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Research and Application of Integrated Sand and Water Control in Horizontal Well

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Abstract: The problem of sand and water coming out of the oil formation has been a difficult problem in horizontal wellsm, especially in unconsolidated sandstone reservoirs. Analysis of the current technology and application effects, sand and water control integration is an effective method to solve this problem. The article analyzes the main difficulties of integrated sand and water control technology, investigates the development and application of sand and water control technology, and selects integrating mechanical water control and gravel packing sand control. The principles, advantages, and disadvantages of Flow channel-controlled and floating disc type AICD water control valve are introduced. The water-oil pressure drop ratio parameter was used to evaluate the performance of different water control valve. At same times, a new type of integrated screen for water and sand control was designed. A horizontal well with water at the bottom of a sparse sandstone reservoir was used as a case study for the field application of integrated water and sand control technology. The integrated sand and water control technology was applied in an offshore horizontal well. Through the summary of the scheme design and construction process, the proposal of the integrated sand and water control scheme design is suggested. The application of this technology is expected to provide a reference for the design of sand and water control integration scheme.

Keywords: Water Control and Sand Prevention Integration, Open-Hole Horizontal Well, Water Control Valve, Production Pressure Difference, AICD

1. Introduction

Open-hole horizontal well technology can effectively increase well production and reduce oil-filed development costs, so it has been widely used. However, in loose sandstone or unconsolidated sandstone, horizontal wells are easy to sanding. Especially, there is water at the bottom of the sediment, which can lead not only to sanding problems but also to serious water problems. The method of prior gravel packing can prevents sand from the formation and prolongs the production time of the well, but it cannot solve the formation water production. When water is produced from the horizontal section of oil well, the water ratio of the well will rise rapidly [1] and the oil production will drop sharply, which may form a flooded oil formation in severe cases and lead to dead oil in the formation that cannot be produced. For active bottom water reservoirs, it is necessary to consider not only sand control but also bottom water breakthrough when designing completion schemes, so the implementation of integrated sand and water control technology is an economical and effective method. However, the integrated technology to achieve sand control and water control faces many difficulties:

(1) The integration of sand control and water control can have an significant impact on short-term good production: Whichever water control technology is used will have an impact on oil flow, and the integration with sand control technology will superimpose flow resistance. Balancing the short-term impact and long-term benefits of integrated water and sand control technology is the main difficulty in designing sand and water control solutions.

(2) Different production stages of oil well have different

needs for water control, so the design of water control solutions is difficult. Early water control is mainly to delay water production in the wellbore and extend the waterless oil recovery period. The effect of medium-term water control is to slow down the rate of water and equalize the fluid production profile. The role of water control in the later stage is mainly to seal the water outlet point to postpone water flooding of the oil reservoir and improve the final recovery rate.

(3) After the implementation of the integrated sand and water control technology, it is difficult to operate late production enhancement measures for oil well. Later in the production phase of an oil well, when it enters the high water rate production phase, it is generally produced utilizing a large displacement of fluid, thus increasing crude oil production. Due to the presence of integrated sand and water control technology, the fluid flow resistance in the lifting process is high. The complex structure of the integrated sand control and water control pipe column makes it impossible to carry out acidizing, fracturing, and other production enhancement measures.

Although the integrated sand and water control technology faces many difficulties, it is still a hot spot for current research due to the demand for actual projects [2-4]. At present, mechanical water control by ICD (Inflow Control Device, hereinafter referred to as ICD) and AICD (Auto-Inflow Control Device, hereinafter referred to as AICD) water control technology has been widely studied and applied at home and abroad [5-7]. Pan Hao et al [8] developed a new composite water control device, C-AICD (Composite Autonomous Inflow Control device, C-AICD), by coupling ICD and AICD. Li Xiaobo et al [9] applied the floating plate type AICD with segmental water control in offshore oil fields, and the water control results were remarkable. Zhang, L. et al [10] applied three techniques in a combination of chemical annular plugging segmentation outside the ACP pipe + chemical plugging agent spot plugging + water control in the central pipe column. Zhou Hongyu [11] et al. conducted a simulation experiment of gravel packing the bypass slip-on AICD screen tube with a conventional AICD screen tube, and the experiment demonstrated the feasibility of gravel packing the bypass slip-on AICD screen. Zhao Xu [12] et al. used STAR-CCM+ furnace simulation software to carry out evaluation tests on the water control performance of the new AICD water control valve and then optimized the design method of the water control valve. Through research and analysis, it was found that the mechanical water control method is more suitable for integrated operation with mechanical sand control. Therefore, research on the integration technology of open-hole gravel packing and mechanical water control valve was carried out. Because the open-hole gravel packing technology is already mature, the research focuses on the study of mechanical water control valve components.

