Simulation Analysis and Engineering Application Research of swirl flow limiting Valve based on XFLow

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Abstract

This article is based on the multiphase flow analysis platform in XFLow, the flow field parameters, such as velocity of outlet tube, internal pressure of valve body and turbulence intensity in valve body, are calculated under different working conditions and structural dimensions of swirl valve. These parameters directly affect the working performance of flow limiting device. By collecting and analyzing the data, the optimal scheme is obtained under the determined operating conditions, which provides the basis for the design and installation of the size and structure of the swirl valve.

Keywords

Swirl valve, current-limiting, flow field analysis.

1. Introduction

The intercepting well is the key structure of the combined urban drainage system. The whole drainage system intercepts the dry season sewage and the initial Rain Water through the intercepting well to ensure that the combined sewage which exceeds the intercepting capacity can be discharged into the water body smoothly. Reasonable interception device not only makes the sewage interception into the sewage interception system to achieve the purpose of regulating the water environment, but also ensures that Rain Water, who exceeds the cut-off discharge during the rainstorm, does not enter the sewage interception system, and prevents the actual discharge of the downstream sewage intercepting pipeline from exceeding the designed flow rate, avoiding the occurrence of sewage reflux and its influence on sewage treatment plant. In order to achieve this goal, the flow limiting valve is generally used in the structure. The urban pipe network system is closely related to the geographical location of the city, the initial design of the system and the climate. In order to adapt to the sewage flow rate and characteristic, and the engineering availability is good, this paper carries on the numerical analysis to the swirl flow limiting valve in the certain operation parameter range, obtains the effective data, and puts forward the theoretical data for the engineering installation of the limited flow valve[1-4].

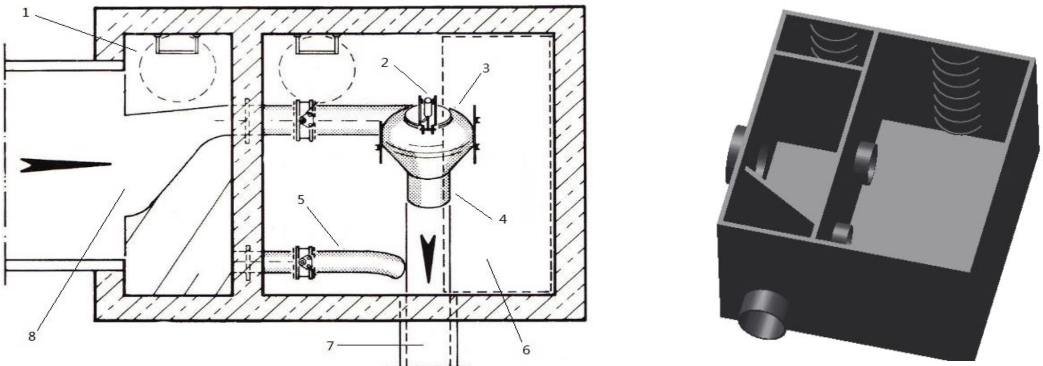
2. Methodlogy

2.1 Working principle and structural characteristic parameters of intercepting well

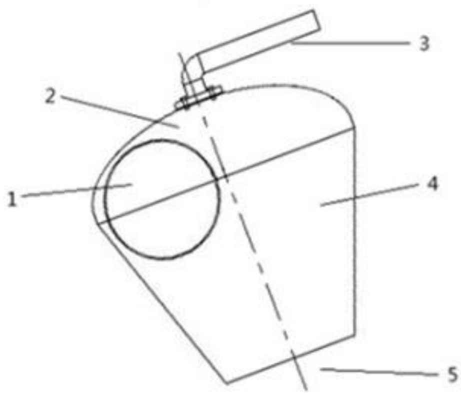
The swirl valve shut off well can control the flow only by the current, and its power comes from the pressure difference between the inlet and outlet of the swirl valve. The installation of swirl valve on the sewage intercepting pipeline in the intercepting well can accurately control the intercepting discharge in the rainy season, and its accuracy can reach 0.1. After the dry season sewage quantity is measured, the size of the sewage intercepting pipe can be determined according to the water quantity and the interception ratio, and the flow rate can be controlled accurately. This type of interception is different from all other interceptions, which is its unique feature. However, in order to facilitate maintenance, it is generally necessary to set up separate flow control wells, see fig.1.

