ISSN: 2664-9640

Simulation and analysis of dual Venturi multiphase flowmeter

Rong Deng, Kun Hu *, Dong Liang, Tingting Hu

College of Mechanical and Electrical Engineering, Southwest Petroleum University, Chengdu, Sichuan 610500, China

Abstract

Using Eulerian multiphase flow model to study the double venturi water two phase flow in multiphase flowmeter flow characteristics, the inlet pressure of saturated steam humidity on double venturi tube flow of fluid pressure differential export results show that the influence of the saturated steam into double venturi tube cone contraction, the pressure gradually decline, speed increase, arrived at the throat pressure to a minimum, maximum speed, laryngeal sectional area is smaller, the lower the pressure, the greater the pressure difference. With the increase of inlet pressure, the pressure difference also increases gradually, showing an approximate linear growth trend. The growth rate of pressure difference with diameter ratio β = 0.7 is 0.6, and that of diameter ratio β = 0.45 is 2.27. It can be seen that the smaller the diameter ratio β is, the greater the pressure difference is and the greater the growth rate is, which increases by 278%. The change of pressure difference is not sensitive to humidity. The higher the humidity, the greater the outlet flow. When the humidity of saturated steam is less than 60%, the growth rate is 10.25 T / (H ·%). At the same time, when the humidity is greater than 60%, the outlet flow and outlet flow also show linear growth, but the growth rate is 58.7% less than that when the humidity is less than 60%. The variation trend of the simulation data is similar to the field data, and the error is less than 50%. It can be used for data processing and analysis in the future.

Keywords

Dual venturi multiphase flowmeter； gas-liquid multiphase flow； flow； computational fluid dynamics； flow field simulation.

1. Introduction

In the oil extraction industry, injecting high temperature and high pressure steam into the well is the main method of heavy oil extraction [1]. In order to grasp the steam injection status of the wellhead and increase the productivity of heavy oil, it is necessary to know the steam injection profile at any time, that is, the online steam flow in the pipe.

Features: The dual venturi tube flow measurement device is currently a more accurate device for measuring flow. It is composed of two venturi tubes with the same pipe, the same inner diameter and different diameter ratios.

At present, the research on the flow of venturi is mostly concentrated on the theoretical aspect, and there are relatively few studies on the simulation of double venturi [2]. Lin Zonghu [3] used the steam-water as the medium to use the orifice plate flowmeter to carry out the experimental research of flow measurement, and established a flow prediction model based on the venturi tube through a large amount of experimental data. M.van Werven and H.R.E.van Maanen [4] analyzed the influence of pressure distribution, throat pressure drop, and total pressure on flow measurement, and modified the Venturi tube vapor-liquid two-phase flow measurement model. With the development of computer technology, the use of computational fluid dynamics method to study the flow characteristics inside the venturi has become a new method. Denghui

He and Bofeng Bai[5] used the Fluent software to select the discrete model (DPM) to carry out the research on the flow characteristics of the multiphase flow in the venturi tube, and found that the pressure of the multiphase flow in the throat area decreased significantly, and with the liquid volume fraction The faster the pressure in the throat drops. YingXu and YiZhao[6] chose RNG k-ε turbulence model and discrete model (DPM) to simulate the numerical study of the flow characteristics of the venturi. KumarPerumal [7] uses computational fluid software to analyze the influence of the geometrical specifications of the venturi on the false height measurement of the venturi flowmeter. SimMei San [8] used computational fluid software to study the influence of contraction angle and expansion angle on flow measurement of multiphase flow. The above researches are all aimed at the venturi tube, and the influencing factors of the flow measurement of the double venturi tube flow device have not been studied yet. In this paper, the computational fluid dynamics method is used to study the flow characteristics of the double venturi using the Eulerian multiphase flow model and the Realizable k-epsilon turbulence model [9]. Use the Fluent software to quantitatively study the influence of external parameters on the pressure difference of the double venturi, and then use the flow model formula to obtain the influence of the external parameters on the flow rate and compare and analyze the data collected on site to measure the multiphase flow for the double venturi. for reference.

2. Double venturi structure

The two-dimensional diagram of the dual venturi polynomial flowmeter is shown in Figure 1. When the water-vapor mixture flows in from the inlet and passes through the conical contraction section in the tube, the fluid flow area decreases, the flow rate increases, and the pressure decreases, which can be reduced according to the pressure. The size is used to predict the flow rate of the fluid, and finally the outlet will flow out.

