ISSN: 2414-1895 DOI: 10.6919/ICJE.202111_7(11).0001

Optimization and practice of oil production engineering technology for intensive and large MULTIwell cluster in low permeability reservoir

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Abstract

In recent years, poor resource endowment and long-term impact of low oil prices have gradually become a common problem faced by China's petroleum industry, the traditional development mode and conventional technology has been difficult to achieve the efficient utilization of low-grade resources. During the 13th Five-Year Plan period of Jilin Oilfield, in order to cope with the problems of low oil price, high investment in production capacity construction and low-grade resources in the new area, Jilin Oilfield carried out the field test of intensive large multiwell cluster platform benefit construction and production in the low permeability reservoir represented by block iii in Xinli oilfield and achieved remarkable results. The field practice of full reservoir pressure flooding, low cost and long-term lift, factory and clean operation has been carried out. The production of this block has achieved the goal of increasing production, increasing benefit, reducing investment and cost, established a new mode and supporting technology series of intensive large multiwell cluster benefit construction, production and development. It can open a new way for similar low permeability oil and gas resources benefit utilization in the future.

Keywords

low permeability, Intensification, large multiwell cluster, full reservoir fracturing and displacement, low cost and long-term lift.

1. Introduction

At present, low permeability residual reserves, difficult-to-produce reserves and unconventional oil and gas reserves have gradually become the main body of oil and gas exploration and development [1]. Since the 12th Five-Year Plan, Jilin oilfield has been in the stage of low permeability, low abundance and low production. The effect and scale of production capacity construction are getting worse year by year, and the investment in production and construction of one million tons is rising sharply. The traditional development technology, mode and practice have been unable to realize the benefit utilization. In recent years, with the development of low-grade unconventional oil and gas resources increasing year by year, cluster well and factory operation has been widely used in oil exploitation, which can realize mass drilling and completion and assembly line construction, effectively improve operation efficiency and reduce costs [2-5]. During the period of the 13th Five-Year Plan, Jilin oilfield implemented the requirements of "re-understanding low permeability, re-constructing low permeability technology system and re-positioning low permeability benefit development mode". Drawing on the experience of tight oil and gas development in North America, the field test and promotion of the efficient construction and production mode of low permeability large well cluster are carried out by adopting unconventional innovative well construction concepts and modes. A series of key engineering technology have been developed and applied, the overall

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efficiency as the core of geology and engineering integrated optimization pattern has been established, "total reservoir fracturing and displacement" reservoir reconstruction model and related technology, the new low-cost long-term lifting technology, factory and clean technology as the main body of the key technologies of production engineering series have been formed. Under the condition of low oil price, the significant effect of "improving quality and efficiency, reducing investment and cost" in the construction and production of low permeability reservoir has been realized, which makes a large number of low permeability reservoir blocks realize the construction and production and development of efficiency, effectively supporting the successful practice of the production construction mode of intensive large multiwell cluster. It shows a great promotion prospect and provides a reference for similar economic development of difficult-to-use reserves under the condition of low oil price in the future.

2. Development overview of the field test area

2.1 Overview of oilfield development in the test area

Jilin Oilfield chose block iii of Xinli oilfield as the field test area of intensive platform for benefit construction and production. Xinli oilfield is a typical low permeability reservoir developed in the early stage, and the target reservoirs are mainly Fuyu and Yangdachengzi reservoirs. The reservoir is mainly composed of fine sandstone and coarse siltstone, with poor physical properties and natural east-to-west fractures. The average porosity is 15%, the average air permeability is 6.7×10-3μm2, and the reservoir depth is 1100-1500m. This oil field opened up a production test area in 1980, and it was fully developed by water injection of 300m square inverse nine-point method in 1983. With the prolongation of oilfield development time, the underground contradictions become increasingly prominent, including the increasing injection pressure of water injection well and the aggravation of oil-water well casing deformation. In 1997, in view of the problems existing in the development process of the old injection-production well pattern, the development test of east-west linear water injection was carried out and good results were achieved. Since then, large-scale infilling adjustment has been carried out in this pattern. At present, Xinli oilfield has entered the "double high" production stage, with more than 2200 oil and water wells, with a comprehensive water cut of 82% and recoverable reserves of 75.5%.

