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Study on parameter Sensitivity of adaptive flow control device for high water cut gas well

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Abstract

The horizontal well mining technology has been widely used in the development of various oil and gas fields. The long horizontal section can greatly increase the contact area between reservoir and tubing and improve oil and gas production efficiency. However, due to the bottom water ridge phenomenon in high water-bearing gas Wells, the rise rate of water content in the horizontal section will be accelerated. In order to solve the above problems, the sensitivity of structural parameters of the adaptive flow control device for high water cut gas well is studied in this paper. Method based on the multiphase flow theory, the establishment of AICD internal flow simulation model, and study the internal flow patterns, and analyzes the different key parameters (throttling channel width, the auxiliary baffle angles, throttle nozzle Angle) influence on throttling effect of water control, the results showed that: as the throttling channel width, the export gas phase volume fraction increases after the first decreases, and when the width is 5.5 mm, water control effect is best; The Angle of the auxiliary baffle has a great influence on the flow state and direction of the gas phase after it enters the disc region. When the Angle is 90°, the device has the best adaptability. When the throttle nozzle Angle is 0°, it has little influence on the tangential flow of water, which is conducive to flow to the central disk region. The analysis results of adaptive flow control and water control mechanism and parameter sensitivity in this paper have important guiding significance in the development of flow control and water control tools for high water cut gas wells.

Keywords

High Water Cut Gas Well; AICD； Regulating The Flow Of Water; Gas-Water Two-Phase Flow; The Numerical Simulation.

1. Introduction

In recent years, various oil fields have developed rapidly in the exploration and development of natural gas Wells, especially the development of horizontal gas Wells, which has become the norm. However, as the exploitation length of horizontal gas Wells expands and the exploitation cycle is too long, the high water cut in horizontal gas Wells limits the exploitation efficiency of horizontal Wells and reduces the exploitation life of horizontal Wells [1-4]. To solve such problems, adaptive flow control water technology (AICD) is mainly adopted at present. It is appropriately improved on the basis of ICD technology, which can not only mitigate the impact of bottom water ridge, balance wellbore profile, but also distinguish different fluids, play a stable throttling role, and greatly improve oil and gas recovery [5-7].

At present, AICD has been used in many oil fields at home and abroad. It is mainly used to regulate water flow according to different fluid properties and flow channel structures. Many scholars at home and abroad have conducted a lot of studies on the structural parameters and production mechanism of AICD [8-11]. The first FLOATING disk AICD designed by Crow[12] et al., mainly generates pressure drop ratio through floating disk to improve gas well production. Although this structure has a certain water control ability, its structural reliability is low and it is not suitable for large-scale use in oil and gas fields. Halvorsen[13], on the basis of predecessors, designed an RCP valve and applied it in Troll oil field for the first time, proving that this structure can slow the bottom water coning speed and effectively extend the production life of horizontal Wells. Subsequently, Youngs et al. [14] introduced an AICD optimization design method, which effectively reflected the practical application value of AICD in drilling technology. With the continuous improvement of the structure, Least[15] et al. combined the advantages of different structures and designed a flow passage TYPE AICD, which showed superior water control performance in the practical application of Ginta oilfield. Stone et al. [16] compared the water control capability of three devices, the floating disc type, the runner type and the self-expanding type, by using numerical simulation method. Combined with the practical application in oil fields, they fully proved that the runner type AICD has better adaptability.

Although the port type AICD has good throttling water control performance, has been a lot of application in horizontal well drilling, but from the implementation of the cases at home and abroad port type AICD practical application conditions, less successful, there exist many problems, especially in the case of horizontal gas well drilling, the reason is the structural parameters of port type and hydraulic parameters influenced the inadequate. Therefore, in this paper, by using CFD software, the k - e turbulence model and two phase flow model, the port type AICD structure parameters influence on gas water separation has carried on the comprehensive analysis, through a series of numerical simulation, respectively, discussed the structure parameters such as throttle channel width, auxiliary baffle angles and throttle nozzle Angle influence on gas mine water control, determine the optimal structure parameters of the gas were studied in the port type AICD gas-water separation rule, make theoretical reference to basins water controlling method.

