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Research and Application of Production Enhancement Technology for Offshore Low Permeability Reservoirs

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Abstract: Offshore oil and gas fields are slow to develop offshore low permeability reservoirs due to the high pre-development costs and post maintenance costs due to the development environment and technical inputs. Due to the low yield of low permeability reservoirs, resulting in some oil and gas wells producing even less than the development cost yield, it is difficult to achieve commercial exploitation of low permeability oil and gas wells without effective reservoir modification to increase production. However, it is difficult to implement large fracturing modifications on land, as usual, to achieve increased production from oil and gas wells due to the small space for offshore operations, the high influence of sea conditions, and high environmental requirements. To realize the development of offshore low-permeability reservoirs, two low-permeability oil wells were selected as test wells to explore the development path of offshore low-permeability reservoirs. Firstly, by analyzing the volumetric fracturing process in onshore oil fields and the main difficulties of offshore construction, the packer + differential pressure slip segmental fracturing technology was optimized and selected as the fracturing solution for offshore low permeability wells. Secondly, according to the drilling situation and post-fracturing release spraying requirements, an integrated process of in-casing packer-stratified slip-on multi-stage injection fracturing and post-fracturing release spraying was formed. Finally, on-site implementation was carried out according to the operating platform situation of the well, offshore production safety and environmental protection, and sea conditions during operation. It successfully achieved the first large-scale segmental fracturing construction in Bohai Bay offshore, and the post-release spraying sought production with the obvious effect of increasing production. Although the process has shortcomings, it still provides new ideas and exploration for the development of offshore low-permeability reservoir.

Keywords: Horizontal Well Fracturing, Production Enhancement Measures, Fracturing Technology, Low Permeability Reservoirs

1. Introduction

With the further development of offshore oil and gas fields, low-permeability reservoirs that have not been developed for reasons of development technology and cost are gradually entering the development plan. The development practice of onshore low-permeability reservoirs proves that it is difficult to achieve commercial recovery prices without fracturing and acidizing and other transformation measures for low-permeability reservoirs due to low reservoir permeability, high seepage resistance, and poor connectivity [1]. Daqing oilfield, Changqing oilfield, and Jilin oilfield have made inefficient and difficult to recover reserves in low permeability reservoirs effectively improved by the application of horizontal well fracturing technology [2-4], especially the application of volume fracturing technology, which has a significant effect on the increase of single good production in low permeability oilfields. x oilfield is a typical offshore low-permeability oilfield [5], to better realize the development of offshore low-permeability reservoirs and improve the single-well production and explore the feasibility of economic and effective exploitation of offshore extra-low-permeability reservoirs, two low-permeability pilot wells of were selected to carry out fracturing and production enhancement tests.

The space of offshore fracturing construction sites is limited, and it is also affected by monsoon and sea conditions. The production enhancement of low-permeability wells should take into account operational safety and reduce environmental risks. In addition, special regulations for offshore oilfield production should be considered. For example, to control the safety of offshore oil and gas field development and prevent environmental pollution, the State Administration of Safety Supervision promulgated the Rules for Offshore Petroleum Safety Management, of which the 2015 amended version of Section V, Well Control Management, Article 61: Gas wells, self-injected wells, and self-overflowing wells should be installed with downhole packers; below 30 meters of the seabed surface, downhole safety valves should be installed as stipulated. Therefore, the development of low-permeability wells in offshore oil fields cannot directly copy the practice of fracturing in onshore oil fields, and the process should be optimized according to offshore production and safety requirements.

