Research and Application of Downhole Oil-Water Separation and Injection Production Technology in the Same Well

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Abstract. China's main oilfields have entered the period of ultra-high water cut development. With the increase of water cut, the cost of produced liquid treatment is increasing, and the oilfield development is close to the economic limit. The surface oil-water separation and wastewater reinjection have become common technical problems in the development of ultra-high water cut oilfields.Since 2000, Daqing Oilfield has carried out research on downhole oil-water separation and injection production technology in the same well, innovated and formed the concept of "downhole oil-water separation and injection production integration", conquered four core technologies of downhole oil-water separation, injection production string, sealing process and supporting monitoring, and has met the block application conditions. Block pilot test shows that the technology breaks the traditional concepts and methods of conventional single production and single injection and surface treatment and reinjection of produced water, realizes the circulation of oil layers product water, and reduces wellbore water output, reconstructs the displacement relationship. The technology also realizes the function of multi-well point and multi-section production and injection with fewer wells, increases the connectivity and effect direction between wells, improves the production degree of oil layer, reduces the comprehensive development costs, and provides a new technical means to extend the life cycle of old oilfields with high water cut and expand the development limit.

Keywords: Ultra-high water cut · Downhole oil-water separation · Injection-production integration · Block pilot application

The comprehensive water cut of the main block of Daqing Oilfield is close to 95%, and a large amount of produced water is invalid circulation, which leads to a substantial increase in energy consumption, poor development benefit, increasing input cost and operation cost of lifting, gathering and transportation and treatment equipment, increasing scale of surface water treatment, and increasingly prominent environmental protection problems [1]. Due to the increase of water cut, the oil well is close to the

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limit of economic exploitation, resulting in shut in and stable production The situation is grim [2]. After years of development, the injection production relationship of Daqing Oilfield has been basically perfect. Under the existing technical conditions, the formation reserves between injection wells and production wells can be effectively displaced. However, there are still a large number of unswept areas between production wells and production wells. In Daqing Oilfield, there are more than 1 billion tons of remaining reserves that can not be exploited due to the lack of economic and effective displacement methods [3]. Therefore, reducing the surface water production, improving the utilization degree of unswept area and reducing the development cost have become the key problems restricting the economic development of ultra-high water cut oilfield [4]. The downhole oil-water separation and injection production technology can separate the oil-water from the produced liquid, lift the liquid with high oil concentration to the surface, and inject the separated water into the formation, which can not only greatly reduce the surface water production, but also use the separated water to displace the remaining reserves of the formation, which can effectively extend the economic production period of the oilfield [5].

1 Downhole Oil Water Separation and Injection Production Technology in The Same Well

1.1 Pipe String Composition

The pipe string (see Fig. 1) is mainly composed of production pump, injection pump and hydrocyclone. The hydrocyclone is located between the production pump and the injection pump. After the fluid of the produced layer enters the hydrocyclone, the oil-water separation is carried out. The separated high oil-bearing fluid is lifted to the ground through the production pump, and the low oil-bearing part enters the reinjection layer after being pressurized by the injection pump. This method of first hydrocyclone and then pressurization can not only improve the reliability of the seal, but also avoid the emulsification phenomenon of oil droplets, which can significantly improve the separation efficiency.

After many years of research, the downhole oil-water separation injection production technology with the same well has been finalized. This technology uses screw pump as the production pump and electric pump as the injection pump. The operation parameters of the injection pump and the production pump can be adjusted separately, which improves the coordination of the injection production relationship and provides conditions for the efficient separation of the hydrocycloner. Different from the general layout of centrifugal pump with motor at the top and motor at the bottom, this scheme creatively adopts the inverted layout of motor at the top and centrifugal pump at the bottom, and a guide hood is designed outside the motor, which not only provides a flow passage for the fluid, but also takes away the heat generated by the motor operation.

The maximum outer diameter of the scheme is 114 mm, which can be used in 5½″ casing. The daily liquid treatment capacity is 60–150 m^3, and the effective injection pressure is 18 MPa, which can meet the application requirements of Daqing placanticline oilfield.