2. Governing equation

2.1. Gas-water constitutive model

According to the water control mechanism of channel AICD, the throttling pressure drop generated by the device facilitates gas-water separation. Therefore, the numerical calculation model of gas-water separation two-phase flow needs to be taken into account. The basic control equation of gas-water two-phase flow is:

$$\frac{\partial\left(\sum_{\beta} X_{\beta}^{\kappa}\phi S_{\beta}\rho_{\beta}\right)}{\partial t} = -div\left(-\sum_{\beta} X_{\beta}^{\kappa}\left[k\frac{\rho_{\beta}k_{r\beta}(S_w)}{\mu_{\beta}}\left(\nabla p_{\beta}-\rho_{\beta}g\right)\right]\right)+q^{\kappa} \tag{1}$$

Where, S_{β} is the saturation of phase β; ϕ is porosity; ρ_{β} is the density of the β-phase fluid; k is the permeability coefficient; μ_{β} is the viscosity coefficient of β phase; $k_{r\beta}$ is the relative permeability coefficient of β phases; p_{β} is the pore pressure of β phases.

In the gas-water separation system, the VG model and VGM model are most commonly used, and the VG model is:

$$p_{cgw} = \begin{cases} p_0\left[\left(S_{we}\right)^{-1/\lambda}-1\right]^{-1/\varsigma} & S_{we}>0 \\ p_{\max} & S_{we}\leqslant 0 \end{cases} \tag{2}$$

Where: p_{cgw} is the pressure on the interface; S_{we} represents the effective water saturation, $S_{we}=(S_w-S_{wr})/(S_{ws}-S_{wr})$, ς is parameters related to the distribution characteristics; λ is a shape-related parameter.

The VGM model is:

$$k_{rg}=(1-S_{we})^{\tau}\left(1-(S_{we})^{1/m}\right)^{2m} \quad (3)$$

$$k_{rw}=(S_{we})^{\tau}\left[1-\left(1-(S_{we})^{1/m}\right)^{m}\right]^{2} \quad (4)$$

Where, k_{rw} and k_{rg} are the relative permeability of water phase and gas phase respectively; τ is tortuosity factor; The functional relationship between the parameters λ and ς satisfies $\lambda=1-1/\varsigma$.

2.2. AICD performance evaluation model

The throttling pressure drop of THE AICD device is mainly manifested as the difference between inlet pressure and outlet pressure, which is an important index reflecting the device's water control ability. It is found through research that the inlet area is an important factor affecting the throttling pressure drop under a certain inlet discharge rate of the device.

The relationship between the flow rate, flow rate and area at the entrance of AICD device:

$$v=\frac{Q}{S} \quad (5)$$

Where, S is the entry cross-sectional area, Q is the flow rate, and V is the average speed.

When designing the structure size of the device, the outlet size should be determined according to the total inlet cross-sectional area. In order to obtain a larger throttling pressure drop, the outlet cross-sectional area should be smaller than the inlet cross-sectional area. Therefore, AICD device is suitable for double inlet type to increase the inlet cross-sectional area.

When the fluid passes through AICD, it has obvious gas-water separation effect. The relationship between Reynolds number and fluid density and viscosity is as follows:

$$\mathrm{Re}=\frac{\rho d v}{\mu} \quad (6)$$

Where, ρ is the fluid density, μ is the fluid viscosity, v is the fluid velocity, d is the hydraulic diameter, and Re is the Reynolds number.

3. The numerical simulation

3.1. Model

AICD device is mainly composed of inlet passage, throttling passage, throttling nozzle, center exit, auxiliary baffle, etc. (as shown in Figure 1).The inlet channel plays the role of introducing gas-water two-phase fluid into the device. The throttle channel is mainly used to guide the water flow to rotate and make the water flow to throttle pressure drop with friction along the way. The throttle nozzle uses the difference in fluid viscosity to guide the gas into the central disk region. The central outlet is the channel through which fluid flows into the base pipe. The working principle of the device is as follows: after the mixture of air and water enters the device from the inlet, due to the different viscous forces of air and water, the low-viscosity water flow is more likely to enter the throttle channel and rotate, while the viscous air flow tends to enter the central disk area through the throttle nozzle. In the inlet flow rate under the same conditions, a lot of Reynolds number is larger than air flow, high Reynolds number flow because of the inertia force is bigger, so it is easier to enter the throttling channel, flow rotation occurs

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within the throttling channel, and natural gas at the entrance of the Reynolds number is lower than that of the water a lot, so the natural gas mainly along the near port throttle nozzle flow, are less likely to happen in the circular flow channel rotation, through this principle, the purpose of water control in basins.

