ISSN 2706-655X Vol.5, Issue 6: 9-14, DOI: 10.25236/IJFET.2023.050602

Simulation and Optimization Design of Tubular Throttle Valve Based on SolidWorks

Zong Rong, Chen Zhao, Zhang Zihan, Hou Qiyu, Hou Pengbo, Sun Kuan

College of New Energy Engineering, Weifang Institute of Technology, Qingzhou, 262500, China

Abstract: *Aiming at the problem of erosion failure of tubular throttle valves caused by an internal fluid medium, this paper adopts a streamlined throttle valve and conducts modeling and finite element simulation analysis based on Auto CAD and SolidWorks software. In this paper, the common KC-02 tubular throttle valve is selected as the object of study and simulated before and after its optimization to obtain the pressure and flow velocity of each part of the throttle space. By analyzing the velocity distribution and static pressure distribution diagrams before and after optimization, this paper finds that the pressure at the interface between the throttle valve inlet and the straight pipe is the highest and the erosion phenomenon is the most obvious. In order to reduce the pressure on the pipe, the straight pipe of the throttle was changed to a streamlined pipe and the optimized KC-02 pipe throttle was simulated and analyzed. The results showed that the pressure at the inlet of the pipeline decreased by about 33.3%, and the outlet velocity increased by about 10.1%. The erosion phenomenon was effectively reduced, thereby improving the service life and efficiency of the throttle valve.*

Keywords: *Throttle valve, Fluid mechanics, SolidWorks, Finite element*

1. Introduction

Throttle valves are widely used in chemical, petroleum, water, and gas engineering fields. The performance of the throttle will directly affect the efficiency of oil and gas extraction and the safety of the applied machinery. Therefore, improving the performance of throttle valves, reducing the erosion of media on the valve body, and increasing the service life of the valve body has become an important parts of ensuring safe production.

Through a review of the literature, domestic and international research on throttle valves has focused on analyzing the laws of erosion and comparing the strength of different types and materials of throttle valves subject to erosion. S Bernad, R Susan-Resig, et al. established a model of the flow field in the valve and obtained the cause of the erosion inside the valve cavity and the location of the serious erosion area.[1] D. W. applied the physical properties of diamonds to throttle valves to enhance their resistance to erosion.[2] HL Sorensen, M.S. Wallace, et al. investigated two different throttle valves by numerical simulation to derive the internal flow pattern and flow characteristics of the valve, the location of the erosion failure, and the erosion wear rate in comparison with experimental results. [3][4] Lin, Jianzhong, Zhu, Zefei, et al. reduce the erosion wear of particles on the wall by changing the motion characteristics of solid particles in the flow field.[5] Based on the single-phase flow principle, Zhan Xiao-xi summarized the factors influencing the erosion of throttle valves and the types of erosion and determined the mechanical principle of throttle valve failure.[6] The analysis revealed that the research on throttle valves did not fully consider issues such as production costs and conversion of results.

Any fluid in the valve will occur energy loss. In order to effectively solve the problem of valve body erosion failure, this paper takes this as the entry point and combines it with the actual, choosing a common KC-02 tubular throttle valve as the object of study, through the design of the internal piping of the throttle valve to reduce the fluid flow process linear loss and local loss.

2. Design principle

2.1 Linear loss

Linear loss is energy loss in a broad sense and is mainly caused by fluid viscous forces. Linear loss per unit gravity fluid in pipeline flow is expressed by h_f.

ISSN 2706-655X Vol.5, Issue 6: 9-14, DOI: 10.25236/IJFET.2023.050602

$$h_f=\lambda\frac{l}{d}\frac{\upsilon^2}{2g} \tag{1}$$

where λ- frictional loss factor;

l- tube length;

d- pipe diameter;

υ- mean velocity in section.

From the above equation, it can be seen that the linear loss h_f becomes larger with the growth of the pipe under the same conditions as other physical parameters. The coefficient of linear loss λ is related to the Reynolds number Re of the fluid and the roughness of the inner wall of the pipe.

The two flow states of viscous fluids, namely laminar and turbulent flow, have a great influence on the magnitude and variation pattern of the linear loss. In laminar flow, h_f can be determined by the formula, and in turbulent flow, h_f can only be obtained by calculation or experiment.

In practice, laminar and turbulent flows exist simultaneously and the fluid flow in the pipe is complex. In order to simplify the calculations, we have chosen to simulate the case where both laminar and turbulent flows are present at the same time.

2.2 Local loss

The local loss is mainly caused by the collision of fluids and the formation of vortices, which is expressed by the velocity head. The local loss h_j is denoted by:

$$h_j=\zeta\frac{\upsilon^2}{2g} \tag{2}$$

where ζ- local loss coefficient;

υ- mean velocity in section.