2.2 Structure and working principle of swirl Valve

The swirl valve uses hydraulics and aerodynamics principles, automatic operation, no power and human force operation and control of the accurate limited closure device. The swirl valve uses hydraulics and aerodynamics principles, operating automatically, without power and human force operation and control of the accurate limited closure device. The structure includes a metal volute with a gas supply pipeline, a transparent observation window that is easy to open, a choke ring, a tail cone, and a flow plate. The swirl flow limiting valve is provided with a structural space without any moving parts, and water flows into the valve chamber through a tangential inlet. When the flow rate is small, the water flows through the valve chamber in the form of gravity flow, and the swirl valve has no water flow resistance. As is shown in figure 2. The flow limiting valve is easy to produce airflow. The flow of water enters the valve chamber through tangential direction. When the flow rate is small, the flow passes by gravity flow, and there is no resistance inside the valve cavity. With the increase of the flow rate, the pressure of the inlet will increase. The flow from the inlet rotates to the outlet along the inner wall of the valve body at a certain speed, and the air flow into the air hole will also enter the center of the shaft of the valve cavity. Thus, the flow of water in the valve cavity forms axisymmetric swirl flow, and the high speed tangential velocity in the valve cavity is formed. The air flow into the valve cavity forms an intermediate gas column, occupies part of the outlet area, reduces the cross-sectional area of the water flowing through the valve cavity while the flow is passing through the valve cavity, blocking most of the water outlets, thus successfully reducing the water production. The greater the inlet pressure is, the faster the tangential velocity of the flow, the larger the diameter of the gas column, and the greater the amount of water produced are, thus achieving the purpose of controlling the flow, that is, stabilizing the flow.



1-Inspection hole,2-Air pipe,3-Swirl flow limiting valve,4-Outlet pipe,5-by-pass pipe,6-inner valve,7-sewage outlet,8-sewage Inlet.
Fig.1 Integral structure of swirl valve closure well



1-induction pipe,2-Upper valve cover,3-Air pipe,4-Valve body,5-sewage outlet
Fig.2 Swirl flow limiting valve structure

2.3 Numerical calculation of flow Field in swirl Valve

The most obvious difference between XFlow and general CFD software is that there is no need for gridding. This analysis belongs to the fluid flow field analysis, which involves the large displacement motion, but also has the instantaneous nature, which needs higher parallel efficiency. In order to save analysis time and reduce workload, this calculation adopts XFlow computing platform.

2.3.1 Establishment of Mathematical Model of swirl Valve

1) Initial Condition

Flow limiting valves are often in contact with corrosive media inside the valve. The austenitic stainless steel S30408 is selected from the view of structural and technological properties. In the given data, the flow limiting valve body has the largest diameter of 1000mm. Refer to thin-walled vessel calculation for thickness of wall calculation formula. The initial mechanism and installation dimensions are shown in Table 1. The physical parameters of the fluid are shown in Tab. 2.

Tab.1 Swirl flow limiting valve initial parameter table

Inlet speed	2.2 m/s	Installation angle	20°	Initial velocity field	0 m/s
Initial relative pressure	0 MPa	Valve body taper	40°	Initial acceleration field	0 m/s2

Tab.2 Fluid property parameter table

Fluid type	relative molecular mass (kg/m2)	temperature K	dynamic viscosity coefficient	specific heat w/(m·k)	thermal conductivity J/(kg·k)
Fluid 1	998.3	288.15	0.001 Pa·s	0.58	4182
Fluid 2	28.996	288.15	1.78e-5 Pa·s	0.0243	1006.43

2) Simulation design in XFlow

Coordinate transformation.In order to accurately set the inlet and inflow direction of the fluid, the model rotates around Y axis and makes the flow direction rotate from Z axis to X axis direction. The initial installation angle of swirl valve is 20 °. The model is rotated around X axis and then rotated to 70 °around X axis to reach the installation angle as is shown in figure 3.

