

# Analysis of flow characteristics and flow measurement accuracy of elbow with different diameters

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**Abstract.** Flow rate is one of the three testing parameters in modern industry, for the elbow, the fluid in the measuring section can not reach the ideal flow state after bending. Therefore, there is a great error in the measurement of flow. The principle of ultrasonic flow measurement based on V method is introduced in this paper, the combination of experimental research and numerical simulation is adopted, the physical model of 90 degree bend pipe with diameter of 273mm, 377mm and 426mm is established, and based on the finite volume method, the flow measurement error at different measuring positions after the elbow is studied by numerical simulation. The results show that the upstream bend in elbow causes local disturbance of fluid that makes the velocity of the fluid in the downstream pipeline in a state of no-ideal distribution, which exerts a great influence on the accuracy of ultrasonic flow measurement. And the fluctuation degree of fluid flow velocity decreases with the rise of the bend radius of the pipe but the accuracy of flow measurement decreases. In the total flow measurement range, the larger the pipe diameter is, the smaller the variation interval of the relative error is. Namely the accuracy of flow measurement is greater.

## 1. Introduction

Flow rate is one of the three inspection parameters in modern industry. Flow meter has been widely used in the measurement of fluid flow in energy and chemical industry<sup>[1-3]</sup>. The ultrasonic flowmeter with the advantages of non-contact measurement and portability has been developed rapidly, the measuring accuracy of the measurement needs high fluid flow state, especially the flow that in the measuring section after bending can not reach the ideal state, which will cause large measuring error<sup>[4-6]</sup>.

Many scholars at home and abroad have studied the flow of working substance in elbow. In 1927, Dean etc. analysed the flow state of refrigerant of circular cross-section in elbow and proposed the two flow phenomenon<sup>[7]</sup>; Kumar and Zheng et al explored the error of ultrasonic flowmeter, compared the velocity and path angle, receiving position of the transducer and inclination angle of measuring



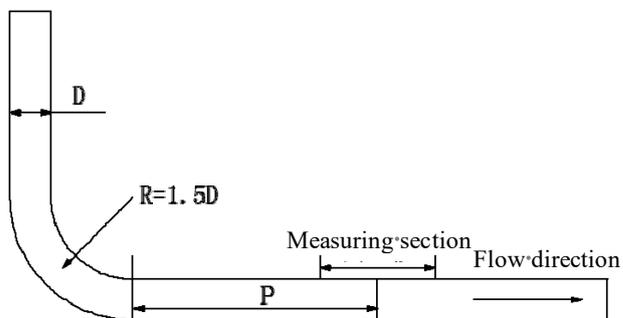
pipeline on impact of flow velocity measurement<sup>[8-9]</sup>. Chen Hong et al found that there is a very obvious vortex in the elbow pipe, and the effect of the space elbow on the flow measurement is greater than that of the plane elbow<sup>[10]</sup>.

In this paper, the calculation results are analyzed under the same flow velocity and different pipe diameters including longitudinal section velocity profile of elbow, velocity profile of longitudinal section of elbow under different pipe diameters, velocity contours on the middle section of different measuring positions after elbow pipe, velocity distribution diagram on speed sampling line, and variation of working fluid flow in pipe at different measuring positions after elbow. Based on the ultrasonic flow measurement principle of V method, the accuracies of flow measurement at different positions after different diameters of elbow are analyzed. Firstly, the average velocity of the sampling path between the two probes in the measuring section is calculated, and the calculated results are corrected as the measured values at this position. After that, the relative error is attained by comparing with the inlet velocity in the pipeline boundary condition. The relative error curve is used to judge the measurement accuracy at different positions of the pipe section, which provides theoretical support for practical engineering measurement

## 2. Establishment of physical model and mesh generation

### 2.1. Establishment of physical model

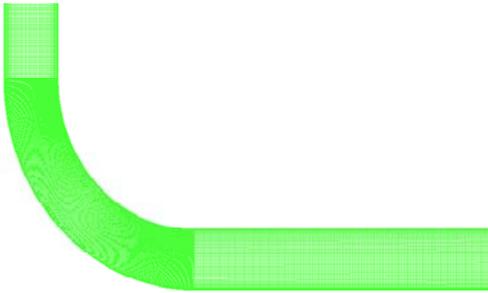
In this paper, 90° bending spiral steel tubes with diameter of 273mm, 377mm, 426mm and wall thickness of 6mm are selected as the research object, The flow law and relative error of the working fluid at different positions after the same bend radius are analyzed. The length of the straight section in front of the elbow is 10D, The length of the straight section after the elbow is 20D, bending radius of elbow  $R=1.5D$ , establishment of working fluid model in pipeline by Solidworks, the physical model of the pipeline is shown in Figure 1