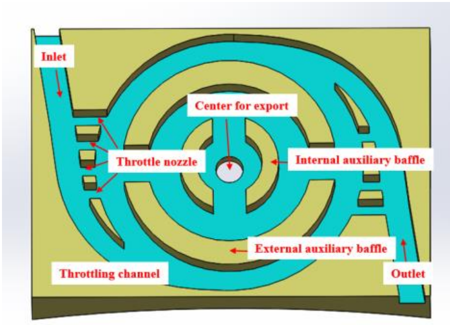

Fig.1 Runner type AICD

3.2. Grid division and boundary conditions

Using CFD software extraction device within the port, in the mesh module for meshing, using unstructured grid technology, grid quality of 0.641 on average, in the center of the disk area and exports to connection through the interface, in order to improve the calculation accuracy, close at the wall, the vortex center, exit the corresponding grid refinement processing, grid model is shown figure 2.

The boundary conditions of flow field are established according to the actual working conditions. The inlet is the velocity inlet boundary, and the outlet is the pressure outlet boundary. Considering that formation fluid enters the base tube from THE AICD device and flows to the ground in the practical application process, the device inlet reflects the production capacity of the reservoir, so the velocity at the inlet of the device is calculated according to the displacement, which is basically consistent with the actual working condition. Therefore, the inlet velocity of the device is 6m/s ($10m^3/d$) and the turbulence intensity is set at 5%.The physical property parameters of natural gas and water are shown in Table 1.

Table 1 Physical properties of natural gas and water

Fluid type	Viscosity ($mPa\cdot s$)	Density (kg/m^3)
Gas	0.1087	0.668
Water	1	998.2

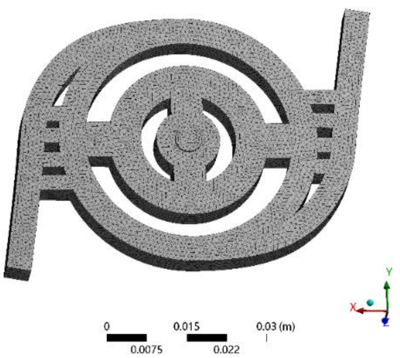

Fig.2 AICD grid model

3.3. Adaptability analysis of simulation model

The AICD flow field was numerically simulated by natural gas and water. Combined with the actual working conditions, the water control adaptability of AICD was analyzed, and the

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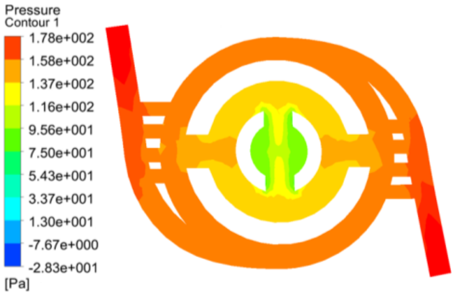
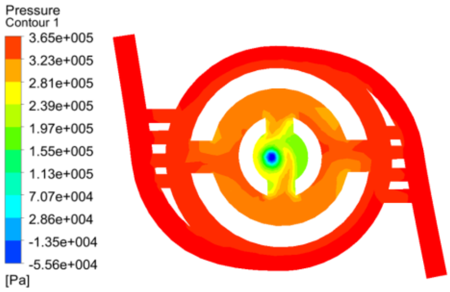
pressure distribution and velocity distribution of the flow field and flow field were plotted, as shown in FIG. 3 and 4, respectively.