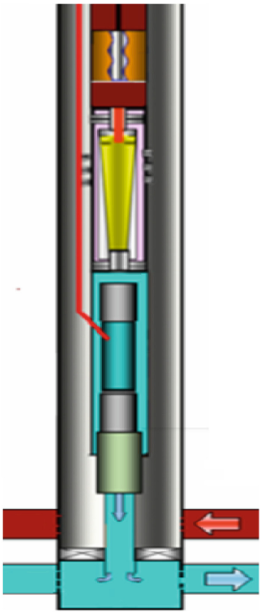

Fig. 1. Screw pump production electric pump injection process string

1.2 Hydrocyclone

When the hydrocyclone (see Fig. 2) is working, the oil-water mixture enters the swirl chamber from the tangential inlet and rotates at high speed along the inner wall of the swirl chamber [6]. Due to the difference of density, the water which is higher density in the oil-water mixture moves tangentially along the inner wall of the swirl chamber and downward along the axis under the action of centrifugal force, forming a downward moving outer swirl, which is discharged at the underflow outlet [7]. In the process of movement, the oil which is lower density gradually separates from the water which is higher density [8]. When the fluid enters the conical section, the flow area gradually shrinks, the flow velocity increases, and the pressure near the center of the hydrocyclone decreases [9]. The oil which is lower density gradually breaks away from the outer cyclone and flows to the low pressure area of the center, and forms an upward inner cyclone, which is finally discharged from the overflow outlet [10].

The hydrocyclone can be used in oil production wells with water cut more than 95%, the separation efficiency is more than 99%, and the oil content of separated reinjection water is less than 100 ppm [11].

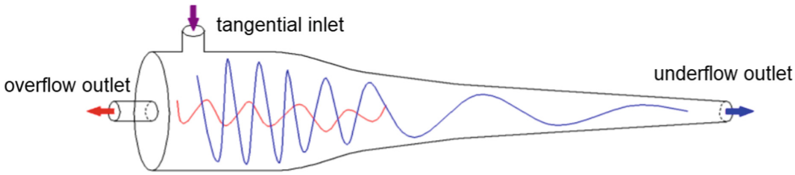

Fig. 2. Hydrocyclone

1.3 Supporting Technology

Packer Process
For the oil wells with more layers, the multi-layer packer process string is developed. The multi-stage packer, prodution device and injection allocator are used to seal the formation, which can realize the application requirements of interactive injection and production between formations. According to the actual application requirements, It can be simplified into many forms, such as upper production and lower injection, lower production and upper injection, production at both ends and injection in the middle and so on.

Monitoring Technology
By installing a parameter sensor at the outlet of the centrifugal pump, the injection pressure, temperature and other parameters can be monitored in real time, the water absorption capacity of the formation can be analyzed, and the working parameters of the injection pump can be adjusted according to the production needs to ensure the qualified rate of injection.

2 Combining Reservoir Engineering to Reconstruct Displacement Relationship

2.1 Well Network Displacement Relationship

In the early stage of oilfield development, the formation energy is sufficient, and the oil well can produce by itself depending on the elastic deformation of formation rock and fluid. With the extension of production time, the formation energy is decreasing, and the oil well must rely on mechanical oil recovery to lift the formation fluid to the surface. At the same time, in order to supplement the formation energy and improve the recovery rate of the reservoir, it is necessary to deploy water injection wells for water flooding, and many oil wells and water wells will form a well pattern. Daqing Oilfield has a large area and good reservoir extensibility. In the early stage of development, some formations in the middle and north of Sazhong and Sabei with high permeability adopt row and column well pattern. Some formations with irregular distribution and poor extensibility and those requiring enhanced water injection usually adopt area well pattern.

Taking the five point water injection method in the area well pattern as an example, as shown in Fig. 3, the main displacement direction is between the water injection well and the production well. The area near the injection production well connection can be effectively displaced, and the remaining oil reserves are low. However, between the oil wells and the oil wells, a large amount of remaining oil has not been produced because there is no effective sweep.

