Numerical analysis of throttling effects based on ANSYS CFX

Mingjun Xu [a], Wenchao Liu, Jun Wu, Zhiqiang Zhao

The kuche oil and gas development department of tarim oilfield, Korla 841003, China

[a]pknnnliang1234@163.com

Abstract

Throttle valve of gas production wellhead is an important component part of the christmas tree. It also plays an important role of ensuring safe production and controlling pressure. The paper uses the ansys cfx software to conduct flow field analysis of a certain of throttle valve. It analyzes the pressure, velocity, temperature and flow state changes when gas passes the throttle valve. It also design features of throttle valve in the fluid domain, and reasons for ice blockage after throttle cooling, aiming to offer simulated analysis and theoretical basis for throttling effects.

Keywords

Throttle valve, ansys cfx, fluid domain

1. Introduction

Natural gas is an common energy used by thousands of households. It is concerned with daily lives of ordinary people. In the process of natural gas exploitation, the throttle valve of christmas tree is rather an important component part of gas production equipment. It aims to control the pressure and flow velocity of natural gas delivery. The metal part of throttle valve consists of valve body and valve element. The valve body is the shell of the throttle valve, which primarily assumes the pressure. The valve element consists of corbula and valve rod. The seal ring with other metal parts are used to seal the high pressure gas in the throttle valve, in order to ensure safe and highly efficient production.

The basic functions of throttle valve is based upon orifice restriction. The throttling action refers to fluid pressure decline caused by resistance when it flows in the pipeline. This phenomenon is known as throttling. Through plunger moving in upward and downward directions, the throttle valve changes the throttling area of the external holes in order to alter flow quantity and intensity of pressure in flowing gas. This type of adjustment is known as opening adjustment.

As accessible oil and gas resources continue to exhaust, high-pressure oil fields and regions are also included in oil extraction plans by local governments. Gas wells with wellhead pressure above 80Mpa become more and more common. Even those with wellhead pressure of 140Mpa have also emerged. As high pressure wells become increasingly popular, the throttle valves, which adjust flows and control pressure, also pose more rigorous requirements on their performance. Currently, for wells with pressure above 60Mpa, two throttles are connected to adjust flows and control pressure. The commonly adopted methods are: Level 1 is the throttle valve with fixed opening; Level 2 is the throttle valve with adjustable opening.

The paper conducts ansys cfx flow field analysis on the throttle valve commonly adopted in the work zones, analyzes the throttling effects of valve elements, identifies change features of gas flow rates, intensity of pressure, flow lines and tracks, in order to offer useful numerical analysis and basis for research objects.

2. Fluid mechanics model and numerical method

With the advancement of science and deepening of difficult research issues, traditional formula computing has failed to accurately and directly offer answers. In recent years, due to enhancement and popularity of computers, as well as constant development in computational fluid mechanics theories and analysis software, analogue simulation has also increasingly enhanced accuracy in revealing practical engineering problems. Therefore, the method of numerical analysis has been widely used to simulate practical engineering problems. The specific processes of numerical analysis include[1]: 1. Set up constitutive equations;2. Set up kinematic equations; 3. Determine boundary conditions; 4. Solve equations; 5. Results analysis.

After throttling, fluid flow is a complicated, polyphase and three-dimensional process. Relevant kinematic equations can be obtained from law of conservation of mass and law of conservation of momentum. The turbulence model adopts the standard k-ε model. This model has different features and advantages, including wide range of application and high accuracy of solving equations. Common and basic equations are listed in the following[2]:

Law of Conservation of Mass:

$$\frac{\partial}{\partial t}(\rho_m)+\nabla.(\rho_m\vec{v}_m)=\dot{m} \tag{1}$$

Law of Conservation of Momentum:

$$\frac{\partial}{\partial t}(\rho_m\vec{v}_m)+\nabla(\rho_m\vec{v}_m\vec{v}_m)=-\nabla p+\nabla.\left[\mu_m\left(\nabla\vec{v}_m+\nabla\vec{v}_m^{\mathrm{T}}\right)\right]+\rho_m\vec{g}+\vec{F}+\nabla.\left(\sum_{k=1}^{n}\alpha_k\rho_k\vec{v}_{dr,k}\vec{v}_{dr,k}\right) \tag{2}$$

Law of Conservation of Energy:

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}(\alpha_k\rho_k\mathrm{E}_k)+\nabla.\sum_{k=1}^{n}\left[\alpha_k\vec{v}_k(\rho_k\mathrm{E}_k+p)\right]=\nabla.\left(\mathrm{K}_{eff}\nabla T\right) \tag{3}$$

In the formula: ρ_m is represented as mixture density (kg/m^3); $\vec{v}_m$ as average mass velocity (m/s); $\dot{m}$ as source item of quality; P as fluid pressure ($\mathrm{P}a$); α_k as volume fraction of k-phase medium; $\vec{v}_{dr,k}$ as drift velocity of k-phase medium (m/s); μ_m as mixed viscosity ($\mathrm{P}a\text{•}s$); $\vec{F}$ as body force (N); E_k as kinetic energy of k-phase fluid (J) and k_{eff} as effective thermal conductivity ($W/(m\text{•}\mathrm{K})$).

Kinetic Energy Equation of Turbulent Fluctuation (K Equation):

$$\rho\frac{\partial\mathrm{K}}{\partial t}+\rho\mu_i\frac{\partial\mathrm{K}}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\mathrm{K}}\right)\frac{\partial\mathrm{K}}{\partial x_j}\right]+G_\mathrm{K}+G_b-\rho\varepsilon-Y_m \tag{4}$$

Dissipation Equation of Turbulent Kinetic Energy (ε Equation):

$$\rho\frac{\partial\varepsilon}{\partial t}+\rho\mu_i\frac{\partial\varepsilon}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+\frac{C_{1\varepsilon}\cdot\varepsilon}{\mathrm{K}}(G_\mathrm{K}+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{\mathrm{K}} \tag{5}$$

$$\mu_t=C_\mu\rho\frac{\mathrm{K}^2}{\varepsilon}$$

In the formula: G_K is represented as generation item of turbulence energy K caused by average velocity gradient; G_b as generation item of turbulence energy K caused by buoyancy; Y_m as pulse expansion contribution in compressible flow; μ_t as turbulence viscosity ($\mathrm{P}a\text{•}s$); μ_i and μ_j as time-averaged velocity (m/s); K as turbulent kinetic energy (J); ε as turbulent dissipation rate; ρ as fluid density (kg/m^3); σ_k and σ_ε as turbulent prandtl value of K and ε equations; $C_{1\varepsilon}=1.44$, $C_{2\varepsilon}=1.92$, $C_{3\varepsilon}=1$ and $C_\mu=0.09$ as empirical constants.

3. Determine conditions in fluid domains and boundary

Fluid domain is the object of cfx. It is also the actual area filled by fluids. The paper uses the creo modeling software and graph paper designs to formulate models for valve body and fluid domain. Fig.1 shows the model of valve body. Fig.2 and Fig.3 demonstrate the model of fluid model.

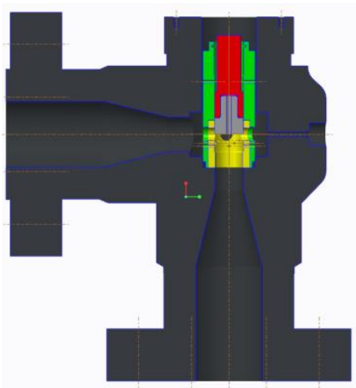
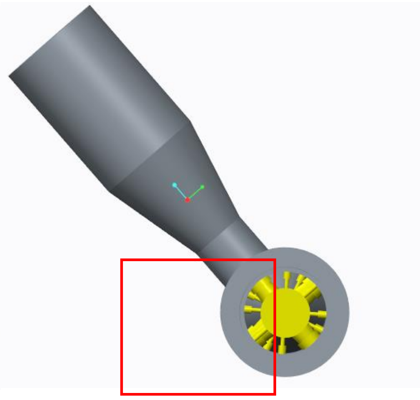
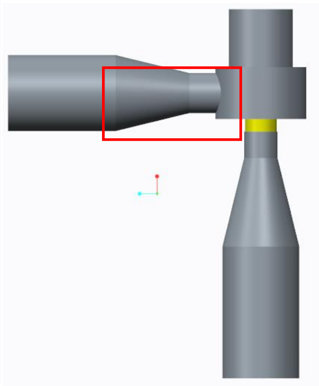

Fig. 1 Model of valve body. Fig. 2 Fluid domain model Fig. 3 Fluid domain model

Fluid domain model in Fig. 2 and Fig. 3(the red frame is the throttling section).

