

# Study on Application of Vortex Drainage Gas Recovery in Daqing Oilfield

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**Abstract**—The vortex drainage gas recovery technology has the advantages of no need for moving pipe column and long maintenance period. Through the mechanism and numerical simulation results of the vortex tool, the geometric parameters of vortex tools suitable for gas well parameters in Daqing oilfield are optimized by using parameter optimization software. The height of liquid is calculated by following the Bernoulli equation. The field application shows that vortex tool has realized the effective separation of water-gas, and changes the flow state of the mixed phase water-gas. However, the positioning depth of vortex tool is too deep, and its swirling distance is insufficient. The gas well is further optimized for drainage gas recovery technology. The results show that better drainage gas recovery results can be obtained by adopting two-stage vortex tool and foam drainage gas recovery. Then, the gas well has a remarkable effect of drainage gas recovery. The decline trend of oil pressure, gas production and water production of the gas well has been significantly improved. The low pressure, low water content and low production gas wells can be effectively promoted by adopting two-stage vortex tool and foam drainage gas recovery. The vortex drainage gas recovery technology provides a technical support for the sustained and stable production of Daqing oilfield.

**Keywords**— drainage gas recovery; vortex tool; optimization design; field test

## I. INTRODUCTION

The gas field of Daqing Xushen is a typical volcanic gas reservoir. The edges and bottom of the gas reservoir contain water, and the fractures are connected to each other, so most gas wells produce water shortly after they are put into production [1]. The ratio of water producing gas wells in Daqing oilfield is more than 95%, and the proportion of effusion wells exceeds 60%. Gas effusion leads to a maximum production decline of 85%. "Water control" has become the key technology to control production decline and prolong the stable production of gas fields.

Vortex tool is a simple and environmentally friendly gas drainage gas recovery tool developed by the United States in 2003. The vortex drainage gas recovery technology has the advantages of no need for moving pipe column and long maintenance period [2-5]. The technology of vortex drainage gas recovery has been carried out in Changqing, Southwest and Daqing oilfields.

However, the vortex tool has many parameters, and its parameter design is complicated. In order to meet the need of applying vortex drainage gas recovery technology in Daqing oilfield gas wells, the optimization design of vortex tool was

carried out. The field application of this technology has achieved good results. It provides a technical support for the sustained and stable production of Daqing oilfield, and it also provides a reference for other oilfields.

## II. VORTEX DRAINAGE GAS RECOVERY TECHNOLOGY

As shown in Figure 1, the vortex tool changes the fluid movement mode in the well bore and realizes the drainage gas recovery of the gas well. The fluid movement mode changes from the original vertical upward to spiral upward movement along the inner wall of the well pipe, and the spiral vortex stratified flow states are formed [6-7].

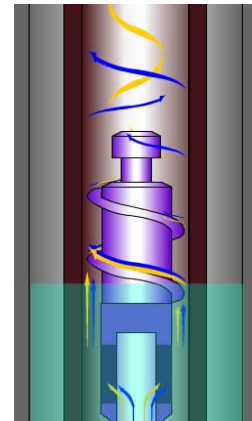


FIGURE I. WORKING DIAGRAM OF VORTEX TOOL

According to the characteristics of different multiphase flow models and the gas-liquid two phase flow in vortex tools, the DPM dispersed phase model is adopted as the multiphase flow calculation model. At the same time, the accuracy and cost of calculation are considered.

Taking the inlet end of vortex tool fluid as the model inlet and the 5 m tubing end as the model outlet, the UG software is used to build the geometric model. The Gambit software is used for grid division and boundary condition setting. The quantity and quality of grid division are the important factors, which affect the simulation accuracy. Due to the complex structure of the entire computational domain, the block method is used to divide the grid. The tool ring cavity section is encrypted by the surface grid control method. The total grid number is approximately 3.5-4.5 million, which ensures the accuracy of the model calculation.

### III. VORTEX TOOL FLOW FIELD DISTRIBUTION

The flow field is the fundamental reason for determining whether vortex tools can effectively realize drainage gas recovery. The study on distribution and shape of the flow field in vortex tool provides the basis for the optimization design of vortex tool [8-9].

