DOI 10.1007/s10553-024-01738-2
Chemistry and Technology of Fuels and Oils, Vol. 60, No.3, July, 2024 (Russian Original No.3, May – June, 2024)

INNOVATIVE TECHNOLOGIES OF OIL AND GAS

RESEARCH ON OIL PRODUCTION FORECASTING METHOD OF TIGHT OIL RESERVOIR BASED ON GREY CORRELATION METHOD

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Horizontal well fracturing technology is an important way to improve the oil recovery efficiency of low-permeability reservoirs. Aiming at a certain test area on the edge of Daqing oilfield, a simulation conceptual model is established using CMG reservoir numerical simulation software. The influence of engineering parameters such as the number of fracture clusters, fracture half-length, fracture permeability, production pressure difference on the peak daily oil production is analyzed. Moreover, the gray correlation method is used to analyze the influence of the above factors on the peak daily oil production. Using key factors as variables in the regression model, a mathematical prediction model for daily oil production peak is established. The findings should make an important contribution to the oil production peak prediction.

Keywords: oil production prediction, fracturing technology, horizontal well, tight oil reservoirs.

1. Introduction

Oil resources are the cornerstone of supporting people's high-quality life and rapid industrial development. At present and for a long time in the future, China's demand for oil resources will remain at a high level. With the increasing demand for oil, the proportion of medium high permeability reservoirs is less and less. It is imperative to exploit low permeability reservoirs. Tight reservoirs have become one of the key points of exploration and development in China in the future [1-4]. Due to the low permeability, it is very difficult to develop this kind of reservoir effectively in the past. In recent years, with the progress in the horizontal well technology and the large-scale volume fracturing technique, it becomes possible to develop these reservoirs economically and efficiently [5-7]. In 2017, the production of tight oil in the United States accounted for 54%, but the domestic production was less than 1%. The research on productivity prediction model of tight reservoir is constantly carried out. The continuous improvement of prediction model can comprehensively consider various factors. The model is closer to the actual production process and the prediction results are more accurate [8].

In 1985, Giger [9] it was first proposed to use horizontal wells and artificial fracturing for production, and established the productivity model of fractured horizontal wells with vertical fractures. It also compared the productivity of fractured horizontal

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wells with that of fractured vertical wells. However, the model is relatively ideal, and there are deficiencies in the coupled flow between matrix and fracture. In 1991, Mukherjee [10] mentioned the method of effective well diameter in the productivity calculation model, and obtained the relationship between the productivity and the number of fractures, fracture conductivity, fracture geometric parameters and fracture spacing. Considering the pressure loss in the wellbore, Mukherjee compared the productivity of production wells under fracturing and non-fracturing, and compared the productivity of fractured horizontal wells and fractured vertical wells. In 2017, He [11] proposed a new model of multistage fracturing horizontal well in tight gas reservoir, further studied the influence of fracture properties on pressure response, and improved the performance of the well through stimulation measures. For horizontal well fracturing, in order to give full play to the productivity advantages of horizontal wells, multi-stage fracturing is generally used.

Therefore, the interaction between artificial fractures needs to be considered in the later stage of production. Crosby [12] verified the developed multiple fracture initiation standard by comparing it with the actual hydraulic fracture initiation pressure, which were obtained from scaled laboratory experiments and numerical results from boundary element analysis. These criteria could be useful to engineers involved with hydraulic fracturing for predicting transverse fracture initiation pressures from horizontal wells drilled parallel to the minimum horizontal in-situ stress. Wigwe and Bougre [13] present two methods for fitting spatial-temporal models: fixed rank kriging and ST generalized additive models using thin plate and cubic regression splines as basic functions in the spline-based smooths. The results highlight the benefits of spatial-temporal models in production prediction as it implicitly accounts for geology and technological changes with time. Feng [14] established a numerical simulation model for multi-stage fractured horizontal well to account for the threshold pressure gradient (TPG), matrix permeability change with stress-sensitive effect and dynamic fracture closure. In multi-stage fracturing horizontal wells, a host of studies have been done in China [15-19].

