# The Establishment and Verification of 90° Elbow Pipe with Circular Cross Section Internal Pressure Distribution Model

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**Abstract.** The flowing condition and the pressure on inner surface of ethylene in the 90°elbow pipe were simulated by means of FLUENT software, on the condition of 4 kinds of fluid density $\rho$, fluid inlet velocity $v$, fluid outlet pressure $P_0$, degree curvature $k$=$R/d$ respectively. The database of elbow pipe pressure on inner surface distribution is established meanwhile. Based on the property of Normal distribution, Trigonometric function, Exponential function and taken account of elbow pipe pressure on inner surface distribution under different parameters influence, the elbow pipe pressure distribution model can be fitted out by 1stOpt software. Through compared the simulated values by FLUENT with computed values by Equation, the agreement is high, that the maximum relative error between them is only 0.024%. The research conclusion contributes to structural design and safety evaluation of the elbow pipe.

## Introduction

The elbow pipe is an important and indispensable component in pipeline system. Due to the convex edge pressure of elbow pipe is much greater than concave edge. The gap of the pressure between convex edge and concave edge often result in the crack, explosion, and fire. This is one of the important reasons for the pipeline system damage [1].Ethylene industry is the core of the petrochemical industry. Ethylene transport mainly adopts pipeline transportation, such as Shanghai Jinshan Petrochemical Factory to Shanghai Chlor Alkali Factory pipeline. The length of pipeline is about 60 km, that crossing the Huangpu River and more than 200 rivers. Considering the pollution and explosion of the ethylene, the safety performance of the pipeline is very important [2]. Hence, Ethylene is regarded as fluid medium.

## The numerical simulation and analysis of flow property in elbow pipe

The geometry parameters of the elbow pipe and the flow parameters of the ethylene selection are referenced [3].The density of ethylene is 200kg/m$^3$, 250kg/m$^3$, 300kg/m$^3$ and 350kg/m$^3$ respectively. The fluid inlet velocity is 10m/s, 12m/s, 14m/s and 16m/s respectively. The outlet pressure is 6Mpa, 7Mpa, 8Mpa and 9Mpa respectively. The degree curvature of elbow pipe is 1.0, 1.5, 2.0 and 2.5 respectively. The flowing conditions of ethylene were simulated by means of FLUENT software, on different condition mentioned above. The database of elbow pipe pressure on inner surface distribution is established, and the regularity of distribution is analyzed.

According to the symmetry of elbow pipe, take the half of elbow pipe as the research object. The elbow pipe model is built and meshed by Gambit software. The angle of bending $A$=90°, inner diameter $d$ =355mm, degree curvature $k$=$R/d$=1.5, axial angle $\alpha$ and circle angle $\beta$, is built as shown in Fig.1. and Fig.2.