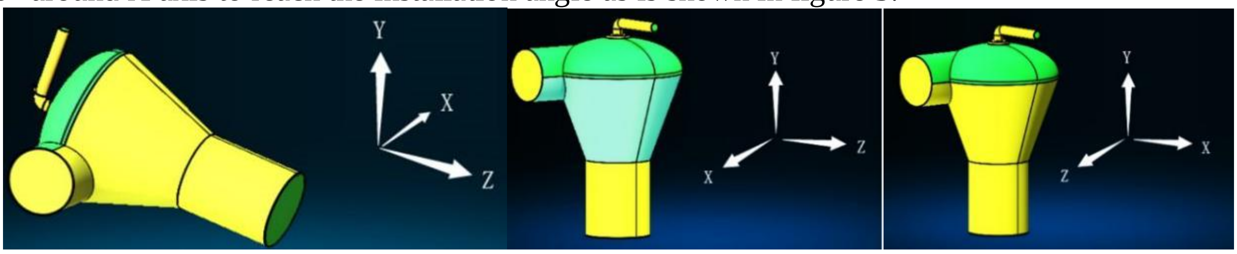


Fig. 3 Model coordinate transformation

Model of engineering analysis.Simulation of sewage flow in swirl Valve by Multiphase flow Simulation is choosed in which the Particle-based tracking model can simulate from the initial distribution of each stage, align the mark with the fluid, and introduce additional force at the interface between the phases to restore the user-specified surface tension. Particle based tracking method distributes discrete markers across most of the fluid and detects interfaces when different types of particles are adjacent to each other. Turbulence model's WALE (Wall-Adapting Local Eddy), model is suitable for the flow near and away from the wall, and can be well simulated for both laminar and turbulent flows. The most important thing is that the asymptotic behavior of the turbulent boundary layer is restored by the model. So that the layer can be directly solved without increasing the artificial turbulence viscosity in the wake shear region, and the simulation results are more accurate. The mathematical model is as follows by formula 1,2,3,4 and 5.

$$V_{turbulent} = \Delta^2 \frac{(G^d_{\alpha\beta}G^d_{\alpha\beta})^{3/2}}{(S_{\alpha\beta}S_{\alpha\beta}{}^{5/2}+G^d_{\alpha\beta}G^d_{\alpha\beta}{}^{5/4})} \tag{1}$$

$$S_{\alpha\beta} = \frac{1}{2}\left(\frac{\partial v_\alpha}{\partial r_\beta} + \frac{\partial v_\beta}{\partial r_\alpha}\right) \tag{2}$$

$$G^d_{\alpha\beta} = \frac{1}{2}\left(g^2_{\alpha\beta} + g^2_{\beta\alpha}\right) - \frac{1}{3}\delta_{\alpha\beta} g^2_{\gamma\gamma} \tag{3}$$

$$g_{\alpha\beta} = \frac{\partial v_\alpha}{\partial r_\beta} \tag{4}$$

$$\Delta = C_\omega Vol^{1/3} \tag{5}$$

Boundary condition .Combined with engineering operation, the inflow surface, outflow surface and wall surface of the fluid are selected as the boundary conditions for the solution, as shown in Figure 4. In the figure, "IN-water" represents the sewage inflow surface, "OUT" represents the fluid efflux surface, "IN-air" represents the air inflow surface, and the wire-frame represents the area of the Wall, that is, the wall surface. The boundary condition parameters are shown in table 3.

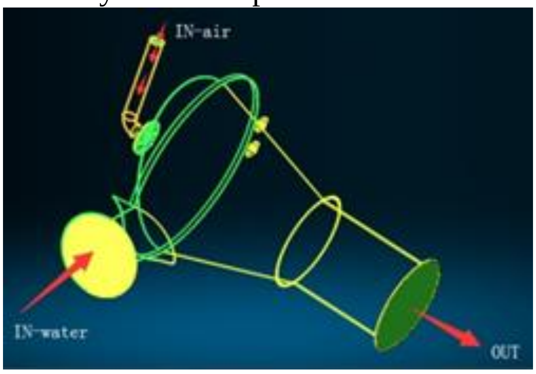


Fig.4 Swirl valve boundary condition

Tab.3 Boundary condition parameter

Name	Type	Model	Value
IN-water	Sewage inlet	Velocity	2.2 m/s
IN-air	Air inlet	Total pressure inlet	0.1 MPa
OUT	Fluid outlet	Pressure outlet	0.1 Mpa
Wall	Valve body wall	Non-Equilibrium Enhanced Wall-function	0

In table 3, pressure inlet / outlet and Total pressure inlet/outlet are different. The pressure outlet represents the boundary condition used to define the static pressure at the flow exit. All other flows are inferred from the internal domain and Total pressure outlet is not selected because the exit condition applies only to free surface flows and multiphase flows where gravitational potential energy fails. Since the gravity potential energy does not fail at the outlet, the pressure out exit model is used at the outlet of the swirl valve. Total pressure inlet represents the boundary condition to define the total pressure rule at the inlet boundary, and the total pressure is defined by formula 6.

