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Research Article

Application of Liquid Flow Cavitation Reservoir Micro Modification Technology in Improving Water Drive Effect in Poor Reservoirs of Bohai A Oilfield

Chai Shichao*, Li Xiang, Zheng Jianjun, Li Enlin, Ren Yuxuan

Tianjin Branch, CNOOC<China>, Co, Ltd, Tianjin, China

Abstract

B9~B8H are the corresponding well groups for injection and production in Bohai River facies A oilfield. There are poor reservoir bands about 100~300m away from the injection well B9, with poor connectivity between oil and water wells. The wellhead pressure of the injection well rises rapidly, resulting in long-term under injection. The water drive effect of the production well B8H is poor, making it a low yield and low efficiency well. Conventional measures such as acidification, microfracturing, and pressurized water injection have limited treatment radii, and fracturing also poses a risk of injection water breaking through along the fracture zone. Therefore, it is necessary to find new process measures that can meet the requirements of a sufficiently large treatment radius and micro modification of poor reservoir bands. The liquid flow cavitation technology achieves the goal of reservoir micro transformation by improving natural micro cracks, directing pore throat channels, and adding new micro cracks, and can meet the requirements of large processing radius. After the implementation of liquid flow cavitation in well B9, the production situation at both ends of the injection and production has improved, and the reservoir properties, connectivity, permeability, and water drive effect between injection and production wells have been significantly improved. The successful application of this technology has provided reliable process measures for solving the problems of poor reservoir bands, weak connectivity between injection and production wells, and poor water drive effects in Bohai Oilfield.

Keywords

Liquid Flow Cavitation, Large Processing Radius, Reservoir Micro Modification, Differential Reservoir, Water Drive Efficiency

1. Introduction

Bohai A Oilfield is a typical fluvial oilfield, with the main oil-bearing layer distributed in the lower section of the Minghuazhen Formation of the Neogene, and a single sand body oil layer thickness of 3~10m. The internal structure of the sand body is complex, with sand bodies from different stages of distributary channels stacked on top of each other vertically [1], and multiple channels migrating laterally on the plane to form a large-scale distributed composite sand body. The reservoir heterogeneity is severe, and the planar connectivity is poor [2], especially when the injection well and production well are located on different channels. Even if the injection and production are connected, the connectivity will be poor, the water drive effect will be poor, the degree of reserve utilization will be low, and the remaining oil will be relatively enriched [3].

*Corresponding author: chaishch@cnooc.com.cn (Chai Shichao)

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The B9~B8H well group is a typical case where the initial production well has normal liquid production capacity and water absorption capacity of the injection well. However, as production progresses, the injection pressure of the injection well gradually increases, and the apparent water absorption index gradually decreases. Correspondingly, due to insufficient energy replenishment, the formation pressure, flow pressure, and liquid production rate of the production well continue to decrease. Conventional measures such as acidizing blockage [4], microfracturing [5], and pressure boosting water injection [6] cannot solve this problem because these technologies are only applicable to reservoir contamination near the wellbore. And what we need to solve is the problem of poor reservoir connectivity far away from the wellbore, so we need to find new process measures that can meet the requirements of processing a sufficiently large radius while micro modifying the poor reservoir bands. Although fracturing is an effective means of reservoir modification and has a large processing radius, it has been successfully applied in low-permeability reservoir modification in Bohai Oilfield [7] and unblocking of loose sandstone reservoirs [8-11]. However, there is no precedent for its application in reservoir modification of water injection wells in offshore oilfields, mainly due to concerns about the rapid breakthrough of injected water along the fracture zone, which may cause explosive flooding of oil wells. According to the technical characteristics of liquid flow cavitation, this technology can meet this requirement.