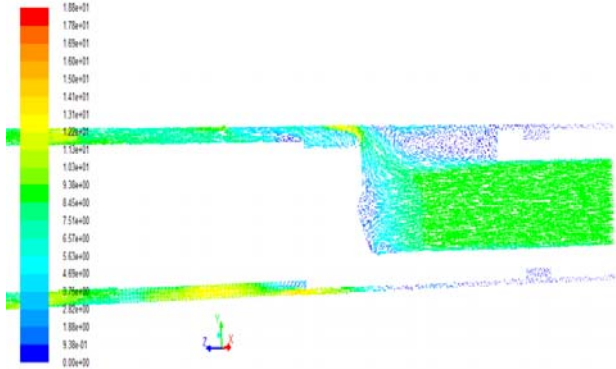


FIGURE II. THE FLOW STATE OF GAS-LIQUID MIXTURE IN VORTEX TOOL

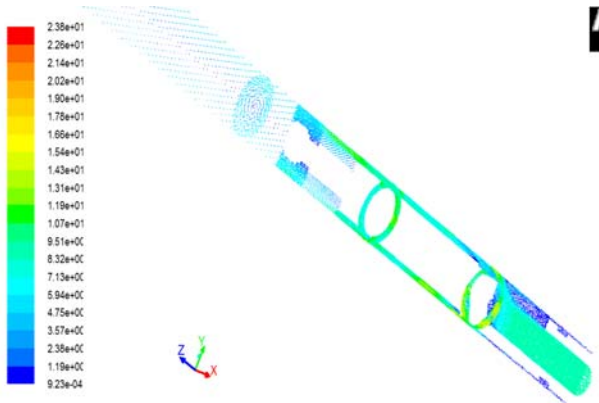


FIGURE III. THE VELOCITY DISTRIBUTION OF GAS-LIQUID MIXTURE IN BOREHOLE



FIGURE IV. THE LIQUID PHASE FLOW PATH IN WELLBORE

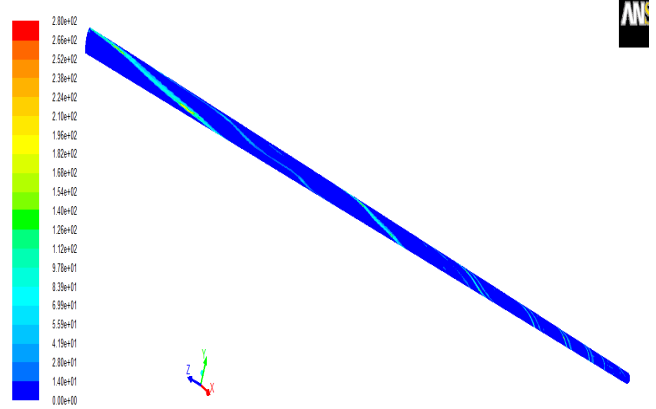


FIGURE V. THE LIQUID PHASE DISTRIBUTION IN WELLBORE WALL

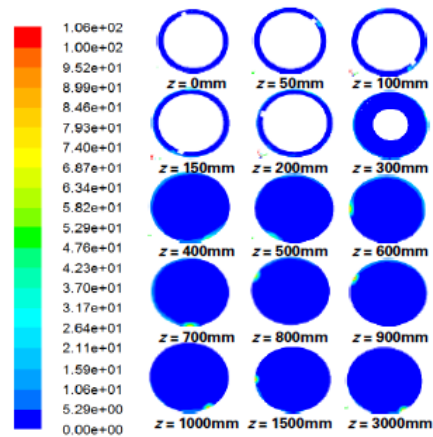


FIGURE VI. THE LIQUID PHASE DISTRIBUTION IN DIFFERENT SECTIONS OF WELLBORE (KG/M3)

The flow pattern of gas-liquid mixture in the wellbore is shown in Figure 2. The gas-water mixed phase flows into the guiding body along the axial direction of the tubing. The mixture is guided through the radial outlet of the guide fluid to the spiral section of the vortex tool. The circumferential velocity is obtained before the mixture enters the helical section, which is beneficial to reducing the swirl loss and increasing the swirl velocity.

The velocity distribution of gas liquid mixture in different sections is shown in Figure 3. As the gas-water mixture flows through the spiral section of the vortex tool, the velocity and the swirl velocity of the mixture increase. After the mixture flows through the vortex tool, the swirling state appears in the tubing. The closer the mixture is to the wall, the greater the swirling speed.

