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# An Analysis Method of Gas Injection Development Effect in the Single well Fractured-Vuggy System

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**Abstract:** In this study, we propose an analysis method of gas injection development effect in the single well fractured-vuggy system. The fractured-vuggy reservoir has a complex spatial structure, oil-water relations and connectivity, of which single well fractured-vuggy system is a simpler model. Aiming at the problems of low recovery rate and production difficulties, based on the elasticity theory and fluid mechanics in porous, the elastic expansion energy and oil-water interface change before and after gas injection in the single well developing fractured-vuggy system are analyzed. And a theoretical mode of development effect after gas injection is built. Then an example analysis of Tarim Oilfield is conducted. The results show that: mining after repeated gas injection, water cut significantly decreased, yield and water free production increases gradually and the replacement rate increases with the gas injection. This shows that gas injection can effectively inhibit the rise of oil-water interface and improve the development effect of fractured-vuggy system.

**Keywords:** Cave, effect, fracture-vuggy, gas injection, recovery

## INTRODUCTION

Carbonate rock oil and gas reservoirs constitutes more than half of the world's total oil reserve, while being a significant part of the carbonate rock oil and gas reservoir, fractured-vuggy reservoir bears considerable development prospects. China's fractured-vuggy reservoir mainly distributes in Tarim Basin, Szechwan Basin and North China. As the main study object of this study, fractured-vuggy reservoir in Tarim Basin behaves like this: diverse reservoir space types, poor connectivity, super-high heterogeneity, unusual fluid flow state and complex oil/gas relations. Besides these, it also has the following characteristics, such as high burial depth, HPHT, highly variation in oil physical properties (Zhang *et al*., 2004; Chen *et al*., 2007; Kang *et al*., 2006). For reservoirs like this, no effective development theory exists now, which renders its recovery and development not satisfactory. Foreign researchers did the work of fractured-vuggy reservoir modeling quite early. Besides the classic triple media mode (Warren and Root, 1963; Camacho, 2002) gives out a new triple porosity model for fractured-vuggy carbonate reservoir description, which takes into account of the two following conditions: solution vug system having or having no connection with the wellbore. Camacho (2002) analyzed the type curve detailed and presented some new understanding about the fractured-vuggy reservoir. As for the study of water flood recovery, J.Cruz-Hernandez *et al.* studied the performance of water flooding in fractured-vuggy reservoir and did some numerical simulation study about it (Farhadinia *et al*., 2011)

In this study, we propose an analysis method of gas injection development effect in the single well fractured-vuggy system. The fractured-vuggy reservoir has a complex spatial structure, oil-water relations and connectivity, of which single well fractured-vuggy system is a simpler model. Aiming at the problems of low recovery rate and production difficulties, based on the elasticity theory and fluid mechanics in porous, the elastic expansion energy and oil-water interface change before and after gas injection in the single well developing fractured-vuggy system are analyzed. And a theoretical mode of development effect after gas injection is built. Then an example analysis of Tarim Oilfield is conducted. The results show that: mining after repeated gas injection, water cut significantly decreased, yield and water free production increases gradually and the replacement rate increases with the

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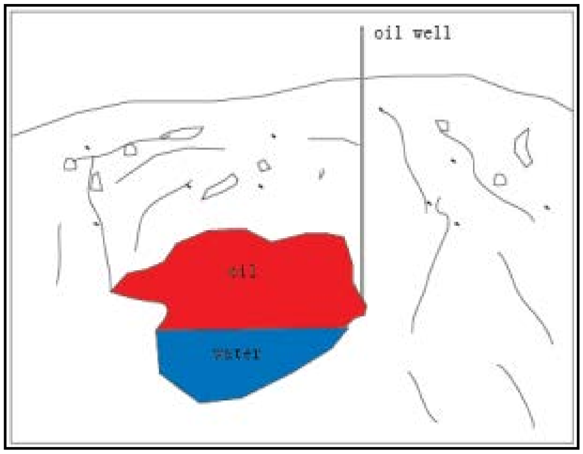
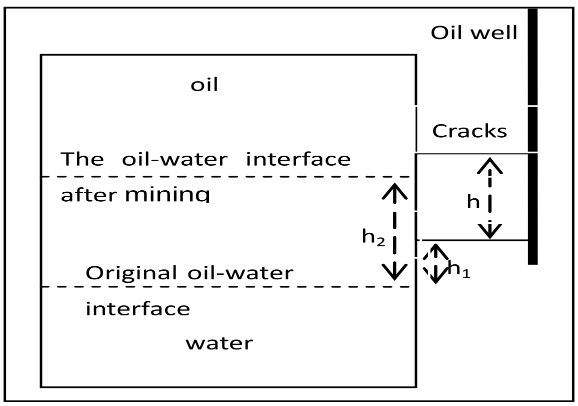



(a)




(b)

Fig. 1: Simplified schematic diagram of Geological model

gas injection. This shows that gas injection can effectively inhibit the rise of oil-water interface and improve the development effect of fractured-vuggy system.

