The Study of Waterflood Stimulation Technology

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Abstract: Aiming at the development status of Liuxi Oilfield, waterflood stimulation is studied to improve the development effect. The process is as follows: in begin with, the displacement liquid is injected into the oil well quickly to replenish energy; then the oil well is closed a while to promote oil and water displacement; finally, let the oil well produce under a reasonable system of production. Strong water-wet, high oil saturation, the degree of fracture development and low oil viscosity are the advantages of using waterflood stimulation by analyzing related researches. Based on the reservoir engineering research, numerical simulation method which is about waterflood stimulation is established using Eclipse software. According to the numerical simulation results, assuming that injection rounds is one time, when injection volume is more, the formation pressure rises higher and the liquid sweep is wider and cumulative production is more. At the same time, the degree of stage production is increasing with the closed time lengthen. But it has the most optimum values about the closed time, and the production increase of the degree of stage production becomes significantly slow.

1. Introduction
The single well of production in Liuxi Oilfield is high but decrease progressively. As a result, the cumulative recovery is low. The reservoirs have difficulty in water injection so that the stratum energy is not replenished persistently. The development effect is not good after using conventional fracturing technology. Aiming at the production reality, waterflood stimulation method is studied and “fracturing-injection-waterflood-production” integrated technology is formed finally to promote single well production and improve the development effect.

2. Reservoir Characteristic
The research area is located in Raoyang Sag of Jizhong Depression and the reservoir includes eleven developing units. The main oil-bearing layer is Shahejie 3 Member Formation. The reservoir depth is
about 3300-3700m and the sand layer thickness is 40-120m. The permeability is 1-5 mD; the porosity is about 10%-15%; the stratum temperature is 120 degrees centigrade. We can find that Liuxi Oilfield belongs to high temperature, low porosity and low permeability reservoir (Fig. 1). The oil saturation is 52%-63%; the clay content is 7.9%; the oil density is 0.8291 g/cm3; the oil viscosity is 6.8 mPa·s.

According to the constant velocity mercury injection curve, the displacement pressure is relative high. It shows that the pore throat radius and the porosity is small and the permeability is low. It is observed that the efficiency of mercury withdrawal is relative low and it shows that pore-throat ratio of pay layer is big and the degree of pore uniformity is bad. The throat radius is less than 2 μm according to the test data. It seems that the research area has extra-low permeability oil reservoirs characteristic because the throat is thin and the displacement pressure (Fig. 2).

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3. Exploitation characteristic
Most wells drilled in the field have to be fractured before production. According to the fracturing curve, fracturing construction pressure is high (75-90MPa) so that the operation discharge is low and adding proppant is difficult (Fig. 3).
Fig. 3 Lu46-29x well, 3650.2-3661.4m, discharge 3.5m³/min, tubing pressure 85MPa.

Nine wells in Lu44 developing unit were fractured in 2006 and the stimulation effect was well at initial stage. The average production of single well risen from 2.5 ton to 12.8 ton every day and the yield was increased by 4.2 times. But the energy went down quickly, the production fallen by 80 ton (nine wells) and declining rate of average month is about 13.1% (Fig.4).

Fig.4 Monthly stack curve of fracturing wells (nine wells, 2006)

4. Waterflood stimulation technology

4.1 Mechanism study of waterflood stimulation
The capillary force performs the function of water absorption and oil displacement in the water reservoir. The displacement liquid is injected into the stratum and stays there. Then the crude oil is displaced to the relative high permeability zone with the action of the capillary force. As a result, the oil and water is redistributed in the stratum. The final result is that the oil and water are produced in the function of imbibition replacement (Fig.5).

Fig.5 The process of imbibition replacement

4.2 The advantage of waterflood stimulation

4.2.1 Wettability
Wettability is important indicator to analyze the ability of washing oil in the process of water flooding\textsuperscript{[5]}. The bigger is the wettability, the smaller is the wetting angle. The bigger is the capillary force, the better is the waterflood stimulation effect. According to the wetting experiment result, is
shows that the reservoir has the characteristic of weak water-wet in Liuxi Oilfield. It is beneficial to promote the effect of waterflood stimulation (Fig.6).