The schematic diagram of liquid flow trajectories in wellbore is shown in Figure 4. After the gas-liquid mixture flows through the spiral section of the vortex tool, the flow state of the mixture changes from axial flow to spiral upward flow under the action of the spiral structure, and the water phase rises close to the wall. From the flow trajectory, it can be seen that the gas-liquid mixture can reach a stable swirl state at about 3 m after being separated by vortex tool.

The liquid phase distribution in the wellbore is shown in Figure 5. Under the action of centrifugal force, the liquid phase is separated to the wall of the tubing and continues to flow upward in a spiral shape, and the center of the tubing becomes the gas channel.

The liquid phase distribution of different sections in wellbore is shown in Figure 6. The separation of gas-liquid mixture is very effective, and there is no liquid phase in the central area of the tubing. The vortex tool realizes the separation of gas-liquid mixture, and the liquid phase spirals up. The energy loss of gas-liquid two-phase mixing decreases and the water carrying capacity is not limited by the critical physical equation of gas-liquid carrying. The energy loss of gas-liquid two-phase mixing is reduced by the vortex tool, and the liquid carrying capacity is not limited by the critical physical equation.

#### IV. POSITIONING DEPTH OF VORTEX TOOL

The operating distance of vortex tool is an important parameter in the design of vortex tool, which directly affects the vortex tool positioning depth [10,11]. If the positioning depth is too deep, the separated water could not be removed from the wellhead and it will reflux back to the bottom of the well. If the positioning depth is too shallow, the bottom hole fluid will can't be cleared.

The height of liquid is calculated by following the Bernoulli equation (1).

$$\frac{P}{\rho g} = \varphi H + \mu \frac{v^2}{2g} \quad (1)$$

Where  $P$  is relative pressure of well bottom,  $\rho$  is liquid-phase density,  $H$  is elevation,  $\mu$  is loss coefficient,  $v$  is swirl velocity, and  $\varphi$  is correction factor.

Under the conditions of gas production  $0.6 \times 10^4$  m<sup>3</sup>/d, water gas ratio 1:15 000, and liquid concentration density 207 kg/m<sup>3</sup>, the positioning depth of vortex tool is calculated by using Bernoulli equation (1). The relation between the positioning depth of vortex tool and the energy ratio is shown in Figure 5. The maximum operating distance of vortex tool is 1950 m. Generally, the positioning depth of vortex tool is 1560-1755 m by retaining 10-20 % allowance. The S-x1 well has perforation sections at depths of 1726 m, 1744 m, and 1772 m. If the positioning depth of vortex tool is too shallow, the bottom hole liquid loading will can't be discharged. In order to maximize vortex tool effect, the positioning depth of vortex tool is set to 1720 m.

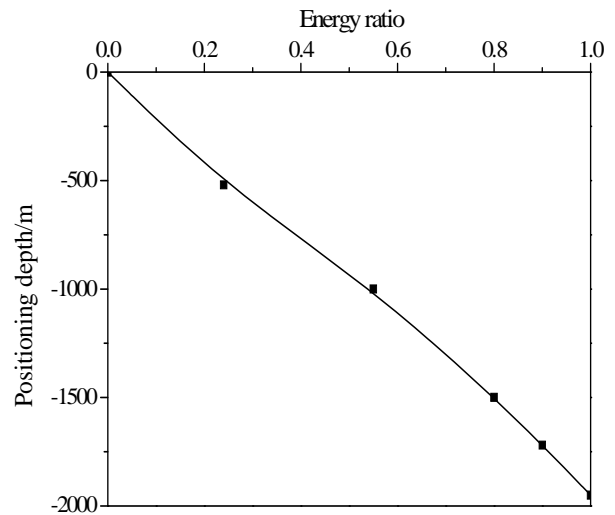


FIGURE VII. RELATION BETWEEN THE POSITIONING DEPTH AND THE ENERGY RATIO OF VORTEX TOOL

#### V. MULTISTAGE DESIGN ANALYSIS OF VORTEX TOOL

When the working distance of vortex tool can not meet the depth of the well, the vortex tool can be designed by multi-stage design. Multiple vortex tools are designed in series in the wellbore to achieve drainage gas recovery. The position of many vortex tools in the wellbore should be combined with the well conditions, and referring to the working distance of a single vortex tool. Ultimately, multiple vortex tools are guaranteed to reach the wellhead at the total operating distance. Taking well S1-1 as an example, the location of the secondary vortex tool in the wellbore is shown in figure 8. It is showed from figure 8 that the drainage gas recovery depth of the gas well can reach 3500 m by using the two stage vortex tool, which meets the need of drainage gas recovery of the gas well S1-1.

