Research and field test of the integrated pipe string of separate layer production and injection

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Abstract. Imbibition oil recovery is an effective technology for tight reservoir development, the working mode of the well needs to be switched between production and injection, when using imbibition oil recovery. It will leads to some disadvantage of imbibition oil recovery, such as long operation time and high development cost. Therefore, a novel integrated technology of separate layer production and injection has been proposed, which is based on the hydraulic feedback pump and bridge concentric zonal water injection technology. When switching the working mode of the well, it is only necessary to trip in or out the plunger into the cylinder of pump. Until recently, this technology had been applied in 3 wells for field test, 2 injection wells and 1 production well. The test results show that this technology can realize switching the working mode of the well without replacing the pipe string. Besides, it also can meet the requirements of tripping in/out the plunger (φ50.8mm) or the measuring instrument (φ42mm). The successful field test of the separate layer production and injection integrated pipe string is very important for changing development method of low-permeability reservoirs from conventional waterflooding to imbibition oil recovery. By using this integrated technology, low permeability reservoirs can be developed economically and effectively.

1. Introduction

Imbibition oil recovery is an effective technology for tight reservoir development [1-3]. 35% of the proven reserves of DG oilfield are low-permeability reservoir reserve. The efficient development of low-permeability reservoirs is very important for the stability of DG oilfield production. Block GD6 is one of the low-permeability blocks in DG oilfield. The main pay zone of Block GD6 is ZV. The average permeability of block GD6 is 3.9mD, which belongs to ultra-low permeability reservoir. Besides, due to poor reservoir physical properties and the broken fault block, the degree of water flooding control of the GD6 fault block is relatively low, 73.2% for upper layer of ZV and 64.5% for lower layer of ZV. In general, GD6 fault block water flooding development effect is poor. In order to improve the waterflooding effect of this fault block, a percolation and oil recovery development test was carried out. The working mode of well needs to be switched between production and injection when using imbibition oil recovery. That will lead to some disadvantages of imbibition oil recovery, such as long operation time and high development cost, which will affect on-site operation. At present, domestic researchers have done more research on imbibition oil recovery, such as mechanism, injection parameter optimization and development effect evaluation. However, there are few studies on operation technology. Therefore, it is very important to study an integrated technology of separate layer production and injection for economic development of low-permeability reservoirs.
2. Imbibition oil recovery
Imbibition oil recovery for GD6 block includes 2 stages. The first stage adopts depletion development which lasts for 2-2.5 years, after large-scale artificial fracturing in low-permeability reservoir. In water-wet tight reservoirs, the elastic force plays a major role at the initial stage. Under the action of elastic force, crude oil flows from the matrix to the fracture. Then, the fracture pressure decreases rapidly and the matrix pressure decreases slowly. When matrix pressure and fracture pressure are close to equilibrium, the imbibition effect which caused by capillary force plays a major role. The second stage is water huff and puff process. The injection well will start to inject when the formation pressure dropped to 70%. The injection will continue until formation pressure recovery to about 100%. That will last about 2 month, then start soaking for one month. The production well is closed for soaking about 3 months, while the injection well is injecting. After soaking, all wells switch to production well to product 9 months. Production time of high-angle well extended to 12 months. There are three cycles for asynchronous injection and production of oil wells, water huff-puff of water injection well and imbibition oil recovery. Five years later, the fracturing was repeated and the oil and water wells were exchanged for the second round.

3. Separate layer production and injection integrated pipe string

3.1 String construction design
The integrated pipe string for production well is composed of pumping rod, pump cylinder, bidirectional anchor, water distributor, packer, liner, blank plug, shown in Fig.1.

![Fig.1 Separate Layer Production And Injection Integrated Pipe String](image)

3.2 Working principle
The water distributor is closed when the integrated string running in hole. The pump truck is pressed to complete the setting of the string packer. In production mode, only need to trip in the plunger pump (φ50.8mm) to start to product. The crude oil will enter pipe string through the water injection channel of the water distributor. Only three steps are needed to switch the production mode of the well. First, tripping out the plunger from the pump cylinder. Second, tripping in the measurement instrument for
measuring and adjusting water distributor. Third, adjusting water injection rate of each layer to meet the requirements.

3.3 Key downhole equipment

3.3.1 φ50.8mm Hydraulic feedback pump. The hydraulic feedback pump mainly consists of pump cylinder, mandrel, plunger, traveling valve and fixed valve, as shown in Figure 2. The diameter of the plunger is 50.8mm, the minimum inner diameter is 46 mm, the maximum stroke is 6 m, the pump constant is 2.03, and the length of the pump barrel is 7675 mm.

