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The Mechanism Study of Vortex Tools Drainage Gas Recovery of Gas Well

WANG Chunsheng[a]; WANG Xiaohu[a]; DU Qiuying[a],*; FENG Bingkai[a]; XU Chang[a]

[a] The Northeast Petroleum University, Daqing, Heilongjiang Province, China.
*Corresponding author.

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Abstract
The liquid loading of gas well is an important issue in deep exploitation of natural gas. The technic of vortex drainage has good prospects because the tool construction and construction work is simple, the technic is environmental and efficient. Currently, the mechanism for the vortex drainage and the theory of fluid motion are still missing. Therefore, in order to further understand the downhole flow field, verify drainage mechanism and select best working conditions, based on computational fluid dynamics and mixture model of multiphase flow through Fluent, the study established a three-dimensional structural model of vortex tools and the numerical simulation has been done. By monitoring the wellhead and the radial distribution of the liquid content and observing the state of the gas-liquid flow and the path line, the study analyzed the influence on gas well flow field by vortex tool. The study revealed the working mechanism of vortex tools to facilitate understanding the nature of the vortex drainage process, guide how to select the preferred process conditions and provide theoretical basis for the application and the dynamics simulation of vortex drainage technology.

Key words: The liquid loading of gas well; Vortex drainage; Multiphase flow; Numerical simulation

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INTRODUCTION
As a clean energy, natural gas consumption boom year by year, natural gas industry development faces new opportunity[1]. However, the liquid loading of gas well is an important issue in deep exploitation of natural gas, and it causes gas well production reduce or even stop, seriously affects the efficiency of gas field exploitation, reduces life and the ultimate recovery ratio of the gas well[2]. For gas well liquid loading problem, we often use bubble drainage, gas lift, electric submersible pump, ejector pump drainage technic, etc[3]. "The technic of vortex drainage" is a new type of technology developed by the U.S. department of energy, and after achieved good results by test in 2005 this technology comes into people's horizons[4]. Now it is used in a large number of promotion in North America, Australia and other countries[5]. Daqing, Sulige, Sichuan, Jilin and other fields have also been successively installation test in China. However, due to the gas-liquid two phase movement situation of downhole vortex flow field was complex, and the depth of the great, the study of the flow field has certain difficulty. Currently, the mechanism for the vortex drainage and the theory of fluid motion are still missing.

1. THE LIQUID DROPLET MODEL OF GAS WELL DRAINAGE THEORY
Assume that droplets that air carries in the gas well is spherical droplets, it deduces the minimum gas velocity of airflow carrying droplets through the study of the stress analysis of spherical droplets.

Figure 1
Spherical Droplet

Analysis of the stress of spherical droplets (pictured above): spherical droplets in well are affected by its own gravity, gas buoyancy and air flow upward thrust.

The vector G of droplet of its own gravity and buoyancy in gas is as follows:

$$G = \frac{4}{3}\pi R^3(\rho_L - \rho_G)g$$

The thrust F of droplet by Sports airflow:

$$F = \pi R^3 C_D V_C \rho_g$$

Where, R means the radius of droplet, m; ρ_L means the density of the liquid phase, kg/m^3; ρ_G means the density of the gas phase, kg/m^3; g means acceleration of gravity, 9.81m/s^2; V_C means critical speed of gas, m/s; C_D means fluid resistance coefficient.

When $F = G$, droplets in gas well force balance in the vertical direction, gas velocity is just critical velocity V_C.

$$V_C = [\frac{8gR(\rho_L - \rho_G)}{3C_D\rho_G}]^{0.5}$$

When the air velocity V_G is greater than or equal to the critical speed of V_C, the airflow within gas well can carry the droplets of radius R to the ground.

2. MECHANISM OF GAS WELL VORTEX DRAINAGE TECHNOLOGY

2.1 The Physical Model

The study used SolidWorks for 3d modeling of vortex tool. Geometric model of the vortex tools is 688 mm long, and the diameter is 59 mm, the diversion channel is 106 mm long and 20 mm wide, the screw length is 127 mm, spiral section diameter is 50 mm, spiral blade rectangular section is 9.1 mm wide and 5 mm high. The calculated area is vortex tools and over 20 meters, divided according to fluid field geometry differences. The mesh is the block division. The meshing method is cooper in wellbore and the spiral section and diversion channel part adopts tetrahedral unstructured meshing method. On the premise of guaranteeing the quality of the grid it minimizes the number of grid to save computational resources and time.

