

Analysis and Experimental Research on Water Control Performance of Integrated Water Control Fracturing Completion Tools

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Abstract: This paper proposes a swirl type water control device to address technical challenges such as gas well formation water output and multi-stage segmented fracturing of long horizontal wells. The geometric and grid models of the fluid region of the water control device are extracted and established. The distribution law of the flow pressure drop of methane gas and pure water passing through the device is analyzed through numerical simulation. The simulation results show that under the same flow rate, the pressure drop of pure water is about 140 times that of methane gas, indicating that the swirl type water control device has a much greater limiting effect on water flow than methane gas; At the same inlet pressure, the production of methane gas is about forty times that of water, indicating that the swirl water control device has a good effect on controlling water gas. At the same time, a set of integrated water control fracturing completion tools was designed, which can directly perform fracturing operations after lowering the pipe column. After fracturing is completed, natural gas production operations can be carried out directly without the need for other auxiliary tools to be lowered. This integrated water control fracturing tool has been applied to 6 gas wells in Changning, significantly improving on-site operational efficiency. The results of this study provide a new and efficient tool for solving the problems of segmented fracturing and water production in gas wells.

Keywords: Water Control - Fracturing Completion Tools; Numerical simulation; Overcurrent pressure drop; On site application.

1. Introduction

The Sichuan Basin boasts 66 trillion cubic meters of natural gas resources, accounting for over 50% of the country's natural gas reserves, and is the main battlefield for natural gas exploration and development in China.^[1] 80% of natural gas wells in our country produce water, and with the development of gas wells, the problem of wellbore fluid accumulation has become prominent. The accumulation of liquid in the wellbore will increase the backpressure of the gas reservoir, and even cause water flooding and closure of the gas well, severely limiting the production capacity of the gas well and affecting the development of the gas field.^[2-4]

Horizontal wells have significant economic benefits in the development of various oil and gas reservoirs, and are currently the main wellbore structure for natural gas development in our province. However, a common problem faced in the development of horizontal wells is that once the production well encounters water, the water content will rapidly increase, which not only significantly reduces the recovery rate but also increases the cost of sewage treatment^[5-6]. At present, the water control methods for horizontal wells mainly adopt a combination of mechanical and chemical water plugging methods^[7], Alain Zaitoun used a new polymer to reduce the relative permeability of water without affecting the oil permeability, resulting in a decrease in water content from 85% to below 50%^[8]. Mechanical water plugging mainly adopts the underground flow control device ICD (Inflow Control Device). ICD is distributed around the production string, utilizing the differences in oil-water properties to increase the pressure drop of water phase flow and achieve the goal of underground water control. According

to the different ways of generating pressure drop, it can be divided into spiral channel type, nozzle type and their combination schemes^[9-11]. Due to the inability to adjust the structure and size of ICD after being put into the well, its structural design highly relies on predicting the actual situation of the reservoir and is difficult to cope with changes in downhole conditions^[12-13]. To this end, an adaptive flow control and water control (AICD) structure has gradually been developed, with representative examples being the use of the principle of material expansion when encountering water to control the flow rate of water in the formation, and the development of a series of self expanding flow control and water control devices^[14]; High thixotropy hydrogel can realize water control in horizontal wells on the basis of precise control of its thixotropy, gel time, plugging performance and degradation performance due to its rapid thickening after shearing^[15]; The disc type flow control water device can achieve the purpose of limiting water by automatically adjusting the overcurrent channel through a movable disc^[16]. The active underground flow control device utilizes temperature and pressure sensors, which can change the opening of the device at any time. However, the accuracy of sensor detection and the long-term harsh underground environment have affected the applicability of this structure^[17-18].

At present, the research on the adaptability of water control technology to gas well water control has not been extensively carried out, and due to the non uniqueness of the channels, the operation process of the water control pipe column relies heavily on continuous oil pipe operation, making it difficult to implement the long horizontal section multi-stage segmented fracturing technology. Therefore, the research on integrated intelligent water control and segmented fracturing

completion tools for natural gas wells in this project is of great significance for improving reservoir transformation efficiency, controlling formation water/liquid accumulation, and thereby increasing natural gas well production capacity. It is an important technical means to support the construction of Sichuan's "5+1" modern industrial system, meet the structural reform requirements of the National Energy Administration's natural gas supply side, and ensure national energy supply.