2.2 General situation of pilot test demonstration area of large multiwell cluster construction and production

The demonstration area of large platform intensive construction and production is carried out in the north of Block iii in Xinli Oilfield. The oil-bearing area of the block is about 4 km2, the producing layer is Fuyang oil layer, with an average porosity of 14.4%, an average permeability of 17.7×10-3μm2, and an average well depth of 1400m. Three intensive large well cluster platforms are built in the test area, and 107 wells are deployed and developed, with an average well depth of 1400m, with designed productivity per well of 1.5 t/d. The largest platform, platform 1#, has deployed 48 Wells (Figure 1). At the same time, the establishment of the platform realizes the anti-collision obstacle under the condition of 5m wellhead spacing on the drilling design, and realizes zero well loss rate through field implementation (Figure 2). The maximum deviation and horizontal displacement of large well cluster platform Wells are 52.8° and 1000m respectively.

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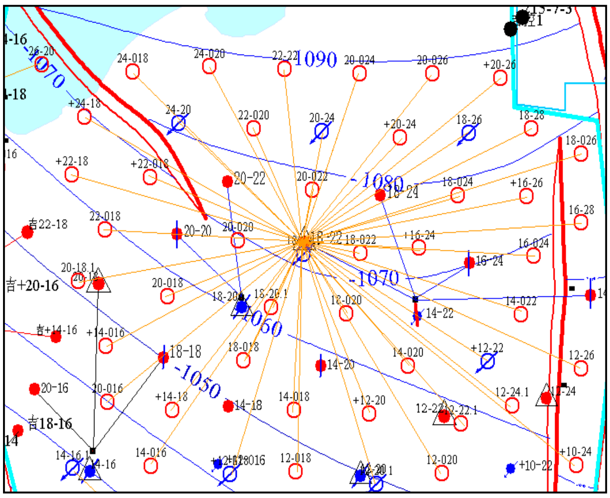

Figure 1. 1# well cluster platform development well location deployment diagram of Xinli Block iii

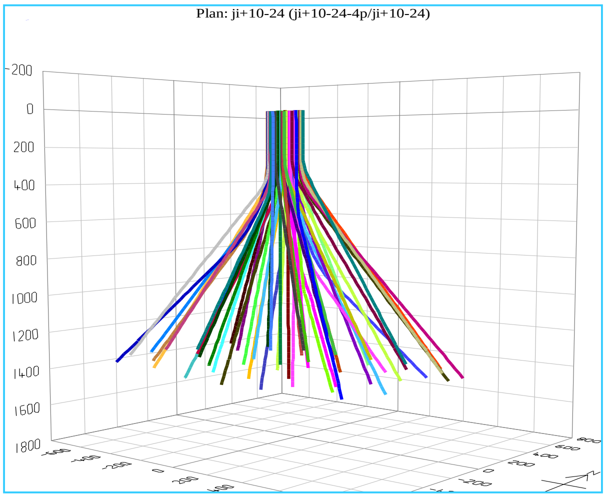

Figure 2. 3D drilling trajectory diagram of 1# platform in Xinli Block iii

Through the pilot test of intensive benefit construction, the better effect of "improving quality and efficiency, reducing investment and cost" has been realized. Production per well increased from the designed 1.5 t/d to 2.4 t/d, the recovery factor increased from 37.3% to 46.4%, investment in capacity construction decreased by 26.9% from the original level of conventional construction and production mode, the operating cost per ton of oil decreased by 53.1% from the previous level. Through the practice of unconventional development concept and technology in conventional low permeability reservoir, it shows a good application prospect.