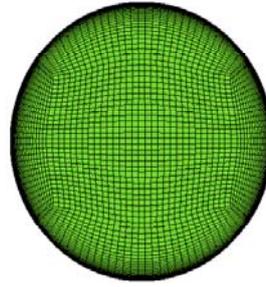
**Figure 1.** Physical model of pipe with bend radius of 1.5D

### 2.2. Mesh generation and boundary conditions

The mesh is divided by ICEM, and the mesh of the elbow is encrypted, the local diagram of grid of the elbow is shown in Figure 2, the Schematic diagram of grid of the elbow is shown in Figure 3. numerical simulation using Ansys Fluent, set the entrance boundary condition as the velocity inlet, the flow rate was 2.1m/s, the outlet boundary condition is free outflow, the wall roughness is 0.19, and the RNG turbulence model is selected, SIMPLE algorithm is used for pressure and velocity coupling, the flow medium is water, the convergence residual is defined as 1e-06.



**Figure 2.** Diagram of local grid



**Figure 3.** Diagram of cross-section grid

### 3. Mathematical model

The basic equations of elbow flow are as follows:

- 1) Continuity equation, See form (1):

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 \quad (1)$$

- 2) Equation of motion, See form (2):

$$\begin{cases} \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g \\ \frac{\partial}{\partial y_j}(\rho u_i u_j) = -\frac{\partial p}{\partial y_i} + \frac{\partial \tau_{ij}}{\partial y_j} + \rho g \\ \frac{\partial}{\partial z_j}(\rho u_i u_j) = -\frac{\partial p}{\partial z_i} + \frac{\partial \tau_{ij}}{\partial z_j} + \rho g \end{cases} \quad (2)$$

$\tau_{ij}$  represents deviatoric stress tensor.

- 3) Constitutive equation, See form (3):

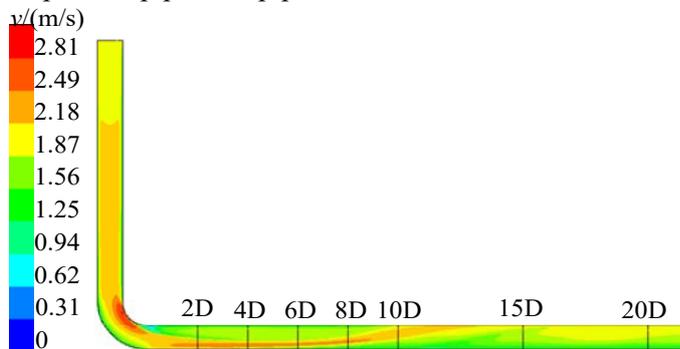
$$\begin{cases} \text{X向: } \tau_{ij} = \left[ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] - \frac{2}{3} \mu \frac{u_i}{x_j} \delta_{ij} \\ \text{Y向: } \tau_{ij} = \left[ \mu \left( \frac{\partial u_i}{\partial y_j} + \frac{\partial u_j}{\partial y_i} \right) \right] - \frac{2}{3} \mu \frac{u_i}{y_j} \delta_{ij} \\ \text{Z向: } \tau_{ij} = \left[ \mu \left( \frac{\partial u_i}{\partial z_j} + \frac{\partial u_j}{\partial z_i} \right) \right] - \frac{2}{3} \mu \frac{u_i}{z_j} \delta_{ij} \end{cases} \quad (3)$$

The  $\mu$  refers to the kinetic viscosity coefficient, the  $\delta_{ij}$  is a Krone Neck symbol,  $\delta_{ij} = \begin{cases} 0, i \neq j \\ 1, i = j \end{cases}$ .

