Research on Flow Characteristics of Throttle Valve Based on Fluent

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Abstract—In order to improve the design of the throttle, a certain throttle is taken as the research object, and its flow coefficient is studied. Investigate the flow line characteristics of the throttle valve flow channel and the value of the flow coefficient of the throttle valve, use Fluent fluid software to perform numerical simulation analysis on the throttle valve flow channel, study the relationship between the throttle opening and the switching stroke, and simulate Calculation results The chamfer design of the throttle valve has a great influence on the initial section of the flow coefficient curve, and the opening range of the valve that can accurately control the flow rate is obtained.

1. INTRODUCTION

In engineering design, conventional valves are usually used for switch control, but with the advent of the fourth industrial revolution at this stage, more and more precision and intelligent valves are used in industrial production. For example, in oil production valves, the demand for opening control valves is increasing. The intelligence of the valve is mainly reflected in the intelligent flow control. According to the data review[1-5], scholars at home and abroad have carried out a lot of research on flow characteristics in order to improve the performance of the throttle valve, and some have used computational fluid dynamics theory to analyze the pressure and velocity distribution of the flow field in the valve using fluid software. Some numerical simulation calculations for the internal flow field of different spool shape types summarize the influence of the spool shape change on the flow field characteristics; some apply the high Reynolds number turbulence energy-turbulence dissipation rate (k-ε) equation model. The three-dimensional steady-state compressible viscous fluid flow field distribution in the valve was studied, and the pressure and velocity distribution of the flow field inside the valve at different openings were obtained. Some use standard and modified k-ε models for different control valves. The internal flow field distribution under the opening degree is simulated and analyzed. It is verified that the standard k-ε model is suitable for high Reynolds number turbulent flow. The modified k-ε model has higher accuracy in two-dimensional symmetrical turbulent flow. In order to accurately...
grasp the specific characteristics of a certain type of throttle valve, Fluent fluid analysis software is used to analyze the existing products to obtain their flow characteristics.

2. VALVE CHARACTERISTIC PARAMETER ANALYSIS

As we all know, most domestic valve products use the $K_v$ value to represent the performance of the valve. The meaning of the $C_v$ value and the $K_v$ value is the same. There is a conversion relationship between the two:

$$C_v = 1.156 K_v$$  \hspace{1cm} (1)

The standard stipulates that the valve flow coefficient $C_v$ value is the flow value recorded in US gal / min when the pressure difference between the two ends is 1 psi (94.8 Pa) when water flows through the valve at 40-100 ° F (4-38 ° C). For turbulence without cavitation and flash evaporation, the calculation formula of the valve $C_v$ value is [6]:

$$C_v = 11.56 \times Q \sqrt{\frac{\rho}{\rho_w \times \Delta P}}$$  \hspace{1cm} (2)

In the formula:

- $Q$—flow rate in cubic meters per hour (m³ / h);
- $\rho$—Density of fluid, unit is kilogram per cubic meter (kg / m³);
- $\rho_w$—the density of water at 15 °C, the unit is kilogram per cubic meter (kg / m³);
- $\Delta P$—The net pressure difference of the valve, in kilopascals (kPa).

Since flow $Q$ and pressure drop $\Delta P$ are not characteristic parameters of the valve itself, $C_v$ is a characteristic parameter of the valve. When the valve is selected, the pressure drop across the valve can be obtained after the corresponding flow rate and fluid density are given. For example, during oilfield service operations, accurately knowing the loss along the corresponding wellhead valve can accurately control the pressure of the target layer downhole and ultimately achieve accurate construction and increase oilfield production.

There are four common forms of $C_v$ curve for commonly used valves, four are equal percentage flow rate, parabolic flow rate, linear flow rate and quick-open flow rate, as shown in FIG. 1.

3. VALVE FLOW FIELD ANALYSIS AND CV VALUE CALCULATION

3.1. Analysis model

In this research, a 2-1 / 26-inch throttle valve was selected for oil pipeline analysis. The structure is shown in FIG. 2. By studying the flow characteristics of the existing throttle structure and analyzing the theoretical basis of the intelligent flow control of the throttle valve, A method of perfecting this type of throttle valve product is developed. As mentioned above, the conventional $C_v$ value is for water, or for
fluids with characteristics similar to water. However, the fluid characteristics in petroleum engineering often differ greatly from water. The conventional $C_v$ value cannot meet the design requirements. This requires the unique $C_v$ characteristic values for tests on crude oil and mud during actual use. The software is used for simulation analysis to solve the problems of insufficient test methods and special $C_v$ value rapid analysis and calculation. Meet actual engineering needs.

![FIG. 2 Structure of throttle valve](image)

The structure of the throttle's fluid domain is relatively complicated. It is divided into unstructured grids and verified for grid independence. The analysis results of different grids differ by less than 1%, and will not be repeated.

Based on the finite volume method, the equations adopt discrete and second-order upwind styles. The turbulence model uses the standard k-ε model. The speed and pressure are coupled based on the simple algorithm. Fluent fluid software [8-9] is used for numerical calculations. In this study, the velocity inlet, pressure outlet, and environmental pressure are defined as a standard atmospheric pressure. The wall surface adopts non-slip conditions, the medium is water, and the analysis is performed according to the relevant parameters given in the definition of $C_v$ value. The results are as follows.

