Introduction

The subject carbonate reservoir in the Tarim Basin is buried below the depth of 6000m in Ordovician. Hydrocarbon exploration in the Tarim Basin proves that strike-slip fault systems play an important role in the migration of hydrocarbon and the development of fractured-vuggy carbonate reservoir (Zhang, J., Ma, P., et al., 2016). With a high formation pressure of around 50~70 MPa, it mainly has three kinds of reservoir space: matrix with tight porosity, fracture with some certain flow conductivity and fluid accumulated, and cave or hole with large fluid storage, which means a serious heterogeneity of the fractured-vuggy reservoir (Figure 1).

![Fig.1 Large cave, vugs and fractures on outcrops of fractured-caved carbonate reservoirs](image)


Geological Modeling

The modeling process should consider the spatial distribution law and major controlling factors of the fractured-caved reservoirs, and to adopt modeling principle of genetic control. According to various major controlling factors of genesis, the caves and fractures were modeled separately: the cave modeling controlled by genesis is mainly from the view of the flowing feature of the karst water to model in various vertical zones and planar regions; the fracture modeling controlled by genesis mainly adopts the idea that the fault distribution controls fracture development; fault development has hierarchy property, and the higher-order large-scale fractures control the lower-order small-scale fractures. In modeling, we adopted the principle of hierarchical modeling to model fracture genesis in various orders and various scales. Based on the above analysis, while modeling the fractured-caved carbonate reservoirs, the reservoirs of large-scale cave, corroded vug, large-scale fracture and small-scale fracture were indeterminately modeled by the principles of genetic modeling and hierarchical modeling. Fig.2 shows the geological models of fractured-caved carbonate reservoirs (by storage spaces) in the Tarim Oilfield.

![Fig.2 Geological modeling](image)

Finally, the geological models of four reservoir models are combined into be one geological model. Fig.3 shows the combined geological model and the connecting body analysis model. It can be seen from the connecting body analysis model that the whole reservoir scope has hundreds of disconnected fracture-cave reservoirs; there are some large-scale connecting bodies (the red ones), and various connecting bodies are mutually disconnected.
Development Strategy Optimization

Based on the combined geological model of fractured-caved carbonate reservoirs established in this study, we optimized three types of reservoirs (cave type, fracture-cave type and connecting fracture-cave unit type) to study water injection and gas injection development. Hereinto, for the caved reservoirs (Figure 4) and fractured-caved reservoirs (Figure 5) with constant volumes, to conduct water injection huff and puff after depletion development. Water injection huff and puff could displace the residual oil at the reservoir bottom. While after water injection huff and puff, to adopt gas injection huff and puff to displace the attic oil at the reservoir top, so as to achieve maximum recovery efficiency. For the connecting fracture-cave unit, they are generally developed by multiple wells, and these wells are mutually connected. For the connecting unit between two wells, oil can be recovered by one water injection well and one oil production well after depletion development, then to produce it by gas injection. For the connecting unit between multiple wells, it can be produced by injecting water and gas with irregular areal well pattern.
Application

For the fractured-caved carbonate reservoir, gas injection and water injection are still the major methods to improve recovery efficiency. For the reservoirs with constant volumes, water injection huff and puff and gas injection huff and puff are mainly applied. In the initial stage, this well is developed by depletion mode. When the reservoir pressure drops, and lower water flows upward along fractures to form water coning, water injection huff and puff is started to further conduct anti-water-coning and displace the residual oil at the bottom. Later, gas is injected to displace oil and soak well. So, the oil in higher cave is displaced, oil-water contact migrates downward, and water-coning disappears. When the well is put into production, gas is produced with oil. And figure 6 shows the whole production flow and displacement mechanism of a fractured-caved connecting unit. During initial stage, two wells were produced in depletion mode. After bottom water coning by strong bottom water, oil production dropped. Then, water injection at the lower position & oil produced from the higher position was applied. Finally, gas injection was started.

And water injection huff-and-puff and water injection has been applied to more than one hundred wells, which have about average 15% oil recovery increment of OOIP. And gas injection huff-and-puff has been applied to more ten wells with about average 5% oil recovery increment of OOIP. These methods have shown successful results.
Conclusions

This paper mainly focuses on development strategy optimization of different reservoir patterns for fractured-caved carbonate reservoirs. The conclusions can be drawn as follows:

- The reservoir types are versatile in the fractured-caved carbonate reservoirs. This paper mainly studied the development strategy optimization for constant volume cave type, large-scale connecting fracture-cave units and fractured-caved connecting units.
- Corresponding simulation models of different kinds of reservoirs are built, and off-take rate, cyclic soak time, etc. of both water injection and gas injection are optimized based on the simulation models. For the reservoir with constant volume, the best development mode is to inject gas during later stage of water injection huff and puff. For the fractured-caved connecting units, the development mode of water injected at lower position & oil produced at higher position after depletion development is recommended.
- The optimized results are applied to a fractured-caved carbonate reservoir in China.

Reference


