The research and application of movable gel flooding technology in horizontal well pattern of Lu 36 block

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Abstract. Lu 36 block in Huabei oilfield uses vertical well to inject and horizontal well to produce. The reservoir heterogeneity of this block is strong and watercut is rising fast. The drilling in reservoirs of horizontal well pattern is long, so it is difficult to find water and shut off water, increasing the difficulty to adjust and develop. To explore an effective way to develop the remaining oil of the horizontal well reservoir in later stage of production. Through analyzing, the movable gel flooding can effectively improve interlayer contradictions, expand swept volume in the plane and innerlayer in Lu 36 block. The gel adaptable in horizontal well pattern is large doses, moderate strength and strong stability. Injecting on the single well can lead to the channeling or streaming. Through detailed reservoir description, the reserves are recalculated. The displacement system and parameters are further optimized. 4 wells in Lu 36 block has carried out the overall displacement. 51,264 m² of flooding agent were injected and the effective rate of corresponding oil wells is 100%. The oil production increased from 5.3 tons to 18.1 tons per day, water cut decreased from 95.43% to 83.18%. The peak of the growing oil is 12.8 tons per day and the valid is 36 months. The cumulative increased oil is 7,965 tons.

1. Introduction

The tectonic position of Lu 36 block is located in the Raoyang depression. The main reservoir development is NgII and NgIII oil layers, belong to high-porosity and high-permeability reservoir. On the lateral, reservoir distribution is stable. The crude oil viscosity in the ground is 30.16 mPa·s, the total salinity of formation water is 1761 mg/L, water type as NaHCO₃, and the initial formation temperature is 76 °C.

The heterogeneity of layer NgII is strong and the reservoir energy is not enough, facing abandoned. Through fine reservoir description, the Lu 36 block still has the material basis for the further exploration. The development method of vertical well injection and horizontal well drilling for secondary development is used. The daily oil production capacity is 100 tons. As the water injection
development, the reservoir interlayer contradiction extrudes, water absorption inside layer is uneven, and plane directional is serious. The drilling in reservoirs of horizontal well pattern is long, finding water and shutting off water is difficult and the remaining oil is in dispersion. So all these reasons increase the difficulty to adjust and develop at high water-cut late stage. To improve water flooding effect of Lu 36 block and explore the effective methods for excavating remaining oil potential of horizontal well reservoirs, since 2010, two rounds of movable gel displacement in Lu 36 block had been carried out.

2. Preliminary analysis of displacement effect

2.1 Implementation conditions
In the first round, profile control agent with high intensity was used to adjust water well profile, and then movable gel was used to displace oil within weak absorption or non-absorption layer. Two wells (well Lu36-1, well Lu36-2) were implemented. The cumulative injection profile control agents and movable gels were 6500 m³. In the second rounds, movable gel and surfactant were in application and the slug strength is relatively weak. Four Wells (well Liu 18-34well, Lu36-1, well Lu36-2, well Lu36-4) were implemented. The cumulative injection volume is 18,700 m³.

2.2 Measure effects
(1) Water well working conditions
In the first round, after flooding the water injection pressure rose and apparent water injectivity index dropped. The increasing pressure is 5.1 to 6.7 MPa. It had reached the purpose of plugging high permeable channels. In the second rounds, after flooding only the water injection pressure well Liu 18-34 rose and apparent water injectivity index dropped. So displacement agent did not enter into the deep formation, only plugged in the near wellbore area.

After the first round of displacement the interlayer contradictions had been improved. After the second round the interlayer contradictions of well Lu 36-4 intensified, that of other wells improved in short-term and then restore to the original state.

Figure 1. Water absorption profile changes before and after displacement of well Lu 36-1.

Figure 2. Water absorption profile changes before and after displacement of well Lu 36-4.
(2) Oil well working conditions
In the first round the effective oil wells were well Lu 36P6 and well Lu 36P4. The main effective mechanism was planar reversing water driving and new layer starting. By point-point method, the cumulative increased oil of this round was 2704 tons and the valid is 18 months. In the second rounds, the effective oil wells were well Lu 36P11, well Lu 36P6, well Lu 36P10 and well Lu 36P4. The main effective mechanism was profile control inner layer of expanding the water flooding sweep volume. By point-point method, the cumulative increased oil was 2454 tons and the valid is 8 months.

![Figure 3. The production curves of flooding well groups in two rounds of Lu 36 block.](image)

2.3 Preliminary displacement conclusions
(1) Two rounds of displacement obtained certain effect of decreasing water and increasing oil. By displacement, the interlayer was adjusted, the water flooding sweep volume of was expanded in the plane and inner layer. So the movable gel flooding technology has strong adaptability in Lu 36 block.

(2) In the second round, the displacement profile quickly returned to original state and the valid is short. The main reason is that the extremely large intensity of displacement agent caused plug and pollution of the near wellbore area. So the displacement agent strength should be further optimized.

(3) The drilling in reservoirs of horizontal well pattern is long, the drainage area is big and the remaining oil is in dispersion. It is beneficial to push the displacement agent to the deep reservoir and plug the seepage channel of high washing degree by increasing injection dosage and enhancing the gel stability. Then the subsequent fluid was forced to shift to the low permeability zone and displace the remaining oil[1].

3. The scheme design of profile control and displacement
3.1 The displacement idea
According to the characteristics of horizontal well pattern and preliminary analysis of application effect, the whole displacement centering on horizontal wells can be thought perfect. The movable gel changes fluid flow direction and speed in deep reservoir, makes oil wells reverse response, enlarges water driving sweep volume. The third round design should optimize the displacement formula, doses and injection rate.