## GEOLOGICAL MODEL SIMPLIFICATION

Storage space of the fractured-vuggy reservoir based on different levels of the cave, the second is the cracks-holes reservoir space that formed by the cave collapsed and tectonic movement. Cavity distribution is very complex and the physical property of surrounding matrix is relatively poor (porosity and permeability is very low), Caves and holes are interconnected by the fracture networks and formed a fractured-vuggy unit that have a uniform pressure system. So the fractured-vuggy system was reduced to a relatively simple conceptual model, showed in Fig. 1 an oil well directly drilled on fracture networks system, then the fracture networks can be reduced to a high-angle fractures and there are large-scale bottom water in the fractured-vuggy system. Assuming that pressure is restored to the original formation pressure after gas injection and oil-water interface is restored to the original position after the first gas injection.

## THEORETICAL BASIS

As shown in Fig. 1, after the flow period, the oil-water interface lifting height is $h_2$, the distance between the original oil-water interface and cracks is h1, the vertical height of cracks is h, the original oil volume is Vo, the original water volume is Vw. Reservoir condition is known. The water compressibility factor is Cw, the total compressibility is Ct, oil volume factor is Bo, injected gas volume is Vg, fractured-vuggy system effective radius is R, the stability water content when flowing quit is fw.

Analysis before gas injection: according to the elastic mechanics and material balance theory, anhydrous production is the oil production when oil-water interface has not submerge the cracks, that is the water expansion volume when the original oil-water interface uplift to the crack bottom, as shown in Eq. (1):

$$V_1 = h_1 \pi R^2 \tag{1}$$

After depletion, water expansion volume is $V_2$, as shown in Eq. (2):

$$V_2 = dV_w = V_w C_w dP_1 \text{-} V_{wc} C_w dP_1 \tag{2}$$

Analysis after gas injection: after gas injection, reservoir pressure is restored to original formation pressure. Starting production, then water expansion volume is $\Delta V_w$,. Under the condition of larger bottom water volume, water expansion conform to the theory of elasticity and the oil-water interface lifting height is dhw, as shown in Eq. (3):

$$dh_w = \frac{\Delta V_w}{\pi R^2} = \frac{dP_2 V_w^2 C_w}{\pi R^2} \tag{3}$$

Gas injection capacity calculation. According to the known effective fractured-cave volume and residual volume of oil, as gas injection restores the formation pressure to the original formation pressure, invert the gas injection depletion process every round, then deduce the cyclic gas injection capacity equation:

$$q = \frac{(Pi - P_{wf})(V_g B_g C_g + (V - V_g B_g) C_t)}{t B_g} \tag{4}$$

Calculation formula of cyclic gas injection time:

$$t = \frac{(Pi - P_{wf})(V_g B_g C_g + (V - V_g B_g) C_t)}{q B_g} \tag{5}$$

Fracture parameter prediction. Without considering cave internal water cone, when oil and water ability is balance, water content tends to be stable. According to the test data, well radius is R, then the vertical height of equivalent crack h can be calculated by formula (6):

$$h = \frac{V_2 - V_1}{f_w \pi R^2} \tag{6}$$

Production capacity prediction. Without considering cave water cone, judging the relationship of water lifting height and the height between original oil-water interface and crack, anhydrous production and water production volume are caculated:

If $dh_w \leq h_1 + V_{wc}\ C_w\ dP_1/A$, oilwell only product oil, as shown in Eq. (7):

$$Q_o = dP_2(V_g B_g C_g + (V_o + V_w - V_g B_g)C_t) / B_o \tag{7}$$

If $dh_w \leq h_1 + V_{wc}\ C_w\ dP_1/A$ , the well product oil and water, then stable water content can be predicted, as shown in Eq. (8):

$$f_w^1 = \frac{dh_w - h_1 - \dfrac{V_{wc} C_w dP_1}{A}}{h} \tag{8}$$

According to the water flooded law of the fractured-vuggy reservoirs, combined with the elasticity theory, the anhydrous productionQ2ow can be got by Eq. (9) and cyclic oil production can be got by Eq. (10):

$$Q_{Ow}^2 = (h_1 + \frac{V_{wc} C_w dP_1}{A}) A / Bo \tag{9}$$

$$\begin{aligned} Q_o = {} & (1 - f_w^1) dP_2 (V_g B_g C_g + (V_o + V_w - V_g B_g) C_t) / B_o \\ & + f_w^1 (h_1 + \frac{V_{wc} C_w dP_1}{A}) A / Bo \end{aligned} \tag{10}$$