2. Offshore Fracturing Technology Selection

At present, for the development of low-permeability reservoirs, the mature fracturing techniques formed in onshore oil fields according to different segmentation techniques are horizontal well double seal single card segmentation fracturing technique, horizontal well-in-casing packer slip segmentation fracturing technique, horizontal well hydraulic sandblasting segmentation fracturing technique, bare-eye packer slip segmentation fracturing technique, and hydraulic pump-in bridge plug segmentation fracturing technique [6]. Wang Wendong proposed volume fracturing technology, which can form a complex fracture network and improve the production increase effect, the key is to adopt the matching process according to the special characteristics of the reservoir [7], in addition, Sun Lin also proposed the burst pressure acidizing technology, the biggest advantage of this technology is that the fracture will create a fracture along the direction of the injection borehole after fracturing, and the longest fracture length can reach about 15m, which is especially suitable for bottom water oil cap reservoir [8].

Offshore oil and gas field operations are difficult, construction risks are high, and uncontrollable factors such as weather and sea conditions have a large impact, and accidents occur with serious environmental pollution and poor social impact. Therefore, the implemented fractured wells are mostly single-well, single-layer generalized fracturing [9-11], which has obvious effect of increasing production initially but poor sustainability. Volume fracturing technology usually adopts casing and oil jacket annular fracturing to form a complex seepage network with large displacement and fluid volume to achieve increased production from low permeability oil and gas reservoirs. Volume fracturing using segmental fracturing can effectively increase the drainage area and improve the reservoir production and oil recovery rate can effectively realize the development of low-permeability reservoirs, and the construction effect proves that volume fracturing technology is effective in the development of low-permeability reservoirs.

Among the mature volume fracturing processes onshore, the horizontal well double seal single card segmental fracturing technology is mainly used for dwnhole reservoir modification in oil wells with thin and multiple reservoirs and large inter-formation physical differences. However, because the uplift of the tubular column to achieve multi-segment fracturing involves the problem of operating with pressure at the wellhead [12], there is no precedent of construction with pressure operation on offshore platforms, which makes implementation difficult and risky. The horizontal well hydraulic sandblasting segmental fracturing technology uses oil tubing and continuous tubing transfer operation. After the end of fracturing if the well self-injects, it cannot be released for a long time because no downhole safety valve is installed, which does not meet the requirements of offshore oil well production. Therefore, the well must be pressurized before it can be released to seek production, but the pressurized well may bring new damage to the reservoir. Meanwhile, the conventional hydraulic sandblasting segmental fracturing construction is inefficient and cannot guarantee the effectiveness of splitting pressure [13]. Explosive pressure technology and derived technologies such as explosive pressure acidizing are effective for plugged wells, but for poor geological conditions and low permeability to increase the amount of pyrotechnics, which is more damaging to the casing [14].

Offshore there are strict regulations for the use and transportation of pyrotechnic products, and the technique is difficult to apply. In view of the various special process requirements for offshore fracturing construction the only feasible technologies for the offshore volume fracturing process are the in-casing packer-slip fracturing technology and the bare-eye packer-slip fracturing technology.

After comparing the characteristics of the two technologies, we chose to use packer + differential pressure sleeve segmental fracturing technology in consideration of the need for later release production. This technology is a non-moving column packer segmental fracturing technology, which can be lowered into the fracturing column at one time to save platform operation time, and the high-temperature and high-pressure resistant packer and differential pressure slip sleeve ensure the safety of downhole tools during the construction process, and the whole column structure is simple and reliable [15], as shown in Figure 1.