The discrimination of flow pattern in formation exists in the established model, and different productivity models are established by stages. In 1994, Larson [20] divided the flow pattern characteristics in fractured horizontal wells into four basic stages, namely fracture linear flow, formation linear flow, quasi radial flow, and boundary control flow. In 2009, Freeman [21] divided the flow pattern of fractured horizontal wells into initial formation linear flow, compound linear flow and elliptical flow in combination with flow and pressure diagnosis curve and pressure distribution map. Ozkan [22] established a three-line flow model on the premise of taking the oil drainage area as the reservoir between hydraulic fractures, further simulated the productivity of multistage fractured horizontal wells, and achieved good results.

In recent years, the research gradually began to consider the non-Darcy effect in order to more accurately characterize the development process of tight reservoir. In 2018, Zeng [23] proposed an analysis model of multistage fracturing horizontal wells considering start-up pressure gradient, partial penetrating fractures and reservoir heterogeneity, and further analyzed the influence of parameters. Tian [24] predicted reservoir performance by coupling dynamic capillary pressure with gas production model, and obtained good prediction effect.

At present, the treatment methods for the establishment of productivity model mainly include elliptic seepage theory, superposition principle, effective well diameter, etc. the factors considered in the research of productivity model of fractured horizontal wells in tight reservoir are relatively complete. The numerical simulation method is also frequently used in the establishment of production capacity model [25-28] with CMG numerical simulation software [29-33]. In the development of tight reservoirs, the peak daily oil production is the key to study the productivity law, while few studies on peak daily oil production simulation of tight reservoir. In this paper, is used to study the peak oil production law and establish the peak prediction model, which lays a foundation for improving the accuracy of tight reservoir productivity prediction and the subsequent analysis of productivity influencing factors.

2. Model description

The research block is a tight oil reservoir with the characteristics of low porosity, low permeability and low production. This feature has always been the main factor restricting the increase in reserves and production in the tight oil demonstration area. The reservoir is a typical tight sandstone reservoir with a burial depth of about 1800 m. The formation crude oil density is 0.7551 g/cm^3, the crude oil viscosity is 5.8 mPa·s, the average porosity is 11.8%, and the average permeability is 1.36 mD. After decades

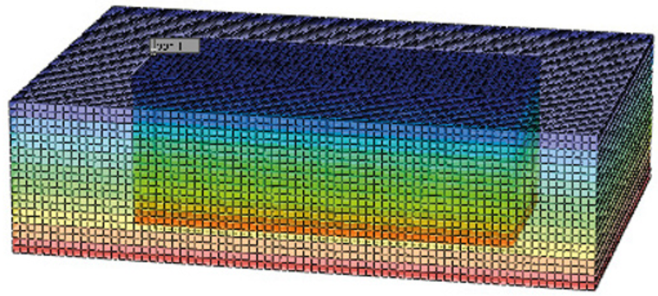

Fig. 1. Geometric model of tight oil fractured horizontal well

Table 1. Sectional views of 13 different well arrangements

Model parameters		Value
Reservoir parameters	Scale (m)	1500×1000×10
	Porosity	0.118
	Permeability (mD)	1.36
	Oil saturation	0.57
Well parameters	Length of horizontal section (m)	1000
Engineering parameters	Fracture number	50
	Fracture half-length (m)	200
	Fracture permeability (mD)	190000
	Production pressure difference (kPa)	6260

of development, horizontal well fracturing technology has been widely used in this oil field and has achieved good development results.

According to field data, substitute corresponding reservoir properties (porosity, permeability, oil saturation, initial formation pressure, reservoir temperature, etc.) and fluid properties (density, viscosity, phase permeability curve, capillary force curve, etc.) into the geological model to establish a dual-medium model for tight oil fracturing simmering wells. Through calculations, the changes of daily production, cumulative production and other parameters under different reservoir parameters and engineering parameters can be obtained.

The numerical simulation model uses a corner grid system. In order to accurately reflect the role of tight oil saturation and porosity in the development of tight oil reservoirs in the block, the model is divided into 10 layers, and the number of model grid nodes is: X = 75, Y = 50, Z = 10. The geometric model is shown in **Figure 1**. Meanwhile, in order to improve the calculation accuracy, mesh refinement processing is carried out on the part of the local complex situation.

Refer to the actual geological parameters and fracturing design of the reservoir. Model parameter settings are shown in **Table 1**.

3. Analysis of factors affecting oil production

Four key engineering parameters of the number of fracture clusters, fracture half-length, fracture permeability and production pressure difference are selected to conduct numerical simulation research on the law of production variation under different engineering parameters. The specific numerical simulation scheme is also listed in Table 1.