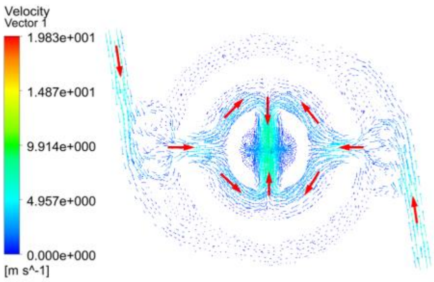


(a) Gas

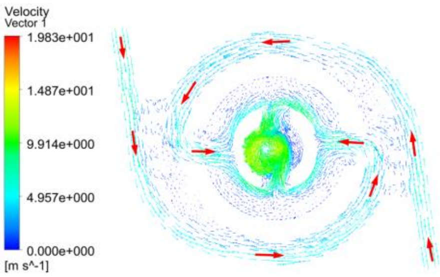


(b) Water

Fig.3 Gas and water pressure distribution cloud map



(a) Gas



(b) Water

Fig.4 Vector diagram of natural gas and water velocity

It is obvious from Figure 3 (a) and Figure 3 (b) that the pressure variation range of natural gas inlet and outlet is mainly concentrated in the range of -0.000028 ~ 0.000178MPa.The inlet and outlet pressure of water mainly varies within the range of -0.0556 ~ 0.365MPa.And, when natural gas into the disc area, because of its own air flow to, airflow will happen to the touch, thereby causing loss to the partial pressure, and the kinetic energy of the water drop is more concentrated in the center of pressure drop at the exit, as a result, the water flows in the new type of gas reservoir AICD pressure drop is mainly embodied in the exit of the instantaneous pressure drop, and in the pressure drop caused by the throttle channel. By comparison, it can be concluded that the overflow pressure drop of water passing through the unit is significantly higher than that of natural gas, which also proves that gas reservoir AICD has a good overflow water-blocking effect.

It can be seen from FIG. 4 (a) and (b) that most of the natural gas flows from the throttling nozzle to the disk region and finally flows out to the central outlet. Compared with water, it can flow to the central outlet faster. After the water enters from the entrance, due to the high density and high speed, it mainly flows to the throttling channel, forming rotation, and then gradually flows to the central disk area, forming vortex at the same time, unable to flow smoothly out of the central exit. Again, AICD has a large resistance to water flow and can inhibit its flow into the wellbore.

4. Simulation model validation

To verify the accuracy of the simulation model, the calculated model should not be too close to Georgina Corona[17] at AICD. This numerical model was used to analyze the overflow pressure drop in the aqueous phase at AICD not close to WW 5W. In addition, the water phase of 0.7 $mPa \cdot s$ was selected as a fluid with the same properties as the simulation and experiment. The comparison results were shown in Figure 5. It can be seen from the figure that the pressure drop of the water phase increases with the increase of the flow rate. When the flow rate is 25m3/d, the pressure drop of the water phase can reach 1.2mpa. At the same time, it can be seen that the numerical simulation differs little from the experimental results, and the error is basically kept within 5%.

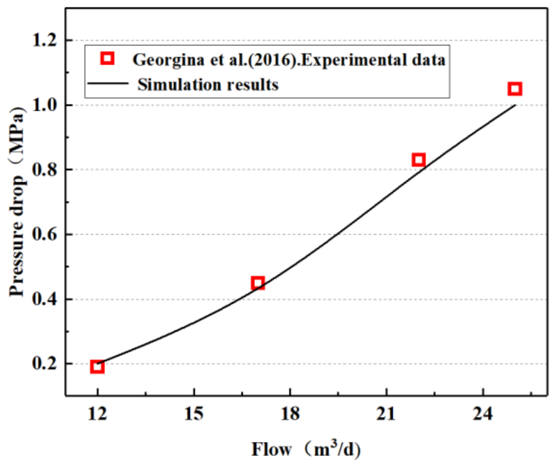


Fig.5 Comparison of simulation and test results

5. Sensitivity analysis of the influence of structural parameters on water control effect

5.1. Influence of throttling channel width on water control effect

When the fluid enters AICD, part of it will enter the throttling channel. The width of the throttling channel affects the rotation speed of the fluid. If the fluid carries sand, the width of the throttling channel is also one of the important indicators to evaluate the anti-clogging performance of AICD. In order to compare the water control performance, the change curve of the gas phase volume fraction at the outlet of the AICD device was drawn according to the change of the gas phase volume fraction at the outlet, as shown in Figure 6.