2. Problems and Countermeasures of B9~B8H Well Group

2.1. Reservoir Configuration Characteristics of Bohai A Oilfield

Bohai A Oilfield is a shallow water delta deposit, characterized by a single distributary channel or a single distributary sand dam. Based on actual drilling data and the study of shallow water delta genesis mechanisms [12], this oilfield has five common reservoir configuration interface contact modes (Figure 1). The configuration boundary provides a certain degree of obstruction to the movement of oil and water in the lateral direction, resulting in uneven water flooding on the plane and the formation of hydrodynamic retention zones locally. The remaining oil is mostly enriched near the configuration boundary. Especially between different sand body facies zones, such as between natural embankments and underwater distributary channels, it can be seen from both seismic attribute characteristics and sand body contact relationships that the sand bodies are connected, but the connectivity is poor [13]. In this case, the water flooding effect is not good, and both oil and water wells are in a low yield and low efficiency state. The B9-B8H well group is a typical representative of this situation in the oilfield.

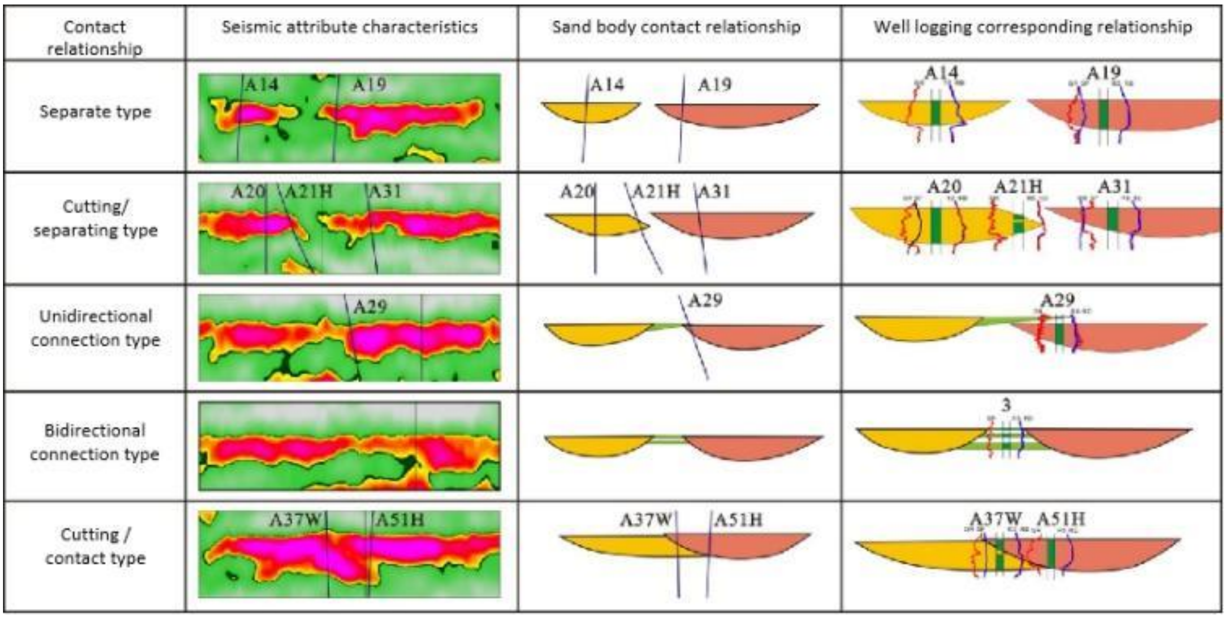

Figure 1. Interface Contact Mode of Reservoir Configuration in Bohai S Oilfield.

2.2. Water Injection Characteristics of B9 Well

B9 well is a water injection well in the 1064 sand body of Bohai A oilfield. It started injecting water in September 2015, with an initial daily injection of $44m^3/d$. The wellhead pressure is 2.0MPa, and the apparent water absorption index is $22.6m^3/(d \cdot MPa)$.

