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Numerical Simulation of Fluid Carrying Pollutant Particles Erosion in Elbow Pipe Is Carried out by COMSOL

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Abstract. With the development of Marine energy to the deep and ultra-deep-water field, the severe environment of high temperature and high pressure in the engineering background makes the problem of flow security in oil and gas transportation system more serious and prominent. For this part of the underwater production and processing system, more stringent requirements are put forward. In order to study the erosion of fluid pipelines such as oil and natural gas, the COMSOL (*A large-scale advanced numerical simulation software*) finite element model was used. Under the condition of different flow parameters, the erosion trajectory of solid particles in the pipeline and the erosion failure rule of the bend are obtained. In this paper, the erosion wear rate of 90° pipe elbow is calculated, and three different erosion models are compared.
Keywords: Bending erosion; Particle trajectory; Numerical simulation.

1. Introduction

The crude oil and natural gas extracted from oil-gas well usually carry a certain number of solid particles, which cause serious erosion damage to the elbows, resulting in the thinning of the oil pipeline, which leads to the failure of the process system [1]. Secondly, the corrosion resistance layer in the pipeline will cause a certain degree of loss. The chemical corrosion inhibitor on the surface of the pipe will also be affected by erosion, leaving the more vulnerable material in the pipe wall exposed. At present, some scholars and enterprises in China study the effect of solid particles on pipeline erosion by building experimental platforms and conducting physical tests. Although this method can accurately reflect the erosion of pipeline caused by solid particles, it is easy to produce a large amount of dust due to its high-test cost and difficult operation [2]. In view of the inconvenience of the actual physical erosion test, it is of great practical significance to obtain the impact of solid particles on the erosion of pipelines by using the efficient and reasonable numerical simulation method.

2. The Erosion Models

2.1. Finnie Model

In 1958, Finnie put forward the micro cutting theory of erosion wear of ductile materials-micro cutting wear theory [3]. The wear of wall surface due to the erosion effect of particles is a complex function of particle impact, particle and wall properties. For most metals, erosion can be considered as a function of particle impact Angle and velocity [4,5].

$$E = kV_p^n f(\gamma) \tag{1}$$

Where, E is the dimensionless mass, V_p is the particle impact velocity, and $f(\gamma)$ is the dimensionless function of the impact Angle. The impact Angle is the Angle between the particle trajectory and the wall surface, and the exponent n is usually 2.3-2.5 [6,7].

2.2. DNV Model

The DNV (*An erosion model*) model [8] believes that the erosion results of pipeline components are ultimately determined by the mean collision Angle and velocity index of large-scale particles. The mean collision Angle of particles is obtained by tracking the movement trajectory of large-scale particles. Other parameters are investigated based on the experimental data, which is also a semi-empirical model [9,10].

$$e_r = Kf(\theta)\left(\frac{u_{rel}}{u_{ref}}\right)^n \tag{2}$$

Where, K=2.0e^{-9}, $f(\theta)$is the particle impact Angle function [11].

2.3. E/CRC Model

The research institution represented by university of Tulsa E/CRC (*An erosion model*) has divided the pipeline sand erosion problem into three steps: flow field simulation, particle tracking and impact damage calculation [12,13]. An effective prediction method is obtained for the sand erosion problem of single-phase gas transport with sand and gas-liquid multiphase mixed transport, especially under the condition of high gas-liquid transport ratio [14].

$$ER = C(HB)^{-0.59} F_s \upsilon_p^n F(\alpha) \tag{3}$$

Where, ER is the erosion rate, C is the material constant, HB is the Brinell hardness of the material, F_s is the shape coefficient of the particles, n is the velocity index, v_p is the collision velocity of the solid particles, and $F(\alpha)$ is a function of the collision Angle of the solid particles [15,16].

3. Method

The bending model was established in the software of COMSOL Multiphysics 5.4. For the geometric model, this paper adopts two cylindrical straight pipe segments with length of 1m and diameter of 2×10^{-1}m, and a 90-degree bend with radius of curvature of 6×10^{-1}m, as shown in Figure 1. A bend connects two straight sections. Water is set inside the pipe as the conveying fluid, and the accompanying pollutant particles are 1.7×10^{-4}m in size. In the pipeline, water fills the whole pipeline as a continuous phase, and pollutant particles are evenly distributed in the liquid phase water as a dispersed phase. Here, the transported water is treated as an incompressible fluid and the pollutant particles as uniform solid particles.

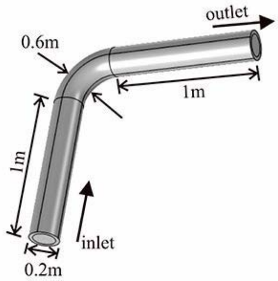

Figure 1. Elbow model.