2. Structure and Simulation Model of Swirl Type Water Control Device

The swirl type water control device mainly consists of an inlet channel, a throttling channel, a main flow channel, a branch flow channel, a nozzle, and an outlet (as shown in Figure 1). The working principle of the device is as follows: when water enters the device from the inlet, it will directly enter the main channel under the action of inertia force, without passing through the throttling channel, and then enter the branch channel under the guidance of the inner wall of the channel. Then, it enters the swirl chamber through the nozzle. Due to the sudden decrease in the flow surface area of the nozzle, the flow velocity of water will undergo a sudden change before and after the nozzle, resulting in energy loss. Finally, the swirl speed will increase in the swirl chamber, further generating energy loss and forming a large flow pressure drop, thereby achieving the goal of water control. The density and viscosity of gas are much lower than that of water, and its diffusion during the flow process is much greater than that of water. Therefore, after the gas flows in, a part of it will flow along the main channel, and a part will flow directly from the branch channel to the outlet. The swirling effect of gas in the device is weaker than that of water, so the capacity loss of gas is lower, and the device has a smaller restriction on gas.

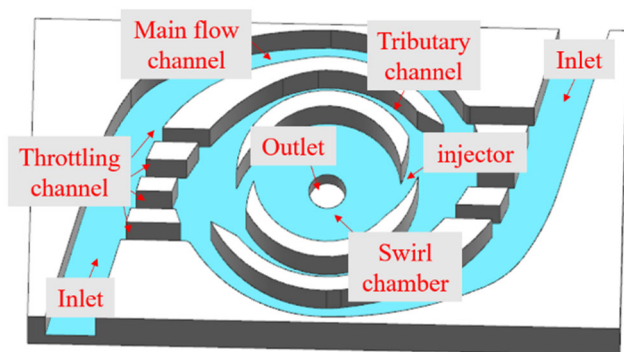


Figure 1. Structural diagram of swirling water control device

2.1. Fluid Region Model and Boundary Conditions

Based on the structure of the swirling water control device, establish a fluid domain model as shown in Figure 2. The watershed model was meshed using tetrahedral grids, with an average grid quality of 0.912 and a total of 30000 grids. The grid partitioning results are shown in Figure 3.



Figure 2. Fluid Region Model

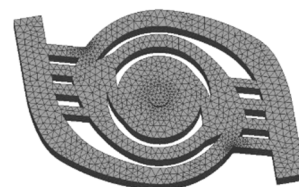


Figure 3. Fluid Region Grid Model

The fluid medium is pure water and methane gas, with a pure water density of 1000kg/m³ and a viscosity of 1cp; Methane gas is an ideal gas, and its density can change with pressure. Two types of inlet boundaries, velocity inlet and pressure inlet, are used for calculation. The outlet is the pressure outlet, and the remaining walls are defined using the wall function method.

2.2. Simulation evaluation of water control effect

The flow pressure drop values of water and methane gas at different flow rates and the production values at different inlet pressures were calculated separately to determine the effectiveness of the swirl water control device in controlling water gas. The calculation results are shown in the table and figure below.

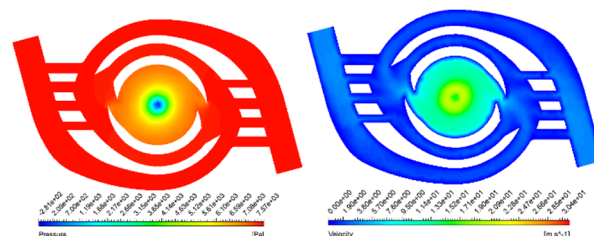


Figure 4. Pressure and velocity cloud map of methane gas

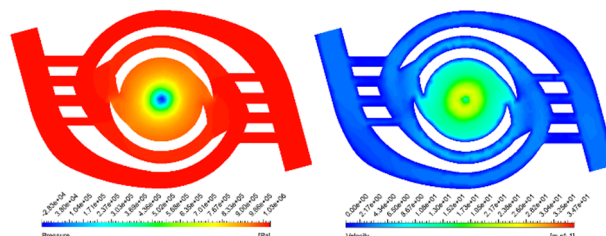


Figure 4. Pressure and velocity cloud map of water

From the pressure cloud map, it can be seen that the pressure distribution of water and methane gas is completely the same. The pressure drop is mainly distributed before and after the nozzle as well as in the swirl chamber. However, at the same flow rate, the pressure drop of methane gas is much smaller than that of water. When the flow rate is 6m³/d, the