The water injection characteristics of B9 well are mainly manifested in the following four aspects: firstly, the water injection pressure rises rapidly, and the apparent water absorption index decreases rapidly. After 2 months of water injection, the water injection pressure rises from 3.2 MPa to the maximum value of 6.5 MPa designed for the ODP wellhead, and the apparent water absorption index decreases from 22.6 $m^3/(d\cdot MPa)$ to 10 $m^3/(d\cdot MPa)$ during the same period; Secondly, in order to prevent overpressure injection, intermittent injection and pressure relief measures need to be taken for the well, which were implemented from March to September 2016 and from August 2017 to March 2018, respectively; The third limitation is the limited ability of the formation to release pressure. In 2016 and 2017, injection was stopped twice, and it took 22 days and 135 days for the wellhead pressure to drop to 0MPa, respectively; The fourth is that the water absorption index after resuming water injection is higher than the level before stopping injection. In 2016, the water absorption index before stopping injection was 7.5$m^3/(d\cdot MPa)$, and after resuming water injection, it was 16.6$m^3/(d\cdot MPa)$.

2.3. Production Characteristics of B8H Well

B8H well is the production well corresponding to B9 well, with a distance of 500m between injection and production wells. The water injection effect characteristics are not obvious (Figure 2), mainly reflected in three aspects: firstly, the bottomhole flowing pressure continues to decrease, from early 2015 to May 2016, the bottomhole flowing pressure increased from 7.7Mpa reduced to 5.6Mpa; Secondly, after the water content reaches 80%, the liquid production is only about 180m^3/d, which is significantly lower than the daily liquid production of other oil wells [14, 15]; Thirdly, during the pressure relief stage of the water injection well, the corresponding rate of decrease in production well flow pressure increases, and there is also a significant decrease in liquid production. After resuming water injection, both flow pressure and liquid production show an increasing trend.

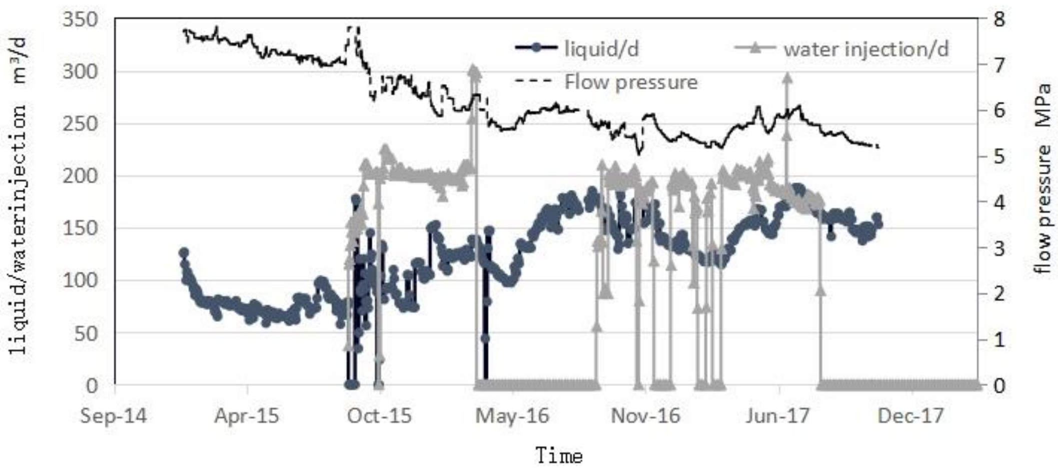

Figure 2. Production curve of B9-B8H well group.

2.4. Understanding of Injection Production Characteristics and Analysis of Reasons

Through the above analysis of injection and production characteristics, the following insights can be obtained:

Firstly, the B9 water injection well itself has good physical properties, as evidenced by its logging interpretation of a permeability of 621mD. At the same time, its initial apparent water absorption index is 22.6$m^3/(d\cdot MPa)$, which is basically consistent with other water injection wells, indicating that its reservoir properties are not poor;

The second reason for the decrease in apparent water absorption index of injection well B9 is not caused by reservoir pollution near the wellbore. This can be confirmed by the increase in apparent water absorption index from 7.5$m^3/(d\cdot MPa)$ before the injection was stopped to 16.6$m^3/(d\cdot MPa)$ after the resumption of injection in well B9 for a period of time, indicating that the decrease in apparent water absorption index is mainly due to the increase in formation pressure near the wellbore;

Thirdly, the reservoirs between injection and production are connected, but the connectivity is poor. By releasing pressure from the injection well and restoring water injection, the water absorption index after injection is higher than the pre injection level, and the reaction of production well flow pressure and liquid production to injection stoppage (Figure 2), it can be indicated that the injection well and the corresponding production well are connected, and the pressure of the injection well can be transmitted to the production well direction, but at a relatively slow speed.