$$P_{total} = P_{static} + P_{dynamic} = P_{static} + \frac{1}{2}\rho V^2 \tag{6}$$

The wall model is based on Non-Equilibrium Enhanced Wall-function. It is a generalized wall function that takes into account the pressure gradient and is more suitable for higher aerodynamic forces and more separation than for enhanced wall functions. But Enhanced Wall-function does not consider the pressure gradient, so the Non-Equilibrium Enhanced Wall-function model is used to analyze the wall condition.

2.3.2 Analysis of Simulation Operation Result of Swirl Valve and Its Engineering Application

1) Analysis of velocity field

At the speed of 2.2m/s, the sewage begins to form swirl flow at 0.5 seconds, air enters the valve body, and the maximum airflow is formed at the welding place between the air inlet and the sealing head, the velocity of flow is about 4.1 m / s, and the maximum velocity is reached at the center of the outlet of the valve body. With the massive inflow of fluid, more and more air is inhaled, and the flow velocity of sewage in the valve body begins to decrease. The most obvious position is at the center of the outlet pipe, and the flow velocity drops to the lowest in about 2.0 seconds. The flow field in the valve body tends to balance. The velocity of flow at the outlet pipe recovered and reached stability. The velocity of fluid entering the outlet pipe was 3.1 m / s after stabilization, and the velocity increased to 5.0 m / s in the outlet tube. As is shown in figure 5.