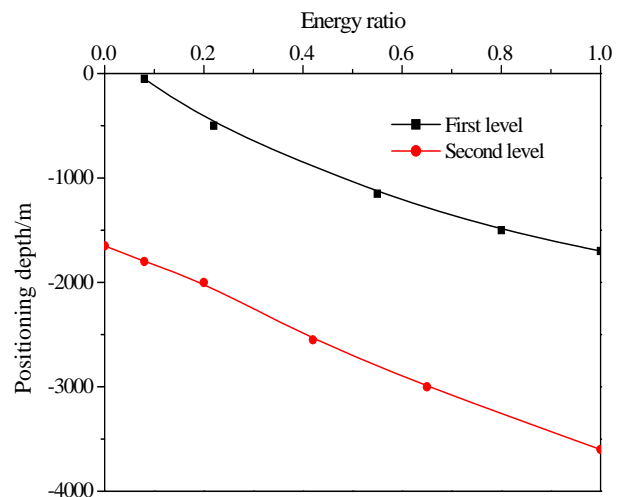


FIGURE VIII. THE LOCATION OF THE SECONDARY VORTEX TOOL IN THE WELLBORE

VI. FIELD TEST RESULTS

A. Field Application of Single Vortex Tool

The structure of vortex tool is composed of sealer, guide cavity, spiral body, and fishing head. The spiral body is the key structure which affects the vortex effect. Through analyzing the mechanism and numerical simulation results of the vortex tool, the geometric parameters of vortex tools suitable for gas well parameters in Daqing oilfield are

TABLE I. THE GEOMETRIC PARAMETERS OF VORTEX TOOL

Center body diameter /mm	Helical angle /°	Spiral width/mm	Spiral high/mm	Section shape	Helical pitch
52	50	4.0	3.5	rectangle	1

The production data of the S1-1 gas well using vortex drainage gas recovery technology is shown in figure 9. The gas well has been installed vortex tool, the gas production increases by about 41.4 %, and the validity period is about 70 days. However, the gas well does not produce water after installing the vortex tool. The vortex tool realizes the effective separation of water-gas, and changes the flow state of water-gas mixed phase. Therefore, the vortex tool is beneficial to natural gas output and increases the gas production.

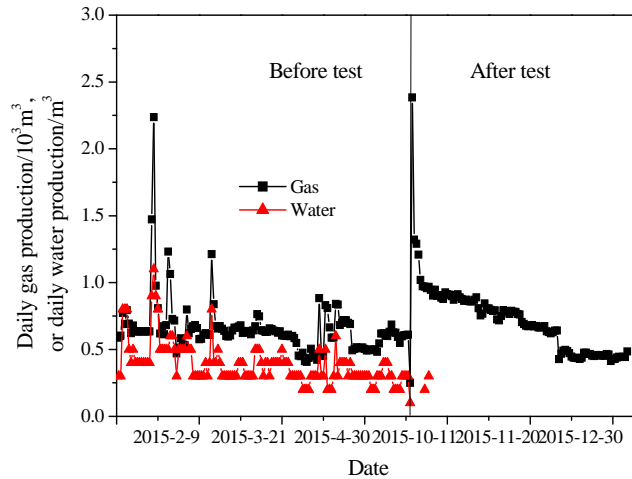


FIGURE IX. PRODUCTION DATA OF GAS WELL

TABLE II. THE GEOMETRIC PARAMETERS OF TWO STAGE VORTEX TOOLS

level	Center body diameter /mm	Helical angle /°	Spiral width/mm	Spiral high/mm	Section shape	Helical pitch
First level	52	55	4.0	3.5	rectangle	1
Second level	52	50	4.0	3.5	rectangle	1

optimized by using parameter optimization software. The result is shown in Table 1. The geometric parameters of vortex tool include helical angle, center body diameter, spiral width, spiral height, and section shape. This provides the basis for the personalized design of vortex tool. According to the well conditions and production data of S1-1 well, the parameters of vortex tool are initially designed. The helical angle is 50 °, the center body diameter is 52 mm, the spiral width is 4 mm, the spiral height is 3.5 mm, and the section shape is rectangular.