The fundamental reason for this phenomenon is the existence of differential reservoir bands between oil and water wells. From the seismic attribute map of B9~B8H wells (Figure 3), it can be seen that there is a significant change zone in seismic attributes along the direction of the injection well B9 towards the production well B8H, about 100~300m away from B9 well, and the reservoir properties deteriorate. This is due to the characteristics of river facies reservoirs being controlled by river channels, narrow sand body facies zones, multi-stage stacking, strong planar heterogeneity, and poor connectivity.

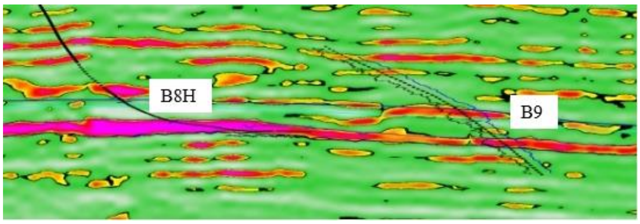

Figure 3. *Seismic attribute profile map of B9-B8H.*

2.5. Process Measures

To solve the poor reservoir connectivity between the injection and production wells of B9~B8H, it is necessary to carry out minor modifications and not form large fractures, otherwise it will cause the injected water to quickly break through along the fracture zone, resulting in explosive water flooding of the oil well. Therefore, fracturing is not a good choice; Similarly, conventional measures such as acidification, microfracturing, and pressurized water injection are effective in addressing reservoir contamination issues near the wellbore, and cannot handle reservoir modifications up to 100~300m away from the wellbore. Liquid flow cavitation [16] reservoir micro modification technology can solve this problem.

3. Micro Modification of Liquid Flow Cavitation Reservoir

3.1. Mechanism of Reservoir Micro Modification

Liquid flow cavitation [17, 18] is the use of high-speed liquid flow passing through a cavitation device, which forms a negative pressure zone due to its throttling effect. After the liquid flow passes through the negative pressure zone, a large number of cavitation nuclei are formed, which is first-order cavitation [19]. The shock wave generated by the first stage cavitation is combined with the vibration wave and sound wave generated by the cavitation device, which are conducted through the liquid medium in the porous medium of the reservoir and generate multi-stage cavitation, generating a large number of cavitation nuclei. The shock wave formed by the explosion of cavitation nuclei penetrates the pore throat (Figure 4), achieving the goal of reservoir micro modification, specifically manifested as improving natural micro cracks in the reservoir, directing pore throat channels, and adding new micro cracks.

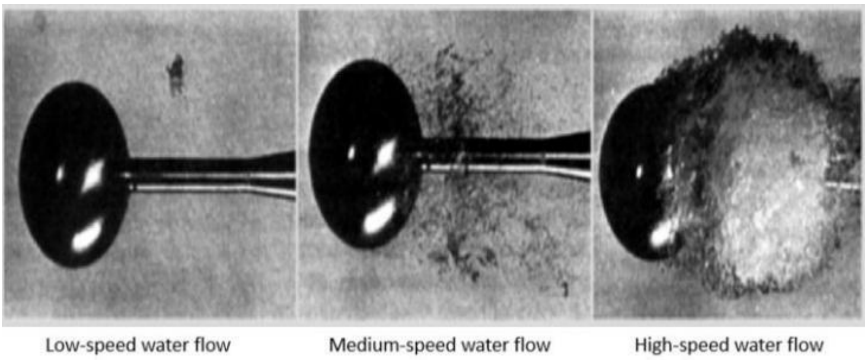

Figure 4. *Cavitation process diagram under different water flow velocities in the laboratory.*

Improving natural microcracks: Through multi-stage cavitation, high-speed microjets generated by the explosion of cavitation nuclei in porous media can erode and close the surface of natural microcracks, improving their permeability.