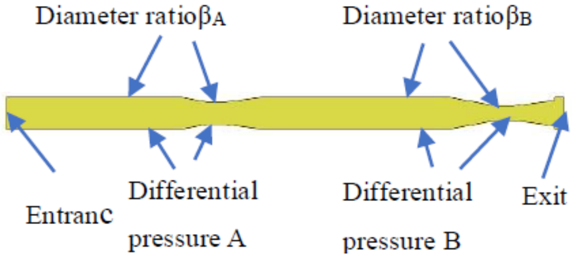

Fig. 1 Two-dimensional diagram of a double Venturi tube

3. Numerical calculation method

3.1. Control equation and calculation model selection

The double venturi tube involves the pressure change of the steam-water mixture, so the multiphase flow calculation uses the Eulerian model [10], which can calculate the mixture with its own velocity, temperature, density and different volume fractions [11]. It is suitable for calculating the pressure change of double venturi. The governing equations in the double venturi include continuous equations and Bernoulli equations [12,13].

Continuous equation:

$$\frac{\partial}{\partial t}(\rho_m)+\nabla(\rho_m\vec{v}_m)=0 \tag{1}$$

Among them, ρ_m is the density of the mixed phase (kg/m3), t is the time (s), and $\vec{v}_m$ is the mass-weighted average velocity of the mixed phase (m/s).

$$\rho_m = \sum_{k=1}^{n} \alpha_k \rho_k \tag{2}$$

ISSN: 2664-9640

$$\vec{v}_m = \frac{\sum_{k=1}^{n} \alpha_k \rho_k \vec{v}_k}{\rho_m} \tag{3}$$

Among them, n is the phase, $\alpha_k, \rho_k, \vec{v}_k$ are the volume fraction, density, and velocity of the k-th phase, respectively.

Bernoulli equation:

$$P_m + \frac{1}{2}\rho_m {v_m}^2 + \rho_m gh = C \tag{4}$$

Among them, P_m is the pressure at a certain point of the mixed phase (MPa), ρ_m is the density of the mixed phase (kg/m3), v_m is the average velocity of the mixed phase (m/s), g is the acceleration of gravity (m/s2), and h is Height (m), C is a constant.

3.2. Meshing and initial conditions

The meshing result of the double venturi is 4445 meshes and 4760 nodes.

The flow field in the double venturi tube can be regarded as an incompressible two-phase turbulent flow. The physical parameters of saturated water vapor are the vapor phase density of 70.57kg/m3, the water phase density of 654.02kg/m3, the temperature of 598.15K, and the water vapor kinematic viscosity. It is 2.09e-5.

The calculation domain in Figure 1 contains three boundary types, namely: (1) Inlet: The pressure inlet is used to specify that the water vapor inlet pressure is 12MPa, the gas phase volume fraction is 80%, the water phase volume fraction is 20%, and (2) the outlet: Use the pressure outlet and specify that the vapor phase pressure and the water phase pressure are both 0MPa. (3) Wall boundary: other boundaries not specified in Figure 1 are wall boundaries and specify that the boundary is smooth without translation. Because the water vapor in the tube is fast, the wall temperature has little effect on the volume distribution of its two phases, so the temperature change is ignored in the calculation, that is, the calculation domain is assumed to be isothermal and the compressibility of the medium is ignored.

4. Simulation result analysis

4.1. Pressure distribution in pipe

The pressure distribution in the double venturi tube is shown in Figure 2. It can be seen from the figure that when saturated steam enters the conical contraction section of the double venturi, the pressure gradually drops, reaching the lowest pressure at the throat, and by observing the pressure of throat a of 0.61Mpa and the pressure of throat b of -19.2Mpa The comparison shows that the smaller the area of the throat, the lower the pressure. When saturated steam passes through the conical expansion section, as the flow area increases, the pressure rises from 0.61Mpa to 7.57Mpa. The main reason for the pressure change is the change of the fluid circulation area. The fluid circulation area decreases, the flow velocity increases, and the pressure decreases.