In the process of model establishment, the established elbow is a symmetrical model about *xy* working plane. The calculation is simplified by modeling half of the pipe. According to the parameters selected by the model, the Reynolds number is Re_D=3.96×10^6. In this paper, the *k-ω* mode was selected because the high Reynolds number Re_D=3.96×10^6 of pipe diameter required the turbulence model with wall function. *k-ω* model is more accurate than *k-ε* model for flow with strong curvature. For grid division, structural grid is adopted to reduce the computing cost of the model. The boundary layer grid is used to ensure full resolution of flows near the pipe wall. The surface mesh of elbow pipe adopts unstructured mesh in the form of automatic subdivision. Two kinds of two-dimensional grids, triangle and quadrilateral, are mainly used for corresponding processing. The grid contains 23,584 domain units, 6,634 boundary units and 523 edge units, as shown in Figure 2. The purpose of setting the relative tolerance to 1e^{-3} is to reduce the computation time.

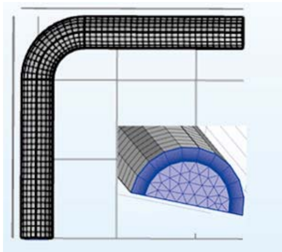

Figure 2. Generating mesh.

4. Results

Three different particle erosion models, Finnie, DNV and E/CRC, were used to simulate the erosion wear rate on the wall of the curved pipe. Set the inlet speed to 15m/s, and the simulation results are shown in Figure 3.

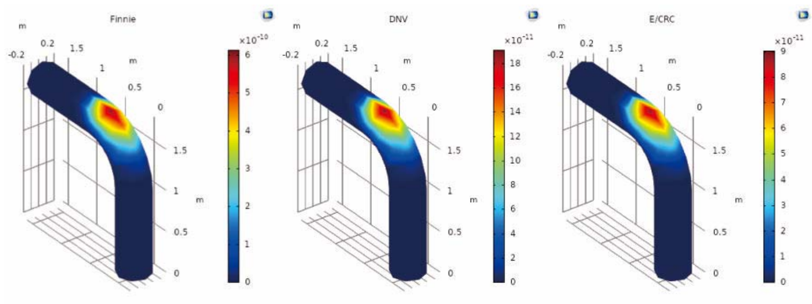

Figure 3. Erosion wear rate on pipe wall.

According to the comparative analysis of the three models, the maximum corrosion wear rates of Finnie and DNV erosion models were 6.13×10^{-10}kg/(m^2·s) and 1.91×10^{-10}kg/(m^2·s), respectively, while the maximum corrosion wear rates of E/CRC erosion models were 9.03×10^{-11}kg/(m^2·s). The comparison shows that the E/CRC model has the smallest maximum corrosion rate compared with the former two.

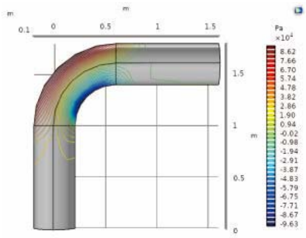

Figure 4. Pressure contour map.

According to the pressure contour map, it can be seen that at the elbow position, the pressure on the outside of the pipe is greater than that on the inside. This is because most fluids change direction under centrifugal force. The pressure on the outer wall is greater than that on the inner wall due to the erosion of the fluid. It can be seen from the image that the inner pressure is negative and the pressure of elbow position is increasing from the inside out, as shown in Figure 4.

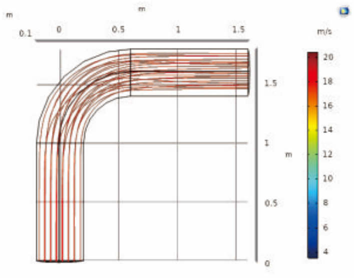

Figure 5. Velocity flow diagram.

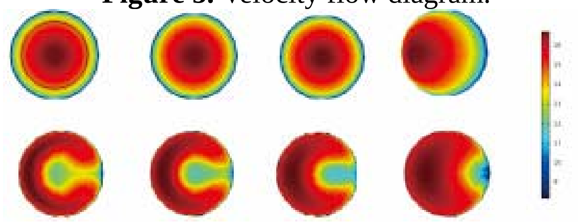

Figure 6. Velocity profile.

When the fluid enters the straight section, its central position velocity is maximum. When the fluid passes through the pipe bend position, the flow direction of the fluid changes, and the velocity flow diagram of the bend is shown in Figure 5. Combined with the velocity profile, it can be seen that the velocity distribution changes accordingly, as shown in Figure 6. When the first straight pipe section enters the elbow position, the velocity inside the pipe is larger. With the further flow of the fluid, the fluid inside the pipe has a certain separation phenomenon. The flow direction changes when the elbow position enters the second straight pipe section. At the same time, the flow velocity distribution is changed by centrifugal force and gravity. At this point, the velocity on the outside of the pipe is larger, while the velocity on the inside is smaller.