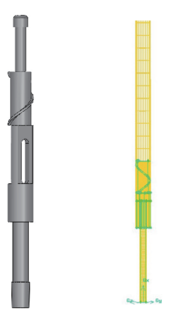

Figure 2
The 3D Model of Vortex Tool and Part of the Mesh

2.2 The Numerical Solution Strategy

The numerical simulation use finite volume method to discrete control equations and use separate solver to solve implicit equations. It chooses k-epsilion RNG turbulent model and multiphase flow model of the mixture and PRESTO! method of pressure discrete control equations and SIMPLE algorithm of pressure solver to solve gas liquid two phase flow of wells which use the vortex tools.

2.3 The Boundary Conditions

(i) The boundary conditions of gas inlet: because the fluid is compressible, the entrance section choose mass flow rate as boundary condition, which is obtained through the conversion of the actual volume flow and the density in corresponding conditions. For gas, it is assumed that entrance velocity perpendicular to the inlet cross sections; for the droplet, it is assumed that the droplets position is uniformly distributed on the inlet cross section and its inlet velocity is the same with and the gas phase.

(ii) The boundary conditions of gas outlet: outlet boundary condition chooses the pressure outlet. Outlet pressure is oil pressure of gas well for 4.8 MPa.

(iii) The boundary conditions of wall: the wall of helical cavity wall and wellbore take related turbulence parameters and fluid velocity as zero. Wall function is used to deal with the wall boundary layers. When the droplets touch the wall it is captured, and small droplets collision coalescence into large droplets. Considering the gravity, when the gravity of gathered large droplets is more than the thrust of gas upward, the droplets drop.

2.4 The Calculation Results Analysis

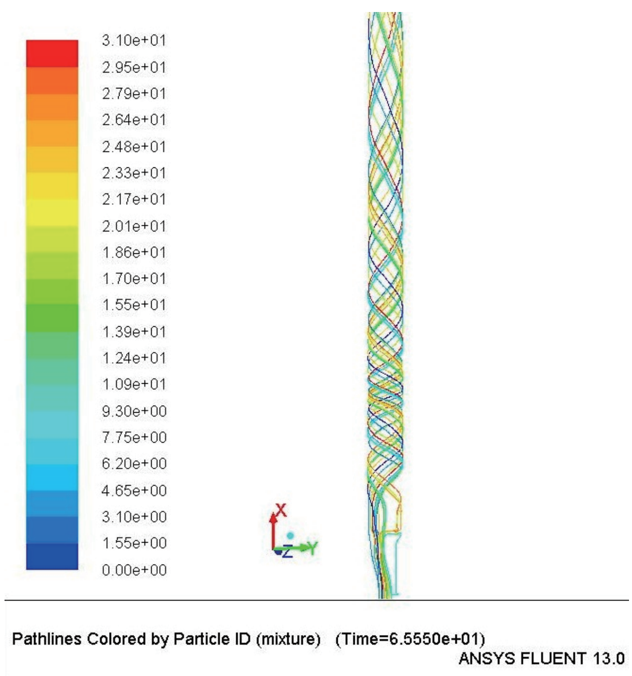

Figure 3
The Flow Field Path Line

Through the flow field path line can be seen: The vortex tool make the high speed gas liquid two phase mixed fluid rotate due to stress. Fluid speed in helical annular space, of which path line and flow state changed significantly. Fluid motions change into spiral upward along the well wall.