So the key to the calculation of local loss is to determine the local loss coefficient. The local loss coefficient of most pipe fittings is measured by experiments.

3. Throttle assembly diagram

The existing KC-02 tubular throttle valve is mainly composed of a Valve body, Valve element, Rating nut, Handwheel, Parallel nut, and Unidirectional nut. Its assembly is shown in Figure 1 and Table 1. The Valve element and Rating nut are made of low carbon alloy steel (40Cr) because of the need for better wear resistance, and the rest of the structure is made of the more common 45 steel.

Table 1: Existing KC-02 tubular throttle parameters

Parameters	Data	Units
Caliber	0.68	mm
A	38	mm
B	24	mm
C	7	mm
L	62	mm
Flow	12	m/s
Maximum pressure	250	kgf/m2
Weight	0.23	kg

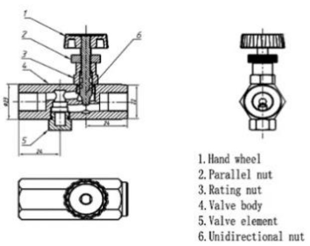

Figure 1: KC-02 tubular throttle valve assembly drawing

ISSN 2706-655X Vol.5, Issue 6: 9-14, DOI: 10.25236/IJFET.2023.050602

Combine the existing data of the KC-02 tubular throttle valve, integrate its relevant parameters, and use Auto CAD software to draw the assembly drawing and parts drawing of the tubular throttle valve.

4. Throttle valve optimization and modeling

4.1 Optimization conditions

KC-02 tubular throttle valve is mainly used in oilfield exploitation and oil and gas transportation, so gasoline is chosen as the reference fluid. Specific parameters are shown in Table 2.

Table 2: Specific parameters of gasoline

Parameters	Data	Units
Oil densityρ	889	kg/m3
Inlet pressureμ	0.036	Pa·s
Melting point	-94.5~-90.5	℃
Boiling point	25~220	℃
Relative vapor density	3~4	g/ml
Saturated vapor pressure	40.5~91.2	kPa
Dynamic viscosity coefficient	331×10^{-6}	m2/s

According to the actual operation of the throttle valve, the boundary conditions of the corresponding calculation space can be determined:

Entrance

The inlet mass flow rate is 0.5 kg/s.

Exit

The outlet pressure is standard atmospheric pressure 101325Pa.

Solid wall

The valve body is an adiabatic wall, assuming a smooth interior.

Throttle valve fluid flow state determination:

The throttle valve bore is 0.68mm, the inlet mass flow rate is set to 0.5m/s, and the kinematic viscosity of gasoline is 31×10^{-6} m2/s.

Reynolds number of oil:

$$Re=\frac{\upsilon d}{\nu}=\frac{0.5\times0.5}{31\times10^{-6}}=8064>2320 \tag{3}$$

where Re- Reynolds number;

d- characteristic length;

υ- rate of curve of flow of fluid;

ν- kinematic viscosity.

It follows that the Reynolds number of petrol in the throttle is greater than 2320 and therefore its flow state is turbulent.

4.2 Throttle simulation before optimization

In this paper, the three-dimensional model and two-dimensional model of the KC-02 tubular throttle valve are established, and the fluid mechanic's analysis is carried out by SolidWorks to obtain the pressure and velocity distribution in the flow field of the throttle valve. Then, the defects in the existing structure of the throttle valve are analyzed and the optimization scheme is sought.

According to the analysis of the graph and the color table, the pressure at the entrance is 2234900.21 Pa and the speed is about 0.5m/s; the exit speed is 1.832m/s and the pressure is 101325 Pa. The pressure at maximum pressure is 2234944.21 Pa.

ISSN 2706-655X Vol.5, Issue 6: 9-14, DOI: 10.25236/IJFET.2023.050602

4.3 Throttle optimization solution

From the analysis results, the high pressure of the pipeline during the operation of the throttle valve is the main reason for the occurrence of erosion, which is not conducive to the work of the throttle valve, and there is room for further improvement of the throttle efficiency. In summary, in this thesis for the throttle body structure for structural optimization, optimization of the desired result is to improve the throttle valve efficiency and reduce the rate of erosion.