The trajectories of pollutant particles in the fluid were tracked and analyzed, and the extent of erosion on pipe elbow was compared under different inlet velocities. In this paper, 2m/s, 4m/s, 6m/s, 8m/s, 10m/s, 12m/s, 15m/s, 18m/s and 20m/s are respectively the inlet velocity of the elbow as the independent variable for erosion simulation, as shown in Figure 7.

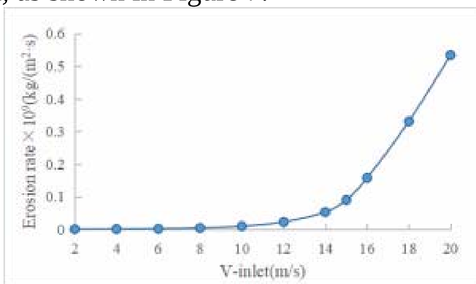

Figure 7. The change trend of erosion rate at different inlet velocities.

According to the change trend chart of erosion rate, the erosion rate at the elbow position is analyzed. The higher the inlet velocity, the higher the erosion rate. When the inlet velocity is in the range of 2m/s-10m/s, the erosion rate at the elbow position of the pipeline slowly increases. However, when the inlet velocity is in the range of 10m/s-20m/s, the erosion rate increases significantly. In this model, 10m/s is the inflection point of erosion rate growth.

Pollutant particles are carried into the pipeline by the fluid. In the straight pipe section, the particles can be regarded as evenly distributed in the continuous phase as the dispersed phase. At this time, the stability of the fluid is good, and the incidence Angle of pollutant particles is larger. At the pipe bend, the outside of the pipe creates a resistance to the flow direction of the fluid, causing the flow direction to change. The incidence of pollutant particles in the elbow position of the sharp Angle is smaller, resulting in cutting erosion of the pipeline, as shown in Figure 8.

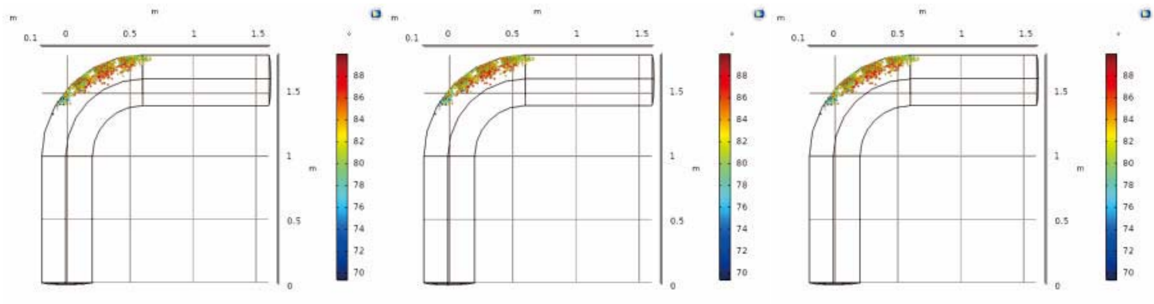

Figure 8. Particle trajectory.

By comparing the movement process of pollutant particles in the bend with different inlet velocity, the change of incident acute Angle is obtained. With the increase of inlet velocity, the incident acute Angle of particles increases, but the change range is small and still smaller than the incident acute Angle of straight pipe segment.

5. Conclusion

(1) Finnie, DNV and E/CRC are three different particle erosion models. For the same elbow under the same working condition, the Finnie model has the largest erosion rate, while the E/CRC model has the smallest erosion rate.

(2) When the fluid carries pollutant particles into the elbow position, the velocity outside the pipe is large, and the fluid flow direction changes at the elbow position. The elbow position under pressure, the outside of the larger, the inside pressure presents a state of negative pressure.

(3) The erosion rate of the bend increases with the increase of inlet velocity. The outer wall of the connection between the straight pipe section and the elbow is the part with large erosion loss. With the increase of inlet velocity, the erosion position moves up to the outer pipe wall of the elbow.

(4) The erosion of the bent pipe is mainly divided into two parts. The second part is the elbow part with a small incident acute Angle, forming a cutting erosion loss. Cutting erosion is the main cause of bending failure.

In the past, the author only analyzed and studied the erosion process of pollutant particles in pipelines based on one model, but the text adopted three different models to study, so as to reach a more reliable conclusion. The different pressure on both sides of the pipeline is analyzed and explained. According to the different inlet velocity, the offset erosion position is studied. The introduction of the concept of incident Angle makes the conclusion of the paper more perfect. In this paper, pollutant particle erosion in elbow pipe is simply analyzed and studied, and the basic parameters of pipe inlet will be further analyzed and compared in the future for the conveying medium.

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