Numerical investigation of elbow with different curvature-diameter ratio based on fluent

Deng Yaoxi, Yao Jiayi, Yang Fuqiao

***Abstract*—Elbow is often used in pipeline transportation, fluid flow velocity and pressure change dramatically when passing through the elbow, therefore the elbow influences the efficiency of pipeline transportation. In this paper, the model of oil-water two-phase flow is established by using FLUENT software. Having Simulated the different initial velocity fluid through elbows of different curvature-diameter ratio, the changes of velocity and pressure were obtained and the secondary motion was imitated. The change regulation of the pressure gradient and velocity along with the curvature-diameter ratio are summarized. It has certain reference value for the design and further studies of the 90 degree elbow.**

***Index Terms*—Two-phase flow, FLUENT, VOF model, Secondary motion.**

I. INTRODUCTION

Elbow pipe is widely used in modern industry, such as shipbuilding, agriculture and so on. It is an indispensable component of chemical fluid machinery. Due to the influence of bending degree, fluid property, environmental temperature and other factors, the flow field in elbow is complex. And the oil-water two-phase oil pipeline transportation makes the flow state more complex. Fluid in the elbow wall to form secondary motion phenomenon, increase the local resistance, reduce the transport energy of the fluid.

The traditional elbow analyses are based on the experiment. For instance, experimental study on the flow field of elbow pipe by using the rotating probe technique .The velocity and pressure distribution data of different cross section of elbow pipe were given by K.Sudo[1]. LDV technique was used to measure the flow pattern in the elbow by Taylor[2]. The theory of existing a large pressure gradient and the secondary motion in the elbow was put forward. In recent years, with the developing of computer technology, analysis based on computational fluid dynamics software are rising. It has solved the problem that the experimental funds are always expensive. Computational fluid dynamics software FLUENT is used in this paper to analyse the two-phase flow in the elbow with different curvature-diameter ratio. Have researched the elbow by setting different initial velocity .

II. COMPUTATIONAL MODEL

A. Turbulence model

This paper chose RNG k－ε turbulence model. RNG k－ε model corrects the turbulent viscosity. And the swirling flow is taken into consideration，compared with the standard k－ε model, it is more reliable to simulate the fluid in the elbow. Fluid of large streamline bending and high strain rates can be better handled. Otherwise, RNG k－ε model is suitable for various Reynolds number conditions. Compared with the laminar flow model, it can simulate the secondary motion more reasonable. The calculation of RNG k－ε model mainly follows the following equation.

1) Continuity equation

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \overline{u_i}) + \frac{\partial}{\partial x_j}(\rho \overline{u_i}\,\overline{u_j}) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(u\frac{\partial \overline{u_i}}{\partial x_j} - \rho \overline{u_i'}\,\overline{u_j'}\right) + s_i \tag{2}$$

Where

ρ =Fluid density, kg/m3

$\overline{u_i}\,\overline{u_j}$ =The average flow velocity of the liquid along the X and Y directions respectively, m/s

P=Pressure, Mpa

$\rho\overline{u_i'}\,\overline{u_j'}$ =Reynolds stress, pa

Which Si is the source item.

2) Turbulence model equation

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\alpha_k u_{eff}\frac{\partial k}{\partial x_j}\right) + G_k + G_b - \rho\varepsilon - Y_M + S_k \tag{3}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial X_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}\left(\partial_\varepsilon u_{eff}\frac{\partial \varepsilon}{\partial x_j}\right) + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + G_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{K} - R_\varepsilon + S_\varepsilon \tag{4}$$

Where

α_k= Turbulent Prandtl number of K equation

α_ε= Turbulent Prandtl number of ε equation

G_k=Turbulent kinetic energy generated by the laminar velocity gradient, Nm

G_b =Turbulent kinetic energy generated by buoyancy, Nm

K=Turbulent kinetic energy, J

U_{eff}=Eddy viscosity

Y_M=Contribution of pulsating expansion in compressible turbulence

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Which ε is a dissipative term, S_k and $S\varepsilon$ are the source items. $R\varepsilon$ is an additional source in ε equation. $C_1\varepsilon = 1.42$; $C_2\varepsilon = 1.68$; $\alpha k = \alpha\varepsilon = 0.7194$