According to the above theoretical model, gas injection rate every round and oil production capacity and water cut variety after gas injection can be calculated. This can provide theoretical basis for enhanced oil recovery of the single well fracture-cave mode in fracture-cave reservoirs.

## EXAMPLE CALCULATION ANALYSIS

As for a typically fractured-vuggy reservoir in Tarim Basin, well A have a poor physical property of the reservoir matrix, where developed large cave. Logging data show that the reservoir fracture is developed, comprehensive judgment the well through

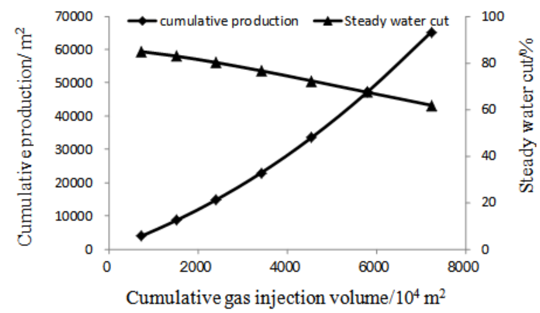



Fig. 2: Cumulative production and steady water cut curve

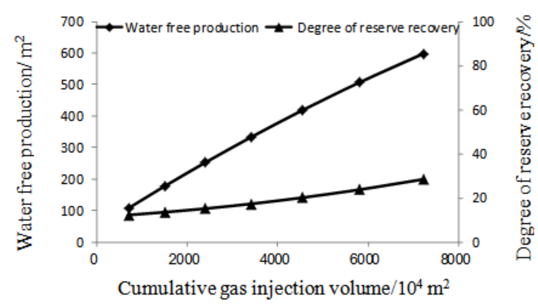



Fig. 3: Water free production and degree of reserve recovery curve

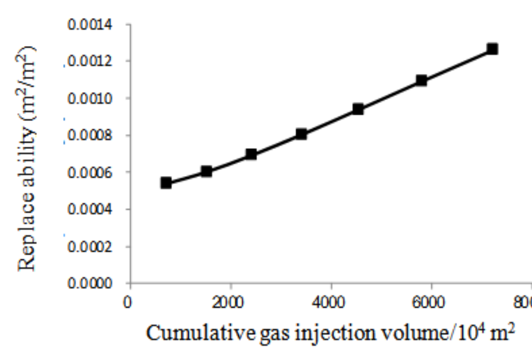



Fig. 4: Replace ability of the oil

cracks connected cave system, computing the effective fractured-cave total volume is about 317×104 $m^3$ and have the larger bottom water. Basic parameters: oil volume factor is 1.22, compression factor is 0.00115/MPa; water volume factor is 1.04, compression factor is 0.0004/MPa; the pressure drop when quit flowing is 5 MPa. Assuming reservoir pressure recovery to the original formation pressure after gas injection every time, by the above theory, the development of gas injection can be predicted. As shown in Fig. 2, with the increase of cumulative gas injection volume, cumulative oil production increases, increasing oil production rate is gradually increases and stable water cut decreases. Figure 3 shows the anhydrous production increases with the cumulative gas injection volume and Fig. 4 shows the replacement rate is increased. These show that gas injection effectively inhibit the rise in oil-water interface, significantly reduce water production and the oil recovery increase is 17.21%.

## CONCLUSION

A theoretical prediction model of gas injection development effectiveness for the SWDFS is established. After gas injection, with increase of cumulative injection volume, water cut is apparent declined and the replacement rate is increased. That means gas injection can effectively improve development effect and in the instance of the well calculations, recovery rate is improved to 17.21%.

## SYMBOLS

dpi = Pressure drop, MPa
Qi = Production of oil/water, $m^3$
Vi = Volume of the oil/water/gas, $m^3$
Bi = Volume factor
Ci = Compressibility, $MPa^{-1}$
h = Height, m
fw = Stable water cut, %
R = Effective radius, m

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