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Research and Application of Nitrogen Assisted for Offshore Fracturing Fluid Flowback

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Abstract: With the deepening of offshore oil exploration and development, low-permeability reservoirs are gradually entering the development plan. Low permeability reservoirs must be commercially exploited by production enhancement measures due to their low production and poor economic efficiency. Therefore, the production enhancement technology mainly fracturing technology has been developed rapidly and also become an important technology for the development of offshore low permeability reservoirs. In this paper, through the investigation, statistics, and analysis of the timing of each part of fracturing construction for medium-sized fracturing wells offshore, we found that the fracturing fluid drainage time is long during the fracturing construction process. The fracturing fluid re-discharge efficiency issue becomes an important factor affecting the fracturing cost and period. Different methods of fracturing fluid drainage are analyzed, and this paper focuses on the applicability of different drainage processes after fracturing in non-self-injected wells. Nitrogen-assisted drainage is preferred as the main means of offshore fracture fluid drainage through analysis. Through the analysis and optimization of the nitrogen-assisted fracturing fluid flowback process, the preferred methods of nitrogen-assisted fluid flowback pressure and auxiliary fluid flowback timing are proposed. Field application and practice show that after adopting nitrogen annular auxiliary drainage process, the fluid flowback volume increases obviously, the oil pressure at the wellhead increases significantly, and the fracturing fluid flowback efficiency improves remarkable.

Keywords: Offshore Fracturing, Nitrogen Assisted, Flowback, Fracturing Fluid

1. Introduction

In the early stage of exploration and drilling and completion of offshore oil field development, we often encounter the situation that no oil or gas is produced because of geological understanding. Since the blocks are not yet in scale, oil and gas development operations require the use of large drilling rigs and related operating vessels. The investment cost of a single well is large and the cost of a single technology is high, so efficiently carrying out all the processes in pre-drilling and completion can greatly shorten the construction period and reduce the operation cost. For low-permeability oil and gas wells, fracturing can effectively increase the production of low-permeability reservoirs and is currently the main measure to increase production in offshore oil and gas fields [1]. Compared with the large-scale fracturing method on land, the overall scale of offshore fracturing is smaller but due to the special operating environment and higher cost, so the construction timeliness requirement is higher in the fracturing process, and the percentage of the fracturing process stages compared to the total construction time for five wells with the offshore fluid volume around 600 square meters was counted, as shown in Table 1.

Table 1 shows that the current offshore fracturing process has basically formed a standard process. The construction process takes up a stable amount of time with small differences, and the process that takes up the longest amount of time is fluid flowback.

For blow wells, fluid flowback is relatively simple and is flowback directly with the fracture tubing. In fact, offshore fields have fewer exploratory wells than onshore fields. Therefore the reservoir is not well known and often it is difficult to blow after fracturing. For non-blowing wells, auxiliary drainage measures must be used to improve the efficiency of fluid flowback.

Table 1. *Time Effectiveness Analysis of Main Fracturing Processes.*

Well No.	Equipment and materials preparation	Transit time	Fracturing preparation	Fracture pump injection	Fracturing fluid return and flowback
CHX305	21%	8%	9%	1%	61%
BHX7	19%	9%	11%	1%	60%
CHx37	23%	7%	10%	1%	59%
BZx38J	21%	9%	12%	1%	57%
SZX251	18%	6%	11%	1%	64%

High safety risk and environmental risk are during offshore fracturing. In order to control the risk of fracturing, the State Oceanic Administration has put forward strict protection casing and wellhead requirements for offshore oil and gas well operations. Therefore, the offshore fracturing pipe string is deeper and relatively simple, as shown in Figure 1 for the common pipe string for offshore fracturing. This tubing structure can effectively protect the casing and wellhead for quick well washing in case of overflow.