Which

$$R_\varepsilon = \frac{C_u \rho \eta^3 (1 - \eta / \eta_0)}{1 + \beta\eta^3} \frac{\varepsilon^2}{K} \quad (5)$$

Where

$\eta = S_K / \varepsilon_i$

$S = (S_{ij} S_{ij})^{1/2}$

$S_{ij} = \frac{1}{2}\left(\frac{\delta u_i}{\delta u_j} + \frac{\delta u_j}{\delta u_i}\right)$

$\eta_0 = 4.377$, $\beta = 0.012$, $Cu = 0.0845$

B. Multiphase flow model

VOF (volume of fluid) model is used in the calculation of multiphase flow in this paper. The so-called VOF model is a kind of surface tracking method which is fixed under the Euler mesh. When we need the interface between one or more incompatible fluid, this model can be used. Because that oil and water are not mutually soluble, the VOF model is used to calculate. The free surface of the VOF model is constructed and followed by the volume function F, which is based on the inner flow of the unit. When F=0, the unit is filled with a specific phase fluid; When F=1, the unit is all for another phase fluid. When 0<F<1, two phase fluid both exists in the unit. VOF model follows the following equation.

1) *The equation of volume function F changes with time*

$$\frac{\partial F}{\partial t} + \nabla\left(F\vec{u}\right) = 0 \quad (6)$$

2) *Continuity equation*

$$\frac{\partial \alpha_i}{\partial} + \vec{u} \vee \alpha_i = 0 \quad (7)$$

Where

$$\sum_{i=1}^{n} \alpha_i = 1 \quad (8)$$

3) *Momentum equation*

In the VOF model, different components share a same set of momentum equations. Momentum equations are as follows:

$$\frac{\partial \rho \vec{u}}{\partial t} + \nabla(\rho \vec{u}\vec{u}) = -\nabla p + \nabla\left[u(\nabla \vec{u} + \nabla \vec{u})\right] + \rho \vec{g} + F_s \quad (9)$$

Where Fs is the original item of the momentum equation caused by surface tension

$$F_s = 2\sigma k \alpha_i \nabla \alpha_i \quad (10)$$

Where

σ =Surface tension constant

$\vec{u}$ =Velocity vector

u=Fluid dynamic viscosity

u_i=Phase i volume fraction

k=Surface curvature

C. Geometric modeling and meshing

In this paper, a comparison is made on 3 elbows bending with different curvature-diameter ratio. The elbow is divided into three parts, the entry section, the bending section and the exit section. Modeled the elbow which used in oil and gas transportation, the external diameter D is 60mm, wall thickness is 6mm. Both the length of the entry section and the exit section are 500mm, the bending radius Rc is 300mm, 360mm and 400mm, respectively. The curvature-diameter ratio(R_C/D) are 5, 6 and 6.7 respectively. Have met the requirements of oil and gas transportation that R_C/D should be greater than 5. Define the θ as the polar angle, $\theta = 0^\circ$ at the connecting part of the entry section and a bending section, $\theta = 90^\circ$ at the connecting part of the exit section and a bending section. On the platform of Workbench, used sweep method to mesh the elbow with hexahedron..