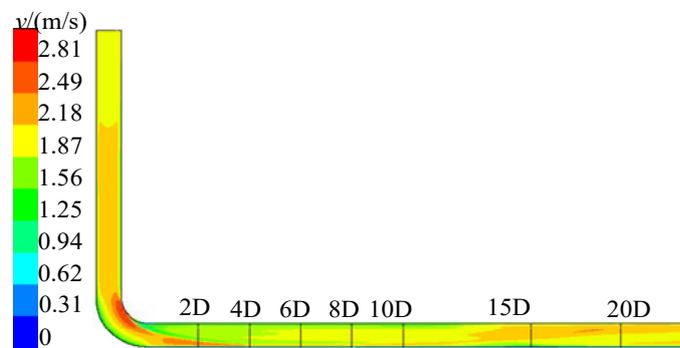
### 4. Analysis of flow law in elbow

Based on the ultrasonic flow measurement principle of V method, the flow rate is set at 2.1m/s, and the distance between center line of the measuring section and elbow end is 2D, 4D, 6D, 8D, 10D, 15D and 20D respectively. In the velocity of 2.1m/s, the longitudinal section velocity contour map of the pipe with pipe diameter 273mm is shown in Figure 4, the longitudinal section velocity contour map of

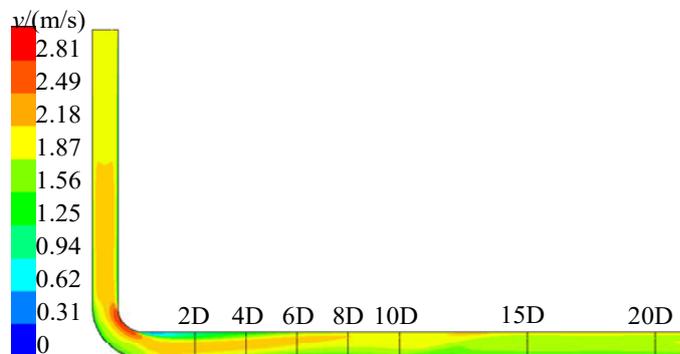
the pipe with pipe diameter 377mm is shown in Figure 5, the longitudinal section velocity contour map of the pipe with pipe diameter 426mm is shown in Figure 6.



**Figure 4.** The longitudinal section velocity contour of the pipe with pipe diameter 273mm



**Figure 5.** The longitudinal section velocity contour of the pipe with pipe diameter 377mm

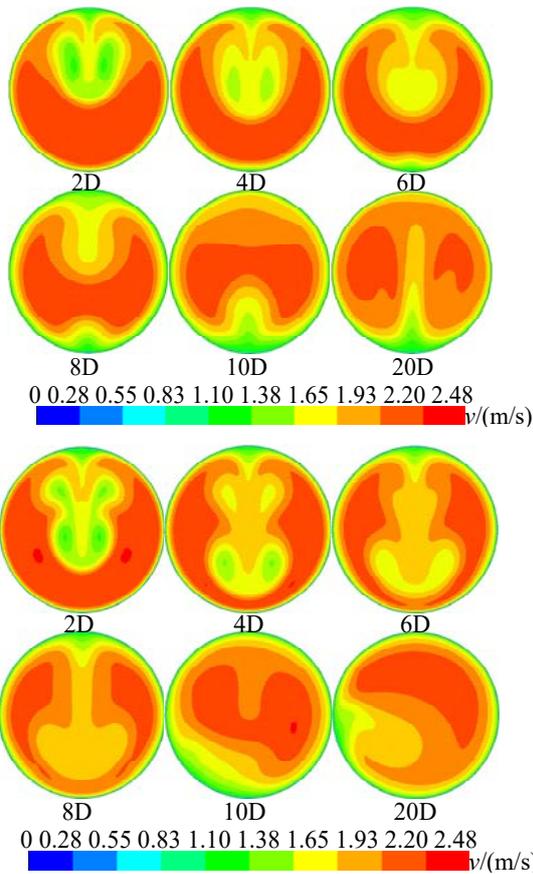


**Figure 6.** The longitudinal section velocity contour of the pipe with pipe diameter 426mm

From Figure 4 to figure 6, it can be seen that the velocity distribution of the working substance from the entrance to the elbow is relatively uniform, and the flow velocity gradually increases to the main flow velocity from the wall boundary layer to the center of the pipeline. Through the elbow, the flow velocity changes greatly. The flow velocity of the working substance inside the elbow increases, and the flow velocity of the working substance outside the elbow decreases. The obvious disturbance is formed in the long distance after the elbow, and the disturbance of the pipe with smaller diameter is more obvious. The flow of the pipe with 273mm diameter is stable when the diameter is about 10 times pipe diameter. The flow of the pipe with the diameter of 377mm and 426mm tends to be stable after the pipe diameter is 8 times pipe diameter.