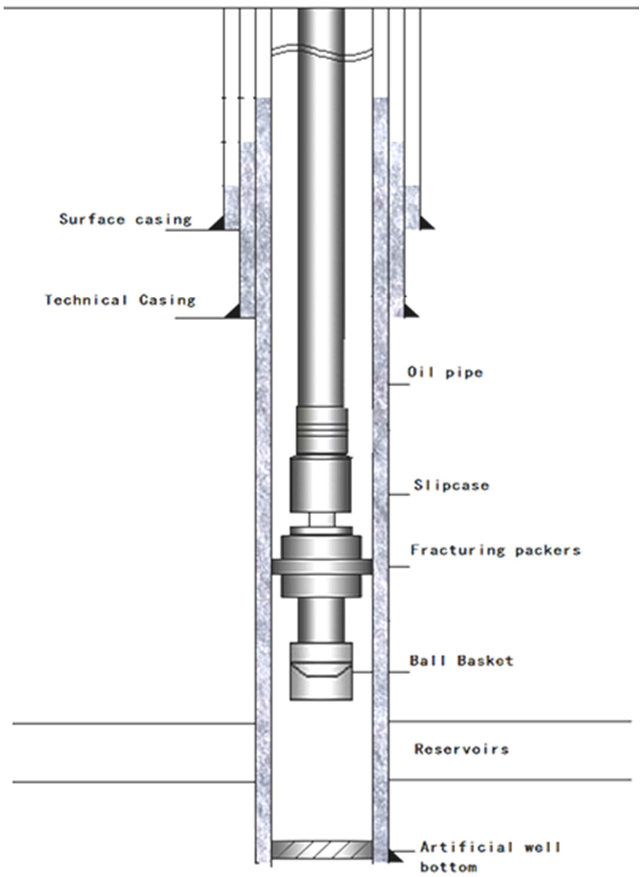

Figure 1. *Schematic Diagram of Typical Fracturing String Structure for Offshore Fracturing.*

In general, if blow is not possible, the fracturing fluid flowback rate is low, and it is difficult to evaluate the capacity later. To further evaluate well production or reservoir reserves, the frac pipe string is lifted out and lowered into the lifting pipe, but this result in higher frac costs. Therefore, reasonable drainage assistance measures after fracturing can effectively shorten the drainage time and reduce the development cost.

2. Fluid Flowback Nitrogen Boosting Process

After fracturing, the fracturing fluid residue is retained on the fracture wall as a filter cake or in the fracture as a free residual fluid after breaking the rubber. When drainage begins, the fracturing fluid in the fracture near the wellbore first begins to flow out. The rejection fluid flushes the filter cake and brings the residual fluid out of the fracture, and the rejection speed needs to be controlled reasonably to prevent the backflow of the proppant. As the return flowback continues, the fracturing fluid starts to flow in the distant fracture, where the mixture contains a large amount of unbroken or incompletely broken high-viscosity fracturing fluid. Because the viscosity of the mixture is higher than that of the crude oil in the reservoir, it is easy to cause viscous finger-in phenomenon, which in turn makes it difficult to return the fracturing fluid to flowback [2]. These mixed fluids are the main reason for the low fluid flowback rate.

For oil and gas wells that cannot sustain blowion after fracturing and have difficulty in fracturing fluid return, the most effective method is to lift out and down into the artificially lifted tubular string. However, replacing the pipe string is not only a long construction period and more expensive, so using fractured pipe string for direct assisted flowback is a cost-effective method [3]. This enables offshore exploratory wells and risk wells to be abandoned after taking geological information, production capacity and reserve evaluation, reducing investment.

The current fracturing fluid rejection and drainage processes mainly include liquid nitrogen drainage, carbon dioxide drainage and continuous tubing drainage [4]. Among them, liquid nitrogen and carbon dioxide construction safety risks, and the need to transport raw materials from land, the cost is higher, offshore applications are less. Offshore fracturing fluid rejection mainly adopts continuous tubing and nitrogen rejection, which requires two sets of equipment: continuous tubing and nitrogen. With this process, the continuous oil pipe is lowered from the oil pipe, and the oil pipe is generally selected to return with the continuous oil pipe loop hollow. Compared with the use of continuous tubing nitrogen assisted flowback, the use of nitrogen ring air lift can be lifted in a larger diameter of the tube, helping to flowback more efficiently.