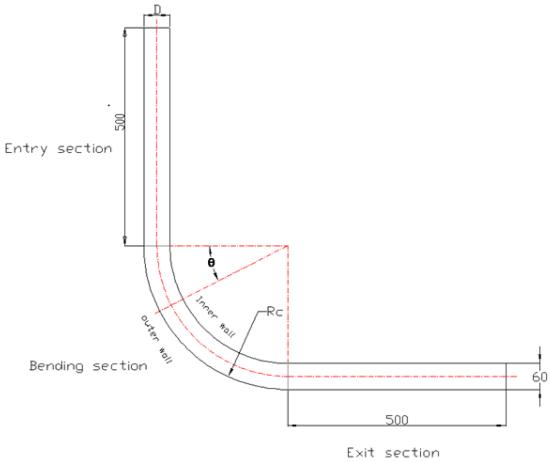


Fig.1-Geometric figure of elbow

D. Boundary conditions and computational settings

In this paper, we study the oil-water two-phase flow. The VOF model and RNG k－ε model were used to calculate the problem and inlet condition was set to velocity inlet, the initial velocities were 1m/s, 5m/s, and 10m/s, respectively. The initial temperature was 296K; outlet condition was set to pressure outlet, pressure was 101325Pa. The momentum equation and the turbulent kinetic energy equation were adopted in the second order upwind difference scheme, SIMPLEC algorithm was used to solve the pressure and velocity. The oil / water properties are as follows.

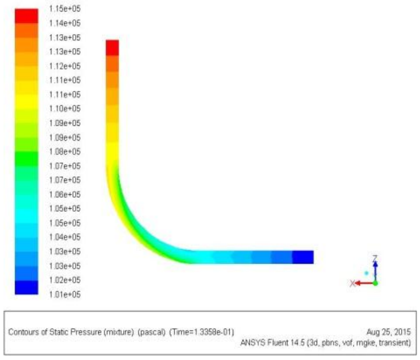
Table1: Properties of materials

Properties	oil	water
Density(kg/m^3)	960	998.2
Viscosity(kg/m-s)	0.048	0.001003
Volume Fraction	0.8	0.2

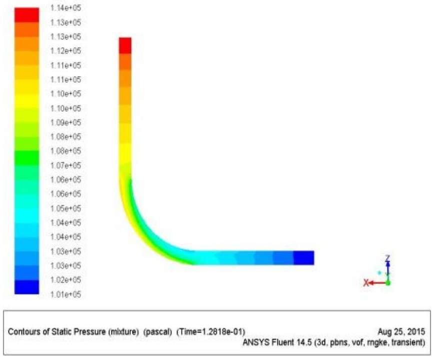
III. CALCULATION RESULTS AND ANALYSIS

A. Pressure field analysis

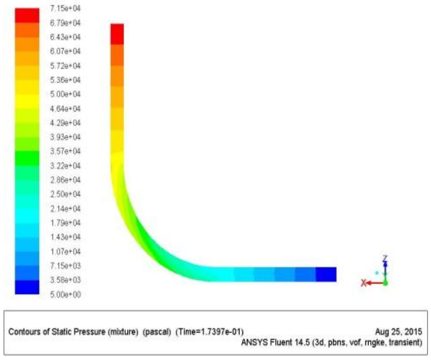
In the first place, as shown in Figure 2. In the case of elbow with different curvature-diameter ratio, the initial velocity was set as 5m/s. The highest pressure was produced at the entrance, compare with the pressure of inlet, the outlet pressure reduced. The reason is that fluid change its velocity direction rapidly when passing through the bending section, cause fluid impact force, form the whirlpool and the secondary motion phenomenon, reduce the energy and pressure of the fluid. Secondly, the pressure at the outer wall of the bending section is greater than the pressure at the inner wall. The analysis shows that it is because the pressure difference which caused by the secondary motion phenomenon. Then, with the increase of Rc/D, the corresponding pressure gradient decreases. On account of the Rc/D is greater ,the bend section is more gentle, then the flow of the fluid is relatively flat, the smaller the impact of the fluid is, the smaller the pressure gradient is.