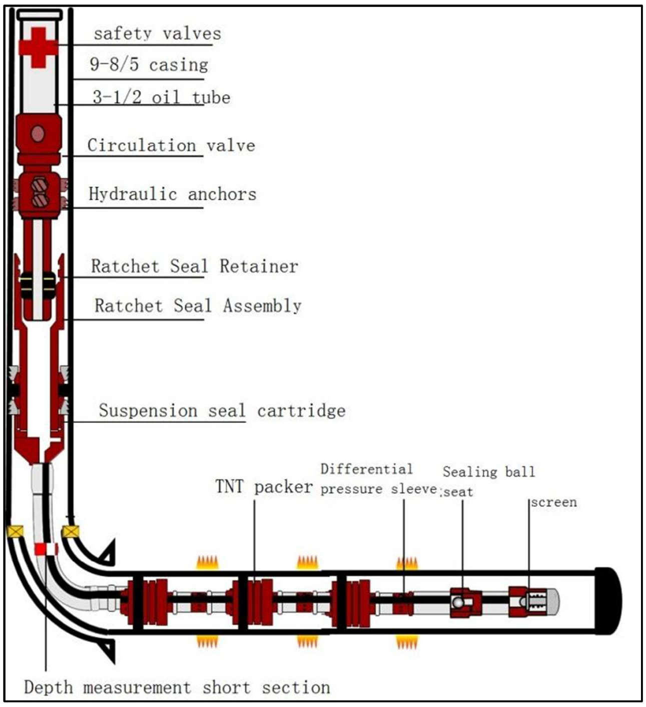

Figure 1. *Schematic diagram of downhole tubular column structure.*

3. Offshore Horizontal Well Segmentation Fracturing Process Optimization

At present, there are mainly two types of in-casing packer slip-on fracturing pipe column structures, one is the integral in-casing packer slip-on fracturing pipe column for shallow and medium fracturing with low construction pressure, and the other is the drop-hand in-casing packer slip-on fracturing pipe column for deep and medium fracturing with high construction pressure. Considering that the fracturing is not moving after the fracturing, the fracturing and spraying combination is designed in the design of the fracturing column. The pipe column design combines the integral casing inner packer slip-on fracturing pipe column and the drop-hand type inner packer slip-on fracturing pipe column structure, and the oil pipe is connected back to the uppermost packer, and the oil pipe is installed with the hanging packer, and the ratchet seal assembly is installed back to the connecting barrel on the hanging packer.

The advantage of this solution is that the fracturing tubing column is equipped with downhole safety valve and packer, which can ensure the fracturing and production meet the offshore well control requirements at the same time. After fracturing, self-injection can be directly put into production, without fracturing wells to reduce operational risks and reservoir contamination. If the first fracturing effect is not good, the pipe combination can continue fracturing at a later stage. The post fracturing column can be sealed by lifting the ratchet and then lowered into the production column for normal production.

4. Field Applications

4.1. Basic Information of the Target Well Reservoir

The X oil field is located in the southern part of the Bohai Bay Basin and consists mainly of the Shahejie Formation and Minghua Town Formation reservoirs, of which the Sand Section 2 (E3S2) and Sand Section 3 (E2S3) reservoirs are the main oil-bearing sections of the field. The reservoirs of the two selected wells are both Shahejie Sand Section 3, and the reservoirs are interbedded with conglomerate sandstone and mudstone. The reservoirs in the target section are core analyzed to have 10.1-15.7% pore space, with an average of 13.9%, and an average permeability of 0.8-2.0md, which is a typical low-permeability reservoir. The permeability is extremely low, the permeability resistance is high, and the connectivity is poor after opening the reservoir generally has no natural production capacity or low natural production capacity.

4.2. Choice of Fracturing Construction Method

There are mainly two modes of offshore fracturing operation construction, one is to place and fix fracturing equipment on a special production enhancement vessel or flat barge, called ship-supported operation. The construction method of this mode is mature, easy to organize and highly effective, and the construction equipment can be fixed for several times after once, without affecting the development of other work on the offshore platform. The disadvantage is that scale fracturing needs to involve multiple personnel, which is not conducive to communication and coordination, and the construction operation plan is easily affected by wind, tide and other weather. The other is to arrange the equipment on the deck of the offshore drilling platform to complete the fracturing construction, called platform-supported operation. Platform-supported operation is good for communication and coordination, and is less affected by bad weather during construction operation. The lifting equipment, storage space and electrical equipment on the platform can provide good support for fracturing construction. The disadvantage is that the size and load-bearing capacity of the platform often restrict the scale fracturing construction displacement. Equipment transportation and material transportation are large, and large-scale fracturing can sometimes be interrupted due to the inability of vessels to berth and deliver materials. In addition, the arrangement of fracturing equipment needs to depend on the shape and space of the site, which is inflexible and difficult to delineate the safety zone.