2. Mechanical Valve Control Water Principle

Mechanical water control valve is mainly divided into ICD water control technology and AICD water control technology, as well as other water control technologies derived from it. AICD water control technology is developed based on the function of ICD water control technology. AICD mainly acts as an inhibitor to further cone in after the adverse fluid breakthrough and retards the further intrusion of the adverse fluid. AICD mainly plays an inhibitory role in the further cone entry after the unfavorable fluid breakthrough, delaying the further intrusion of the unfavorable fluid, extending the production time of the well, and improving the recovery rate of the reservoir. The technology has received extensive attention and research from major companies at home and abroad since its inception. The current research and application mainly focus on floating disc type AICD, and flow channel control type AICD, whose basic structure is shown in Figure 1.

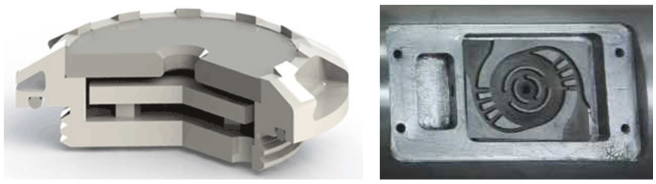

Figure 1. *Floating disc type, flow channel type AICD structure schematic.*

The floating disc type AICD is based on the principle of constant sum of dynamic fluid pressure and local pressure loss in Bernoulli's equation, the schematic diagram is shown in Figure 2. The opening of the disc inside the valve varies with the viscosity of the different fluids flowing through the valve body. Low viscosity liquid through the valve body, due to less frictional resistance, pressure potential energy into kinetic energy is larger, the inertial force increases, generating greater stagnation pressure at the edge of the disc, the disc moves toward the inlet, the flow resistance increases, and the opening is reduced. When the high viscosity liquid flows through, the disc opening becomes larger and the flow resistance is reduced, which is beneficial to the production of high viscosity liquid. The use of disc type AICD devices is not recommended in sandy formations because sandy formations can cause accelerated wear of the discs, which not only affects the AICD water control performance but also has an impact on the life of the valve.

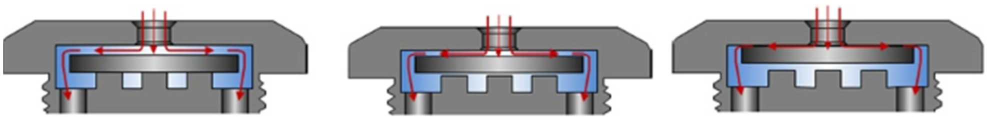

Figure 2. *Schematic diagram of the working principle of floating disc type AICD.*

Flow channel-controlled AICD is based on the equilibrium between viscous and inertial forces, and the design of the flow channel can be changed according to the target reservoir fluid properties, and its working principle is shown in Figure 3.

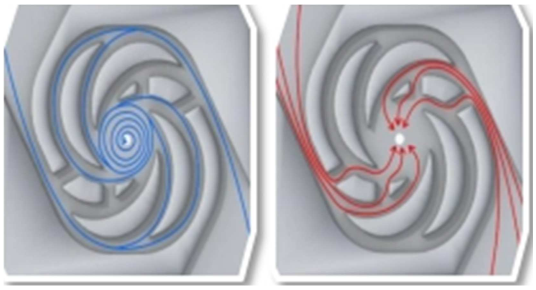

Figure 3. Schematic diagram of the working principle of flow channel type AICD.

When the viscous liquid enters the flow channel, it flows directly into the center outlet along the lateral direction due to the smaller inertia force, and the additional pressure drop caused by the vortex effect is minimal, which is conducive to the output of highly viscous liquids. When the viscosity of small fluid inflows, the fluid has a larger inertial force to obtain a larger angular velocity, and to reach the exit vortex loss increases.