**Fig.6 The relative wetting index in Liuxi Oilfield**

### 4.2.2 Oil saturation

The oil saturation has the direct bearing on the reserves. The higher is the saturation, the better is effect of imbibition replacement. The oil saturation value of Liuxi Oilfield is about 52%-63%. Therefore, the material base is relative well (Tab. 1).

| block | Stratum | Effective thickness (m) | Porosity (%) | Saturation (%) | Oil density (g/cm³) |
|-------|---------|------------------------|--------------|---------------|-------------------|
| Lu44  | E₃Ⅲ₁  | 36.5                   | 13           | 63            | 0.895             |
|       | E₃Ⅲ₂  | 18.3                   | 12           | 60            | 0.919             |
| Liu462| E₃Ⅲ₁  | 28.7                   | 13           | 61            | 0.897             |
| Lu48  | E₃Ⅲ₁  | 18.1                   | 13           | 52            | 0.886             |

### 4.2.3 The development degree of fractures

The more the fracture develops, the bigger the contact area of fluid and reservoir is and the shorter the flow distance from matrix to fracture is.[6-8]. The natural fracture is not developed in research area but the fracture network will be formed by volume treatment (Fig.7).

**Fig.7 Schematic diagram of fracture network**

### 4.2.4 Oil viscosity

The oil density has important influence on single well production to some extent.[5]. The lower the viscosity of crude oil is, the smaller flow resistance is. The viscosity of Lu46 Block is 6.8mPa·s. We can find that the flow resistance is small and it is easier to promote waterflood stimulation effect (Tab. 2).

| Density / (g/cm³) | viscosity / mPa·s | Volume factor / dimensionless | GOR / (m³/t) | Saturation pressure / MPa |
|------------------|-------------------|-------------------------------|--------------|--------------------------|
| 0.8291           | 6.8               | 28.4                          | 11-48.4      | 7.9                      |

In conclusion, it shows that weak water-wet, relative high saturation, low oil viscosity is the characteristic of Liuxi Oilfield. And it is beneficial to use waterflood stimulation technology. Although
the natural fracture is not developed, the fracture network will be formed by volume treatment.

4.3 Numerical simulation about waterflood stimulation

4.3.1 The process of numerical simulation
As is well-known, Eclipse software is an important tool in reservoir engineering. We tend to study the waterflood stimulation by reservoir engineering method. Based on the Eclipse software, the key parameter of target stratum is input and the model is divided into rational grid. At the same time, man-made fracture existed is simulated. And single well geologic model is built in this way. Then we input different injection fluid volume value by different injection mode, the distribution and increase amplitude of formation pressure is obtained. The simulation result can provide important evidence to the designing scheme (Fig. 8).

4.3.2 Numerical simulation example
Lu46-17x well is the production well in Lu43 Block. The daily fluid production is 0.26m³ and the daily oil production is 0.23m³ before using the waterflood simulation technology. And the cumulative fluid and oil production is about 498m³ and 237m³. The formation pressure coefficient is 0.61. Base data used to simulate is as follows (Tab. 3).

| porosity (%) | Sand body thickness m | Effective thickness m | Depth m | Initial formation pressure MPa | Viscosity mPa·s | Model m×m | Grid xyz×z |
|--------------|----------------------|----------------------|---------|-------------------------------|----------------|-----------|-----------|
| 12.53        | 27.2                 | 15.8                 | 3000    | 22.77                         | 6.8            | 246×246   | 41×41×4   |

The design scheme is that the injection rounds is one time and the injection volume is 2500m³, 5000m³, 7500m³, 10000m³ respectively. According to the numerical simulation results, the distance of pressure coverage is sixty meters after injecting 2500m³ displacement fluid (Fig. 9).
The formation pressure rises 2.8 MPa after injecting 2500 m$^3$ displacement fluid, similarly, 3.8 MPa after injecting 5000 m$^3$, 4.7 MPa after injecting 7500 m$^3$, 5.1 MPa after injecting 10000 m$^3$. It shows that the cumulative production is higher when injection volume is more but increase of the degree of stage production becomes significantly slow (Fig. 10).

The injection round is one time and the injection volume is 2500 m$^3$. The longer the closed time is, the higher the degree of stage production is in different closed time (5-60d). According to the curve, the production increase of the degree of stage production becomes significantly slow when closed time is 30 days. Moreover, the more the injection volume is, the more the cumulative production is on equal conditions (Fig. 11).

5. Conclusion
(1) The development effect in Liuxi Oilfield is not good after applying common fracturing technology and cumulative production is relative low;
(2) Strong water-wet, high oil saturation, the degree of fracture development and low viscosity is beneficial to promote the effect of waterflood stimulation;
(3) According to the numerical simulation result, the cumulative production is higher when injection volume is more but increase of the degree of stage production becomes significantly slow.
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