3. Optimization and practice of oil production engineering technology in large well cluster mode

3.1 Break through the traditional transformation mode, form "full reservoir fracturing and displacement" supporting technology series

The mode of intensive construction and production reservoir reconstruction in large well cluster is changed from the traditional pursuit of single main fracture and well pattern matching to the establishment of full reservoir displacement reconstruction mode matching with sand body, well pattern and fracture pattern. On the one hand, an overall optimization design model of large well cluster is established based on fine reservoir understanding and the optimization of single layer. Combined with reservoir characteristics and platform completion conditions, the single layer understanding is further refined, the potential direction and transformation needs are clarified, and the personalized design of single layer is implemented to improve the reasonable match between fracturing and reservoir. Taking injection-production unit as the research object, and aiming at improving injection-production relationship, the volume of reservoir reconstruction in areas with sand body edge, low output and no effect of water injection increased , the fracture scale of main sand body and injection-production perfect area can be controlled, and the fracture conductivity can be improved. On this basis, the supporting fracturing technology was optimized. The orientation and scale of fractures are optimized according to different well positions and exploitation degrees in the well area to match fractures with well pattern density, water injection front and remaining oil, the injection-production relationship and the overall production status of the well area can be improved at the same time.

On the other hand, a series of supporting technologies of "full reservoir fracturing and displacement" featuring "turning, storage, disturbance, regulation and plugging" have been formed to effectively promote the overall production improvement of the large well cluster construction production area. In the pilot test of large well cluster in Xinli block iii, the whole block synchronous interference

Volume 7 Issue 11, 2021
DOI: 10.6919/ICJE.202111_7(11).0001

fracturing is carried out by implementing "four changes" in practice, that is, from a single main fracture to a complex fracture network, from conventional fracturing to energy storage fracturing, from single well fracturing to group fracturing and transformation from fracture reconstruction to matrix reconstruction. The regional complex fracture network formed by inter-row interference and inter-well interference can improve fracture-controlled reserves and single well production by pursuing the maximum contact area with the reservoir. According to the characteristics of well pattern and the drilling situation of reservoir, personalized reconstruction is adopted for different well layers. The water well is mainly optimized by plugging to fracturing technology, increasing the direction of water flooding. The well layer located at the edge of sand body adopts energy storage fracturing technology to improve formation pressure. The interference and diversion fracturing techniques are optimized to achieve fracturing efficiency in the well layer corresponding to the water well. For the well layer with a good corresponding to the water well, small-scale and diversion fracturing should be optimized to avoid the water injection front and tap the potential lateral remaining oil. Using fracture diversion to create new fracture fracturing technology, high pressure temporary plugging agent, solidified resin sand, fiber and other plugging materials are used to seal the original fracture end and middle, increase fracture net pressure and realize horizontal stress inversion, and then pump proppant again to realize fracture diversion and improve the potential exploitation of remaining oil from north to south near the well zone. The integration of multiple fracturing techniques to maximize the matrix reconstruction (Figure 7) creates a complex fracture system that creates better seepage conditions for increased production per well. After fracturing, the average production of single well is 1.3 tons higher than that of conventional wells in the same area, and the fracture-controlled reserves of reservoir are 55.5% higher than that of conventional fracturing mode, which has achieved a significant effect of fracturing and production improvement.