### 3.2. Analysis of valve flow field characteristics

In the initial stage of valve opening, the resistance is mainly concentrated in the open position, which will generate turbulence. The flow field analysis result of the valve is shown in FIG. 3. It can be seen from the flow velocity cloud diagram of the valve that the fluid passing through the valve exhibits a clear turbulent state, and the maximum flow velocity appears at about 45° in front of the left of the valve core, reaching 2.827 m/s. Querying the data shows that under this kind of flow rate, water will vaporize and other phenomena [10], resulting in a more uneven distribution of the flow field at this location.
When the opening stroke of the valve is 20 mm, the maximum flow velocity of the fluid passing through the valve is 4.02 m/s, as shown in FIG. 4. In combination with the aforementioned maximum flow velocity of 2.827 m/s in the initial stage of the valve opening, from the perspective of the use of the valve, the valve is not easy to use under conditions of extremely high or low velocity. By consulting the references, we can know that the valve that controls the flow rate under normal circumstances, when the opening range is in the range of 30% - 70%, the flow rate control value is very accurate. Combining the analysis results of Fluent, the opening range of the valve's precise flow control is given.
From the streamline and velocity distribution of the aforementioned flow field analysis, the flow velocity on the annulus cross section of the entire valve body is uneven, and the streamline passes from the fluid inflow end on the left side. The flow velocity on the right inflow section is small. If the reduction and efficiency of the valve are taken into consideration, the flow channel of the valve can be improved to make the flow line at the inlet smoother, so that the corresponding effect is better and more efficient. At the same time, a certain eddy current effect is generated after flowing out of the section. This vortex will also hinder the passage of the positive fluid. It is recommended to add an extension section in the future to make the fluid flow more uniform.

According to the calculation formula of the value of $C_v$, when the pressure difference between the two sides of the valve does not change, if the value of $C_v$ is larger, the corresponding flow is larger. That is, under the same operating conditions (under the premise of fixed flow), the less pressure drop is consumed, the more energy-efficient the valve is. In this sense, the better the streamlined design of the valve, the better the valve.

3.3. Research on $C_v$ curve of valve

Calculate the flow of the valve at different openings through Fluent software, and then calculate the corresponding $C_v$ value according to the valve opening stroke and its corresponding flow, and get the relationship table between the $C_v$ value and the stroke, as shown in Table 1. The valve opening degree in the table refers to the degree of valve opening, and is expressed by the ratio of the valve over-flow area corresponding to the valve stroke to the maximum over-flow area of the valve.

| Valve stroke /mm | valve opening | $C_v$ value |
|-----------------|--------------|-------------|
| 0               | 0.00%        | 0           |
| 3.4             | 0.84%        | 4.416682    |
| 5.4             | 1.33%        | 6.321521    |
| 7.4             | 1.83%        | 8.253461    |
| 9.4             | 2.32%        | 11.26049    |
| 11.4            | 2.81%        | 17.02066    |
| 13.4            | 5.41%        | 33.8383     |
| 15.4            | 10.77%       | 47.2433     |
| 17.4            | 16.33%       | 61.03185    |
| 19.4            | 21.95%       | 80.57806    |
| 21.4            | 27.58%       | 96.98704    |
| 23.4            | 33.23%       | 110.7684    |
| 25.4            | 38.88%       | 122.135     |
| 27.4            | 44.53%       | 129.776     |
| 29.4            | 50.19%       | 136.7702    |
| 31.4            | 55.85%       | 146.4431    |
| 33.4            | 61.50%       | 152.3246    |
| 35.4            | 67.16%       | 156.1757    |
| 37.4            | 72.82%       | 162.5727    |
| 39.4            | 78.49%       | 166.2943    |
| 41.4            | 84.15%       | 166.9324    |
| 43.4            | 89.81%       | 168.2807    |
| 45.4            | 95.47%       | 180.9775    |

The fitting of the $C_v$ curve according to the above calculation results is shown in FIG. 5. Obviously, this curve is different from the aforementioned four classic $C_v$ curves, and it has two types of parabola,
positive and negative. At the same time, querying the data found that many conventional valves also have this phenomenon [11]. Research on the valve structure found that the chamfer design of the valve in the initial stage resulted in the valve having similar characteristics to the needle valve in the initial stage [12]. The theoretical $C_v$ curve of the needle valve is shown in FIG. 6. When the valve opening stroke exceeds 11.78 mm, the characteristics of a gate valve are exhibited. So there is a combination of two positive and negative parabolic forms. In order to eliminate the influence of the stroke, it is converted into the relationship between the valve opening degree and the $C_v$ curve, as shown in FIG. 7.
The result of fitting according to the converted data is shown in FIG. 8. Then fit the converted curve in exponential mode, and set the format of the fitting formula as:

$$y = y_0 + A_1 \cdot e^{-x/t_1}$$  \hspace{1cm} (3)

Get the parameter values according to the boundary conditions:

$$\begin{cases} y_0 = 192.33026 \\ A_1 = -190.41662 \\ t_1 = 14.1148 \end{cases}$$  \hspace{1cm} (4)

The standard deviation is 1.45821, which means that the maximum deviation of the $C_v$ curve corresponding to the fitting formula is 1.45821. At the same time, it can be seen from the fitted deviation graph that the corresponding deviation is smaller when it is in the range of 5-30, as shown in FIG. 9. That is, the accuracy of this area is very high. The real stroke is converted between the switching stroke of 15-42mm (the total stroke is 47mm), that is, the high-precision adjustment range of this valve is between 32% and 90% of the opening.
FIG. 9 Standard deviation distribution

4. CONCLUSION
The analyzed valve does not fully meet the characteristics of a throttle valve. There are two variations of the valve flow characteristic curve, positive and negative parabola. If it is used for precise control, the stroke and the valve opening degree need to be converted and applied. From the valve flow characteristic curve, it can be seen that the opening range of its precise use is between 32% -90%, corresponding to the valve stroke of 15mm-42mm (the total valve stroke is 47mm).

ACKNOWLEDGMENTS
This work was supported by the project of shandong province higher education science and technology program" Research on Key Technologies of Tracked Tank Cleaning Robot" (NO. J17KA034).

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