Rc/D=5

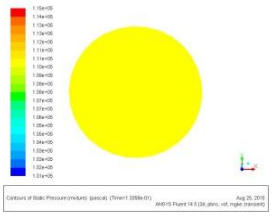


Rc/D=6

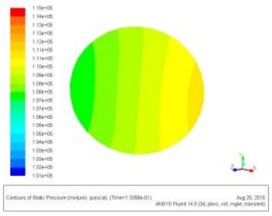


Rc/D=6.7

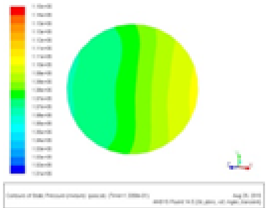
Fig.2- Pressure contours of different Rc/D values



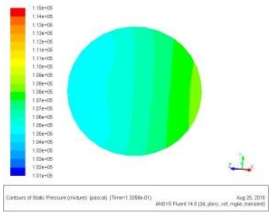
θ =0°



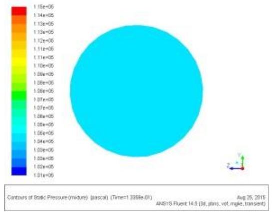
θ =30°



θ =45°



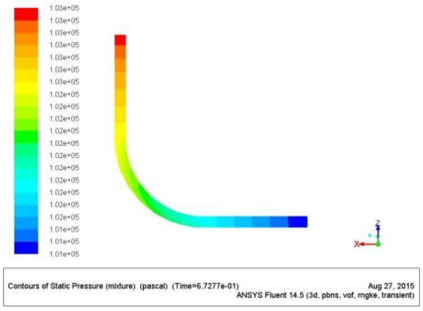
θ =60°



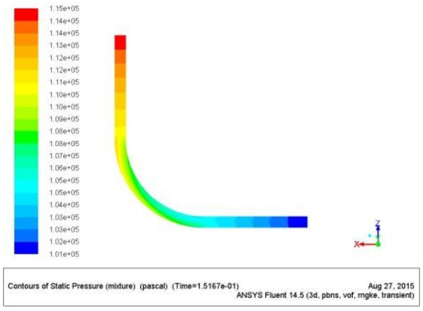
θ =90°

Fig.3- pressure contours of section under different θ values

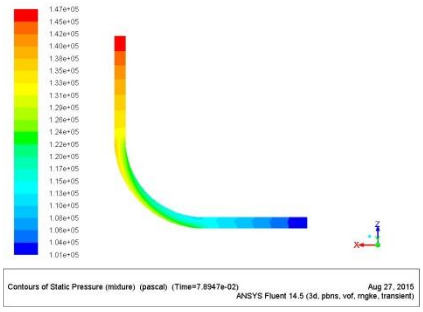
As shown in Figure 4,when Rc/D=5, the initial velocity is 1m/s, 5m/s, 10m/s, respectively, consistenting with the actual situation, the pressure drop increased in turn. The greater the velocity is, the greater the impact. Then produce a greater pressure drop across the elbow.



V=1m/s



V=5m/s



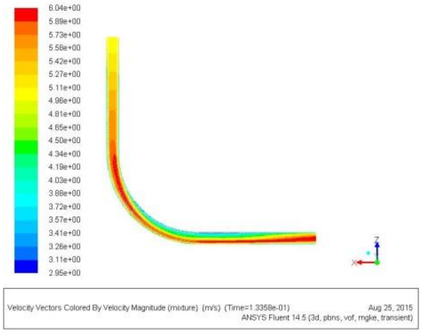
V=10m/s

Fig.4 Pressure contours of different initial velocity

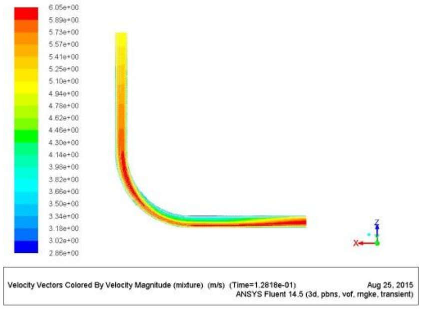
B. Velocity field analysis

The below Figs. show that velocity distribution of elbow with different curvature-diameter ratio under the same initial conditions. At the entrance, velocity is maintained at an initial rate of about 5m/s, then gradually increases with the flow process. It reached the maximum value at bending section. And at the same section, the velocity difference is generated. We can see that the velocity of the inner wall is smaller than that of the outer wall.