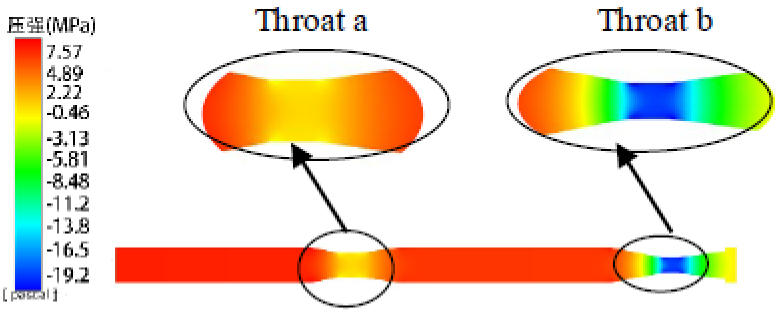

Fig 2 pressure distribution

4.2. Velocity distribution in the tube

The velocity distribution in the double venturi tube is shown in Figures 3 and 4. The maximum velocity of the gas phase is 548m/s, the minimum velocity is 0m/s, the maximum velocity of the water phase is 543m/s, and the minimum velocity is 0m/s. It can be clearly seen that the distribution and size of the gas phase velocity and the water phase velocity are similar. When the water vapor passes through the conical contraction section, the speed increases with the decrease in diameter. When it reaches the throat a, the speed rises from 219m/s to 348m/s, an increase of 58.9%. When reaching the throat b, the speed rose from 256m/s to 548m/s, an increase of 114%. It can be seen that when the water vapor flows through the double venturi, the smaller the diameter, the faster the speed.

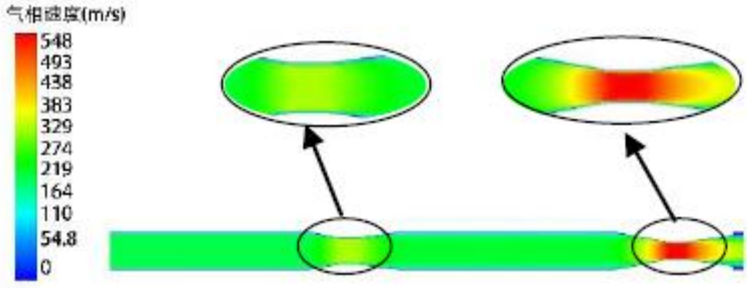

Fig. 3 Gas phase velocity

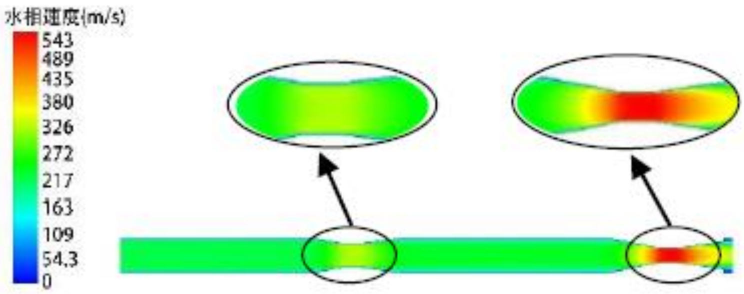

Fig. 4 Water phase velocity

4.3. Phase distribution in the tube

The phase distribution in the double venturi tube is shown in Figures 5 and 6. Figure 5 can clearly see the distribution of the gas phase in the double venturi. The minimum volume fraction is 0.771 and the maximum volume fraction is 0.987. It can be seen that when the gas passes through the contraction section, the volume fraction of the gas close to the wall decreases as the diameter decreases. Decrease and reach a minimum of 0.771. When passing through the expansion section, the gas phase is mainly concentrated in the center of the pipeline, but also gathers on the wall. At the vertical position of the outlet, the maximum gathers is 0.987. The distribution of the water phase is shown in Figure 6, the maximum volume fraction is 0.229, and the minimum volume fraction is 0.013. Its distribution is just the opposite of the gas phase distribution. The water phase aggregates on the wall during the contraction section. When passing through the expansion section, the water phase Mainly concentrated in the center of the pipeline, the volume fraction gradually decreases as it gets closer to the wall, and the volume fraction at the vertical of the outlet reaches a minimum of 0.013.

