressure (PWF).

4) According to the above parameters, a simulation model is established to synthesize the production curve, which is used to draw the special identification curve.

5) Find the inflection point, and determine when to use Duong production decline method by comparing the economic limit production rate and the production rate at the inflection point: if the inflection point does not appear before the economic limit production rate, you can directly use Duong production decline method (which was a linear relationship before); if the inflection point has appeared before the economic limit production rate, you can not directly use Duong production decline method.

6) If the production curve has been bent before the economic limit production is reached, the parameters a and m of Duong production decline method are generated from the production data after the inflection point, so as to predict the future production data and related technical recoverable reserves.

3. Prediction method of uncertain production decline

In the shale oil and gas block to be evaluated, if there are sufficient production performance data, the basic idea of the prediction and analysis method of uncertain production decline is: for a shale oil and gas block, select typical production wells with good production performance and long production history as the research object, carry out typical curve prediction, and obtain the initial production of each well. The probability distribution of each typical curve parameter in the block is determined, and the probability distribution function is obtained by analyzing the probability distribution. Then the typical curve parameters are randomly sampled by Monte Carlo method, and the ultimate recoverable reserves (EUR) is calculated by using the typical curve model. The probability distribution of EUR is analyzed, and the final recoverable reserves (EUR) is calculated P10, P50, P90 EUR are recommended to determine the typical curve parameters under different probability conditions [4, 5, 6].

Taking a shale gas block in the United States as the research object, 54 shale gas wells are selected as the research objects for typical curve prediction. In order to eliminate the influence of horizontal section length on production, the production data of all wells are normalized to the production corresponding to each 100m horizontal section length. Based on this, the initial production, decline rate, decline index and other parameters are obtained. The probability distribution of initial production is shown in Figure 1, which belongs to triangular probability distribution. The minimum value is 2728 m³ / (D · 100 m level section), the maximum value is 8685 m³ / (CL · 100 m level section), and the mode value is 7584 m³ / (D · 100 m level section). The probability distribution of decline index is shown in Figure 2, which belongs to Weibull distribution. Weibull probability density function is obtained by fitting, with scale parameter of 1.21 and shape parameter of 4.1997. Figure 3 shows the probability distribution of the decline rate, which belongs to lognormal distribution, with an average of 0.01 and a standard deviation of 0.01 [7].
Although the predicted EUR of 54 wells can also give the probability distribution function of EUR per 100m horizontal section in the block, the prediction accuracy is limited due to the relatively small number of sample points. Therefore, it is necessary to increase the number of samples of EUR [8]. According to the probability distribution function of initial production, decline rate and decline index, Monte Carlo random sampling method is adopted, and a large number of EUR samples are obtained according to the typical curve function. In this case, 100 000 times of random sampling simulation was
carried out, and the probability distribution of EUR per 100 m horizontal section was obtained as shown in Figure 4. It can be seen that the probability distribution curve is smooth, and the probability distribution of EUR is gamma distribution, which is different from the lognormal probability distribution of EUR obtained only by actual well prediction, and the probability distribution of every 100 m horizontal section is smooth. The P10, P50 and P90 of 100 m horizontal section of EUR are 9.36 × 106 m³ respectively, 4.28 × 106 m³ and 1.56 × 106 m³, which are quite different from P10, P50 and P90 of EUR predicted by actual wells only. After obtaining the EUR of P10, P50 and P90, the corresponding typical curve parameters can be obtained [9].

![Fig. 4 100 m level calculated from 100 000 random samples probability distribution of segment EUR](image)

4. Prediction method of certain production decline
Considering the oscillation of production performance of shale oil and gas wells, the typical curves obtained by using daily production data and monthly production data are different, so it is recommended to use daily production data as the basis. The initial production of shale oil and gas is a very important parameter, which represents the productivity of shale oil and gas wells. At present, there is no unified calculation standard for how to calculate the initial production of shale oil and gas wells. Recommended determination method: Based on the maximum value of initial production, 29 points slightly smaller than the maximum production value are selected in turn, and then the 30 values are summed and averaged as the initial daily production [10].

In the production process of shale oil and gas wells, due to various reasons, it is often necessary to shut in the well for a period of time and then open the well to continue production. Data points with zero production will appear on the production performance curve, and the shape of the performance curve will also change. Recommended treatment method: deduct the zero production point, ignore the shut in time period, and then move the time point of reopening to the shut in time point, so as to ensure that the time point is continuous.

It is found that when analyzing the production decline of the same shale oil and gas well, the length of production history will affect the typical curve, and ultimately affect the EUR. It is suggested that when analyzing the typical production decline curve of shale oil and gas blocks, on the basis of selecting representative wells, the wells with a production history of more than one year should be selected as the research objects for prediction.

Different shale oil and gas wells usually have different fracturing stages. At the same time, with the progress of technology, the length of horizontal section and fracturing stages are gradually increasing. At present, the fracturing stages of field operation can reach 30–40 stages, and the length of horizontal section can reach 4000 m. When the fracturing stages of each well in a block vary greatly, it is recommended to use single-stage converted production or converted production per unit length of horizontal section as the analysis data of production decline typical curve, and the results can better reflect the production characteristics of typical wells.
5. Conclusion
Shale oil and gas typical curve models widely used in the world include: ARPS based typical curve model, modified hyperbolic decline model, power exponent model, mixed typical curve model, Duong model, etc. Because the long horizontal well multi-stage fracturing technology is only developed in recent years, the current multi-stage fracturing horizontal production history is not long enough, it is difficult to verify the decline situation in the late production period. Therefore, the hyperbolic decline model or modified hyperbolic decline model is more widely used in industry.

For the blocks with production data, an uncertain shale oil and gas production decline prediction method is proposed. The results are consistent with the actual production data, and can be applied to the project productivity evaluation.

Due to the nanometer pore size, nadasi permeability, strong heterogeneity, and the intensive fracturing of long horizontal wells in shale reservoirs, the production of single shale oil and gas well varies greatly. The typical production decline curve obtained by deterministic method has certain risks.

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