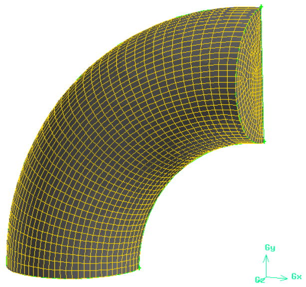


Fig.1.The model and mesh generation of elbow pipe

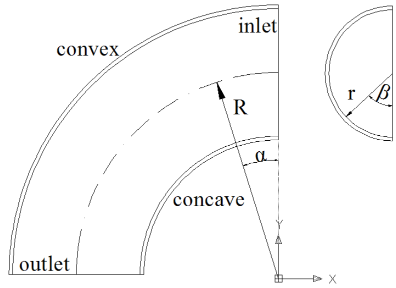



Fig.2. The coordinate system of elbow pipe

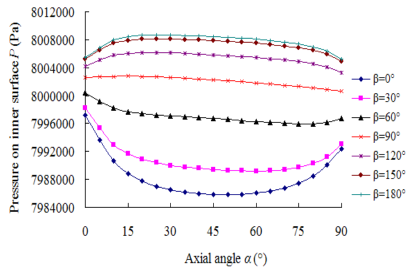



Fig.3. The pressure with $\alpha$ in different $\beta$ cross section

On the condition of ethylene density $\rho$=300kg/m$^3$, fluid inlet velocity $v$=10m/s, fluid outlet pressure $P_0$=8Mpa, the variation of the pressure with $\alpha$ in different $\beta$ cross section is shown in Fig.3.The convex edge ($\beta$=180°) of elbow pipe form area of high pressure. The pressure from the entrance ($\alpha$=0°) begins to increase gradually and reached the maximum 8008664.0Pa at the position of ($\alpha$=25°, $\beta$=180°), then begins to decrease gradually. The concave edge ($\beta$=0°) of elbow pipe form low pressure area. The pressure begin to decrease rapidly from the entrance and reached the minimum 7985845.5Pa at the position of ($\alpha$=50°, $\beta$=0°), then increase gradually.

The variation of the pressure with $\beta$ in different $\alpha$ cross section is shown in Fig.4, the pressure increase gradually from the concave edge ($\beta$=0°) to the convex edge ($\beta$=180°). The gap of pressure between the concave edge ($\beta$=0°) and convex edge ($\beta$=180°) reach the maximum 22560.5Pa at $\alpha$=45°cross section. It is the dangerous cross section that often occur damage easily.

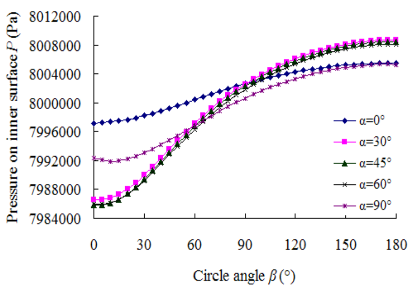



Fig.4. The pressure with $\beta$ in different $\alpha$ cross section

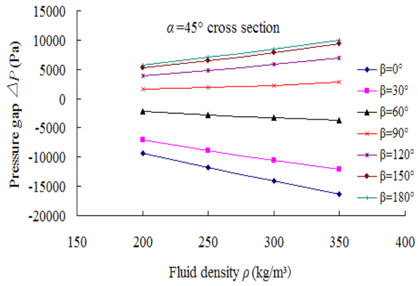



Fig.5. Relationship between the gas $\Delta P$ and fluid density

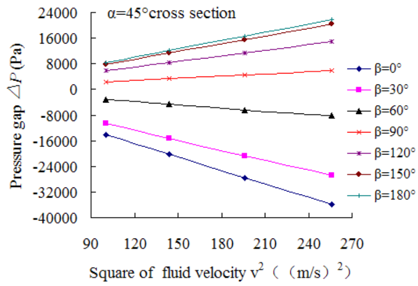



Fig.6. Relationship between the gap $\Delta P$ and spare of fluid velocity

## The effect of elbow pipe geometry parameters and ethylene flow parameter

The influence factor of pressure on inner surface is curvature radius $R$, inner diameter $d$, degree curvature $k=R/d$, axial angle $\alpha$ and circle angle $\beta$ of any position on the inner surface of elbow pipe, fluid density $\rho$, fluid outlet pressure $P_0$ and fluid velocity $v$. The distribution model of inner pressure can be got equation (1) that is referenced [4].

$$P = P_0 + f(k) f(a\ ,\ b) r v^2 \tag{1}$$

According to the data analysis, the pressure on inner surface of elbow pipe always reach the maximum 8008664.0Pa at the position of ($\alpha$=25°, $\beta$=180°), and the minimum 7985845.5Pa at the position of ($\alpha$=50°, $\beta$=0°). Based on the character of Normal distribution, the extreme value appeared at the axis of symmetry. As shown in Figure 3, when regarded $\alpha$=25° as the axis of symmetry, the law curve is asymmetry. Hence regarded $\alpha$=50° as the axis of symmetry , that attempt to calculate. The distribution of amplitude is used as $n_2$. Then the equation is $g(\alpha) = n_1 e^{-(\frac{\alpha-0.873}{n_2})^2}$ .