gas pressure drop is 0.007MPa, the water pressure drop is 1.06MPa, and the water gas pressure drop ratio is 140 times. Therefore, it can be concluded that the swirl type water control device has a much greater control effect on water than on gas. From the velocity cloud map, it can be seen that both water and methane gas generate a swirl rate increase in the swirl chamber, but the flow velocity of water is greater than that of methane gas. In addition, water enters the swirl chamber sequentially through the main flow channel and branch flow channels, while methane gas enters the swirl chamber through the throttling channel and branch flow channels, and its flow diffusion is significantly greater than that of water. The relationship between pressure and flow rate is shown in the table and figure below.

Table 1. Relationship between Out-inflow Pressure Drop

Inlet flow rate (m ³ /d)	Gas pressure drop(Pa)	Water pressure drop(Pa)	Water to air pressure drop ratio
1	170	25000	147
2	755	110000	146
4	3270	470000	144
6	7500	1060000	141
8	13600	1910000	140
10	21700	3040000	140

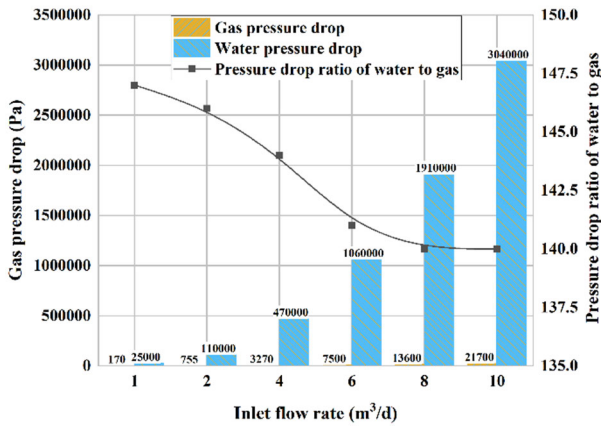


Figure 6. Overflow pressure drop and flow rate relationship curve

From the above figure, it can be seen that the water to gas pressure drop ratio decreases with increasing flow rate, but overall, the water pressure drop is much greater than the gas pressure drop. The swirl type water control device has a much greater resistance to water flow than methane gas.

Table 2. Relationship between outlet flow rate and inlet pressure

Inlet pressure (MPa)	Gas flow rate (m ³ /d)	Water flow rate (m ³ /d)	Water to air flow rate ratio
0.5	181.4	4.11	44
1	184.6	5.8	32
2	185.1	8.1	23
5	182	12.7	14
7	183.2	15	12
10	185.6	17.8	10

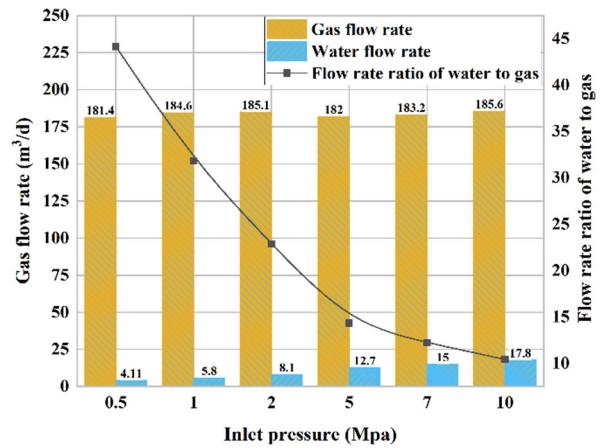


Figure 7. Flow rate and inlet pressure relationship curve

From the above figure, it can be seen that the water flow rate gradually increases with the increase of inlet pressure, while the gas flow rate hardly changes. This is because methane gas has compressibility, and the gas density gradually increases with the increase of pressure. Although the gas volume remains unchanged, the mass of gas contained per unit volume gradually increases. At the same inlet pressure, the gas production is much greater than the water production, and the gas water flow rate ratio can reach up to 44 times. Therefore, it can be inferred that the swirl type water control device has a strong effect on controlling water and gas.