3.2 Fine reservoir description
By fine reservoir description, the underground reservoir is re-recognized. The flow field distribution is determined and the road map of adjusting water flow direction is decided. According to the interpretation results and dynamic reports, the waterflooded figure is depicted. Reserves and remaining oil are re-calculated, which show greater potential.

Four wells are selected for displacement in the north. They are well Liu 18-34well, Lu36-1, well
Lu36-2, well Lu36-4. Through optimizing displacement formula and adjusting injection parameters, the development effect of Lu 36 block is improved.

3.3 Engineering proposal design

3.3.1 Formula optimization. Recently, movable gel crosslinking system commonly used at home and abroad is metal ion crosslinking and phenol formaldehyde crosslinking, for example, polyacrylamide, organic chromium and aluminum organic crosslinker. Metal ion crosslinking system is mainly used for medium and low temperature reservoir (<70°C), usually using water liquor. Phenol formaldehyde crosslinking system do not gel in low temperature, so it is mainly used for high temperature reservoir (> 80°C) [2-4]. According to the formation temperature and fluid property of Lu 36 block, the heat-resistant polymer KY - 2 and phenol formaldehyde crosslinking system JBT-1A and JBT-1B are identified.

Through indoor test, based on gelling performance in the different concentration of polymer, crosslinking, due to the intensity of displacement agent should not be too large, using the experience of previous displacement, the movable gel viscosity is controlled within 2000 mPa·s[5]. Combined with the result of stability test, movable gel formula suitable for Lu 36 block is recommended, which is shown in table 1.

| Formula | HPAM(KY-2) (mg/L) | Crosslinking agent A (JBT-1A) (mg/L) | Crosslinking agent B (JBT-1B) (mg/L) |
|---------|------------------|-------------------------------------|-------------------------------------|
| 1500-2000 | 2000-2500        | 1000-1500                           |
| Property | Gel time (hours) | Gel viscosity (mPa·s) | Viscosity retention rate after 60 days (%) |
| 36       | 1400-2000        | 90                                  |

3.3.2 Plug and dosage design. In order to make displacement agent enter deep formation gradually, three plugs whose strength is in the order from low to high are designed. Contrast with the two rounds, the dose for each injector is increased, the injection speed is reduced, advantageous for displacement agent to enter deep formation slowly and evenly. The designed injection of four wells is 50,000 m³. The injection capacity is as 1.1 to 1.2 times as the water injection rate.

| Well   | Injection rate (m³/d) | Rate design (m³/d) | Increasing pressure design (MPa) | NO.1 gel plug (m³) | NO.2 gel plug (m³) | Sealed plug (m³) | Total (m³) |
|--------|-----------------------|--------------------|----------------------------------|--------------------|--------------------|------------------|------------|
| Lu 36-1 | 20                    | 40-50              | 2-5                              | 7800               | 3900               | 800              | 12500      |
| Lu 36-2 | 20                    | 40-50              | 2-5                              | 3600               | 12700              | 200              | 16500      |
| Lu 36-4 | 20                    | 40-50              | 3-6                              | 3000               | 12000              | 1000             | 16000      |
| Liu18-34 | 20                   | 40-50              | 2-5                              | 3000               | 1800               | 200              | 5000       |
| Total   | 17400                | 30400              | 2200                            |                     |                     |                  | 50000      |

4. Application

From June 2014 to July 2015, the third displacement round construction in Lu 36 block was carried out. The actual gel injection is 51,264 m³. The injection profiles of four wells after gel flooding displacement were improved to different degrees. By the transformation of the water flooding direction, the water driving sweep volume was expanded, all the corresponding oil wells worked, the effective rate is 100%. The oil production increased from 5.3 tons to 18.1 tons per day, water cut
decreased from 95.43% to 83.18%, the natural decline rate fell from 37.61% to -7.08%. The valid is 36 months. The cumulative increased oil is 7,965 tons.

Figure 4. Production relation curves of the third displacement round in Lu 36 block.

5 Conclusions
(1) From the analysis of early measures effect, the movable gel flooding can effectively improve interlayer contradictions, expand swept volume in the plane and innerlayer in Lu 36 block. The gel adaptable in horizontal well pattern is large doses, moderate strength and strong stability. Injecting on the single well can lead to the channeling or streaming.

(2) By fine reservoir description, the underground reservoir is re-recognized. The flow field distribution is determined and the road map of adjusting water flow direction is decided. And reserves of every layer are re-calculated, to clear the development potential the displacement well groups.

(3) On the basis of the previous displacement effect, the intensity of displacement agent in Lu 36 block should not be more than 2000 mPa·s. on this basis, the optimization of displacement system is completed. The method "large doses and small rate" is advantageous for displacement agent to enter deep formation slowly and evenly. The designed injection of four wells is 50,000 m³. The injection capacity is as 1.1 to 1.2 times as the water injection rate.

(4) Lu 36 block has obtained remarkable effect of increasing oil and decreasing water after implementing displacement scheme. The oil production increased from 5.3 tons to 18.1 tons per day, water cut decreased from 95.43% to 83.18%, the natural decline rate fell from 37.61% to -7.08%. The valid is 36 months. The cumulative increased oil is 7965 tons.

(5) The successful application of movable gel flooding technology in Lu 36 block lays the theoretical foundation for horizontal wells development potentialities and has very important significance.

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