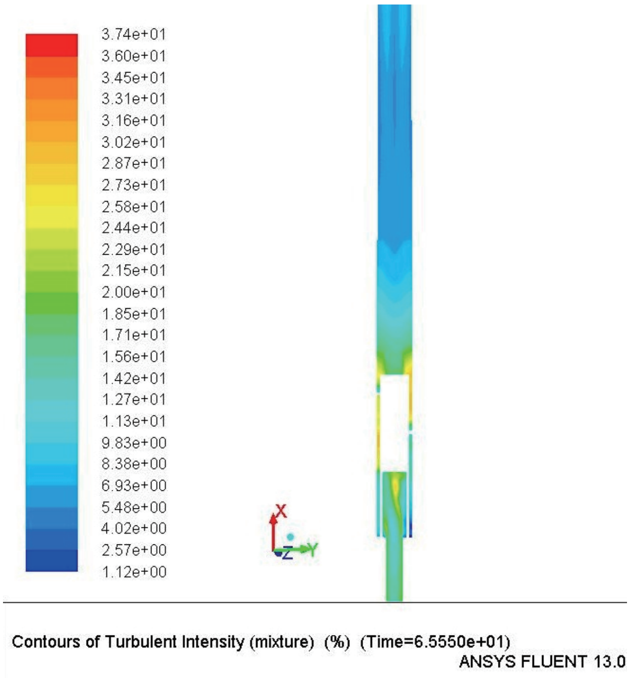

Figure 4
The Gas Well Flow Field Turbulence Intensity Contours

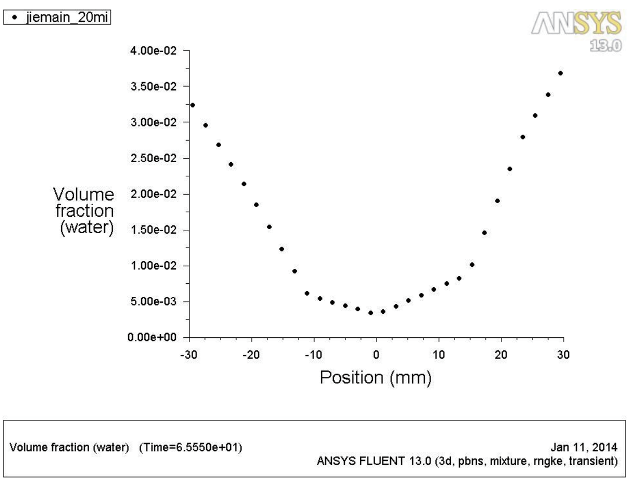

Figure 5
Liquid Volume Fraction Distribution in Wellhead Section Radial

Through the gas well flow field turbulence intensity contours can be seen: not only does the path line and speed change significantly, but also the gas-liquid two-phase mixture fluid turbulence intensity decrease significantly after the fluid pass the vortex tool. The mixture of two-phase turbulent flow in the well change into two phase stratified helical flow. This kind of flow pattern reduce the Slippage loss and friction between the medium, It improves the gas flow rate and greatly improve the gas ability of carrying liquid.

Through the liquid volume fraction distribution in wellhead section radial can be seen: due to the effects of the centrifugal force which caused by high speed rotating of mixing gas-liquid two phase fluid, most of the denser liquid is threw to the well wall and very few stays in the center of the well, while gas gathers and upward transport in the center of the wellbore after the fluid pass the vortex tool. That effectively improves the density gradient distribution of the fluid. The fluid in the well changes into obvious gas-liquid two phase stratified spiral flow.

3. OPTIMIZATION OF GAS WELL VORTEX DRAINAGE CONDITIONS

It is important for this technology's experiment, testing, application and promotion to find suitable conditions for the application of vortex drainage technology. Gas production rate, water production rate and bubble diameter of the water in the well have an important influence for vortex tools to improve the ability of carrying liquids.

3.1 The Influence of Gas Production Rate to Drainage

The gas production rate of wells directly affects the ability of carrying liquid. Remaining liquid flow rate of bottom of a well unchanged as $2m^3/d$, the study separately calculate the quantity of liquid in wellhead of the wells which use vortex tool and ordinary gas well when gas production rate are 2500 m^3/d, 5000 m^3/d, 10000 m^3/d, 15000 m^3/d and 20000 m^3/d.

Relation curves between Increase of the percentage of drainage by vortex tool and gas production rate per day are as follows:

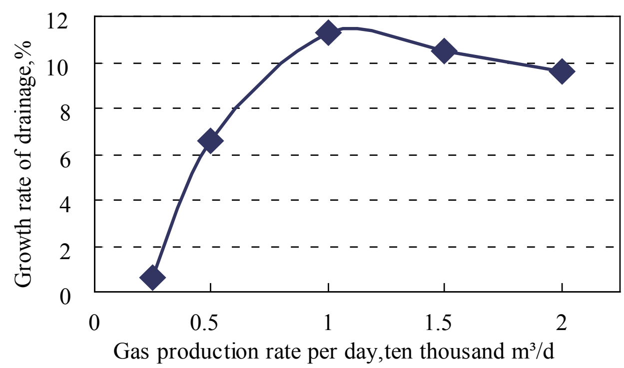

Figure 6
Relation Curves Between Growth Rate of Drainage and Gas Production Rate Per Day

Through the calculation results can be concluded that: the vortex drainage technology can indeed improve the gas well's ability of carrying liquid and the gas production rate of wells directly affects the ability of carrying liquid. For vortex tools to improve the effect of drainage has a best gas production. Under the simulation condition, for vortex tools to improve the quantity of drainage the best gas production is 10^4 m³/d. When gas production exceeds a certain value, the gas of the well has enough ability to complete drainage without vortex tools and it is not conducive to the production because the using of vortex tools can loss gas pressure at this point.

3.2 The Influence of Liquid Producing Capacity to Drainage

The liquid producing capacity of wells affects the ability of carrying liquid too. Remaining gas production rate of a well unchanged as 5000 m³/d, the study separately calculate the quantity of liquid in wellhead of the wells which use vortex tool and ordinary gas wells when liquid producing capacity are 1 m³/d, 2 m³/d, 3 m³/d, 4 m³/d and 5 m³/d.