Effect of number of fracture clusters. On the basis of the established simulation model, set the number of fracture clusters to 10, 13, 17, 25 and 50 respectively to study the effect of the number of fracture clusters on productivity. The daily oil production curve under different fracture clusters is shown in **Figure 2**. It can be seen from Figure 2 that the change of daily oil production is basically the same with the extension of production time. The daily oil production reaches the peak value rapidly, and the decline rate changes from fast to slow after the peak value. According to the peak value of daily oil production under different fracture clusters, it is found that the number of fracture clusters has a great impact on the peak value of daily oil production. With

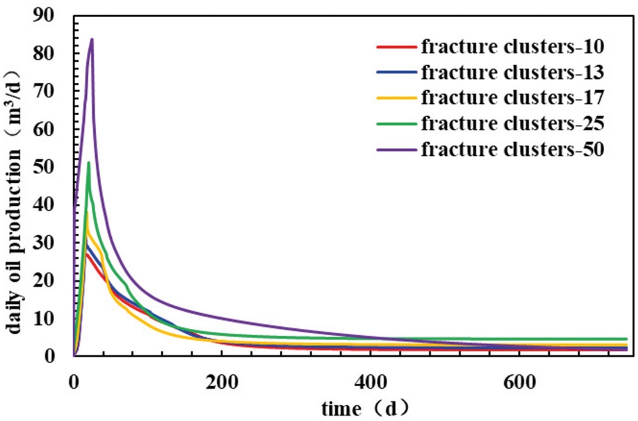

Fig. 2. Variation curve of daily oil production under different number of fracture clu

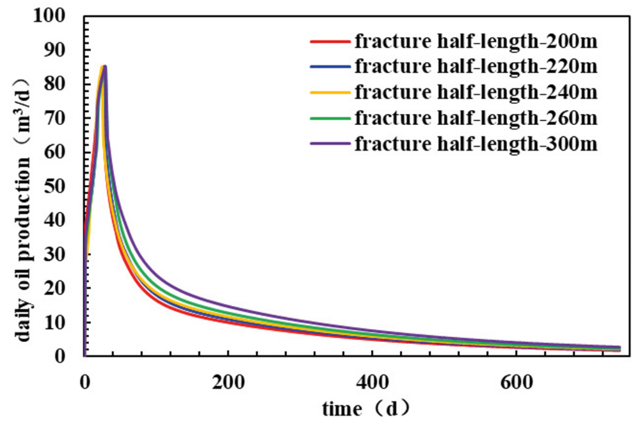

Fig. 3. Variation curve of daily oil production under different fracture half-length

the increase of the number of fracture clusters, the peak value of daily oil production gradually increases, but has little impact on the overall change trend.

Effect of fracture half-length. On the basis of the established simulation model, set the fracture half-length to 200, 220, 240, 260 and 300 m respectively to study the effect of the length of fracture half-length on productivity. The daily oil production curve under different fracture half-length is shown in **Figure 3**. It can be observed from Figure 3 that the change of daily oil production is basically the same with the extension of production time. The daily oil production reaches the peak value rapidly, and the decline rate changes from fast to slow after the peak value. According to the peak value of daily oil production under different fracture half-length, it is found that the fracture half-length has a great impact on the peak value of daily oil production. With the increase of fracture half-length, the peak value of daily oil production gradually increases, but has little impact on the overall change trend.

Effect of fracture permeability. On the basis of the established simulation model, set the fracture permeability to 5000, 10000, 19000, 100000 and 190000mD respectively to study the effect of the fracture permeability on productivity. The daily oil production curve under different fracture permeability is shown in **Figure 4**. It can be seen from Figure 4 that the change of daily oil production is basically the same with the extension of production time. The daily oil production reaches the peak value rapidly and the decline rate changes from fast to slow after the peak value. According to the peak value of daily oil production under different fracture permeability, it can be found that the fracture permeability has a great impact on the peak value of daily oil production. With the increase of the fracture permeability, the peak value of daily oil production gradually increases, but has little impact on the overall change trend.