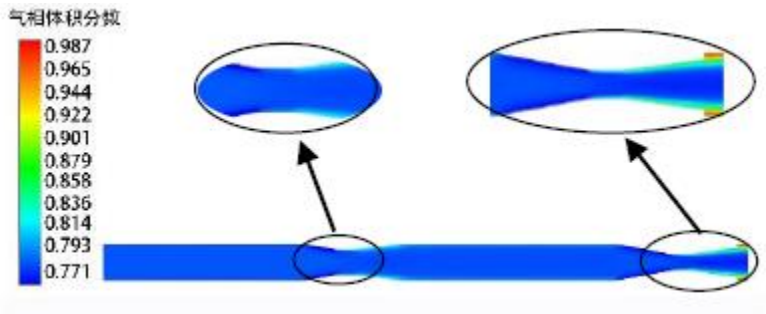

Fig. 5 Gas phase distribution

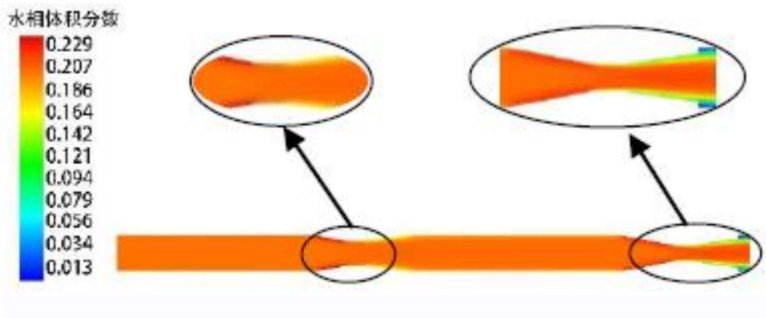

Fig. 6 Water phase distribution

4.4. Flow calculation

Taking into account the compressibility of the fluid and the deviation between the actual flow rate and the theoretical flow rate, a commonly used actual flow rate prediction formula [14] is given, namely

$$W_m = \frac{CA_2\varepsilon}{(1-\beta^4)}\sqrt{2\Delta P_m\rho_m} \tag{5}$$

Among them: W_m is the fluid mass flow rate (kg/s), ΔP_m is the pressure drop (Pa) produced when the mixed fluid flows through the venturi tube, and A_2 is the cross-sectional area of the venturi tube area , P_m mixed fluid density (kg/m^3), C is the outflow coefficient of the venturi tube, ε is the expansion coefficient, for incompressible fluid "ε=1", β is the diameter ratio of the venturi tube.

$$\rho_m = \varphi\rho_g + (1-\varphi)\rho_l \tag{6}$$

Among them: φ is the volume fraction of the vapor phase, ρ_g is the vapor density (kg/m^3), and ρ_l is the liquid density (kg/m^3).

The calculated flow rate out of the double venturi tube is 848t/h.

5. Analysis of influencing factors

5.1. Influence of inlet pressure

Investigate the change of pressure difference and outlet flow when the humidity of the double venturi inlet is 20% and the inlet pressure is 2, 4, 6, 8, 10, 12, 14, 16, 18, 20MPa. First of all, it can be seen from Figure 7 that the relationship between the inlet pressure and the pressure difference, as the pressure increases, the pressure difference between the two places in the double venturi tube also gradually increases, showing an approximately linear growth trend, with a diameter ratio of β=0.7 The pressure difference increased from 0.65Mpa to 12.7Mpa, the growth rate was 0.6, and the pressure difference with the diameter ratio β=0.45 increased from 2.34Mpa to 47.7Mpa, the growth rate was 2.27. It can be seen that the smaller the diameter ratio β, the greater its pressure difference, the greater the growth rate, and the increase rate increased by 278%. Finally, the influence of inlet pressure on outlet flow is analyzed, and the result is shown in Figure 8. It can be seen from the figure that the outlet flow rate of the double

ISSN: 2664-9640

venturi tube increases with the increase in inlet pressure, from 174t/h to 895t/h, showing an approximate linear growth trend, with a growth rate of 36.05t/(h·Mpa) .

