Numerical Simulation of Elbow Erosion in Liquid-Solid Two-Phase Flow

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Abstract. In order to study the erosion and wear of elbows caused by solid-liquid two-phase flow, CFD numerical simulation of elbows with different geometric parameters was carried out based on hydrodynamics and tribology theory. The rules of geometric parameters and wear rate of elbows were summarized, and the wear mechanism of pipelines was analysed with related theories. The main conclusions are as follows: the maximum erosion rate decreases with the increase of the pipe diameter and bending angle and increases with the increase of the pipe length and bending radius. Among the above factors, the bending angle has the greatest impact on the maximum erosion rate of the pipeline.

1. Introduction

In pipelines such as tailings paste slurry transport pipelines, concrete pumping pipelines, deep-sea oil and gas production pipelines, the two-phase flow composed of liquid and particulate matter has a non-negligible erosion effect on the pipe wall, and this adverse effect will lead to the decline of pipeline strength, longevity, and reliability. In order to grasp the erosion mechanism of the pipeline and reduce the amount of erosion of the pipeline, some experiments and numerical studies have been carried out in this field [1-5].

According to the conclusions of Thiana A. Sedrez et al [6], the numerical simulation of the solid-liquid two-phase flow or multiphase flow using the Euler-Lagrangian method can predict the maximum erosion rate, erosion position and erosion mode that are consistent with the actual experiment. Amir Mansouri et al[7] carried out a numerical simulation of the erosion of water sand in a 90° elbow, and proposed that wall calculation using wall function model can significantly affect the erosion prediction results of small particles (25 μm); For large particles (256 μm), the wall function model and the low Reynolds number model predict the erosion depth to be very consistent with the experimental measurements. Wu Aixiang et al [5] improved the yield stress detection method of tailings paste based on the theory of slump yield stress, and proposed that the rheological properties of tailings paste conform to the Bingham fluid model.

Carlos Antonio Ribeiro Duarte et al [8] proposed a new wall design that can reduce the erosive wear of 90° elbow, and used the CFD model based on the Euler-Lagrangian method to make comparative
analysis on wall thickness loss. Liu Zhishuang [9] analysed the factor of slack line flow and the pipe wear mechanism in the tailings filled slurry transport pipeline and by the slurry physical property test and numerical simulation.

In this paper the tailings paste slurry is used as the two-phase flow test material, and its physical property data is obtained by rheological property test. Based on the numerical simulation of fluid mechanics and tribology theory, the difference of solid-liquid two-phase flow transportation pipeline is proposed. The geometric parameters affect the erosion rate of the pipe wall at the elbow, and the mechanism of the erosion of the pipe wall by two-phase flow is studied.

2. Methods and materials

The tailings used in this study were taken from a uranium tailings pond with a density of 1790 kg/m³ and a water content of 7.5%. Particle size distribution of the fine sand with a fineness modulus of MX=1.65 is shown in Table 1. Tailings, water, Portland cement and water reducing agent are formulated to study the tailings paste filling slurry. The cement used is a composite Portland cement with a density of 3000 kg/m³; the water reducing agent is mainly a β-naphthalene sulfonate formaldehyde condensate; the test water is taken from urban tap water.

Table 1. Distribution of tailings particle size

| Particle size d/mm | Proportion/% |
|--------------------|-------------|
| 1.25≤d             | 1.99        |
| 0.63≤d<1.25        | 8.96        |
| 0.315≤d<0.6        | 56.90       |
| 0.16≤d<0.315       | 16.50       |
| 0.08≤d<0.16        | 11.18       |
| d<0.08             | 4.47        |

According to the water reducing agent content of 1%, the cement-sand ratio is 1:5, and the mass concentration is 75% to prepare the tailings filling material paste slurry. The slurry was subjected to rheological parameters test using a MCR52 modular multi-function advanced rheometer. The test results are shown in Table 2:

Table 2. Rheological parameters of tailings filled paste slurry

| Mass Concentration | Yield stress τ₀/Pa | Plastic viscosity η/Pa·s | Density kg/m³ |
|--------------------|--------------------|--------------------------|---------------|
| 75%                | 99.17              | 1.105                    | 2050          |
| 75%                | 99.17              | 1.105                    | 2050          |

When studying the wear law of the paste on the pipeline, the numerical simulation test and the result analysis of the pipelines with different parameters will be carried out based on an L-form pipeline containing the elbow structure.

The pipe model is shown in figure 1

![Pipe model three views](image-url)
The pipeline parameters of the four test groups are designed as follows:

Pipe diameter variable test group: In the test group, inner diameter D (mm) of four pipes are set as 100, 150, 200 and 250 respectively; Pipe length variable test group: In the test group, straight pipes length L1+L2 (mm) of four pipes are set as 750+1500, 1000+2000, 1250+2500 and 1500+3000 respectively; Bending radius variable test group: in the test group, bending radii R (mm) of four pipes are 150, 300, 450 and 600; Bending angle variable test group: In the test group, four pipes have bending angles (°) of 75, 90, 105, and 120.