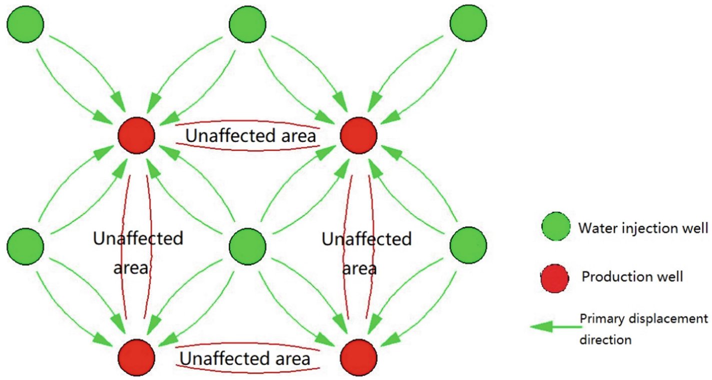

Fig. 3. Schematic diagram of original displacement relationship

2.2 Reconstruction of Displacement Relationship

If we want to exploit the remaining reserves between production wells, we must reconstruct the existing injection production well pattern and reconstruct a new displacement relationship. The common means include increasing water injection wells, transferring oil wells to water injection wells, etc. Although it can also achieve the effect of expanding swept volume and enhancing oil recovery, it will increase the drilling cost, reduce the number of production wells and have poor economy.

In view of the above problems, the combination of downhole oil-water separation with well injection production technology and reservoir engineering is carried out in high water cut block. Relying on reservoir engineering, the test block is optimized, the fine geological analysis is carried out, the distribution of remaining oil and the connection between wells are clarified, the injection production relationship is reconstructed, the displacement direction of injection water is changed, the swept volume is expanded, and the recovery factor of the block is further improved on the basis of reducing the surface water production.

Taking the well pattern in Fig. 3 as an example, the stratum in the test block is divided into two sets of strata, and the sealing is conducted, the injection wells in the middle are shut down, four production wells are adjusted to the same well injection production wells, two wells are produced in the upper layer and injected in the lower layer, two wells are produced in the lower layer and injected in the upper layer, and four test wells form a longitudinal circular phase displacement relationship. The modified well pattern is shown in Fig. 4. A new displacement relationship is constructed between the oil well and the oil well. It has a significant displacement effect on the original well network's non affected area, expanded the sweep volume and realized the effective development of remaining reserves.

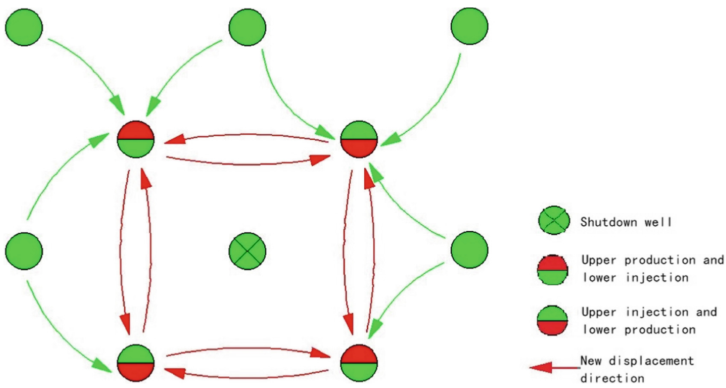

Fig. 4. Schematic diagram of new displacement relationship

3 Field Application

3.1 Test Purpose

By means of downhole oil-water separation and injection production in the same well, the circulation of oil-water production wells can be realized, the scale of wellbore effluent can be reduced, the cost of sewage treatment and reinjection can be reduced, the construction scale of surface water injection system can be reduced, and the capital construction cost can be reduced. In order to achieve multi-function of one well, multi well point and multi-layer production and injection can be achieved with fewer wells, inter well and interlayer mutual injection and production can increase the effect of connecting direction and benefit direction, and expand wave volume; a connecting body between wellbore and reservoir can be constructed, energy recycling can be used, reservoir development index can be improved, and the technical and economic feasibility of production and injection integration can be verified, so as to explore a new way for later economic development of ultra-high water cut oilfield.