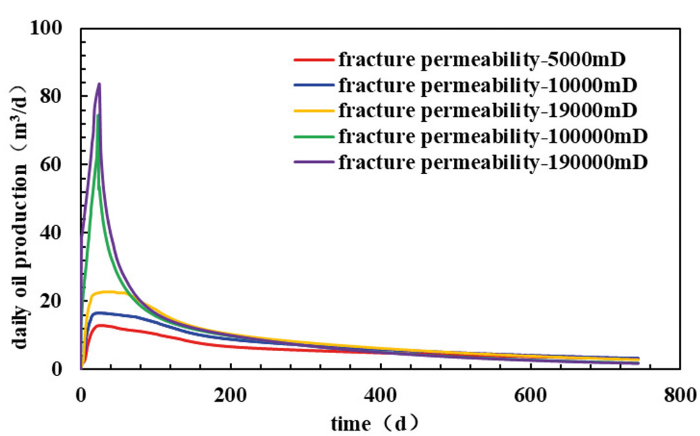

Fig. 4. Variation curve of daily oil production under different fracture permeability

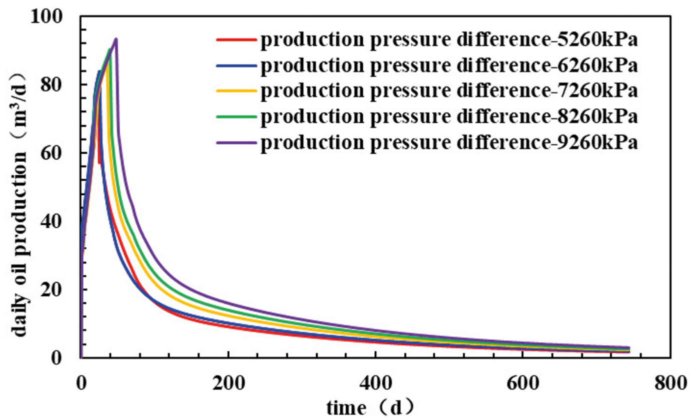

Fig. 5. Variation curve of daily oil production under different production pressure difference

Effect of production pressure difference. On the basis of the established simulation model, set the production pressure difference to 5260, 6260, 7260, 8260 and 9260 kPa respectively to study the effect of the production pressure difference on productivity. The daily oil production curve under different production pressure difference is shown in **Figure 5**. It can be observed from Figure 5 that the change of daily oil production is basically the same with the extension of production time. The daily oil production reaches the peak value rapidly, and the decline rate changes from fast to slow after the peak value. According to the peak value of daily oil production under different production pressure difference, it is found that the production pressure difference has a great impact on the peak value of daily oil production. With the increase of the production pressure difference, the peak value of daily oil production gradually increases, but has little impact on the overall change trend.

4. Peak productivity prediction of horizontal wells

The grey correlation analysis method is used to judge whether the relationship is close according to the similarity of sequence curve geometry. The closer the curve is, the greater the correlation degree between the corresponding sequences, and vice versa.

The calculation formula of correlation coefficient in grey correlation analysis can be expressed as:

$$\gamma = \frac{a + \rho b}{\left| x_0(k) - x_i(k) \right| + \rho b}, \tag{1}$$

$$a = \min \left| x_0(k) - x_i(k) \right|, \tag{2}$$

$$b = \max \left| x_0(k) - x_i(k) \right|, \tag{3}$$

where, ρ (ρ= 0.5) is the resolution coefficient. The grey correlation method is used to analyze the numerical simulation results under different parameters to find out the main control factors.

The grey correlation degree of different factors on the peak oil production of horizontal wells is calculated, and the results are shown in **Figure 6**. The grey correlation analysis of peak oil production shows that the order of the influence of engineering factors on peak oil production is: fracture cluster number>fracture half-length>production pressure difference>fracture permeability.

According to the calculation results of grey correlation degree, the correlation degree between each factor studied and the peak oil production is greater than 0.5. Therefore, the production change of each factor is fitted for capacity prediction. The late yield under different influencing factors was fitted by power function, and the late yield was expressed as:

$$Q = \mathrm{c}_1 t^{\mathrm{d}_1}, \tag{4}$$

where Q denotes the output and t denotes the time.

The peak fitting curve of fracture cluster number is drawn according to the peak oil production under different fracture cluster numbers, as shown in **Figure 7**.