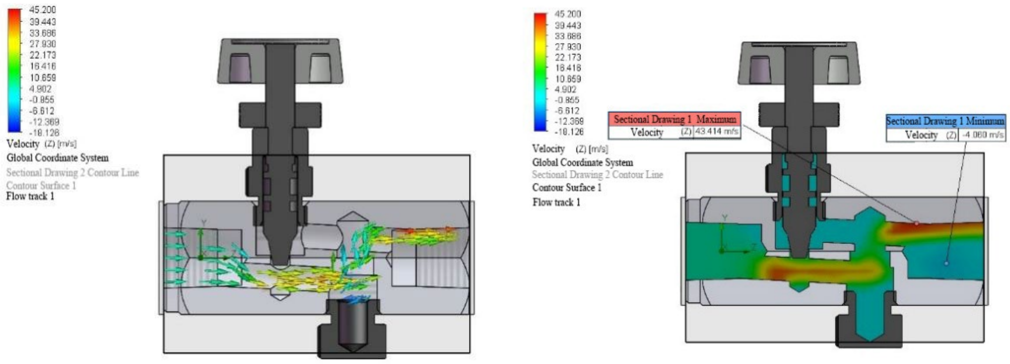

Figure 2: Flow body velocity distribution before optimization

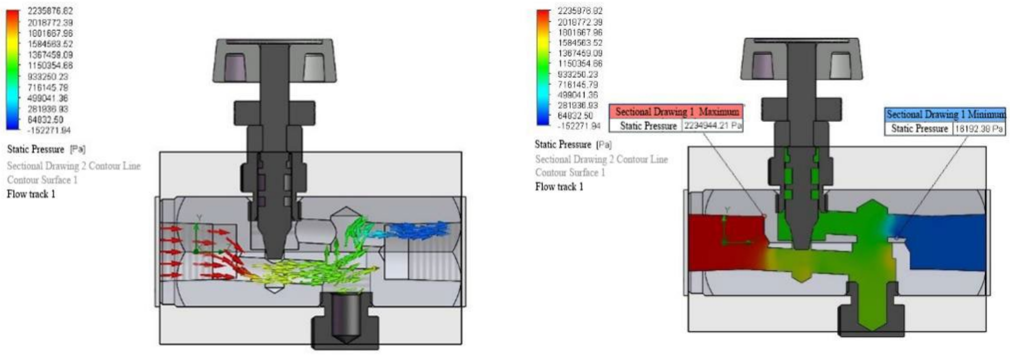

Figure 3: Static pressure distribution before optimization

From Figure 2 and Figure 3, we can get the maximum pressure at the straight pipe near the throttle valve inlet. Analyzing the cause of the maximum pressure point, it is found that it is caused by the inlet velocity too fast and the structure is not smooth. Therefore, how make the fluid influx more smoothly becomes the primary goal. In this paper, we try to change the straight pipe inside the valve into a streamlined pipe, and we want to use this structural change to reduce the pressure at the maximum pressure point and increase the outlet velocity.

4.4 Optimized throttle valve simulation

The optimized KC-02 tubular throttle valve is parametrically modeled using SolidWorks and Auto CAD, and then the optimized throttle valve is analyzed hydrodynamically using SolidWorks, and the above optimization scheme is verified according to the analysis results.

CFD simulation of the optimized KC-02 tubular throttle valve was carried out using SolidWorks, and after calculation, iterations reached 65 times to reach convergence, and the distribution graphs of static pressure and flow velocity of the flow field in the optimized valve was obtained as shown in figure 4 and figure 5.