The variation of the pressure with $\beta$ in different $\alpha$ cross section is similar to the trigonometric function $n_0^{\cos(b)}$, and $n_0$>0, $n_0$≠1. When 0°≤ $\beta$≤ 180°, the $n_0^{\cos(b)}$ is monotone function. When 0<$n_0^{\cos(b)}$<1, $n_0^{\cos(b)} g(\alpha)$ makes $g(\alpha)$ decrease. When $n_0^{\cos(b)}$≥ 1, $n_0^{\cos(b)} g(\alpha)$ makes $g(\alpha)$ increase. It is corresponding to the law curve in Fig.3. The formation of $f(\alpha, \beta)$ are used trigonometric function $n_3 sin(2\alpha)+n_4$ that the cycle is $\pi$, and $n_5^{\cos(b)}$ in addition. The $f(\alpha, \beta)$ can be obtained equation (2). The undetermined coefficient is $n_0$, $n_1$, $n_2$, $n_3$, $n_4$, $n_5$.

$$\begin{aligned} f(a,b) &= n_0^{\cos(b)} g(a) + j(a,b) \\ g(\alpha) &= n_1 e^{-(\frac{\alpha-0.873}{n_2})^2} \\ j(a,b) &= n_3 \sin(2a) + n_4 + n_5^{\cos(b)} \end{aligned} \tag{2}$$

The gap between the pressure on inner surface of elbow pipe and the fluid outlet pressure $P_0$ is defined as $\Delta P$. At the $\alpha$=45° cross section (the dangerous cross section), the relationship between $\Delta P$ and the square of fluid velocity $v^2$ and the fluid density $\rho$ respectively is linear, as shown in Fig.5, Fig.6.

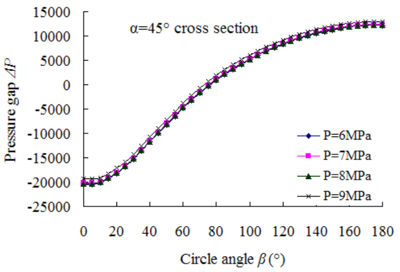


Fig.7. Relationship between the gas $\Delta P$ and outlet pressure

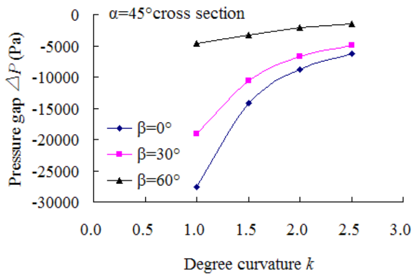


Fig.8. Relationship between the gas $\Delta P$ and degree curvature

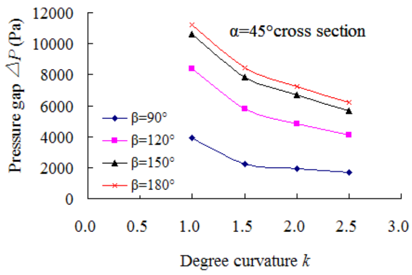


Fig.9. Relationship between the gas $\Delta P$ and degree curvature

On the condition of different outlet pressure, the variation of the $\Delta P$ with circle angle $\beta$ at $\alpha$=45° cross section is no difference, as shown in Fig.7.Thus $\Delta P=P-P_0$. The $\Delta P$ is increased with the degree curvature of elbow pipe $k$ decreased every 30° of circle angle $\beta$ .The relationship between them are approximate inverse proportion, as shown in Fig.8.and Fig.9. Thus $f(k)=n_6 k^{-1}$. The undetermined coefficient is $n_6$.