Dredging pore throat channels: By high-frequency vibration, free particles in the pore throat are dispersed and removed, and the pore throat channels are unblocked to improve the permeability of the reservoir.

Newly added microcracks: On the one hand, the high-frequency shock wave causes the cement between the rock skeleton particles to loosen, eroding the cement between the skeleton particles, thereby generating new microcracks; On the other hand, the high-pressure microjet generated by the collapse of cavitation nuclei acts on areas of rock with lower crack resistance strength, resulting in fatigue microcracks. As the number of microcracks increases, more seepage channels are added, changing the discharge profile.

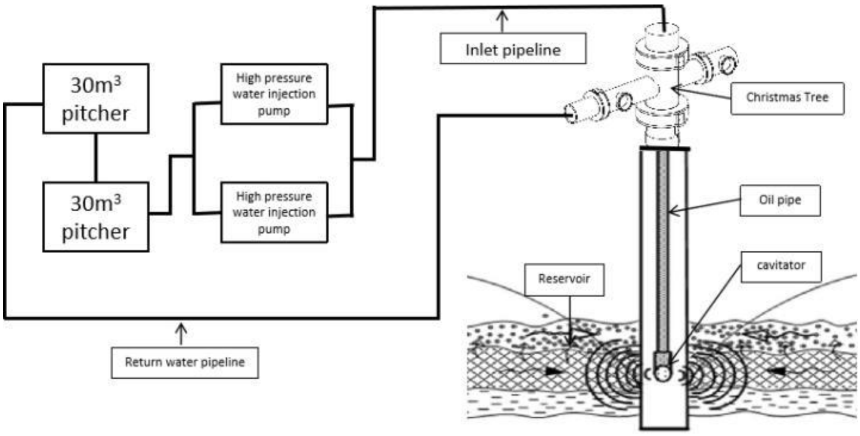

Figure 5. Schematic diagram of fluid flow cavitation reservoir reconstruction.

3.2. Technical Features

There are four characteristics of liquid flow cavitation reservoir transformation: firstly, micro transformation: multi-stage cavitation penetrates the pore throat, achieving the goal of reservoir micro transformation by improving natural micro cracks, directing pore throat channels, and adding micro cracks; Secondly, the transformation radius is large: the shock wave generated by cavitation produces multi-stage cavitation effects in the reservoir, with a processing radius of up to 200~300m; Thirdly, there are few ground equipment: only one backup water storage tank, water injection pump (Figure 5), and platform water injection are needed on the ground; The fourth is simple construction technology: connect the cavitation device to the end of the oil pipe and lower it into the target layer. During construction, the high-pressure water injection pump injects the injected water into the cavitation device through the oil pipe, generating cavitation effect. At the same time, adjust the depth of the pipe column according to the design requirements to achieve the purpose of micro modification of the reservoir (Figure 5).

4. Implementation Effect

4.1. Process Design and Construction Parameters

Design principle: Based on the understanding of reservoir thickness, heterogeneity, potential size, and oil, gas, and water distribution, deploy operation points for the target layer, improve poor reservoir connectivity, increase seepage area, change the discharge profile, improve water drive efficiency, and effectively utilize the remaining oil enrichment area.

Design parameters: According to the requirements of the B9 well reservoir renovation, combined with the characteristics of reservoir development, the target layer is evenly distributed. A total of 17 construction points are designed, with a designed construction displacement of 2.4~2.6m^3/min, a construction pressure of 22~26MPa, and a single point action time of 45~90min. The construction sequence starts from the bottom of the target layer and runs from bottom to top.