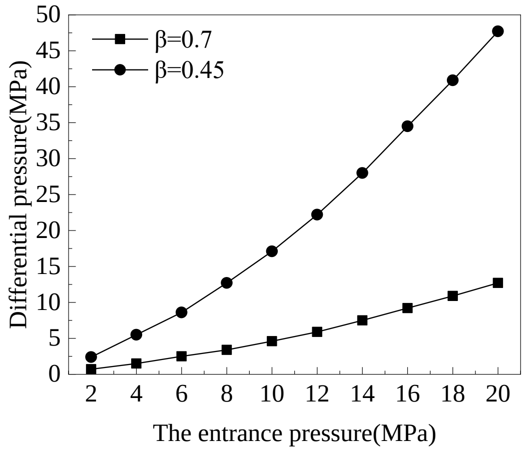

Fig. 7 Variation of pressure difference with inlet strength

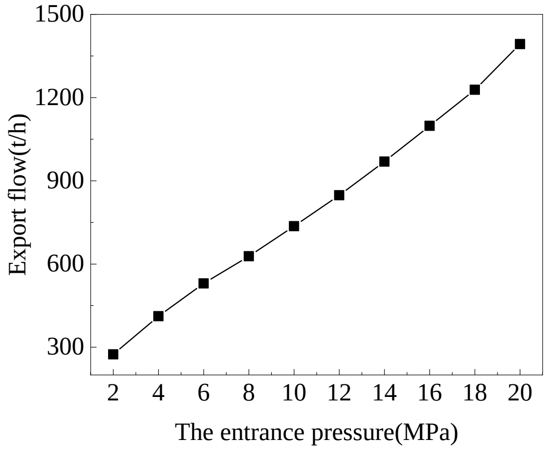

Fig. 8 Changes of outlet flow with inlet strength

5.2. Influence of water vapor humidity

Under the condition that the inlet pressure of the double venturi is 12MPa, the influence of saturated water vapor humidity [15] on the pressure difference and outlet flow rate at 10, 20, 30, 40, 50, 60, 70, 80, 90% is studied. Figure 9 shows the relationship between saturated water vapor humidity and pressure difference. As the humidity increases, the pressure difference between the two venturi tubes fluctuates up and down at a certain value, and the amplitude of the fluctuation increases as the diameter ratio β decreases. increase. It can be seen that the influence of humidity on the pressure difference is small. Figure 10 shows the influence of the humidity of the inlet saturated water vapor on the outlet flow. As the humidity increases, the outlet flow increases. When the humidity of the saturated water vapor is less than 60%, the outlet flow increases from 723Mpa to 1338Mpa. Shows a linear growth trend. The growth rate is 10.25t/(h·%). At the same time, when the humidity is greater than 60%, the outlet flow rate increases from 1338Mpa to 1465Mpa. The growth rate is 4.23 t/(h·%), and the outlet flow rate also shows a linear growth but increasing The rate is 58.7% smaller than the rate of increase when the humidity is less than 60%.

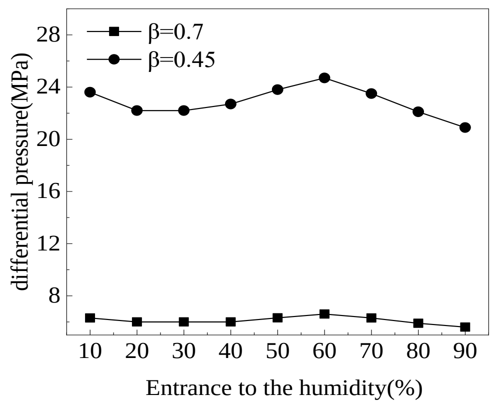

Fig.9 Variation of pressure difference with water vapor humidity

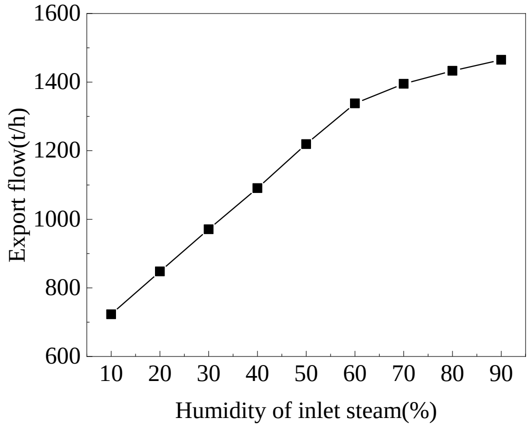

Fig. 10 Change of outlet flow with water vapor

5.3. Comparative analysis of on-site working condition data

Study the flow comparison and analysis when the humidity of saturated water vapor is 30% and the inlet pressure is 7, 8, 9, 10, 11, 12, 13, 14, and the field conditions collected from Henan Oilfield. The results are shown in the figure. 11 shown. It can be seen from the figure that the outlet flow rate obtained by the field conditions and simulation simulation increases with the increase of pressure, and approximately shows a linear growth trend, but the flow rate of the simulation simulation is more smooth than the growth trend of the field working condition data. The reason is that the on-site working conditions are complex, which affects the measurement of data, and the simulation cannot simulate the on-site working conditions 100%, with a maximum error of 41%, which can be used for future on-site data processing and analysis.