The principle of fracturing fluid rejection with nitrogen is relatively simple, using nitrogen to cause mixed pressure relief and then reverse gas lift to recycle the fracturing fluid. First, nitrogen is injected from the annulus of the oil jacket, the fracturing fluid mixture is mixed with nitrogen, the fluid gas-liquid ratio in the tubing increases, and then the fluid pressure drop gradient decreases by reducing the density of the gas-liquid two-phase mixture flowing upward along the tubing, which acts to reduce the pressure at the bottom of the well and helps fracturing fluid return and reservoir fluid supply [5]. The fracturing fluid return rate is regulated by adjusting the gas injection volume and gas injection pressure. Nitrogen assisted drainage is not required to lift out the original fracturing string and can be performed at any time depending on the fracturing fluid return. The nitrogen rejection process is simple and efficient, especially for fractured wells with insufficient formation energy.

3. Nitrogen Assisted Flowback Solution Design

3.1. Selection of Nitrogen Injection Pressure

Nitrogen is injected from the surface through the annulus of the oil jacket by a high-pressure pump, and the nitrogen enters the tubing through the bottom of the well. Nitrogen has a large compression coefficient and flows upward from the tubing after mixing with the fluid at the bottom of the well, expanding rapidly as the pressure decreases during the flow. Nitrogen expansion reduces the density of the mixture in the wellbore and lifts the formation fluid flowing into the wellbore to the surface [6]. In order to improve construction efficiency, fracture return flowbacks are injected in a continuous manner. There are some differences between post-fracturing nitrogen rejection and the gas lift oil recovery process. Due to the large amount of fracturing fluid injected, even low-pressure wells will have a certain amount of bottomhole flow pressure. During the fracturing fluid rejection process, the wellbore is always full of fluid and the mixture of fracturing fluid and formation fluid is in a wellhead overflow condition. The start-up pressure of the nitrogen assisted flowback is equal to the pressure of the fluid string of the fracturing fluid and formation mixed liquid-gas mixture in the wellbore. That is

$$P_e = \rho g L \tag{1}$$

In the formula

Pe - maximum start-up pressure of nitrogen-assisted flowback, MPa.

L-The length of the oil pipe, m.

ρ-The density of mixed liquid in the pipe string, MPa.

Fracturing fluid return nitrogen assisted flowback is a continuous lift process. However, there are individual wells with severe reservoir energy deficiencies that do not create continuous flow. In order to evaluate reserves and production capacity, only intermittent gas lifts can be performed. Intermittent gas lift requires that the well be given a time interval to allow fluid to gradually build up at the bottom of the well, followed by nitrogen assisted flowback.

3.2. Selection of Nitrogen Assisted Flowback Time

After fracturing was completed, the artificially caused fractures began to close. If the fracturing fluid is flowbackd too fast during the fracturing fluid rejection process, the proppant filled in the artificial fracture will follow the rejection fluid out of the fracture. The proppant flows back into the wellbore, resulting in fracture closure without proppant support and reduced fracture conductivity. Therefore, the fracturing fluid return and flowback process must choose the right timing and the right flowback volume to avoid the damage caused by the fracturing fluid to the formation and prevent the proppant backflow at the same time [7-9].