The budgeted construction time for the two fracturing wells entered the winter season. Considering the weather conditions, sea depth, berthing capacity, rig deck area, platform crane capacity and other factors, it was decided to use rig support operation. The rig storage space was fully utilized to reduce the use of liquid tanks, and the deck area was efficiently utilized through reasonable layout of equipment and stacking of materials.

4.3. Segmented Fracturing Construction

Before the formal fracturing, a small fracture test was conducted, the main purpose of which was to obtain parameters such as formation true permeability, near-well zone friction, and closure pressure. It was found that the formation fracture pressure was higher than the predicted value through the small fracture test, and it was difficult to add sand, so the original design high sand ratio stage was cancelled, the highest sand ratio was adjusted from the original 35% to the highest 30%, and 25%-30% sand ratio stage was added to increase the average sand ratio, and the average sand ratio was increased from the original 18% to 19~20%. Due to normal formation filtration loss, 2 powder ceramic section plugs were removed and 30/50 and 20/40 mesh proppant section plugs were used to hit the friction borehole and near-wellbore fracture, effectively reducing the near-well friction in the pre-fluid stage.

The original pumping procedure table was modified according to the results of the small pressure test, and the construction was started by opening the fixed pressure slip sleeve. A total of 252.9 m^3 of sand and 2856 m^3 of actual fracturing fluid were used in the construction of the two wells, achieving for the first time a fracturing scale of a thousand cubic meters of fluid and a hundred cubic meters of sand offshore China [16], and the site construction statistics are shown in Table 1.

Table 1. *Statistical data list of 2 fracturing wells.*

well No.	sections	fluid/m^3	sand volume/m^3	average sand ratio/%	discharge volume/m^3	pressure/MPa
1#	S1	336.3	28.5	29	3.0~3.5	66~72
	S2	349.4	32.1	32	3.3~3.5	63~68
	S3	320.1	29.2	29	3.1~3.3	61~68
2#	S1	337.9	31.5	32	2.8~3.0	63~72
	S2	378.7	28.8	29	3.0~3.1	63~69
	S3	403.5	35.8	36	3.4~3.6	63~69
	S4	381.1	35.7	36	3.5	61~66
	S5	349.8	31.3	31	3.5~3.8	57~65

4.4. Analysis of Fracturing Effect

The two fractured wells were put into production with a total cumulative oil production of 24125.80m^3 and gas production of 2684752.8m^3 within one year. The process uses 88.9mm tubing fracturing in the implementation process, and the construction volume is limited. Compared with the construction of large-volume fracturing onshore, the fracturing effect was affected to some extent. Due to the loss of the hand tubing column left in the well, the small diameter, 9-5/8" suspended packer can not be salvaged and the impact of the ball seat, the later two wells appear different degrees of sand out of the situation, can only use continuous tubing to flush sand regularly, other measures to deal with the difficulties.

5. Conclusion

(1) Using two oil wells as test wells and combining the experience of onshore volumetric fracturing, the integrated fracturing and blowout release in-casing slip-on segmental fracturing process was proposed. The integrated segmental fracturing process meets the safety requirements of offshore operations and has a high success rate of process implementation.

(2) The implementation scale of two offshore fractured wells is far from the scale of onshore segmented fracturing, but the initial offshore segmented fracturing operation has been realized, and the fracturing effect is remarkable from the long-term production, which has certain significance for the development of offshore low-permeability oil and gas reservoirs.

(3) Due to the embedding of formation proppant, loss of fracturing fluid, and the possibility of fracture of proppant in the fracture, the inflow capacity is greatly reduced. To ensure the fracture inflow requirements and the fracturing effect, offshore fracturing should be further studied on a larger scale to achieve better results.

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