Study on tapping measures in carbonate reservoirs based on integrated fracture modeling technology

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Abstract. As the main seepage channel of carbonate reservoirs, the spatial distribution and the development range of the fractures are crucial for the deployment of the measures wells in the carbonate oil fields. Taking the high water cut fracture reservoir of R oilfield as an example, the advanced fracture prediction technology is used to predict the development and distribution characteristics of medium and large scale fractures, and the space of complex carbonate reservoirs is quantitatively characterized by fracture-porosity dual medium modeling technology. According to the distribution law, the dual medium numerical simulation technology is carried out to study the distribution characteristics of the remaining oil in the oilfield, and the well selection scheme is determined by combining the geological factors and the development factors. Through the implementation of on-site measures, the wells have achieved good oil-increasing effects, which provides a guarantee for the cost reduction and efficiency of the oilfield.

1. Introduction

As a double-edged sword, the fracture is the seepage channel of oil and gas, and it is also the turbulent channel of water [1]. The development of fractures is controlled by multiple factors such as sedimentation, diagenesis and structure. The background is complex and variable, and the prediction is difficult. If the scale and scope of fracture development can be accurately predicted, it has positive significance for guiding the deployment of oilfield development plans, and it is a key factor in tapping potential of carbonate reservoirs.

R Oilfield located in the Sunda Basin of Indonesia, which is one of the most mature oil and gas fields in Indonesia. It has a development history of nearly 40 years. The current degree of reserve recovery is as high as 68% (calculated by recoverable reserves) and the comprehensive water content is 94%. The high degree of reserve recovery comes from the contribution of fracture net to oil and gas migration. The high water content is due to insufficient understanding of fractures in the water injection development stage, resulting in serious turbulence of injected water along the fracture and water content rapid rise. Therefore, before the analysis of the stimulation treatment in the R oil field, the spatial distribution of the fracture-type reservoirs becomes more important. The difficulty of reservoir research has the following three aspects: ①fracture as the main seepage channel, its spatial distribution plays a key role in reservoir engineering research, how to identify fracture and quantitative characterization is difficult [2]; ②reef limestone reservoir is a dual-medium reservoir, which not only develops pores but also develops fractures. The heterogeneity is extremely strong, which makes it
difficult to predict the spatial distribution of reservoir physical properties. ③There is fluid exchange between the dual media, and how to simulate the coupling relationship between the two is difficult. Aiming at the difficulties faced by R oilfield reservoir research, this paper proposes an integrated fracture modeling study.

2. Research on integrated modeling

2.1 Dual medium geological modeling

Compared with the pore-type reservoir, the dual medium reservoir is more complicated and variable due to the fracture. In order to quantitatively characterize the spatial distribution law of reservoirs, a matrix model with pores and a fracture network model with fracture were established.

2.1.1 Matric model. In order to build the property model in the matrix model, the method is that porosity model is controlled by lithfacies model and permeability model is controlled by flow unit model. The lithology of the R oilfield reservoir is divided into five types: reef limestone, bioclastic limestone, muddy limestone, dolomite and mudstone. Each type of facies is counted, and the facies probability distribution in each sub-layer is obtained. On this basis, the well lithology data is used as the control data, and the facies probability distribution is used as the trend between wells, then using the sequential indication simulation method to obtain the lithofacies model (Figure 1). Under the control of the structural model and the lithofacies model, the porosity model is built by using the sequential Gaussian simulation algorithm (Figure 2).

The correlation between porosity and permeability in carbonate reservoirs in R oilfield is poor. The reservoir is divided into different flow units by rock classification technology, and each type of flow unit is formed by similar genesis under similar geological backgrounds [3-4]. According to the core experimental data of the R oilfield, six types of flow units (Figure 3) are classified, and each type of flow unit has a corresponding pore-permeability relationship.

Through the neural network algorithm, the function relationship between the logging curve of the core section and the flow unit is calculated, and the flow unit of the uncored section is obtained by taking the log of the uncored section into a functional relationship. After calculating the flow units of all wells, the flow unit model is established by the geostatistical interpolation algorithm. Under the control of the flow unit model, according to the pore-permeability relationship of different flow units,
combined with the porosity model, the matching permeability model is calculated. By comparison, it is found that the calculated permeability of the flow unit is in good agreement with the core permeability (Figure 4).