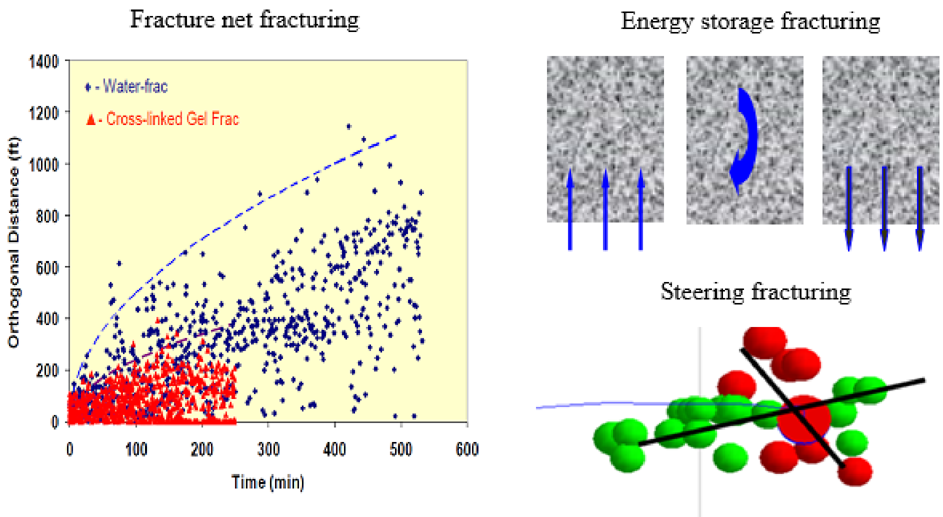

Figure 3. The integration of multiple fracturing techniques in reservoir reconstruction of large well cluster

3.2 A series of supporting technologies for platform lifting of Large well cluster to meet the needs of low cost and long-term production

(1) Development and application of new low cost lifting equipment

Under the situation of low oil price, different optimization technologies are studied and applied to save energy and reduce cost in the oil fields with pumping wells as the main exploitation mode[20]. Concentrated surface well location and small spacing of wells can be the characteristics of large platforms, the surface well spacing is generally controlled at 6.5m to 7.5m. In terms of lifting equipment in the test area of Xinli iii block, Jilin Oilfield innovatively applied the new lifting equipment of "one machine, two wells" and "one machine, many wells" represented by "dual horsehead" and "hydraulic pumping" and realized industrial application, effectively reducing production capacity construction investment and operating cost. The dual horsehead pumping unit is

ISSN: 2414-1895 DOI: 10.6919/ICJE.202111_7(11).0001

a pumping equipment shared by two wells (Figure 8), which changes the idle work of the lower stroke of one pumping unit into the useful work of the other pumping unit. The two Wells are used to balance each other during the work, thus improving the utilization rate of equipment and energy. This technology has been mature through field promotion, application and improvement, and can meet the matching requirements of 3-10 type pumping units. On the other hand, the technology of one-machine multi-well hydraulic pumping unit has been independently developed and field tested, and improved into a direct-connected hydraulic pumping unit (Figure 9). This unit has simple structure and light weight, only about 10% of the weight of the conventional pumping unit. The hydraulic system of "1 towing 2" and "1 towing 4" can be realized. The equipment input cost is low, and the field application equipment runs smoothly through the large well cluster platform in the field test area.

Figure 4. Double donkey head pumping unit

Figure 5. Hydraulic pumping unit

Two types of unconventional lifting equipment, dual horsehead pumping unit and hydraulic pumping unit, were used in the test area of Xinli Block iii in 3# large well cluster platform. It significantly saves the investment of oil production equipment for new wells. Taking the type 8 pumping unit as an example, compared with the conventional pumping unit, the investment of dual horsehead is reduced by 30%, and the investment of one tow dual wells hydraulic pumping unit is reduced by 50%. At the meanwhile, the operation energy consumption of oil well after putting into operation is greatly reduced. Compared with conventional pumping units, the average power saving of the dual horsehead one-unit dual-well pumping unit is about 49%. The average power saving of the one tow two wells hydraulic pumping unit is about 22%. It provides an effective support for the low cost and benefit construction and production in the large well cluster test area.

(2) Long - term production lift optimization technology for platform wells in large well cluster

The model of centralized well construction with large well clusters and platforms inevitably leads to the increase in the number of highly deviated Wells and the complex well trajectory conditions put forward more stringent requirements for lifting. Taking the 1-3# well cluster platform in the test area of Xinli Block iii as an example, there are 42 Wells with inclination Angle greater than 30° after drilling, accounting for 39% of the total number of platform Wells, and the maximum inclination is 52.8°. Due to the relatively shallow inclination point of platform wells, generally in the range of 230m-370m, the inclination section of platform wells is relatively long. There are 23 wells with a vertical ratio greater than 0.5, and the maximum vertical ratio is 0.73 (Table 1). Large well cluster platform wells have complex well trajectory characteristics, such as shallow inclination point, large inclination angle, long horizontal displacement at the bottom of the well, and vertical well section is much lower than the inclined well section. As a result, the downhole pipe string cannot be effectively centralized due to the influence of well track, and some well sections are prone to downhole rod and pipe wear, which brings great difficulty in long-term lift of oil wells.