The flow-channeled AICD delays the breakthrough time and further flow after the breakthrough of unfavorable fluids and still distinguishes a significant efficiency of water flow inhibition at high viscosities. The disadvantage of flow-through AICD is that it does not completely inhibit the inflow of water at high water content, and the advantage is that it achieves continuous good flow.

3. Integrated Design of Horizontal Well Sand Control and Water Control Scheme

The core of AICD water control solution design lies in the selection of valve components, different valve components have different characteristic curves. Only based on the accurate characteristic curves of valve components and reservoir data, the design of reasonable water control differential pressure can achieve the effect of water control without reducing production. At present, different manufacturers produce the same basic structure of the water control valve, but there are subtle structural differences and dimensional changes, Water control valve test characteristic curve, the best test fluid is to use the reservoir fluid for testing, but the fluid is more difficult to obtain. which can affect the effectiveness of its water control technology. Therefore, the characteristic curve test of the water control valve must be carried out before the design of the water control scheme.

3.1. Study of the Characteristic Curve of Water Control Valve

Characteristic curve testing of valve components is best performed using well formation fluids, but which is not easily available before completion production. A more feasible method is to use a variety of frictional mineral oil for water control valve testing and plotting water control valve characteristic curves. However, there is no unified standard for testing and evaluating the performance of AICD water control valves, and it is difficult to evaluate the performance of water control valves even after testing. However, there is no unified standard for testing and evaluating the performance of AICD water control valves, and it is difficult to evaluate the performance of water control valves even after testing. To evaluate the water control capacity of different water control valves, the water-oil pressure drop ratio parameter is used. The water-oil pressure drop ratio is the ratio of the pressure drop generated by water and oil through the valve under the same temperature, pressure, and flow rate. AICD water control valve of the same flow type with different size center holes was tested to verify the usefulness of the water-oil pressure drop ratio parameter. Four randomly selected flow-through AICD valves with 2.5 mm center bore from different manufacturers were tested with 100 mPa-s mineral oil, and the pressure drop and flow rate relationship curves are shown in Figure 4.

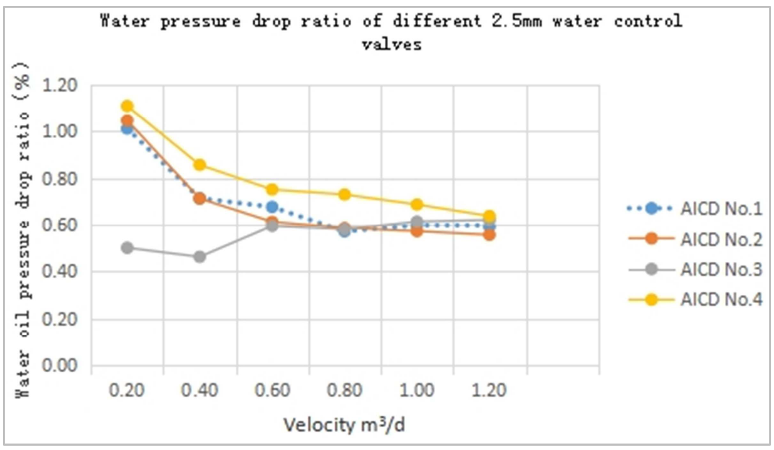

Figure 4. Pressure drop curve and water-oil pressure drop ratio curve of AICD valve of different manufacturers' flow channel type.

The selected water control valves were labeled with the same performance parameters, and even their recommended optimal flow rates were essentially the same, but testing revealed that each valve exhibited different characteristics. In particular, the water-oil pressure drop ratio parameters vary greatly from valve to valve, which is the main reason for the poor water control effect. The water control valve is mainly to achieve the flow control of oil and water overflow, the water-oil pressure drop ratio parameter is proposed to effectively evaluate the comprehensive ability of the water control valve to control oil and water. According to the reservoir bottom water condition of the well, the water-oil pressure drop ratio is used as the basis for water control valve selection, combined with the completion scheme, to achieve different water control requirements.