In Fig.1, red and gray sections consist of the valve rod. The red section uses stainless steel, and the gray section uses tungsten carbide. Green and yellow sections consist of corbula. The green section uses stainless steel, and the yellow section uses tungsten carbide. The exterior black section is the stainless-steel valve body, which is adopted to withstand the tremendous pressure force in the valve body. Stainless steel resist deformation and damage, and tungsten carbide can resist ablation. Hence, throttling devices tend to involve tungsten carbide materials to reduce ablation effects high-speed fluids. The other parts are made up of stainless steel to withstand deformation. They are the domain of fluid in this research. The corbula has small holes, which are uniquely arranged according to output and openings. The valve rod controls the total area of exposed holes, in order to accurately adjust output and outlet pressure.

Fig. 2 and Fig. 3 are two different views of fluid domain models. The fluid domain covers half of the exposed big hole above the valve rod. The specific position is indicated in gray and yellow sections in Fig. 1. In Fig. 2 and Fig. 3, the yellow part is the model of fluid domain in the throttling region. The gray part is the model of fluid domain in the entrance and exit, which are in the left and bottom sections of Fig. 3.

Main parameters of the simulation include: ch4 is the gas matter. It is defined as continuous fluid, thermal energy is the condition for heat transfer, no slip wall is the wall condition, static pressure 45Mpa and 110℃ are the entrance conditions. Static pres.dirn 12Mpa 69℃ are the exit conditions of opening. Based on medium turbulence intensity, backflow can occur near the exist of the fluid domain.

4. Demonstration and analysis of simulation results

As for the throttling action, the most direct phenomena are decline in intensity of pressure, temperature drops and increase in flow velocity. In relevant research and studies on fluids, the sum of pressure energy, potential energy and kinetic energy is a constant. It is converted to conservation of mechanical energy. For mechanical energy of fluid, reciprocal conversion is involved in the three types of energy, but the weight always remains unchanged. Conservation of mechanical energy and fluid power are common theories used in the research. Based on simulation results and relevant theories, the following section discusses the changes in intensity of pressure, flow state and temperature after the throttling action occurs. In the following analysis, sectional views derive from the symmetry plane in the center of fluid.

4.1 Pressure and Density Contour

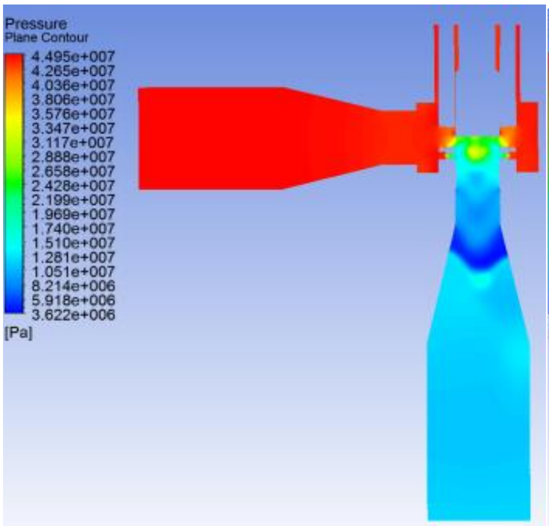

Fig. 4 Pressure Contour

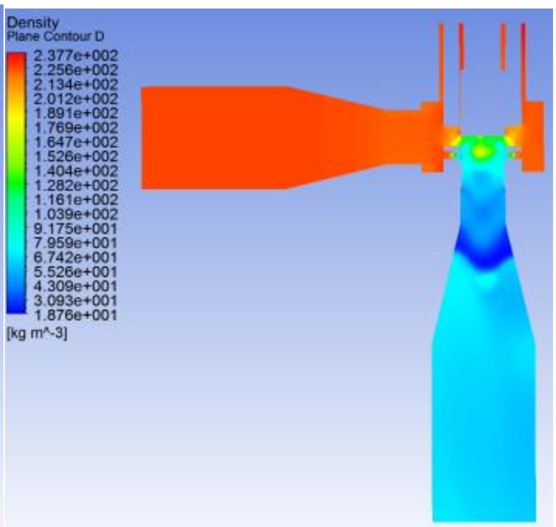

Fig. 5 Density Contour

Fig.4 is the pressure contour of methane gas. Fig.4 shows that: gas enters the throttling region from the left with the original 45Mpa. Most gases is involved in throttling action through orifice. Some gases enter corbula and the top of valve rod through the pressure balance pipes. Because of pressure balance pipes, pressure in the cavity can maintain balance with external pressure, so that it is easy for the valve rod to move upward and downward.