3. Design Principles of Integrated Water Control and Fracturing Completion Tools

The schematic diagram of the integrated water control fracturing completion tool structure is shown in Figure 8. The integrated water control and fracturing completion tool can be divided into a flow control and fracturing part. The flow control and fracturing part mainly consists of a water control device and a single flow valve. The fluid enters from the right end of the single flow valve after passing through the screen tube, and then flows into the oil pipe through the water control device to complete the recovery process. Fracturing involves injecting fracturing fluid into the oil pipe, with a portion of the liquid flowing along the pipe to the water control device and flowing in from the outlet and out of the inlet to the single flow valve. At this time, the steel ball in the single flow valve blocks the valve opening under the push of the liquid to prevent pressure leakage. The other part of the fracturing fluid drives the soluble ball and inner slide sleeve to move to the right, and the fracturing fluid is smoothly discharged after the side wall opening, completing the fracturing process. After the pressure is released, the inner slide sleeve moves to the original position under the action of the spring, closing the side wall hole. The soluble ball dissolves on its own in the later stage, achieving cleanliness and no falling objects inside the column. The integrated water control and fracturing completion tool can achieve direct water injection and fracturing inside the pipe after lowering the pipe column. After fracturing is completed, production can be carried out directly without the need for repeated lifting and lowering of the pipe column, greatly improving operational efficiency.

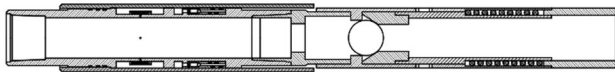


Figure 8. Schematic diagram of integrated water control fracturing completion tool structure

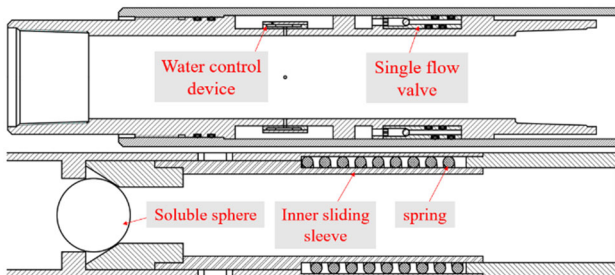


Figure 9. Partial schematic diagram of water control structure (upper) and fracturing structure (lower)

4. On Site Application Situation

Six wells have been applied in the Sichuan Chongqing region, and the water and gas throttling pressure drop ratio of the intelligent water control device has all reached over 20. The horizontal well can be segmented into more than 25 levels. The designed automatic switch slide sleeve does not require the cooperation of continuous tubing operation, achieving "zero" dependence on continuous tubing operation and significantly improving on-site construction efficiency.



Figure 10. On site testing

5. Conclusion

This article focuses on the problems of water accumulation in gas well formations and the difficulty in implementing long horizontal multi-stage fracturing technology. A set of integrated water control fracturing completion tools and a swirl type water control device are designed. The working principle of the integrated water control fracturing completion tool is analyzed, and the water and gas control effect of the water control device is simulated and calculated. The following conclusions are drawn:

1) At the same flow rate, the maximum pressure drop of water over flow is about 140 times that of methane gas, indicating that the swirl type water control device has a much greater limiting effect on water flow than methane gas; At the same import pressure, the maximum production of methane gas is about 40 times that of water, and the swirl type water control device has excellent water gas control effect.

2) The integrated water control and fracturing completion

tool has both fracturing and production water control functions, which can directly perform fracturing operations after lowering the pipe string. Production operations begin after fracturing is completed, without the need for additional auxiliary tools, greatly improving operational efficiency.

3) The integrated water control fracturing completion tool has been successfully applied to a natural gas well in Changning. The water and gas throttling pressure drop ratio of the water control device has reached over 20, and the integrated production fracturing operation has been achieved, avoiding the use of continuous tubing and significantly improving the operation efficiency.

Acknowledgement

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