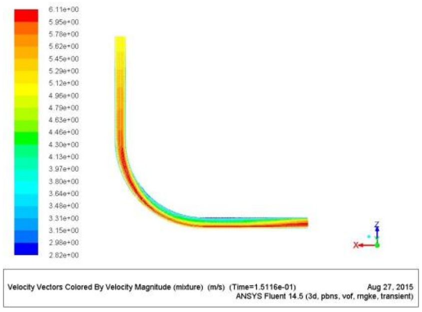
It can also be seen from the Figs. The larger the curvature-diameter ratio is, the greater the velocity difference is. When Rc/D was equal to 5, 6, 6.7, respectively, the corresponding maximum speed difference was 3.09m/s, 3.29m/s, 3.19m/s. Analysis of its causes, when fluid through a bending section, lateral pressure generated by impact, so the velocity direction has been shifted, formed secondary motion and produced velocity difference. The elbow with a larger Rc/D produced greater centrifugal force, to generate the secondary motion easier and cause greater velocity difference.



Rc/D=5

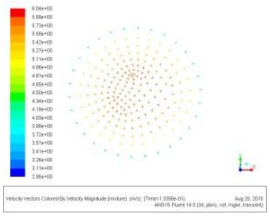


Rc/D=6

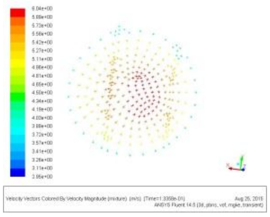


Rc/D=6.7

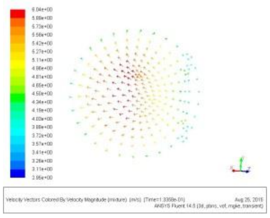
Fig.5-Velocity vector diagram of different Rc/D values



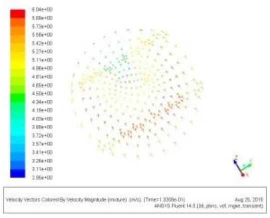
θ =0°



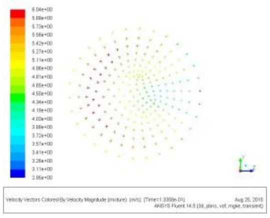
θ=30°



θ=45°



θ=60°



θ=90°

Fig.6- velocity vector of section under different θ values

It can be seen from Fig.6 When θ=0°, the velocity distribution of the elbow was uniform, the velocity increased from wall to center. From θ=30° to θ=90°, the velocity center gradually shifted to the Z axis. Finally, it reached the maximum offsets when θ=90°. At the same section, the velocity difference was also the biggest. At this time, the whirlpool and the secondary motion phenomena shot up, it has a bad influence on the fluid transportation.

IV. CONCLUSIONS

This paper used RNG k－ε turbulence model and VOF multiphase flow model to calculate internal flow field when oil water mixture got through the elbow. The internal flow field of different Rc/D values and different initial velocitys were simulated respectively. The following conclusions are drawn.

(1)Fluid flow through the elbow will produce a secondary motion phenomenon, causing pressure drop. And the pressure and velocity are larger at the outer wall than the inner wall. It will lead to an increasing in the resistance of the fluid transport process, and reduce the fluid transportation efficiency.

(2)At the entrance, the larger the initial velocity is, the greater the pressure drop inside flow field, and the greater the dissipation of energy.

(3)When Rc/D is larger, the greater the velocity difference, secondary motion phenomenon is more obvious, but the smaller of pressure loss. So it should be overall considered that the influence of curvature-diameter ratio (Rc/D) on velocity and pressure. Choosing elbow with appropriate curvature-diameter ratio, increasing the transportation efficiency.

(4)In this paper, we only did research from the perspective of simulation software. Which involved lots of simplifications and hypothesis. And it can’t completely simulate the situation on the scene. If we want to study the flow field inside the elbow more accurately, we need to do further research on the basis of the experiment. So as to provide useful guidance for production design.

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