2.1.2 Fracture model. Conventional corner grids can only describe the permeability of fluids flowing in and out in the same direction. Obviously, such grids do not accommodate the multi-directionality of fluid flow in fractures. The DFN grid solves this problem very well [5-6]. It can describe the permeability of fluid inflow and outflow in different directions, and it is more in line with the flow characteristics of fluid in the fracture. In the fracture modeling of R oilfield, the DFN fracture network modeling method is used to hierarchically build fracture network models of different scales. For medium to large scale fractures, the location and spatial geometry are completely determined by seismic data [7]. In the fracture prediction, the medium to large scale fracture density is predicted by the integrated geophysical method, and the predicted fracture density is passed. The method of deterministic modeling is directly sampled into the model grid; for small-scale fractures, according to the statistical information of the single-well fracture parameters, under the constraint of the fracture density body, the geostatistical method is randomly generated. Figure 5 is discrete fracture network model of R oilfield, it can be seen that the northern and central fractures of the oilfield have high density.

![Figure 5. DFN model](image1)

![Figure 7. Water-flooding areas](image2)

For the generation of fracture properties, the fracture network model is transformed into a model of porosity and permeability (I, J, K) using Petrel software's Golder technology. And generate a sigma factor that describes the degree of fracture and matrix connectivity. According to the statistical results, the porosity of the fracture system is only 0.01%-0.35%, with an average of 0.02%. The fracture system has a high permeability and plays a leading role in fluid seepage, but there are certain differences in permeability in different directions, wherein the maximum permeability in the I direction reaches 5500 mD, the ratio of high permeability fractures is less than 0.1%, and the maximum permeability in the J direction is 4800mD, the ratio of high-permeability fractures is less than 0.1%; the maximum permeability in the K direction is 4500mD, and the proportion of high-permeability fractures is 0.1%, and the I direction contributes the most to the fluid seepage.

2.2 Numerical simulation of dual media
In the process of establishing and fitting the dual media reservoir model in the R oilfield, the idea of integrated geological and reservoir modeling is fully embodied. Firstly, the sensitivity factors affecting the productivity of oil wells are analysed. Based on the analysis results, the static property fields of the matrix model and the fracture model are corrected, the connectivity of the fracture, the permeability and the distribution of micro-fractures are adjusted, and the simulation correction is repeated until the final simulation results are met production actual. Figure 6 shows the oilfield production history fit curve obtained from the dual media model of the R oilfield carbonate reservoir. From the oil production rate and water-fluidity fit, the oilfield dynamic data fits well (Figure 6).
From the simulation results, the dual medium model of R oilfield has the following advantages: First, it can better describe the phenomenon of fluid turbulence in the fracture; Second, the modeling process fully considers the effect of fracture on oil recovery, and it can predict the ultimate recovery of the oil field; third, the simulated residual oil distribution results are more reasonable, and it can tap the potential for oil fields. Through numerical research, the current degree of recovery in the fracture is 60%, and the overall recovery of the oilfield is only 18% (calculated by geological reserves), and there is still huge potential for remaining oil development.

3. Residual oil distribution and potential area optimization

R oilfield development has experienced four stages: natural energy development, first large-scale water injection development, post-injection development, and recovery water injection development. In the first large-scale water injection stage, due to mistakes in decision-making, the development method of edge water injection and top water injection was adopted, and the directionality of the fracture was not considered, so that the injected water rapidly flowed along the fracture, resulting in serious flooding in the central main producing area. Due to the complicated reservoir-forming conditions of the R oilfield carbonate reservoir, the remaining oil distribution is congenitally different, and the violent flooding in the first water injection stage that causes the remaining oil distribution in the entire oilfield to be scattered. Through the results of the dual medium model, combined with the geological factors and development factors, the distribution rules of the remaining oil in the R oilfield are summarized. It is considered that the area where the fracture is not developed and the reservoir property is poor is the main remaining oil distribution area.

1) Plane residual oil distribution: First, the high part of the structure, the degree of water flooding is low, there is residual oil distribution; the second is the area where the fracture is not developed, the water flooding effect is poor, forming the remaining oil enrichment area; the third is the marginal area with few wells, the side water and bottom water are difficult to reach the reservoir, resulting in low utilization and enrichment of the remaining oil. The fourth is deposition zone of marginal facies or transitional facies in the lower part, which has poor physical properties and strong heterogeneity, and is easy to form a barrier to oil and gas flow, forming a residual oil enrichment zone.

2) Longitudinal residual oil distribution: First, the reef and shoal facies are interbedded in the area, and the inter-layer heterogeneity is strong. The remaining oil is concentrated in the areas with poor physical properties of the longitudinal reservoir and the thin layer; the second is in the fracture development area. The bottom water is tapered upward from the lower part along the fracture, and the poor reservoir is not used. Third, due to the driving action of the gas top and bottom water, the remaining oil in the vertical direction is mainly concentrated in the middle and upper layers.