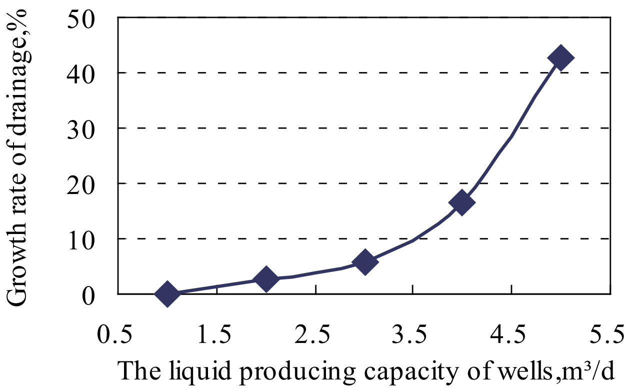

Figure 7
Relation Curves Between Growth Rate of Drainage and Liquid Producing Capacity of Wells Per Day

Through the calculation results can be concluded that: the liquid producing capacity of wells affects the ability of carrying liquid significantly. And when the liquid producing capacity of wells is above 3 m³/d, the water in the well could not be completely bled off from the wellhead and gas wells are liquid loading, and that the liquid quantity of wellhead drop quickly. At this time using vortex tools can significantly improve the effect of drainage and the more the liquid producing capacity is, the bigger the growth rate of drainage of wells is. When the liquid producing capacity of wells is 5 m³/d, the growth rate of drainage of well reach up to 42.5%. There is no need to use vortex tools for production when the liquid producing capacity of wells is under 3 m³/d.

3.3 The Influence of Bubble Diameter of the Water in the Gas Well to Drainage

The water in the saturated gas mainly exists in the form of small droplets and the droplet size directly affects the probability of small droplet coalescence fell to the bottom of a well and the critical flow rate of gas to carry liquid. Remaining gas production rate of a well unchanged as 5000 m³/d and liquid producing capacity as 2 m³/d, the study separately calculate the quantity of liquid in wellhead of the gas wells which use vortex tool and ordinary gas wells when the bubble diameter of the water in the gas well are 0.01 mm, 0.03 mm, 0.05 mm, 0.07 mm, 0.09 mm.

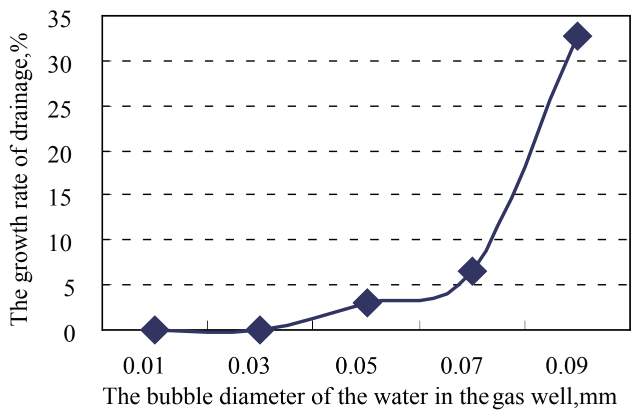

Figure 8
Relation Curves Between Growth Rate of Drainage of Well and Bubble Diameter of the Water

Through the calculation results can be concluded that: when the bubble diameter of the water in water-bearing gas well is less than 0.03 mm, the drainage effect of vortex tools is not significant and even be no match for ordinary gas well under the same conditions. When the bubble diameter of the water is lager than 0.05 mm, the wells using vortex tools carry out more liquid than ordinary gas well at the same conditions. The lager the bubble diameter of the water is and the more water is in the well, the more significant the effect of drainage by vortex tool is.

CONCLUSIONS AND SUGGESTIONS

Aiming at the vortex drainage process, the numerical simulation has been done and the drainage mechanism is verified through computational fluid dynamics. The study analyses the internal flow field and calculates effects of drainage by vortex tools in different working conditions. The following conclusions and Suggestions can be obtained that:

a. The saturated gas in well flow upward in the form of gas-liquid two phase spiral stratified flow after the vortex tool. Most of the denser liquid is threw to the well wall and very few stays in the center of the well, while gas gathers and upward transport in the center of the wellbore. Fluid turbulence intensity weaken.

b. The vortex drainage technology can indeed improve the gas well's ability of carrying liquid. The growth rate of drainage of well is more than 10% in the gas wells with good effect.

c. Vortex tolls are suitable for the gas wells whose production decline due to liquid loading in bottom of a well. When the bubble diameter of the water is lager than 0.05 mm, the wells using vortex tools carry out more liquid than ordinary gas well at the same conditions. The lager the bubble diameter of the water is, the more significant the effect of drainage by vortex tool is.

d. Application of the vortex drainage technology require that the gas wells have certain ability of artesian flowing, that is the gas should have a certain velocity to guarantee ability of carrying liquid. The gas production rate should exceed 2500 m³/d and when the gas production rate is 104 m³/d, applying this drainage technology works best. If the gas well go dead, there is need to apply other production process to recover flow production.

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