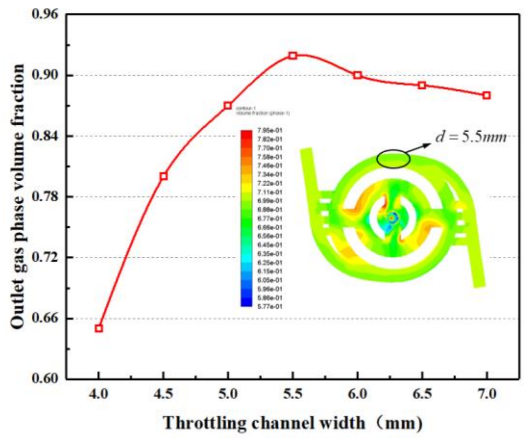


Fig. 6 Variation curve of gas phase volume fraction at outlet with different throttling channel widths

From figure 6, you can see that the throttling channel width d increased from 4 mm to 5.5 mm, the export gas phase volume fraction increased rapidly, and, when d = 5.5 mm maximum of 0.92, and with the throttle channel width d continue to increase, the export gas phase volume fraction begin to drop, when d = 7 mm, export volume fraction decreased to 0.87, this is because the natural gas by throttle nozzle into the disc area, only rarely part into throttling channel, the density of water, into the rotation of the throttle channel, therefore, throttling channel width on the affected the pressure drop of water, And then play a good flow control of water. In the design, when the throttling channel width is set as D =5mm, AICD has the best adaptability to natural gas and the best water control effect.

5.2. The influence of the Angle of the internal auxiliary baffle on the effect of water control

The function of the auxiliary baffle is to assist the water to do rotational motion and improve the pressure drop of the water. In order not to hinder the effective outflow of airflow, the opening of the auxiliary baffle is designed to face the throttling nozzle. If the orifice is not aligned with the throttling nozzle, the natural gas flowing into the disk region will rotate under the driving effect of tangential inflow fluid, thus increasing the pressure drop of natural gas. When the orientation of the external auxiliary baffle is determined, the orientation design of the internal auxiliary baffle is also an important index to evaluate the water control performance of the device. The variation curve of gas phase volume fraction at the outlet at different angles of the internal auxiliary baffle is shown in FIG. 7.

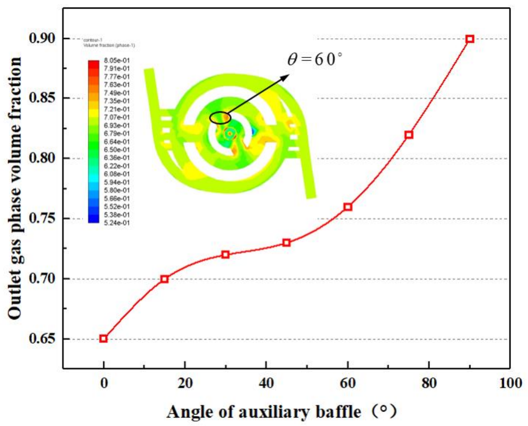


Fig.7 Variation curve of gas phase volume fraction at exit with different angles of internal auxiliary baffle

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From figure 7, you can see that in the secondary baffle angles by 0 ~ 50 ° change process, the export gas phase volume fraction increased from 0.65 to 0.73, growing more slowly, and when the auxiliary flap Angle change by 50 ~ 90 °, and the export gas phase volume fraction increased rapidly, and when the θ = 90 °, export gas phase volume fraction reaches maximum value 0.9, although this is due to the secondary baffle toward Angle will change the air flow, but little impact on the export of natural gas flow to the center. Because the auxiliary baffle helps the water flow to rotate, the internal auxiliary baffle has a great influence on the change of water flow pressure drop, which fully indicates that the orientation Angle of the internal auxiliary baffle can improve the water flow pressure drop and the water control performance of the lifting device. At the same time, it can be seen that when the internal auxiliary baffle is perpendicular to the throttling nozzle (θ =90°), the water control effect is the best. Therefore, in the design and application process of the device, the Angle of the internal auxiliary baffle is 90°, which is the most ideal choice.