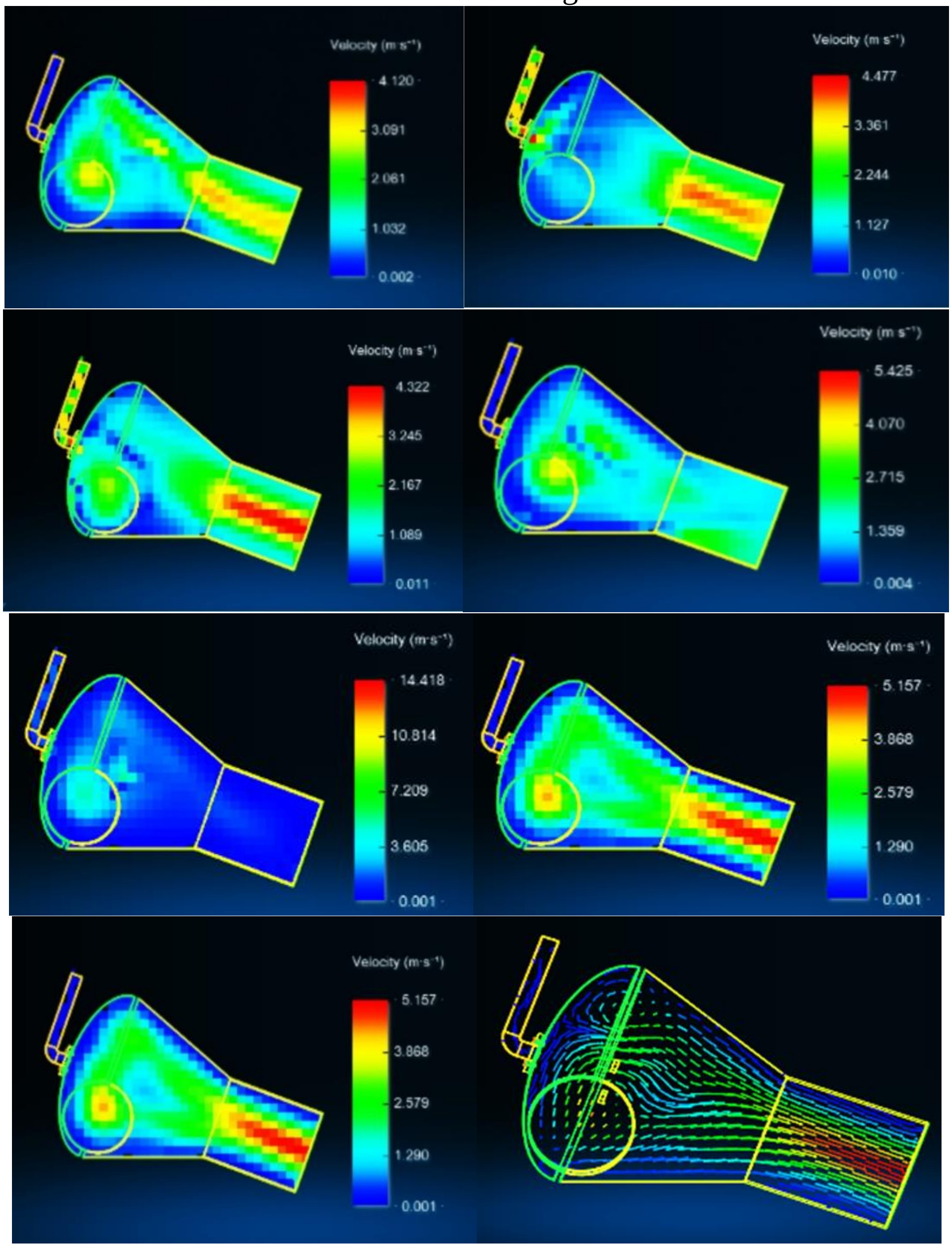


Fig.5side the valve body velocity change cloud chart and velocity vector chart

2) Analysis of pressure field

The pressure in the valve body is mainly concentrated at the air inlet. With the inflow of fluid, negative pressure forms in the valve body, the air begins to be inhaled, the pressure at the air inlet begins to rise, and the pressure inside the valve body changes from negative pressure to positive pressure with the inflow of gas. The pressure rises from the lowest -0.03MPa to the 0.1007MPa during the rising process, and then starts to shake in the 0.1MPa, finally the pressure stabilizes between the

0.09-0.11MPa. This shows that the swirl valve involved in the fluid entry process is safe, there will be no strength damage as is shown in figure 6 and 7.