After the main current is throttled, pressure intensity rapidly declines. Due to the property of free expansion of gas, the throttled gas movement may expand near the valve body exit compared to the orifice, and the intensity of pressure will continue to decrease. As the section surface area of pipeline remains unchanged, the pressure intensity begins to stabilize. When the throttle valve is operating, water and sand may be contained in the gas. If the high-speed throttled gas directly impacts internal surface of corbula, it will further damage the interior surface. In order to avoid this problem, the central axis of each orifice lies in the same straight line. In this way, when the gases are throttled, they impact in mutual movement within the corbula, so the speed decreases. The horizontal direction also converts to vertical orientation. The originally decreasing intensity of pressure and kinetic energy begin to increase. The gas expands in the downward direction, and the pressure decreases at slower pace. As long as the total mass of gas remains the same, the volume and density are inversely proportional. As the volume and pressure intensity are inversely proportional, higher pressure intensity also signifies greater intensity. Therefore, gas density contour in Fig. 5 is almost identical to the pressure density in Fig. 4.

4.2 Streamline and Vector

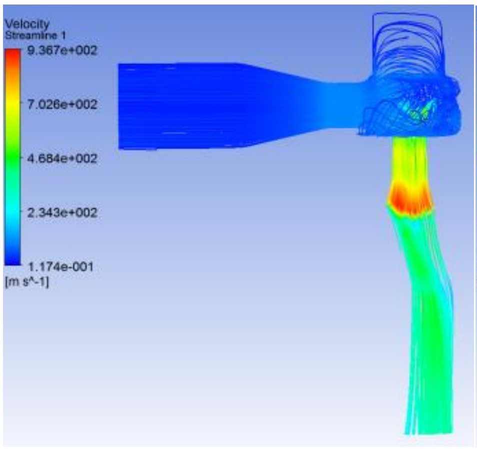

Fig. 6 Gas flow graph

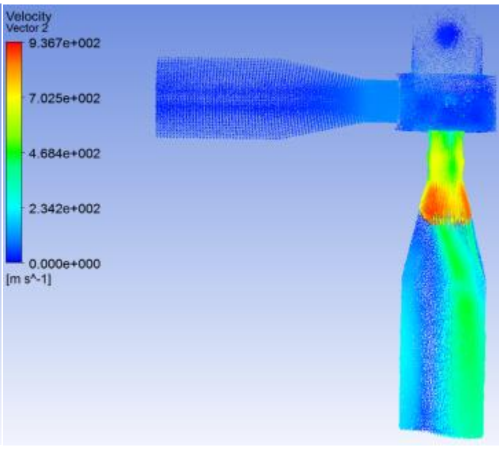

Fig. 7 Gas velocity vector graph

Fig. 6 is the gas flow graph. It is the curve consisting of different fluid particles in the same moment. This graph shows the movement directions of various fluid particles. These directions are the tangential directions of the curves at different points. Fig. 7 is the gas velocity vector graph. It can demonstrate the movement direction and strength of different fluid particles in a certain point. Fig. 6 and 7 clearly show: gases are in orderly laminar conditions before throttled. After being throttled, gases are in disordered turbulent flows. They also flow away out of the right side of tube wall, and the phenomenon of back flow occurs on the left side of tube wall. After the gas is throttled, the volume expands, pressure intensity declines, potential energy remains the same, so the kinetic energy increases. Therefore, near the nozzle of exit in the throttling area, gas pressure decreases at an increasing rate. Then, when the throttled gas encounters back-flow gas, they collide with each other, kinetic energy decreases at a slower rate, and pressure intensity of gas increases again.

The main current of gas forces back-flow gas to reverse. Due to viscous resistance between fluids, the main current and the back flow discharge from the throttle valve. The main reason for back-flow gas is: according to the Bernoulli equation, when fluid velocity increases, the pressure declines, in order to maintain the conservation of mechanical energy. Because the flow area of the nozzle is at the minimal level, the fluid may erupt out of the limited space at high speed, so the pressure is the lowest in the region. As a result, the fluid with higher pressure flows back to the low-pressure area. Fig. 8 is the partially enlarged graph of the back-flow region.