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Table 1. Statistical table of well trajectory parameters of 1-3# Large well cluster platform in Block iii of Xinli oilfield

Inclination angle	Well number	Horizontal displacement	Well number	Displacement-TVD ratio	Well number
<20 °	33	<400m	36	<0.3	37
20－30 °	32	400－600m	32	0.3-0.4	23
30－40 °	31	600-800	32	0.4-0.5	24
>40 °	11	>800	7	>0.5	23
Maximum inclination 52.8 °		Maximum horizontal displacement 1000m		Maximum displacement-TVD ratio 0.73	

Restricted by the actual conditions of low production fluid and the investment requirements of production capacity construction control, the conventional rod pump lifting method can only be adopted in Xinli block iii of large well cluster construction test area. Therefore, a lifting optimization technology is formed to meet the long-term production requirements of complex well trajectory with large slope of platform. First, in order to improve the smoothness of the contact surface and reduce the friction coefficient, wear resistant materials with smooth surface compared with steel materials are adopted. High molecular weight polyethylene tubing liner is used in the test area, which has high wear resistance and low friction coefficient (Table 2). It can buffer wear by viscoelasticity and self-lubricity, and has the advantages of two-way protection and no damage to sucker rod coupling. And its own chemical material performance is stable, with good corrosion resistance and anti-scaling, so it plays an effective role in underground rod and tube protection.

Second, in terms of establishing spacing and preventing contact between rod and pipe, nickel-based alloy anti-wear collar is selected to deal with the problem of sucker rod righting in the design of platform oil well. The collar has three functions of wear resistance, wear resistance and wear resistance reduction. Different from the lining pipe material, it plays the role of anti-wear.

The third is to reduce the contact pressure by increasing the size of the first stage tubing. The high strength two-stage combination of 22mm+19mm H class rod string is widely used in Xinli test area, 89mm tubing (inner diameter of tubing 76mm, inner diameter of polyethylene liner about 67mm) is used to replace the 73mm tubing used in conventional oil wells. In this way, the annulus clearance of pipe rod is increased, the contact pressure of pipe rod in deviated section with large dogleg degree is effectively reduced, and the wear degree of pipe rod is reduced.

Fourth, in terms of reducing the contact frequency between rod and pipe, in order to ensure the need of free repair period after production, the lifting design of large cluster platform well is based on the principle of "long stroke, slow stroke and appropriate pump diameter", and the pumping system is appropriately reduced. By enlarging the diameter of pump and replacing the 32mm pump with 38mm pump, the stroke times can be reduced to about 2 times in the stable production stage, so that the wear rate of the pipe and rod can be greatly reduced, and the pump inspection period of the platform oil well can be greatly extended. In addition, for part of the oil well pump hanging hole deviation will reach 40-50 °, special pump is selected. The suction valve and delivery valve have steering mechanism, which can effective assist the valve ball return to seat seal, and may be forced open/close. The effect of well inclination on valve ball reset seat seal is effectively eliminated, and the pump efficiency of oil well with large inclination of platform can be effectively guaranteed. Within 3 years after the early platform oil wells of large wells cluster 1# and 2# in Xinli block iii were put into operation, the number of maintenance wells only accounted for half of the number, and the maintenance free operating period was nearly 1800 days, which was much higher than the previous wells with 1000 days in the same block. Moreover, there was no large amount of workover caused by downhole rod and tube wear. Thus, the problem of short pump checking period due to large well deviation when conventional rod pump lifting method used in large well cluster platform wells is effectively solved.