According to the fitting curve of the number of fracture clusters and the peak productivity, the relationship between the number of fracture clusters and the peak productivity is expressed as:

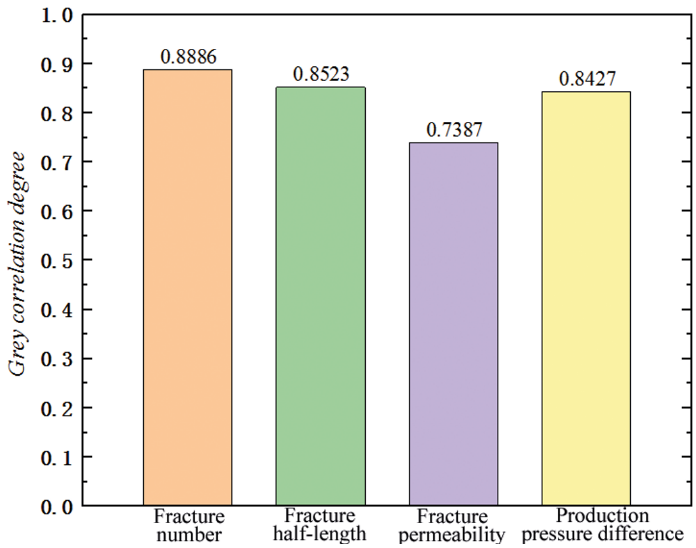

Fig. 6. Grey correlation degree of different factors on peak oil production of horizontal wells

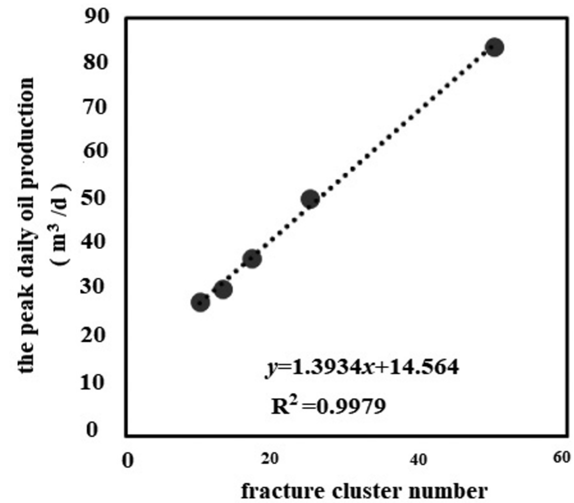

Fig. 7. Fitting curve of fracture cluster number and peak productivity

$$Q_{o\_max} = 1.3934k_f + 14.564. \tag{5}$$

The peak fitting curve of fracture half-length is drawn according to the peak oil production under different fracture half-length, as shown in **Figure 8**.

According to the fitting curve of fracture half-length and the peak productivity, the relationship between fracture half-length and the peak productivity is expressed as:

$$Q_{o\_max} = 0.0108L + 82.171. \tag{6}$$

The peak fitting curve of fracture permeability is drawn according to the peak oil production under different fracture permeability, as shown in **Figure 9**.