In this paper, through numerical simulation, the cross section velocity at different measuring positions of three kinds elbow are obtained when the flow velocity is 2.1m/s. The cross section velocity contour map at the measuring section of pipe with pipe diameter 273mm is shown in Figure 7, the cross section velocity contour map at the measuring section of pipe with pipe diameter 377mm is

shown in Figure 8, the cross section velocity contour map at the measuring section of pipe with pipe diameter 426mm is shown in Figure 9.



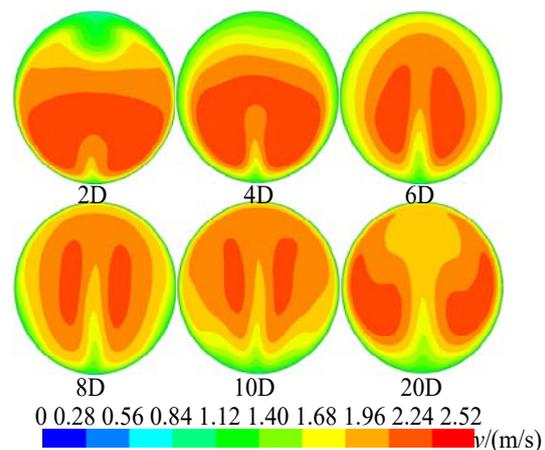
**Figure 8.** The cross section velocity contour of pipe with pipe diameter 377mm

As shown in Figure 7, for the pipe with pipe diameter 273mm, the velocity contours at the middle section of different elbow position are approximately symmetrical distribution at the 2.1m/s velocity, and there is a boundary layer about 3mm in the outer circumference of the cross section. After the end of the elbow, the velocity curve at 2D shows a concave distribution, the velocity increases gradually from the center to the outside, and the velocity at the lower part of the pipe is higher than that at the upper part. In the measuring section from 2D to 6D after the end of elbow, with the distance from the end of the elbow increasing, the position of the low velocity at the center of the concave gradually moves down, and the vulgar area spreads slowly to both sides of the pipe. At the bottom of the pipe at 6D, the velocity is low, and it begins to show an inverted "concave" trend, which is more obvious with the distance from the end of the elbow, symmetrical vortices<sup>[11]</sup> gradually appear at 20D.

As shown in Figure 8, for the pipe with pipe diameter 377mm, at the 2.1m/s velocity, the velocity contours at the middle section before 10D measurement section is approximately symmetrical distribution. In the measuring section from 2D to 8D, the speed curve presents "concave" pattern, and with the distance from the pipe end increasing, the point of low velocity inside concaves and spreads on both sides, the concave becomes gradually weaker, which reach the weakest at 10D, and present the target distribution trend.

As shown in Figure 9, for the pipe with pipe diameter 377mm, at the 2.1m/s velocity, the velocity contours at the middle section of different measuring section are approximately symmetrical distribution. There has been position of low speed at 2D. With the measuring section retreating, the

**Figure 7.** The cross section velocity contour of pipe with pipe diameter 273mm



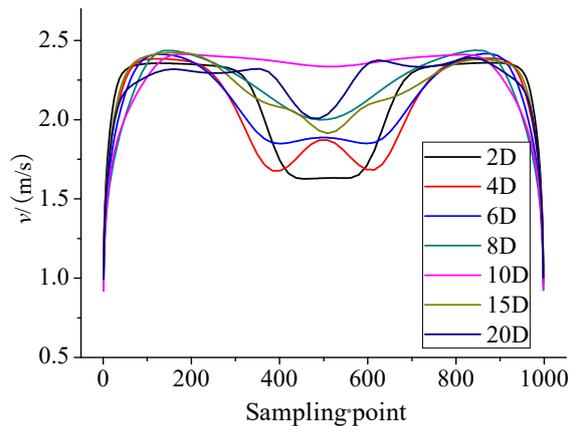
**Figure 9.** The cross section velocity contour of pipe with pipe diameter 426mm

velocity contours showed inverted "concave" trend, the velocity contours trend to separate the two sides, and there is obviously symmetric eddies at 20D.