In order to understand the potential of oilfield development, according to the water content of oil wells, the water-flooding areas of R oilfields are classified, including: the violent water-flooding areas, water content is greater than 95%; the strong water-flooding areas, water content is between 80%-95%; the middle water-flooding area, the water content is between 40% and 80%, and the weak water-flooding area, the water content is between 10% and 40% (Figure 7). Combined with the remaining oil distribution range, flooding situation and single well productivity, three favorable areas were found, include low water content and remaining oil enrichment area in the northeast part of the oilfield; poor physical properties, low liquid volume and low water content in the southeast of the oilfield; and a low pressure zone located in the southwestern part of the field.
4. Potential tapping measures and application effects

The oil production and water cut of the oil wells before and after the implementation of the measures in the R oilfield over the years were counted. Measures to increase the oil production or reduce the water content after the implementation of the measures were set as effective measures. Through the statistical analysis of the effective measures of the R oilfield, the effective measures of plugging, acidification, perforation and fracturing are 75%, 54%, 64% and 47%. The acidification and plugging effects are better than other types of measures. The reasons for the good effect of acidification measures in R oilfield are as follows: First, a large amount of untreated seawater is injected into the main producing layer during the large-scale water injection stage, and the water injection intensity is too large, resulting in pollution of the production layer, and the oilfield development effect is worse. Acidification measures can significantly improve the conductivity of carbonate reservoirs and increase the production capacity of oil wells. Second, acidification measures are more effective in the structure of lower-level, poorly-formed edge facies and fracture-undeveloped areas.

The reasons for the good results of the plugging measures in the R oilfield are as follows: First, in the natural energy development stage, the higher oil recovery speed leads to the oil well seeing water; at the same time, because the fracture communicates with the reservoir and the bottom water, the edge water advances rapidly and the bottom water rapidly taps, so that the water content of the oil well rises rapidly. In the water injection development stage, the water injection is too large, and the injection-production ratio is too high, resulting in violent flooding of the production well. Therefore, these two stages can plug the bottom and edge water and inject water, reduce the water content of the oil well and improve the oil production capacity. Secondly, the reef-shoal facies developed in the higher part of the structure have better physical properties and they are favorable reservoir areas. In the large-scale water injection stage, the injection level displacement is stronger than gravity displacement due to high-pressure water injection, and these favorable areas are more easily water flooding, the effect of plugging in the area is good; indicating that for carbonate reservoirs, plugging high aquifers is beneficial to reduce water of oil well. Therefore, the selection principle of plugging and acidification in R oilfield is formulated:

1) Principles of plug well selection: ①when the water content reaches the limit of economic water content, the high aquifer is plugged, and the water content of the plugging (well) layer is greater than 80%; ②the oil well with high production capacity at the initial stage of production, the production is about 2000 barrels per day; ③the accumulated oil production is less, and the oil production is less than 100 barrels per day: ④water layers are located in the lower part of the target layer; ⑤ the area with higher residual oil, the well control remaining oil is more than 1 million barrels; ⑥well condition is good.

2) Principles of acid well selection: ①water content should not be too high, generally less than 90%; ② the current liquid production is less than 1000 barrels per day; ③ accumulated oil production is less, the oil production is less than 100 barrels/day; ④the remaining oil is relatively enriched, and the well control residual oil is more than 1 million barrels; ⑤ well condition is good.

According to the principle of well selection and the prediction of potential area, the acidification and plugging schemes of 9 wells were proposed. The overall design of the scheme reflects the water blockage of the bottom production layer, the acidification of the upper production layer, and the acidification operation of the fracture underdeveloped area.

In the year when the plan was proposed, three wells were acidified and plugged, and two of them were effective. The F-09 well produced an average daily oil production of 90 barrels before acidification. After acidification, the average daily oil production increased to 322 barrels. The comprehensive water content decreased from 41% to 36%. The E-02 well was combined with acidification and plugging. The average daily oil production was 9 barrels before the operation. After the measure, the average daily oil production increased to 430 barrels. The comprehensive water content decreased from 97% to 83%. The oil production has increased dramatically and the water content has dropped rapidly.
5. Result
1) Understanding the distribution and development of fractures in carbonate reservoirs is the key to developing such oil fields. Through fracture integrated modeling technology, it can quantitatively describe the development characteristics of fractures in different scales; the flow of fluid between pores and pores, pores and fractures, fractures and fractures can also be simulated by DFN model, which facilitates the dynamic fitting and scheme prediction of the dual medium model.

2) Through the analysis of stimulation measures, single-well acidification and plugging measures are proposed in the preferred potential area; plugging measures are proposed for high-water wells in the fracture development area, and acidification measures are proposed for potential wells in the fracture-undeveloped area. Practice has shown that the stimulation measures proposed by the comprehensive research have greatly improved the oil production capacity and optimized the liquid production structure. Therefore, for fracture-type reservoirs, the premise of effective production stimulation measures is to find out the distribution law of fracture in the reservoir and use it effectively.

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