5.3. Effect of throttle nozzle Angle on water control effect

Natural gas flows mainly from the throttling nozzle. If the Angle of the throttling nozzle is not well designed, part of the water flow will flow to the central disk area through the throttling nozzle, which will affect the water control effect of the device. Therefore, the Angle of the throttling nozzle is an important factor affecting the flow to the central outlet of natural gas. The variation curve of gas phase volume fraction at different throttling nozzle angles is shown in FIG. 8.

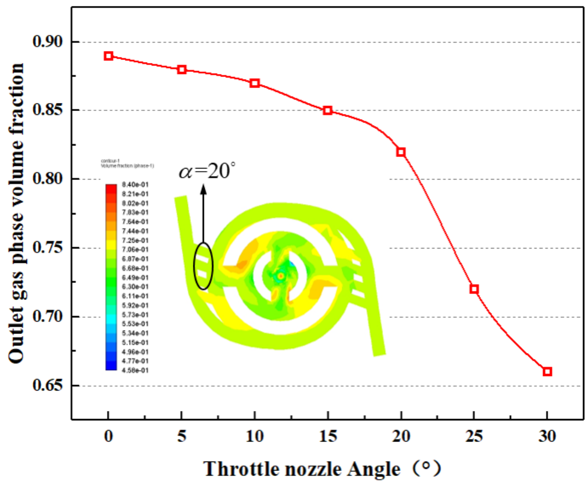

Fig.8 Variation curve of gas phase volume fraction at different throttling nozzle angles

As shown in figure 8, when the throttle nozzle Angle increases, the export gas phase volume fraction as a whole is on the decline, when α from 0 ~ 15 °, export gas phase volume fraction, slow down, in 0 ~ 30 °, the sharp decline in exports of gas phase volume fraction, and α = 30 °, export of gas phase volume fraction decreased to the lowest, at 0.66, this is because when the throttle nozzle Angle increases, increases the air flow through the throttle nozzle into the possibility of throttling channel, causing airflow rotating, is not conducive to natural gas into the center of the disc area. Part of the water flow flows into the throttling nozzle and collides with the rotating water flow in the throttling passage, which affects the rotation of the water flow and results in the decrease of the pressure drop of the water flow. Therefore, in order to avoid water flow from the throttling nozzle, the throttling nozzle is set horizontally (α =0°), where the water control energy is the best.

6. Conclusion

Based on the gas-water two-phase flow theory, the AICD structure internal flow simulation model was established in this paper to solve the problem of flow regulation and water control in high water-bearing gas reservoirs. The influence of structural parameters on water control effect was compared and analyzed, and the following conclusions were drawn:

(1)Based on the water control principle of AICD, through the analysis of numerical simulation results, under the interaction of inertia force and viscous force, most of the water phase enters from the inlet channel and rotates at high speed in the throttle channel to produce a large pressure drop. Most of the gas phase passes through the throttling nozzle and flows to the central disk region, and the pressure difference generated is small, which proves that the device has a good water control effect.

(2)The throttling channel width has a great influence on the water flow rotation speed and flow rate. When the throttling channel width increases, the gas phase volume fraction at the outlet presents a trend of first increasing and then decreasing. When the width is 5.5mm, it reaches the maximum value of 0.92, and the water control effect is the best. Considering the anti-clogging ability, choosing a large throttling channel width as far as possible has a better effect on the application of the device.

(3)The Angle of the auxiliary baffle has a great influence on the flow state and direction of the gas phase after entering the disc region. With the increase of the Angle of the auxiliary baffle, the volume fraction of the gas phase at the outlet increases, reaching its maximum value when θ =90°.In the process of device design and application, the auxiliary baffle Angle 90° is the best choice.

(4)The throttle nozzle Angle mainly affects the tangential flow of water and the direction of gas inflow. As the Angle of the throttling nozzle increases, the gas phase volume fraction at the exit presents a downward trend. In order to avoid water flowing in from the throttling nozzle, the throttling nozzle is set horizontally (α =0°). At this time, the gas phase volume fraction at the exit is at a maximum of 0.89 and the water control energy is the best.

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