During the upstroke, the plunger pulls the traveling valve to form a seal with the ball socket on the plunger, and the liquid above the plunger is lifted to the ground. At the same time, a low-pressure cavity is formed between the traveling valve and the fixed valve seat. Under the effect of the pressure from formation and the friction of the mandrel, the hemispheres of the fixed valve are separated from the seat. Then, the well fluid enters the pump chamber.

And during the downstroke, the traveling hemisphere is pushed by mandrel and separated from the plunger. The plunger will fall down slowly under the action of high pressure feedback force from the pump chamber and gravity. But the speed of plunger is slower than the traveling hemisphere’s. At this time, the liquid in pump chamber enters the upper part of the plunger. Under the action of the pressure from pump chamber and the friction of mandrel, the fixed hemisphere forms a seal with fixed valve seat. Then, channel which fluid enter the pump chamber is closed.

3.3.2 Water distributor. The main feature of the water distributor is concentric adjustment and eccentric water distribution structure. Compared with the conventional bridge concentric water distributor [6-7], a transmission structure and an eccentric water distribution structure were added in this new water distributor. The water distributor is mainly composed of main structure, sealing system of transmission parts, gear transmission system and water nozzle, shown in Figure 3.

During measuring and adjusting, measurement instrument is connected to the ground via a cable. It will be run in hole and docked to downhole water distributor. The measurement instrument is
controlled to drive 2 gears in the distributor from ground. The smaller gear will transform rotary motion into linear motion, which drives the movement of the inner sleeve of the water nozzle. The inner sleeve of water nozzle moves upward which will increase the area of water outlet and increase injection rate. And vice versa.

According to the test data, the open torque of this new water distributor is 70-85% less than that of conventional one. It successfully solved the problem of conventional bridge concentric water distributor, such as large opening torque and failure to open the nozzle.

![Water Distributor](image)

Fig. 3 Water Distributor

3.3.3 High performance Y341-114 packer. Y341-114 packer is mainly composed of set part, seal structure, well flushing channel and unsealing structure, as shown in Figure 4. Slotted design is adopted for the water inlet of packer flushing channel. This design can effectively prevent the well flushing fluid from carrying large particles into the well flushing channel of the packer. This new design reduces the risk that the packer flushing channel is blocked by particulates and the packer flushing channel cannot be closed completely.

The unsealing load of the packer is only 4-6 tons. When the separate layer injection string is tripped out, the unpacking load of each packer does not stack. It will reduce the risk of string sticking. The packer rubber cylinder has a pressure resistance of 50MPa and a temperature resistance of 150℃.
4. Field test

Until recently, this technology had been applied in 3 wells in GD block for field test, 2 injection wells used separate layer production and injection integrated pipe string and 1 production well. The maximum well depth is 3645m, the maximum deviation is 23.95°, the maximum depth of pump is 1810m, and the maximum depth of water distributor is 3207m. The test success rate is 100%, and qualified rate of layered water injection is 100%. The test results show that this technology Can meet the requirements of oil production and layered water injection. Those test wells had been in stable production for 2 years. The expanded scope of field trials is still in progress.

### Table 1. Statistical table of field test wells.

| Well No. | Depth of Distributor (m) | Injection Rate (m³/d) | Injection Allocation | After Measurement |
|----------|--------------------------|-----------------------|----------------------|------------------|
| D3       | 2904                     | 27.1                  | 29.8                 |                  |
|          | 3161                     | 40.1                  |                      | 40.1             |
| D4       | 2992                     | 18                    | 20.1                 |                  |
|          | 3207                     | 30.3                  | 30.1                 |                  |

### Table 2. Statistical table of response well.

| Well No. | Depth of Pump (m) | Oil Production Rate (m³/d) | Pump Efficiency (%) |
|----------|-------------------|---------------------------|--------------------|
| D5       | 2904              | 1.1                       | 87.8               |

5. Conclusion

(1) The separate layer production and injection integrated pipe string can meet request of switching well working mode without replacing the pipe string, which includes hydraulic feedback pump, concentric water distributor, high-performance packer and other down hole equipment.

(2) The integrated technology of separate layer production and injection can avoid pipe string from pulling out of hole. That will lead to multiple benefits, such as significantly reduce occupation period and operation cost. This technology also provides an economical and feasible technical solution for imbibition oil recovery. In addition, it also has a better alternative meaning for low-permeability reservoirs and other difficult-to-operate water injection development reservoirs.
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