3.2. Sand and Water Control Integrated Composite Screen Tube Design

The difficulty in the implementation of integrated gravel packing and water control technology is that the sand-carrying liquid needs to enter the screen pipe from the water control valve after the sand-carrying liquid is desanded during the gravel packing process and then flow back to the wellhead in the flushing pipe, but the AICD water control valve generates large additional friction when pure water is flowing, making the surface pumping pressure very high and the pumping discharge very small. Too high pumping pressure may open the reservoir causing uncontrollable cracks, and low pumping speed will not only increase the construction time but also may cause the gravel to settle too fast due to the low flow rate of sand-carrying liquid, resulting in early desanding leading to construction failure. Reducing the flow resistance of the gravel-filled sand-carrying liquid after desanding, achieving a reduction in pumping pressure and an increase in pumping speed are essential for the integrated sand and water control technology.

If there is another overflow channel in the screen tube during the construction process, it can act as a backflow circulation channel for sand-carrying liquid when gravel packing, which can effectively reduce the filling pressure and improve the construction discharge; closing the channel after the construction is finished does not affect the flow control function of the water control and sand prevention screen tube. The channel not only solves the problem of integrated construction of gravel packing and water control but also allows the opening of the overflow channel to withdraw liquid in large discharges when the water content is high in late production.

In response to the above assumptions about the screen tube, a composite screen was designed to focus on the gravel packing process and to take into account the reserved process requirements at the late production. The composite screen pipe is equipped with a slide sleeve device at one end, which forms a gravel-packed backflow channel to reduce construction pressure when the sliding sleeve is open; it is equivalent to an ordinary AICD screen pipe when the sliding sleeve is closed. By comparing the pressure data of filling ordinary AICD screen tubes and AICD screen tubes with slip-on under the same conditions through indoor experiments, it was found that the packing pressure of the new composite screen tube was 30%~40% lower than that of ordinary AICD screen tube. The processing of this composite screen tube is simple, and the slip-on device is installed between the original AICD screen tube and the base tube to achieve low friction filling by changing the inner structure of the screen tube. Since the size of the original screen pipe does not change, the construction tools do not need to be changed to realize the integrated sand and water control technology. This method is easy to operate on-site while reducing costs.

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4. Horizontal Well Sand Control and Water Integration Technology Application

4.1. Basic Parameters of the Target Well

Well X1, the target reservoir, the sparse sandstone of the Pavilion Tao Formation, was drilled to a depth of 3,520m, with a vertical depth of 1,269m and a horizontal section length of 83m. Analysis of the follow-up drilling data revealed uneven fluid production profiles in the horizontal section of the well, severe longitudinal in homogeneities in the reservoir, and large differences in bottom water distribution distances. There was a bottom water breakthrough in the later production period, so the original design horizontal section length was shortened and the completion process was entered after drilling was completed.

4.2. Optimization of the Implementation Plan of Sand and Water Control Joint Work Integration

By simulating the fluid production profile of the horizontal section, it is found that although the horizontal section of the well is not long, the probability of sand and water breakout is large. If the water control is not carried out outside the tubular section of the bare section, it is easy to form lateral flow near the open horizontal section, and then form a cascade flow. If bottom water is not controlled, bottom water breakthroughs can easily occur after production causing uneven production profiles and serious flooding can occur. Therefore, in the design of the integrated sand and water control solution, the formation of the well was segmented outside the pipe according to the bottom water condition of the reservoir, and four external water contact expansion packers were placed as shown in Figure 5.

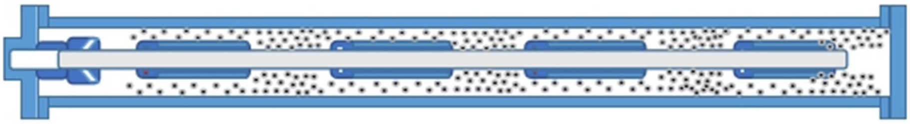

Figure 5. *Schematic diagram of X1 well tubing outer segmentation.*

Through the packer to achieve lateral flow blockage, the water control valve balances the production profile, to achieve the purpose of section water control. Different water control pressure differentials are used for different segments to control the uniform advancement of the water production profile and to achieve the purpose of water control and oil stabilization for long-term exploitation.

After optimization, the combination of sand and water control joint work pipe column of X1 well is: floating shoe + short blind pipe + anti-liquid lock sealing cylinder + expansion sealer + new AICD sand and water control composite sieve pipe + expansion sealer + new AICD sand and water control composite sieve pipe + expansion sealer + new AICD sand and water control composite sieve pipe + expansion sealer + new AICD sand and water control composite sieve pipe + expansion sealer + new AICD sand and water control composite sieve pipe + blind pipe.