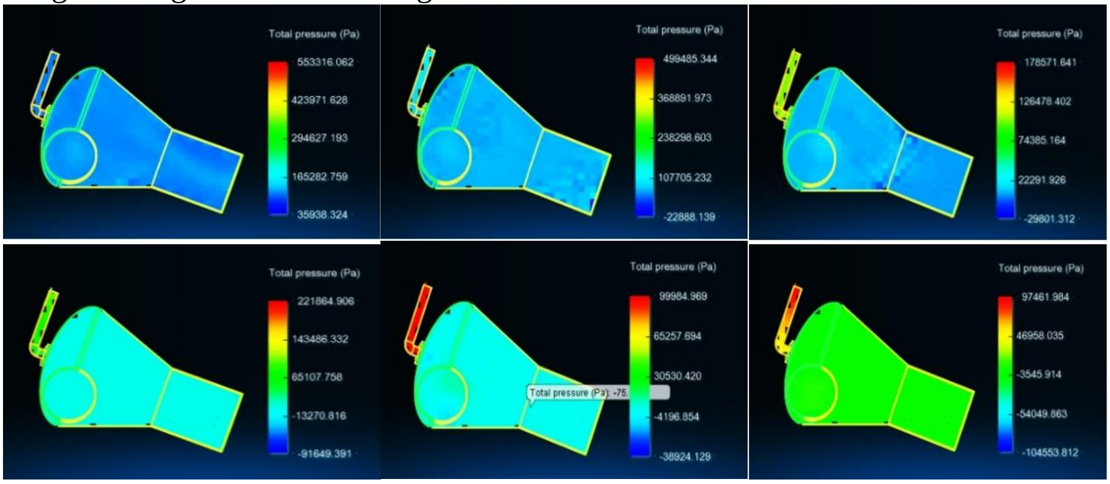


Fig .6 Cloud diagram of pressure change in valve body

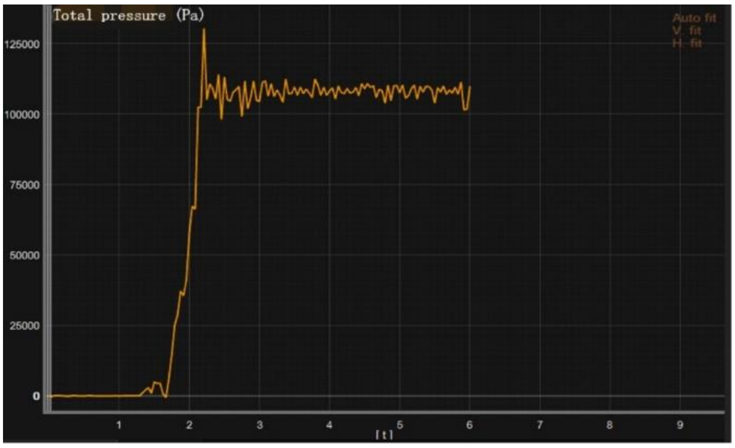


Fig.7 Variation of pressure in body with time

3) Analysis of liquid pressure field

The six pressure clouds in Fig. 8 represent the liquid pressure field at 0.1 sm 0.5 sg 0.10 sm 0.15 sm 0.20 sm 0.25 s, respectively. As you can see, the flow of sewage in the valve body is flowing along the wall, forming a swirl. At 2.5 s, the sewage fills the valve body and begins to flow out of the outlet.

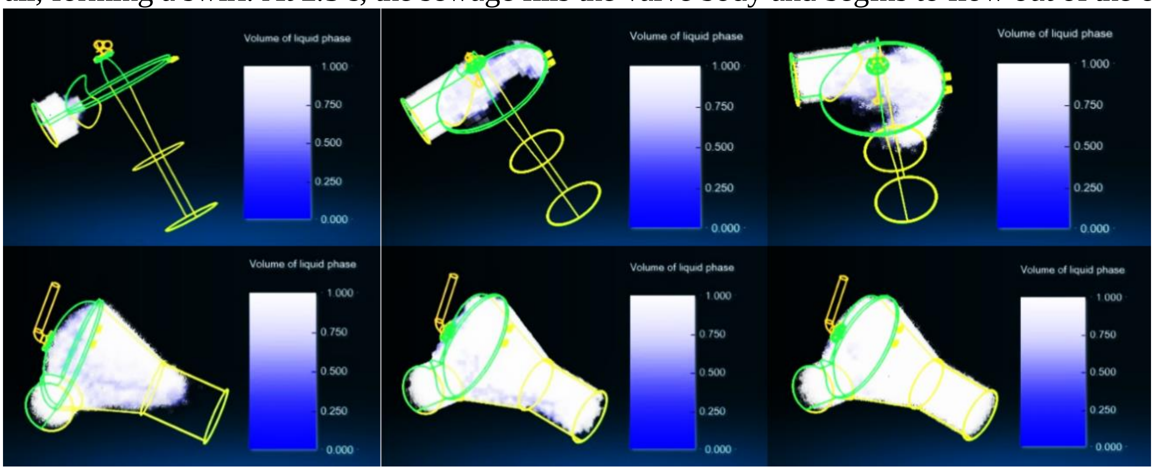


Fig. 8 Cloud diagram of liquid phase variation in valve body

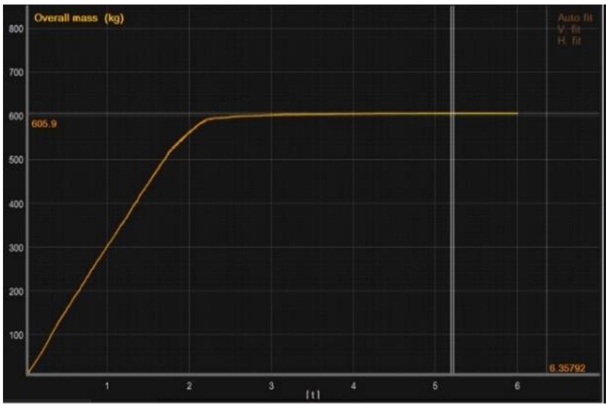


Fig. 9 Fluid mass change in valve body

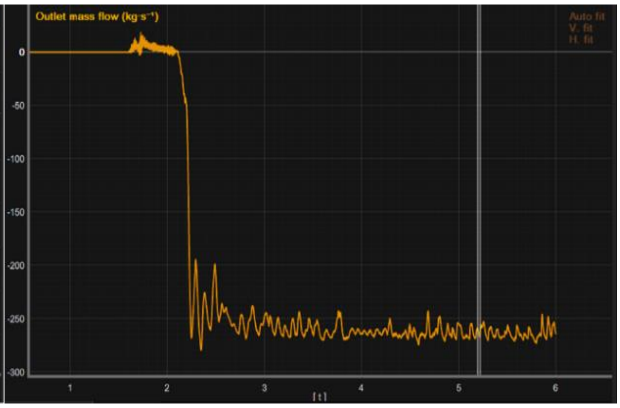


Fig. 10 Valve body outlet mass flow curve

When the sewage flows into the valve body at a steady speed, the quality of sewage in the valve body increases steadily. It can be inferred that it is not related to the shape of the valve body. When the effluent begins to flow out of the outlet pipe of the valve body after 3.0s, the mass of the sewage in the valve body reaches a maximum of 605.9 kg and will not rise after that, as shown in Fig. 9 and 10.