Construction parameters: The number of construction points, displacement, pressure, and construction sequence are basically consistent with the design. Considering the first on-site test, in order to ensure the effectiveness of reservoir renovation, the single point action time has been extended from 45~90 minutes to 2~3 hours.

4.2. Implementation Effect

After the implementation of liquid flow cavitation reservoir micro transformation in well B9, significant effects have been observed in both injection and production wells. The reservoir properties, connectivity, permeability, and water drive effect between injection and production wells have been significantly improved. The implementation effects are as follows:

The B9 well is mainly reflected in: firstly, the increase in water absorption capacity. As shown in Figure 6, the slope of the water absorption indicator curve after the measures has significantly slowed down, that is, the required injection pressure under the same injection volume conditions has significantly decreased. The apparent water absorption index has increased from 7.5m^3/(d·MPa) before the measures to 18.3m^3/(d·MPa) after the measures, indicating that the reservoir properties near the injection wellbore have been improved; Secondly, the pressure relief time has been significantly shortened. Prior to the measures, injection and pressure relief were stopped twice in 2016 and 2017, and it took 22 days and 135 days for the wellhead pressure to drop to 0MPa, respectively. After the measures, it only took 5 days. This is the best proof of the significant improvement in reservoir band and connectivity between injection and production wells, and directly proves that the processing radius of this technology can reach 200~300m.

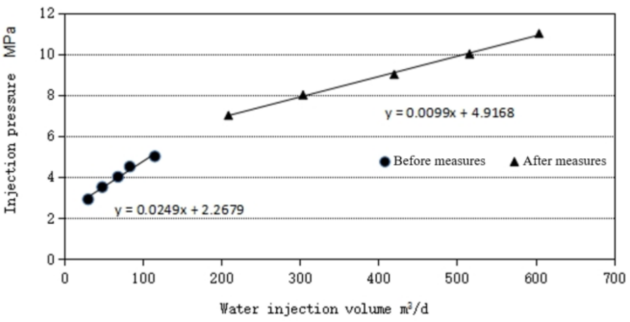

Figure 6. *Comparison chart of water absorption indicator curves before and after.*

The B8H well shows that: firstly, after one month of measures, the production well flow pressure gradually increased. Under the same daily liquid production conditions, the flow pressure increased from 4.3 MPa to 7.1 MPa, which also indicates that the connectivity between injection and production has been significantly improved, and the permeability of injected water has been strengthened; Secondly, the effect of precipitation on oil production was observed. After water injection, the comprehensive water content decreased by about 7%, and the daily oil production was about 10m^3/d. This indicates that liquid flow cavitation can increase the seepage area, change the discharge profile, and effectively utilize the remaining oil enrichment area.

5. Conclusion and Understanding

There are poor reservoir bands between wells B9 and B8H, and the connectivity between injection and production wells has deteriorated. This is the fundamental reason for the gradual decrease in water absorption capacity of injection wells, making it difficult to meet the requirements of injection allocation, resulting in poor water drive effect of production wells and low yield and efficiency.

After implementing liquid flow cavitation, the production situation at both ends of the B9~B8H well group has significantly improved, and the reservoir properties, connectivity, permeability, and water drive effect between injection and production wells have been significantly improved. The successful application of this technology has provided reliable process measures for solving the problems of poor reservoir bands, weak connectivity between injection and production wells, and poor water drive effects in Bohai Oilfield.

The liquid flow cavitation technology is suitable for the transformation of effective low-permeability reservoirs with pore throat structures and filled with fluids. It can not only micro transform the reservoir, but also treat a radius of up to 200~300m, which is an advantage that acidification, micro fracturing, pressure boosting water injection, and fracturing measures do not have.

Abbreviations

ODP Overall Development Plan

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Chai Shichao (1971-), male, China Petroleum Exploration and Development Research Institute, July 2002, master's degree, Chief Engineer/Senior Engineer, Oil and Gas Field Development, Tianjin Branch of CNOOC (China) Co., Ltd. Address: Block A, Bohai Petroleum Building, No. 2121 Haichuan Road, Binhai New Area, Tianjin, China.