After the design of the sand control and water control integration scheme was completed, to ensure the smooth implementation of the scheme, ultra-lightweight gravel was selected for the gravel packing to prevent possible sand blockage at high pressure and low discharge and to effectively improve the filling efficiency [13-15].

4.3. Sand Control and Water Integration Technology Application

The optimized integrated sand and water control construction procedure for well X1 is the same as the ordinary open-hole gravel packing process for horizontal well, so there are no major differences in construction organization and implementation. The optimized integrated sand and water control solution is mature and reliable, can use the original construction equipment for sand control, and has no special requirements for the construction personnel, which not only improves the operation efficiency but also makes the implementation of the solution more reliable.

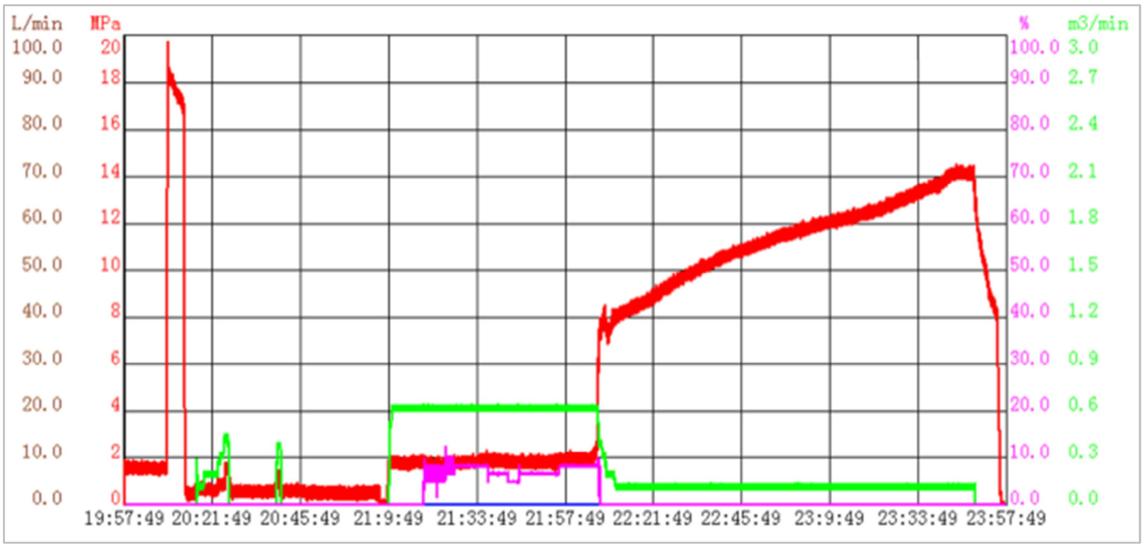

Figure 6. *Construction curve of X1 well.*

The construction curve of X1 well is shown in Figure 6, pump pressure 1.2~14.5MPa, desanding pressure 14.5MPa; sand ratio 5.15-8.77%, pumping speed 0.6-0.1m^3/min, total filling liquid volume 55.67m^3; pumping in sand volume 2.0m^3, backwashing out 0.6m^3, actual filling sand volume 1.4m^3, rechecking well diameter 9.2″, filling efficiency 140%, the construction went well. It can be seen from the graph that the pressure rises rapidly after the sand is buried in the new water control screen tube, which proves the overflow capacity of the new water control screen. The well started production after completion and initial production was in line with expectations. The effect of water control and oil increase in the later period is being followed up continuously.

5. Conclusions and Recommendations

1) The application of the results of the sand and water control joint work program proves the feasibility of integrating the horizontal well gravel packing with water and sand control, and provides a new solution for

the development of bottom water reservoir in loose sandstone.

2) The sieve pipe with slip sleeve has played a part in the sand control and water control joint operation scheme, but the lateral friction is still large, and the setting of the number and distance of the sieve pipe with slip sleeve needs to be further optimized.
3) The key to the water control effect lies in the water control design scheme combined with the reservoir characteristics. Only by fully combining the specific conditions of the well to carry out the optimized design can the effect of sand control and oil increase be realized.
4) The development of high viscosity and low friction completion fluids can reduce the construction pressure, which is conducive to increasing the construction displacement and improving the construction efficiency.

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