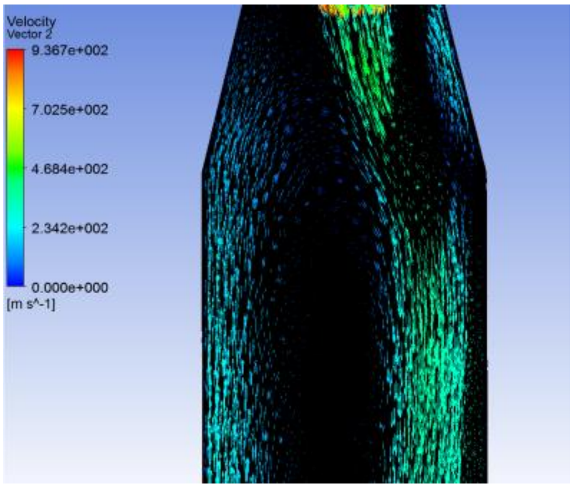

Fig. 8 Partially enlarged graph of the back-flow region.

4.3 Temperature

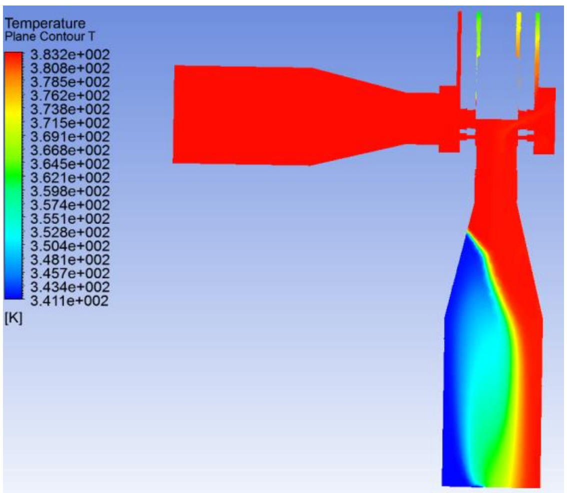

Fig. 9 Temperature graph

Fig. 9 is temperature graph after throttling. This graph shows: expanded back-flow gas has higher temperature than throttled gas. The reason for this phenomenon is: because there is adequate expansion space in the pipeline, the gas will expand when it enters the pipeline, the internal energy converts to mechanical energy. The internal energy decreases. As long as state of matter remains the same, the temperature will decline. It is because that the internal energy is the sum of molecular energy and potential energy in the object. Temperature is the macroscopic demonstration of average molecular energy. The state of matter doesn't change, the relative distance between molecules remain the same, and molecular potential energy stays unchanged. At this point, changes in internal energy also induce changes in kinetic energy. When internal energy declines, molecular movement decreases, kinetic energy of molecules and temperature also reduce. Back-flow cryogenic gas neutralizes with hot gas, and lead to color separation in Fig. 8.

When the throttle valve is operating, if environment temperature in internal fluid is low, based on throttling effect, ice will freeze on the shell of the outlet conduit of the throttle valve, and ice blockage will occur within the pipeline. After the gas is throttled, its own temperature will decrease. Due to heat conduction, external heat will enter the fluid in the pipeline, so the temperature around the outlet of throttle valve also will decline. If the temperature declines below zero, ice will occur. Ice blockage of natural is gas natural gas hydrate. It is the solid crystal formed by natural gas in high-pressure and low-temperature conditions. Ice blockage may impact the normal operation of equipment. Hence, it is quite necessary to take relevant measures to prevent ice blockage after throttling.

5. Conclusion

Based on the above analysis, it can be concluded: when the gas is throttled, conservation of mechanical energy, compressibility and expan of gas, and thermodynamic theories are the basis for throttling analysis. After the gas is throttled, the pressure tends to decrease, fluid velocity increases, back flow occurs, laminar flow converts to turbulent flow, and the gas absorbs the external heat and power. They are the four basic features of throttling effect. On the basis of these four features, when designing throttle valves, it is necessary to consider the erosive wear resistance of the valve element (corbula and valve rod). Tungsten carbide, a material with excellent erosion resistance should be directly installed. Relevant measures should be taken to prevent ice blockage from occurring at the throttle valve(such as heating equipment). Reasonable selection and design can ensure that equipment and facilities work and operate normally in rigorous conditions, so as to save costs and ensure safety production for companies.

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