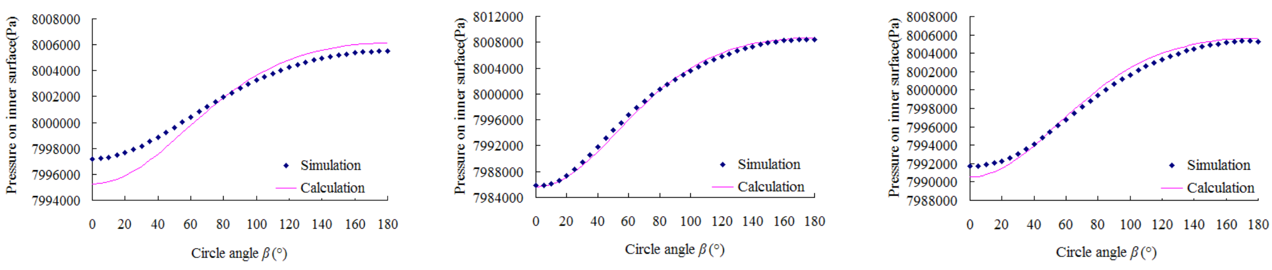
Through the mentioned analysis above and combined the undetermined coefficients, it can obtain equation (3). The undetermined coefficient is $n_0$, $n_1$, $n_2$, $n_3$, $n_4$, $n_5$.

$$\begin{aligned} P &= P_0 + [n_0^{\cos(\beta)} g(\alpha) + j(\alpha,b)]\rho v^2 / k \\ g(\alpha) &= n_1 e^{-(\frac{\alpha-0.873}{n_2})^2} \\ j(a,b) &= n_3 \sin(2a) + n_4 + n_5^{\cos(\beta)} \end{aligned} \tag{3}$$

## The determination and verification of elbow pipe pressure distribution model

According to the database of elbow pipe pressure on inner surface distribution, the distribution model can be fitted out by 1stOpt software. The equation (4) can be obtained.

$$\begin{aligned} P &= P_0 + [2.959^{\cos(\beta)} g(\alpha) + j(\alpha,b)]\rho v^2 / k \\ g(\alpha) &= -1.491 e^{-(\frac{\alpha-0.873}{2.182})^2} \\ j(a,b) &= 0.198\sin(2a) + 0.412 + 3.31^{\cos(\beta)} \end{aligned} \tag{4}$$



( a ) $\alpha$=0° ( b ) $\alpha$=45° ( c ) $\alpha$=90°

Fig.10. Comparison of simulated values and computed values of pressurewith $\beta$ in different $\alpha$ cross section

Through compared the simulated values by FLUENT on the condition of ethylene density $\rho$=300kg/m$^3$, fluid inlet velocity $v$=10m/s, fluid outlet pressure $P_0$=8Mpa, with computed values by Equation (4), the agreement is high, that the maximum relative error between them is only 0.024% at the position of ($\alpha$=0°, $\beta$=0°), as shown in Fig.10.

## Conclusions

The pressure distribution model is taken a full account of the geometry parameters of elbow pipe and the flow parameter of fluid. The significance of engineering conclusions can be got as followed:

Based on the pressure with axial angle $\alpha$ in different circle angle $\beta$ cross section and the pressure with $\beta$ in different $\alpha$ cross section, the function $f(\alpha, \beta)$ is made up by Normal distribution, Trigonometric function, and Exponential function.

The relationship between $\Delta P$ and the square of fluid velocity $v^2$ and the fluid density $\rho$ respectively is linear. The variation of the $\Delta P$ with circle angle $\beta$ is no difference. The relationship between $\Delta P$ and the degree curvature of elbow pipe $k$ is inverse proportion.

When fluid medium is transported in elbow pipe, the variation of pressure on inner surface is complex. It is significant to calculate and analyze the pressure, in order to keep working safe and design the elbow pipe. The pressure distribution model is composed of elementary function. Not only the pressure distribution model is relative simple and has few undetermined coefficients, but also the accuracy is high. When fluid medium is transported in the pipeline, give priority to reduce the fluid inlet velocity and increase the degree curvature of elbow pipe in order to reduce the pressure and ensure safety in transportation. It provides a theoretical basis for strength check and structural design of the elbow pipe.


## Acknowledgements

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