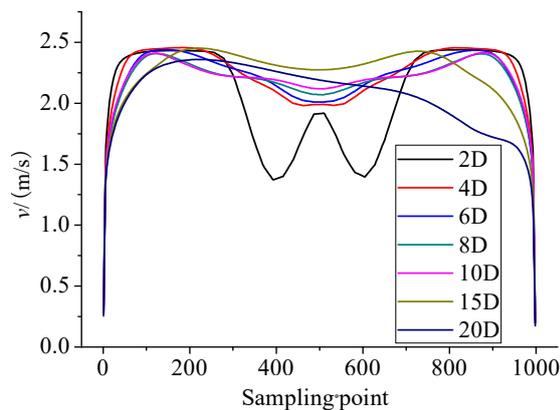
### 5. Measurement error analysis

In this paper, for the elbow which size are 273mm, 377mm, 426mm, and the velocity of fluid is 2.1m/s, the velocity curve is plotted according to the speed of each point on the 1 sampling line at different measuring positions are measured.

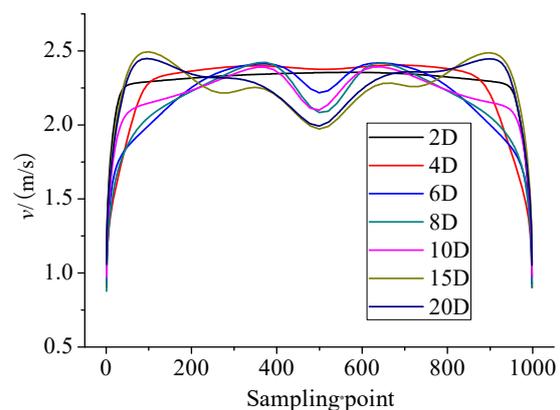
Figure 10 is the velocity curve of the 1 sampling line at the different measuring positions of the elbow of 273mm



**Figure 10.** Sampling linear velocity diagram in measuring section in 273mm elbow



**Figure 11.** Sampling linear velocity diagram in measuring section speed in 377mm elbow



**Figure 12.** Sampling linear velocity diagram in measuring section in 426mm elbow

From Figure 10 to figure 12 can be seen, the velocity distributions of three kinds of pipe diameter sampling lines are basically axisymmetric, the sampling line speed starts at 0m/s on both sides, gradually increase to the main velocity after the boundary layer. In Figure 10, there is a trough in the middle of the speed sampling line at 2D, and the velocity sampling line is gradually gentle with the increase of the distance from after the elbow, in Figure 11, speed sampling lines at 2D showed one peak and two valley, speed sampling line at 4D has leveled off.

The difference between the sum of the velocity accumulation values at 2D and the sum of the velocity accumulation values at 10D in the 273mm pipe is obvious larger than that in the 377mm pipe. And the difference between the sum of the velocity accumulation values at 2D and the sum of the velocity accumulation values at 10D in the 377mm pipe is significantly larger than that in the 426mm pipe. It can be seen that the smaller the pipe diameter is, the greater the absolute value of the relative error is and the lower the accuracy of measurement is in the same measurement position.

## 6. Conclusion

1.The elbow of upriver causes the fluid producing local disturbing flow after bending, and the velocity of the fluid in the downstream pipe presents a non ideal uniform distribution state, which has a great influence on the accuracy for measuring flow rate of ultrasonic flowmeter with V-Method of sound channel layout method.

2.The distribution of velocity contours (of the cross section) in the 273mm pipe are approximately symmetrical in the measured section of the pipe after bending and it is concave in the front of the measuring section, however, the inverted concave shape began to appear after the 6D measurement section. After the 377mm pipe bend and before the 8D measurement section, the velocity contours of the middle cross section of the measuring section show a concave shape. The trend of concentric distribution began to appear at the 10D measurement section. The velocity contours of the middle cross section of the measuring section after the 426mm pipe bend show an inverted concave shape, and the 20D measurement section begins to exhibit symmetrical vortices.

3.The contours of pipes i.e. 273mm, 377mm and 426mm are approximately symmetrical when the flow velocity is 2.1m/s and it increases gradually from 0m/s to mainstream velocity after passing through the boundary layer of pipeline.

4.At the same working fluid velocity and measuring position, the smaller the pipe diameter is, the larger the absolute value of the relative error of measurement is, and the lower the accuracy of measurement is.

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