3. Results and discussion

3.1. Influence of pipe diameter, pipe length, bending radius and bending angle on erosive wear

When the pipe diameter is 100, 150, 200 and 200mm, the erosion rate cloud diagram of the pipe elbow is shown in Figure 5: the wall surface of the outer arc and the upper wall of the downstream are prone to erosive wear, while the erosion rate of the inner arc wall surface is low. The maximum wear rate of the paste transportation pipeline is shown in Fig. 2. The variance of the maximum erosion rate of the diameter test group is \( \sigma^2 = 1.275 \times 10^{-16} \).

A linear regression model was established for the maximum erosion rate of the independent variable \( D \) (mm) and the dependent variable (kg·s⁻¹·m⁻¹), as shown in Fig. 3. The results of linear regression show that the maximum erosion rate (kg·s⁻¹·m⁻¹) is negatively correlated with the pipe diameter \( D \) (mm).

It is not difficult to find that the pipe diameter \( D \) (mm) is proportional to the pipe cross-sectional area \( \pi(D/2)^2 \) (mm²), so when the pipe diameter is doubled, the pipe area is increased by four times. The interaction between the pipe and the paste is greatly reduced, so the maximum erosion rate is also reduced.
When the pipe length is (750+1500), (1000+2000), (1250+2500), or (1500+3000)mm, the outer arc wall surface and the upper wall surface of the downstream are prone to erosive wear, while the erosion rate of the inner arc wall surface is low. The maximum wear rate of the paste transport pipeline is shown in Fig. 8. The variance of the maximum erosion rate of the pipe length variable test group is \( \sigma^2 = 2.376 \times 10^{-17} \).

A linear regression model was established for the maximum erosion rate of the independent variable \( L_1+L_2 \text{(mm)} \) and the dependent variable (kg·s⁻¹·m⁻¹). The results of linear regression show that the maximum erosion rate (kg·s⁻¹·m⁻¹) is positively correlated with the pipe diameter D (mm).

When the bending radius is 150, 300, 450 and 600mm, the wall surface of the outer arc and the upper wall of the downstream are prone to erosive wear, while the erosion rate of the inner arc wall is low. The variance of the maximum erosion rate of the bending radius variable test group is \( \sigma^2 = 7.443 \times 10^{-17} \).

A linear regression model was established for the maximum erosion rate of the independent variable \( R \text{(mm)} \) and the dependent variable (kg·s⁻¹·m⁻¹). The results of linear regression show that the maximum erosion rate (kg·s⁻¹·m⁻¹) is positively correlated with the bending radius R(mm).

When the bending angle is 75, 90, 105 and 120°, the wall surface of the outer arc and the upper wall of the downstream are prone to erosive wear, while the erosion rate of the inner arc wall surface is low. The variance of the maximum erosion rate of the test group of the bending angle variable is calculated as: \( \sigma^2 = 1.420 \times 10^{-16} \).

A linear regression model was established for the maximum erosion rate of the independent variable \( \theta \text{(°)} \) and the dependent variable (kg·s⁻¹·m⁻¹). The results of linear regression show that the maximum erosion rate (kg·s⁻¹·m⁻¹) is negatively correlated with the bending radius R(mm).

3.2. Comprehensive analysis of erosive wear of various parameters of pipelines

Regarding the wear rate test of the paste transport pipeline conducted in this study, the differences between the pipeline test groups are shown in Table 3:

| Variable type     | \( \sigma^2 \)       | Sort | \( |B_i| \)          | Sort |
|-------------------|----------------------|------|-------------------|------|
| Pipe diameter     | \( 1.275 \times 10^{-16} \) | 2nd  | \( 1.523 \times 10^{-10} \) | 2nd  |
| Tube Length       | \( 2.376 \times 10^{-17} \) | 4th  | \( 4.819 \times 10^{-12} \) | 4th  |
| Bending radius    | \( 7.443 \times 10^{-17} \) | 3rd  | \( 4.288 \times 10^{-11} \) | 3rd  |
| Bending angle     | \( 1.420 \times 10^{-16} \) | 1st  | \( 6.060 \times 10^{-10} \) | 1st  |
It can be intuitively found that changing the bending angle of the pipe has the most obvious influence on the maximum erosion rate; changing the pipe diameter has the second most significant effect on the maximum erosion rate; changing the bending radius has not obvious influence on the maximum erosion rate; changing the length of the pipe, the impact on the maximum erosion rate is the least obvious.

4. Concluding
The main findings are as follows:
(1) The maximum erosion rate of the tailings paste transportation pipeline has the following relationship with the parameters of the paste transportation pipeline: the maximum erosion rate increases with the increase of the pipe length, increases with the bending radius of the elbow, and decreases with the increase of bending angle.

(2) The four types of pipeline parameters affecting the maximum erosion rate of the tailings paste transportation pipeline: pipe diameter, pipe length, bending radius of the elbow and bending angle of the elbow. Among them, the bending angle has the greatest influence on the maximum erosion rate of the pipe; the influence of pipe diameter on the maximum erosion rate of the pipeline is second, the influence of the bending radius is small, and the length of the pipe is the least affected.

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