The positioning depth of vortex tool is too deep, and its swirling distance is insufficient. The liquid cannot swirl out of wellhead and return to the bottom of well after gas-liquid separation. At the same time, the liquid flows along the inner wall of tubing, and the gas-phase could not carry it to the ground. Therefore the water production of gas well is reduced. The gas well is further optimized for drainage gas recovery technology. The results show that better drainage gas recovery results can be obtained by adopting two-stage vortex tool and foam drainage gas recovery.

B. Field Application of Two-stage Vortex Tool

In order to further improve the drainage performance of S1-1 well, two-stage vortex tool was designed according to the parameters of gas well. The geometric parameters of the two-stage vortex tool are shown in table 2. The two-stage vortex tool works together in the same well. The flow, pressure, water-gas ratio and other operating parameters of the gas well remain unchanged. The center body diameter and helix structure of the vortex tool can't change. However, in order to ensure the same swirl velocity and the stability of the liquid cyclone, the spiral angle of the second tool is slightly lesser than that of the first tool.

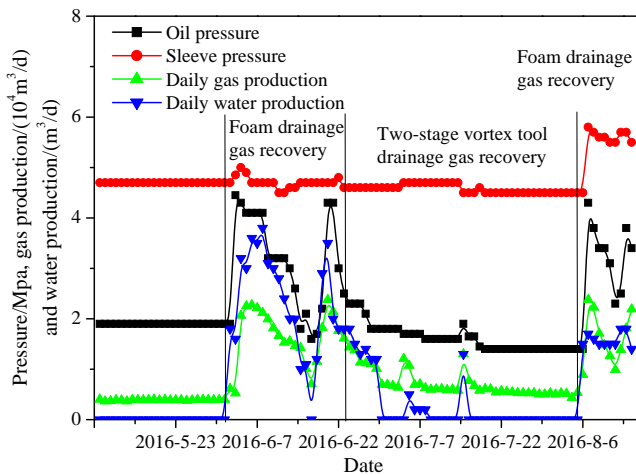


FIGURE X. THE PRODUCTION DATA OF GAS WELL ADOPTING TWO-STAGE VORTEX TOOL AND FOAM DRAINAGE GAS RECOVERY

The production data of gas well S1-1 adopting two-stage vortex tool and foam drainage gas recovery are shown in Figure 10. The two-stage vortex tool and foam drainage gas recovery technology has been adopted in this well. The results show that the gas well S1-1 has a remarkable effect of drainage gas recovery. The decline trend of oil pressure, gas production and water production of the gas well S1-1 has been significantly improved. The oil pressure is increased from 2.2MPa to 2.3MPa. The casing pressure is reduced from 4.9MPa to 4.8MPa. Gas production increased from  $0.40 \times 10^4 \text{m}^3/\text{d}$  to  $1.1 \times 10^4 \text{m}^3/\text{d}$ . At the same time, the water production has been greatly improved, and the expected goal of drainage gas recovery has been achieved.

Even if the technology of foam drainage gas recovery has been stopped, the daily production capacity of the gas well is still remain above  $6000 \text{m}^3/\text{d}$ . The gas production is increased by more than 50% before installing the two-stage vortex tool. Therefore low pressure, low water content and low production gas wells can be effectively promoted by adopting two-stage vortex tool and foam drainage gas recovery.

## VII. CONCLUSIONS

Through the mechanism and numerical simulation results of the vortex tool, the geometric parameters of vortex tools suitable for gas well parameters in Daqing oilfield are optimized by using parameter optimization software. The height of liquid is calculated by following the Bernoulli equation. The field application shows that vortex tool has realized the effective separation of water-gas, and changes the flow state of the mixed phase water-gas. However, the positioning depth of vortex tool is too deep, and its swirling distance is insufficient. The gas well is further optimized for drainage gas recovery technology. The results show that better drainage gas recovery results can be obtained by adopting two-stage vortex tool and foam drainage gas recovery. Then, the gas well has a remarkable effect of drainage gas recovery. The decline trend of oil pressure, gas production and water production of the gas well has been significantly improved.

The low pressure, low water content and low production gas wells can be effectively promoted by adopting two-stage vortex tool and foam drainage gas recovery.

## ACKNOWLEDGMENTS

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