3.2 Well Selection Conditions

In order to achieve the ideal test effect, the selection of test block is particularly important. According to the characteristics of downhole oil-water separation and injection production technology in the same well, the test block should meet the following conditions: high formation permeability, good interlayer connectivity, thickness of interlayer between injection layer and production layer > 5 m, qualified cementing quality, the deviation angle above the electric pump is less than 20°, full angle change rate < 3°/30 m, no casing deformation, daily fluid production > 60 m^3, water cut > 95%, no sand production and gas production The quantity is small.

3.3 Block Overview

According to the optimization, block a can meet the needs of field test, with oil-bearing area of 2.8 km^2, geological reserves of 562 × 10^4t, recoverable reserves of 237 × 10^4t, remaining recoverable reserves of 58.4 × 10^4t, buried depth of main reservoir of 2250–2700 m, pressure coefficient of 1.0–1.1, temperature gradient of 2.95°C/100 m, belonging to normal temperature pressure system. The density of crude oil is 0.84 g/cm^3, the viscosity of underground crude oil is 0.81 mPa·s, and the viscosity of surface crude oil is 4.5mPa·s. the oil is light, low viscosity and good fluidity. Before the measures, there were 21 wells, including 16 production wells, with an average daily oil production of 1.2t, water cut of 96%, and 5 water injection wells, with an average daily injection of 66 m^3. The physical properties of reservoir and crude oil are shown in Table 1.

Table 1. Physical properties of reservoir and crude oil.

Reservoir physical property				Physical properties of crude oil					
				High pressure physical properties		Physical properties of degassed crude oil		Properties of formation water	
Porosity (%)	Permeability ($10^{-3}μm^2$)	Pressure coefficient	Reservoir temperature (°C)	Oil gas ratio (m^3/t)	Underground viscosity (mPa·s)	Density (g/cm^3)	Viscosity (mPa·s)	Total salinity (mg/l)	Cl^- content (mg/l)
27	296	1.0-1.1	95.5	175	0.81	0.84	4.5	8828	3597

3.4 Test Scheme

Combined with the formation and injection production relationship, the same well injection production was implemented for 10 wells in the block, including 6 wells in upper production and lower injection scheme and 4 wells in the lower production and upper injection scheme. The original 5 injection 16 production was adjusted to 13 injection 18 production. After the implementation of the scheme, the corresponding injection production ratio is increased from 87.5% to 100%, and the water drive control degree is increased from 75% to 95%.

3.5 Test Effect

After the field test in block A, by the end of 2020, the average operation time of 10 test wells is 412 days, the daily liquid production is reduced by 70.3%, the daily oil production is increased by 0.9t, the water cut is decreased by 5.1%, the cumulative oil production is increased by 3708t, and the surface water production is reduced by 2.8 × $10^4 m^3$. The comparison of single well effect before and after the measures is shown in Table 2.

Table 2. Comparison of single well effect before and after a measure.

Project	Nissan liquid (m^3)	Daily oil production (t)	Moisture content (%)
Before measures	97.2	0.8	99.2
After measures	28.9	1.7	94.1
Difference	-68.3	+0.9	-5.1

4 Conclusions

(1) Due to the difference of oil and water density, the centrifugal effect in the hydrocyclone is different. Water tends to flow outward, and oil tends to flow toward the center, so as to achieve the effect of efficient oil-water separation.
(2) The technology of screw pump production and electric pump injection is to separate the liquid produced from the formation first, and then increase the pressure, which is not only conducive to sealing, but also avoids emulsification, and can improve the separation efficiency of hydrocyclone. The screw pump is driven by sucker rod, and the electric pump is driven by power cable, so as to realize the independent adjustment of two systems and ensure the long-term stable operation of the system.
(3) Combining downhole oil-water separation with well injection production technology and reservoir engineering, according to the distribution of remaining oil in the block, the injection production well pattern is reconstructed, which reduces the development costs of drilling, oil production and water injection, and realizes infill development with the existing well pattern, which can increase the new displacement direction, expand the wave and volume, improve the recovery rate of the block, and extend the economic production period of ultra-high water cut oilfield.

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