4)Engineering applications

Tab.4 The outlet flow rate variation table at assumed initial speed 2.7m/s

Time(s)	3.0	3.5	4.0	4.5	5.0	5.5	6.0
flow mass (kg/s)	321.16	318.15	328.61	326.81	337.20	341.33	345.94
volume flow (L/s)	321.64	318.62	329.10	327.30	337.70	341.84	346.45

Adjust inlet valve opening, change inlet tube velocity, improve swirl effect. When the velocity was 2.2 m / s and the valve body installation angle was 20 °, the volume flow of the outlet fluctuated roughly around 264L/s -281L / s. But the maximum sewage flow was 345.104 L / s in actual engineering, which did not achieve the best flow limiting effect. Besides, the fluid in the valve body was unstable. The speed at the outlet is 2.7 m / s. As can be seen from the above table, when the initial velocity rose to 2.7m/s and the fluid in the valve body was stable, the volume flow at the outlet pipe was approximately stable at 341L/s, close to the maximum flow rate of the sewage treatment plant during the rainy season. It can be seen that the initial speed of 2.7m/s, the valve body flow-limiting effect will reach a more ideal position.

Change the mounting angle of valve body.With the increase of the mounting angle of the valve body, the increment of the gravity potential energy of the water in the vertical direction is increased, and the flow velocity of the sewage flowing through the outlet pipe is increased, and then the optimum volume flow rate is achieved at the outlet. See Table 5.

Tab.5Table of relationship between valve body mounting angle and volume flow at outlet

Valve body mounting angle	20°	25°	30°	35°	40°
Mean volume flow	270.2 L/s	276.5 L/s	282.4 L/s	286.1 L/s	290.3 L/s
The difference between the maximum treatment flow rate and the sewage treatment plant	75 L/s	69 L/s	63 L/s	59 L/s	55 L/s

It can be clearly seen from the table above that with the increase of the mounting angle of the valve body, the flow volume flow at the outlet of the flow limiting valve will increase with the increase of the valve body installation angle, and the volume flow at the outlet of the flow limiting valve will increase by 5 L / s for each increase of 5 °.

Changing taper angle of valve body.The flow rate will be changed by changing the taper angle of the valve body, because changing the inlet speed is difficult and changing the valve body mounting angle is too realistic. The other parts of the whole swirl valve can be easily changed with the taper parameters by changing the taper parameters of the valve body as the whole swirl flow limiting valve model has been parameterized as a whole.

Tab.6 Initial parameter table for analysis of different taper limiting valves

Body taper angle	Sewage inlet speed	Air pipe inlet pressure	Outlet pressure	medium
40°	2.2 m/s	0.1 MPa	0.1 MPa	Water&air
50°	2.2 m/s	0.1 MPa	0.1 MPa	Water&air
60°	2.2 m/s	0.1 MPa	0.1 MPa	Water&air

Tab.7 Comparison of analysis results of swirl flow limiting valve with different taper angles

taper	flow mass	volume flow	Maximum volume flow of treatment plant	Difference value
40°	270.4 kg/s	271.3 L/s	345.104L/s	-74.2 L/s
50°	343.3 kg/s	345.2 L/s	345.104L/s	-2.1L/s
60°	405.8 kg/s	406.2 L/s	345.104L/s	61.1 L/s

3. Conclusion

The flow limiting valve can slow down the increasing trend of the water interception of the well with the increase of the water level. It can be realized that the increase of the water level in the well has no obvious effect on the increase of the intercepting rate when the maximum closure is reached. During the rainy season, the discharge of the interceptor will not fluctuate greatly with the increase of precipitation in the rainy season. Accurate flow control to 0.1 L / s effectively reduces the workload of municipal wastewater treatment plants during the rainy season and plays a particularly good role in limiting current.

Acknowledgments

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