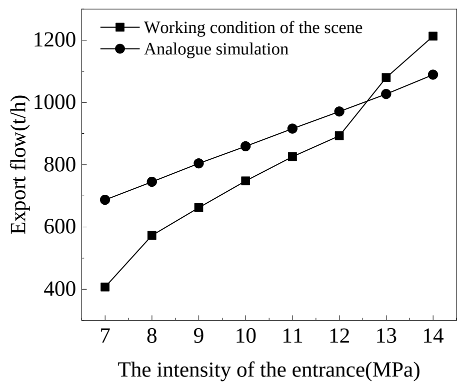

Fig.11 Comparison of on-site operating conditions and simulated flow

6. Conclusion

Using computational fluid dynamics to study the flow field in the double venturi tube, analyze the influence of various factors on the pressure difference and outlet flow rate of the double venturi tube, and get the following conclusions:

(1) When saturated water vapor enters the conical contraction section of the double venturi, the pressure gradually drops, reaching the lowest pressure at the throat. The smaller the throat cross-sectional area, the lower the pressure, and the greater the pressure difference.

(2) As the inlet pressure increases, the pressure difference is gradually increasing, showing an approximate linear growth trend. The pressure difference growth rate for the diameter ratio β=0.7 is 0.6, and the pressure difference growth rate for the diameter ratio β=0.45 is 2.27. It can be seen that the smaller the diameter ratio β, the greater its pressure difference, the greater the growth rate, and the increase rate increased by 278%.

(3) The change of the differential pressure value is not sensitive to humidity. The higher the humidity, the greater the outlet flow. When the humidity of saturated water vapor is less than 60%, it shows a linear growth trend. The growth rate is 10.25t/(h·%). At the same time, when the humidity is greater than 60%, the outlet flow also shows a linear growth but the growth rate is less than 60%. % When the growth rate is 58.7% smaller.

(4) The simulation data has a similar change trend with the field working condition data, and the error is less than 50%. It can be used to process and analyze on-site data in the future.

References

[1]Wu C S, Wu N F, Gong Y Z.Study on technical measures for heavy oil development [J]. Chemical industry management, 2020(20):195-196.(in Chinese)
[2]Peining Yu,Ying Xu,Tao Zhang,Zicheng Zhu,Xili Ba,JingLi,Zigeng Qin. A study on the modeling of static pressure distribution of wet gas in V enturi[J]. AIChE Journal,2015,61(2).
[3]Lin Z.H.Two-phase flow measurements with sharp-edged orifices[J]. Lin Z.H.,1982,8(6).
[4]M.van Wervenl,H.R.E.van Maanen,G.Ooms et al.Modeling wet-gas annular /dispersed flow through a Venturi[J].Aiche Journal.American Institute Of Chemical Engineers,2003,49(6):1383-1391
[5]Denghui He,Bofeng Bai.Numercial investigation of wet gas flow in ventuei meter[J].Flow Measurement and Instrumentation,2012,28:1-6
[6]Ying Xu,Yi Zhao,Zheng Hai Long. Study on the Key Factors of Wet Gas Metering Overreading in Standard Venturi Tube Base on DPM[J]. Applied Mechanics and Materials,2012,2025.
[7]Kumar Perumal, Jagannathan Krishnan. A CFD study of the effect of venturi geometry on high pressure wet gas metering[J]. Int. J. of Oil, Gas and Coal Technology,2013,6(5).
[8]Sim Mei San. CFD study of the Effect of Venturi Convergent and Divergent Angles on Low Pressure Wet Gas Metering[J].Journal of Applied SCIENCES,2014,14(22):3036-3045.
[9]Liu F Y, Hu X D, Liang Z X, et al. Numerical simulation of flow stability of venturi tube based on FLUENT [J]. Journal of system simulation,2019,31(07):1460-1468(in Chinese)
[10]R. Silva,C. Cotas,F.A.P. Garcia,P.M. Faia,M.G. Rasteiro. Particle Distribution Studies in Highly Concentrated Solid-liquid Flows in Pipe Using the Mixture Model[J]. Procedia Engineering,2015,102.
[11]Wang F J. Principle and Application of CFD software for Computational fluid Dynamics analysis [M]. Beijing: Tsinghua University Press,2004:87-88(in Chinese)
[12]Anderson J D.Fundamentals of Computational fluid Dynamics and its Applications[M].Wu S P,Liu Z M,Translate. Beijing: Mechanical Engineering Press,2008:149-189(in Chinese)
[13]Wu M Y. Principle and Application of Bernoulli equation [J]. Information Recording Materials, 2008,19(09):115-117(in Chinese)
[14]Liang Q, Zhang H J, Sun B, et al. Flow measurement of gas-liquid two-phase flow based on the split phase flow model [J]. Chemical Engineering Automation and Instrumentation,2006(04):53-57(in Chinese)
[15Luo Y. Application of venturi tube in moisture measurement [D]. Tianjin University,2005(in Chinese)