There is no reference standard for the division of the rejection stage, which is mainly based on the rejection pressure at the site wellhead, the size of the release nozzle, the rejection volume and other factors. According to the different rejection stages, fracturing fluid rejection can be divided into fracture closure stage rejection, large displacement fracturing fluid rejection stage, mixed rejection stage, and well blowion production stage. Among them, the fracture closure stage cannot be injected with nitrogen to increase the energy to return to the flowback, to prevent the excitement of the formation proppant out of the sand, and the release of the spray rate to be less than the critical sand-carrying flow [10-12]. When the large displacement fracturing fluid is flowback, the bottom fracture has been completely closed and the fracturing fluid is fully broken, which is the main stage of fracturing fluid flow back. At this time, the wellbore fluid and formation fluids have been communicated, and the return flow back energy is sufficient, belonging to the initial stage of self-jet. At this point, the formation energy can be well evaluated, and if the return flowback is large at this point, the fracturing fluid can be naturally returned without assisted flowback. If the rejection pressure is low and the flowback volume is small, nitrogen rejection is required to improve the rejection efficiency. The use of nitrogen assisted drainage measures can effectively reduce the bottomhole pressure and reduce the fluid outflow friction in the fracture, which is conducive to improving the fracturing fluid rejection rate [13, 14].

4. Field Application and Analysis

The average permeability of an offshore X1 well is 3.85md and the average porosity is 8.92%. After drilling, the target layer was shot open for wireline testing for 4h fluid recovery test, and the folded daily fluid production was 0.048m^3. The temperature in the middle of the formation was 147.38°C, and the pressure in the middle of the formation was 37.86MPa. Later, well tests were conducted with poor results, and the reservoir intended for the well was fractured by generalized combined pressure. A total of 648m^3 of seawater-based fracturing fluid was injected for the fracturing construction. In order to reduce the construction pressure and improve the fracturing effect, two sizes of proppant, 40/70 mesh ceramic granules (0.212~0.425mm) and 30/50 mesh ceramic granules (0.3~0.6mm), are used for fracturing construction. The first type of ceramic granules is used to polish the holes and cracks to reduce the construction pressure and the difficulty of adding sand, and the second type of ceramic granules is used to support the crack joints and increase the inflow capacity [15].

After fracturing, the fracturing fluid is returned to drain, starting with a 3-5 mm nozzle controlled until the wellhead pressure is zero and then released freely. The fluid production from well X1 decreased significantly after 38 hours and continued to decline for the next 24 hours. In order to improve the efficiency of fracturing fluid rejection, a nitrogen annular gas assisted extraction process was used. Firstly, shut down the oil recovery tree, put Φ53mm steel balls in the oil pipe, turn on the mud pump to pressurize to 9.5MPa and open the slip sleeve. Next connect the nitrogen equipment pump injection process and prepare the reverse cycle gas lift flowback. After the start of nitrogen gas lift, the nitrogen injection volume was slowly increased and the wellhead oil pressure rose from 0 to 1.8 MPa, and the volume of returned fracturing fluid increased significantly. After the oil pressure at the wellhead rises to 3MPa, the fluid production reaches the maximum, which is 3~4 times of the maximum amount of normal fluid flowback. When the flowback rate increases significantly, the wellhead oil pressure is controlled at 2MPa in order to prevent the formation proppant from flowing back. he well produced 338.56m^3 of fluid in 5 days after fracturing and 342.3m^3 of fluid in 3 days after nitrogen rejection, with a fracturing fluid rejection rate of 1.05 and an obvious effect of nitrogen to help flowback.

5. Conclusion

(1) By comparing with natural drainage, we found that the nitrogen assisted drainage process has better economy and practicality, and can be one of the effective methods to drain fracturing fluid from fractured non-spontaneous injection wells in offshore oil fields.
(2) The application of nitrogen assisted drainage process for offshore fracturing fluid was carried out. By reasonably selecting the nitrogen assisted drainage pressure and timing, the drainage volume increased significantly and the oil pressure at the wellhead regained significantly, which proved that nitrogen assisted drainage can effectively improve the drainage efficiency of fracturing fluid.
(3) For oil and gas wells in the early stage of offshore exploration, it is recommended to consider the problem of low rejection rate when fracturing and make a good plan to assist in rejection.

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