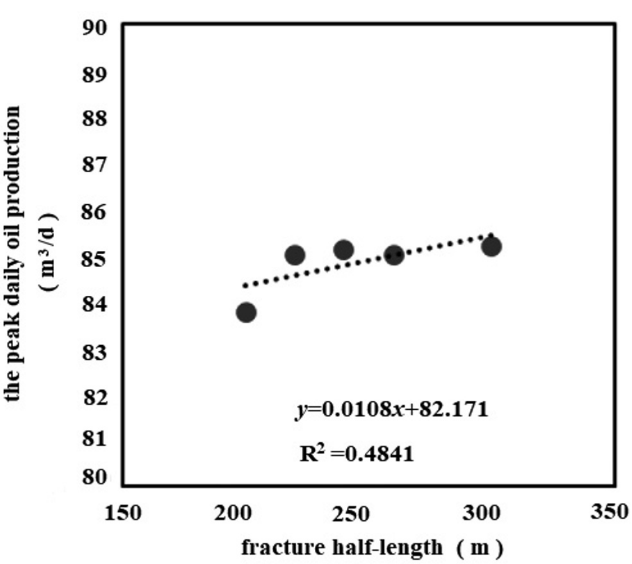

Fig. 8. Fitting curve of fracture half-length and peak productivity

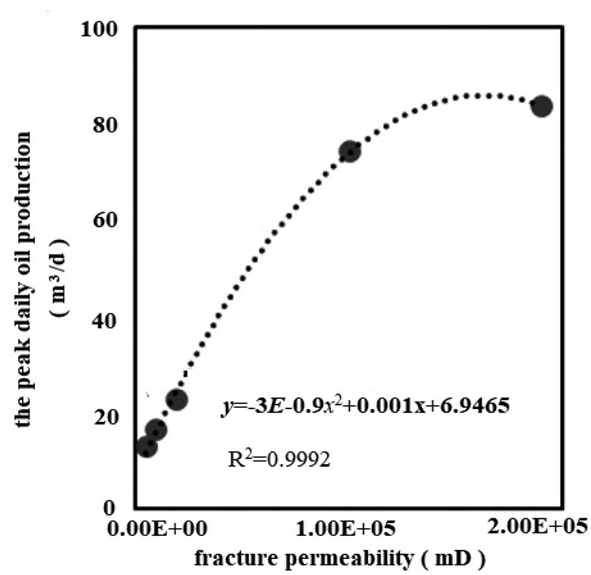

Fig. 9. Fitting curve of fracture permeability and peak productivity

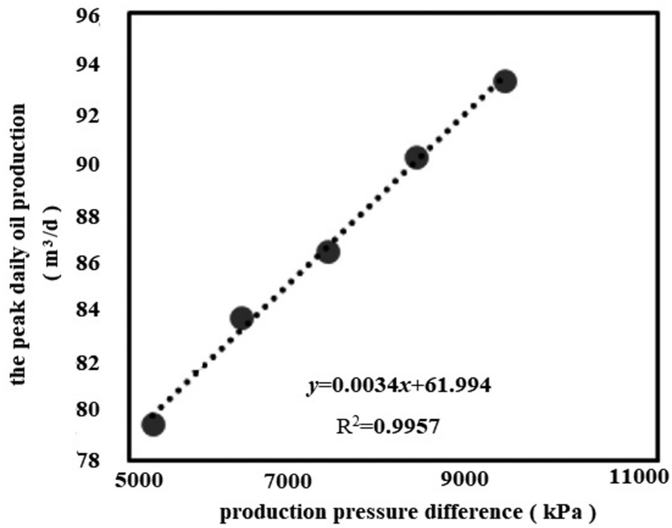

Fig. 10. Fitting curve of production pressure difference and peak productivity

According to the fitting curve of fracture permeability and the peak productivity, the relationship between fracture permeability and the peak productivity is expressed as:

$$Q_{\mathrm{o\_max}} = -3 \cdot 10^{-9} k_f^{\ 2} + 0.001 k_f + 6.9465. \tag{7}$$

The peak fitting curve of production pressure difference is drawn according to the peak oil production under different production pressure difference, as shown in **Figure 10**.

According to the fitting curve of production pressure difference and the peak productivity, the relationship between production pressure difference and the peak productivity is expressed as:

$$Q_{\mathrm{o\_max}} = 0.0034 \Delta p + 61.994. \tag{8}$$

Taking the number of fractures, fracture half-length, fracture permeability and production differential pressure as variables, the calculation formula of peak oil production is obtained by fitting. The formula can be expressed as follows

$$Q_{o\_\max} = 1.3934N + 0.0108L + 10^{-10} k_f^{\ 2} + 3 \cdot 10^{-5} k_f + 0.0034 \Delta p - 402.765. \tag{9}$$

Using the peak oil production formula, it can calculate the peak oil production of fractured horizontal wells under different engineering conditions when the engineering parameters are known

5. Conclusions

In this paper, a simulation conceptual model is established using CMG reservoir numerical simulation software. The influence of engineering parameters on the peak daily oil production is analyzed,and a mathematical prediction model for daily oil production peak is established. The detailed conclusion is as follows.

1. With the increase of the number of fracture clusters, half-length, fracture permeability and production pressure difference,the daily oil production gradually increases,but has little impact on the overall change trend.

2. The main controlling factors affecting production capacity are found out by grey correlation method. The influence of engineering factors on peak oil production is that: the cluster number is the largest, fracture half-length is the second, the production pressure difference is the third and fracture permeability is the last.

3. The prediction model of peak oil production is fitted with the variables of fracture cluster number, fracture half-length, fracture permeability and production pressure difference.

Acknowledgements

This work was supported by the project of National Science Foundation of China (No.51904075 and No.11972114), the Project of Natural Science Foundation of Heilongjiang Province in China（LH2022E018) and China postdoctoral science foundation (2021M690592).

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