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Table 2. Surface properties comparison between lining tubing material and steel

Materials	Friction coefficient	Roughness of material (m)
steel	0.4-0.8	0.00015
polyethylene	0.16-0.23	0.000005
glass lining	0.2-0.35	0.000015

3.3 A series of factory and clean operation technology to meet environmental protection

(1) Establish factory construction operation mode to realize the whole assembly line type operation

The "factory" operation mode can effectively improve efficiency and reduce cost [7], while the assembly line operation mode is to concentrate and continuously operate the same operation procedures of wells within the well group by optimizing the production organization mode, so as to shorten the operation period and reduce the operation cost. All processes shorten cycles through seamless connection, and achieve benefits through large-scale continuous operations. The greater the number of wells in a single well site, the greater the advantage of assembly line operation mode [8].

The integrated design, management and operation of large well cluster construction and production in block iii of Xinli Oilfield guarantee the industrial operation of drilling, fracturing and production. Four drilling RIGS were staggered at the same time; after the completion of drilling, it will enter the prepareption of fracturing; two groups of fracturing trucks are in continuous operation. All steps are closely connected to achieve the goal of "no waiting for drilling, no waiting for fracturing", effectively improve the construction efficiency. Fracturing efficiency increased from one well per day in conventional mode to three wells per day in factory mode, increasing by 200%. Production efficiency increased from 0.58 wells per shift one day in conventional mode to 1 well per shift in factory mode, increasing by 72%. Thus, the well construction period is shortened by 2.7 days from 12.3 days in the original conventional mode to 9.6 days in the factory mode. The surface construction period is shortened from 40 days of conventional mode to 14 days of factory works, shortening 26 days.

(2) Clean operation supporting technology for no pollution green production

On the one hand, harmless treatment and reuse of drilling waste realized. Solid can be used to pave roads and make building materials after treatment. Liquid after treatment can directly enter the water injection system of the united station. In the early stage of block iii of Xinli oilfield, the accumulative processing of mud, solid phase and liquid phase exceeds 30,000 m^3, 20,000 m^3 and 10,000 m^3 respectively. The goal of "no pit digging on site, no mud falling and no pollution in the process" has been realized.

On the other hand, the integration of profile control and cleaning operation for fracturing flowback fluid online injection well is realized. The backflow fluid + low-cost sodium bentonite system is formed to meet the needs of field injection profile control. In Xinli iii block, a total of 3,500 cubic meters of flowback fluid has been injected back into the wells. At the same time, clean workover operation supporting technologies are adopted in site construction, including wellhead closed steam cleaning technology, low environmental protection platform supporting technology and surface environmental protection platform technology, which can realize the environmental protection operation of "no oil and water out of the wellhead, no landing out of the wellhead", providing guarantee for zero pollution green production.

4. Conclusion

(1) In the process of benefit development practice of intensive large well cluster in low permeability reservoir jilin oilfield. In terms of reservoir reconstruction of intensive large well cluster, the "full reservoir fracturing and displacement" supporting technology series is established based on reservoir fine understanding, with fine optimization of single layer as the core, and with the integration of multiple fracturing technologies such as "tuning, storage, disturbance, regulation and plugging" as the means, so as to fully reconstruct the reservoir and effectively improve the overall injection-

production relationship of the block. The whole reservoir reconstruction mode is set up matching with sand body, well pattern and fracture pattern.

(2) In view of the advantages of intensive platform well concentration, the new lifting equipment of "one unit two wells" and "one unit multiwells" represented by "dual horsehead" and "hydraulic pumping" has been formed and applied in industrialization, which significantly reduces the investment in oil production equipment and energy consumption. At the same time, in view of the complex well trajectory conditions of the platform with large slope, the supporting technology of oil production lift optimization focusing on preventing wear is put forward. Through field practice, the pump inspection period of the platform with highly-deviated well is effectively prolonged, and the long-term lift under complex well conditions is realized.

(3) A factory and clean construction technology has been formed, fracturing efficiency and production efficiency have been significantly improved by large-scale centralized and continuous operation. The whole assembly line operation is realized, and each step is closely connected across specialties, effectively shortening the well construction period. Through harmless treatment of drilling waste, injection of fracturing flowback fluid and supporting technology of clean operation, no pollution production of large well cluster is effectively guaranteed.

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