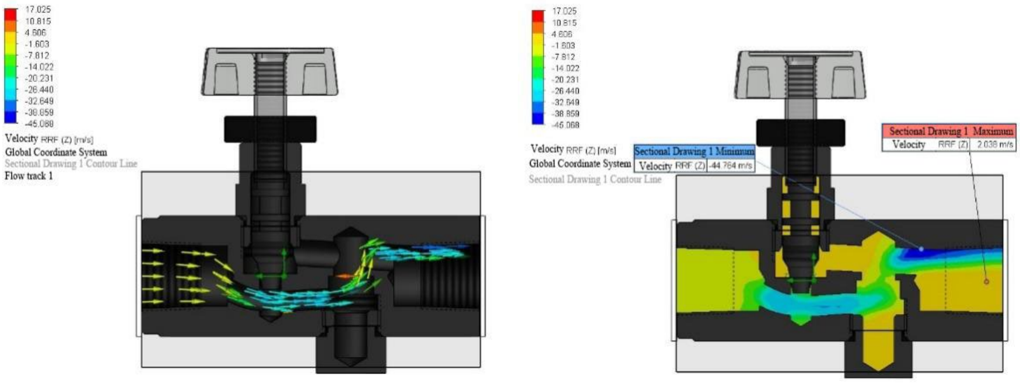

Figure 4: Fluid velocity distribution after optimization

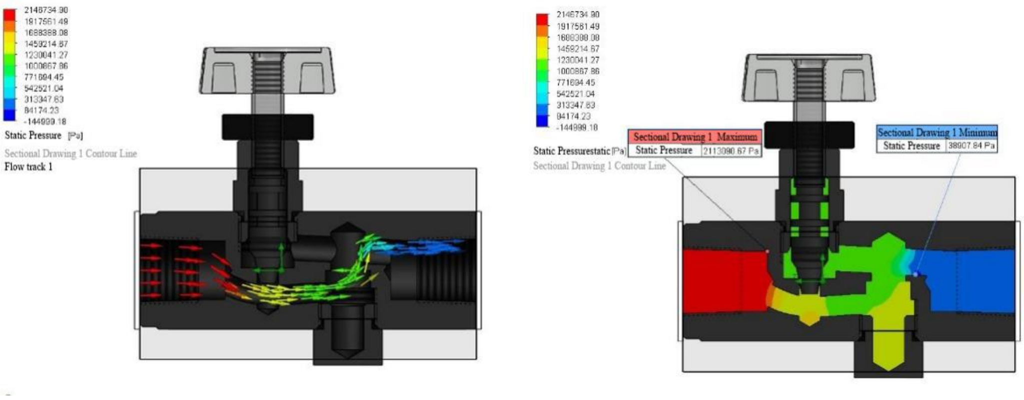

Figure 5: Optimized fluid static pressure distribution

Comprehensive simulation results can be obtained from Table 3, the optimized pressure at the maximum pressure point is 2113090.67 Pa; the velocity of the fluid at the outlet is about 2.038 m/s and the pressure is about 101325 Pa. It can be seen that the optimization of the throttle valve makes the pressure at the inlet of the original KC-02 tubular throttle valve decrease by about 33.3% and the velocity at the outlet increase by about 10.1%. The decrease in pressure at the maximum pressure point indicates that the optimized throttle valve has a weaker erosion effect and increased service life; the increase in outlet velocity with the same inlet velocity indicates that the throttle valve efficiency is increased.

Table 3: Comparison of data

optimization	Outlet speed(m/s)	Maximum pressure(Pa)
Before	1.832	2234944.21
After	2.038	101325
rate	10.1%	33.3%

5. Conclusion

In this paper, 2D and 3D modeling of the KC-02 tubular throttle valve was carried out using AutoCAD and SolidWorks software, and simulations were carried out using CFD methods. The simulation results show that the pressure at the valve inlet and straight pipe connection is the highest and the erosion is the most severe. In order to solve this problem, we proposed an optimization scheme, which changed the original straight pipe into a streamlined pipe, and modeled and simulated the optimized KC-02 tubular throttle valve. Simulation results show an increase in fluid exit velocity of approximately 10.1% in the optimized throttle valve and a pressure reduction of approximately 33.3% at the maximum pressure in the valve body.

It is important to note that the available simulations were carried out under specific conditions and therefore the design conclusions may differ from the actual situation. In addition, there may be deviations from the design during the manufacturing process. Therefore, we need to further refine and deepen our research on the KC-02 tubular throttle valve, taking into account the effects of gravity, linear loss, fluid resistance, and temperature on fluid flow within the valve. The choice of valve body material is also

ISSN 2706-655X Vol.5, Issue 6: 9-14, DOI: 10.25236/IJFET.2023.050602

important in practical applications, for example, the use of stronger, more erosion-resistant materials at the inlet of the pipeline. In addition, for fragile structures such as valve cores, higher- strength materials can also be considered to enhance their durability.

Acknowledgement

Fund program: Exploration and practice of multi-dimensional collaborative education model based on OBE concept - taking energy and power engineering as an example (M2021160), Design of Tubular Throttle Valve (X202213379065), Research on Key Technology of Biomass Variable Phase Clean Heat Supply (2021GX108).

References

[1] Susan-Resiga Sbr. "Vortex flow modeling inside the poppet valve chamber." (2001).
[2] Fu Yunhao. Research and optimization of throttle valve cemented carbide cage structure. Diss. Southwest Petroleum University, 2016.
[3] M.S. Wallace, W. M. Dempster, T. Scanlon, J. Peters, S. McCullochet "Prediction of impact erosion in valve geometries." Wear 256.9(2004):927-936.
[4] Sorensen Henrik L. "Numerical and experimental analyses of flow and flow force characteristics for hydraulic seat valves with difference in shape." Proceedings of the Bath Workshop on Power Transmission & Motion Control. University of Bath UK, 1999.
[5] Lin Jianzhong, Zhu Zefei, Shen Liping. "The Effect of Coherent Structure on the Erosion of Wall in the Gas-Particles Two-Phase Boundary Layer." Journal of Engineering Thermophysics 21.4(2000):5.
[6] Zhan Xiaoxi, Li Yueqin, Liu Pingping, Feng Chunyu, Pei Yanbo. "Failure Mechanism of Control Choke." Corrosion & Protection 9(2010):5.