Effect of Particle Shape on Pipeline Damage in Liquid-Solid Two-Phase Flow

Lumin Chen¹, Zhiyong Zhao¹,*, Shijie Zhang² and Yuxiang Sun¹

¹Zhengzhou University of light industry, Zhengzhou, China
²Chongqing University, chongqin, China

*Corresponding author e-mail: 510311944@qq.com

Abstract. The shield machine is an indispensable mechanical equipment in the construction of urban rail transit. The mud shield is currently the most commonly used in urban rail transit construction. For the circulation system of the mud-water shield, the damage of the different shapes of the particles to the slurry pipeline was studied. According to the shape of clay, stone and gravel in practice, five different shapes of particle models were established for the sake of simplicity. In order to better study the characteristics of different materials, the particle model was established by discrete element software EDEM, and the mud model was established by fluid software Fluent. The fluid model is then coupled to the particle model in the discrete element. The effect of the movement of the particles in the pipe and the presence of the particles on the flow of the slurry in the pipe is analyzed. The study found that under the same volume, the shape of the particles has little effect on the fluid, but the damage to the pipeline is quite different. Among them, the lower the sphericity, the greater the collision number and energy loss between the particles and the pipeline.

1. Introduction

The shield machine is an indispensable large-scale mechanical equipment for urban development and construction. As the urban population continues to gather, the availability of urban space above the ground continues to decrease, and traffic pressures are increasing. Therefore, the rational and effective development of underground space resources has become an important way to solve this phenomenon.

The mud-water circulation system is an important part of the shield machine. It plays an important role in transporting the slag in the shield machine. The study on the movement characteristics of the slag particles in the pipeline of the mud-water circulation system can effectively solve the blockage of the shield machine. Wear and other phenomena. The mud-water circulation system belongs to the liquid-solid two-phase flow. At present, some research has been done on the liquid-solid two-phase flow, and various mathematical models have been established, such as single fluid model, multi-fluid model, particle orbit model, etc. [1-2] At the same time, considering the interaction between particles and fluids has made great progress. There are two main models: Kuo et al. [3] proposed discrete element model (DEM). Based on the Euler-Langrign model and Gidaspow [4], the Euler-Euler model based on particle dynamics is proposed. However, the study of solid-liquid two-phase flow still has great limitations, and the influence of particle shape cannot be considered.
In this paper, a section of the pipeline in the mud-water shield circulation system is intercepted, five kinds of particles of different shapes are established, the motion characteristics of the particles are studied, and the influence of the different shape of the particles on the damage of the pipeline is explored.

2. Mathematical model
Any flow problem is governed by the law of conservation of the physics. A mathematical model describing the flow characteristics from the law of conservation of mass and the law of conservation of momentum can be expressed as follows.

2.1. Continuity equation

\[
\frac{\partial}{\partial t} \left( \alpha_i \rho_i \right) + \nabla \left( \alpha_i \rho_i \mathbf{u}_i \right) = 0
\] (1)

In the middle, \( i = f, p \) represents liquid phase and particle phase, \( \nabla \) Laplace operator, \( \alpha \) indicates the volume fraction of fluid and particles, \( \rho \) Indicates the density of the fluid, \( \mathbf{u} \) express velocity vector.

2.2. Momentum equation

\[
\frac{\partial}{\partial t} \left( \alpha_i \rho_i \mathbf{u}_i \right) + \nabla \left( \alpha_i \rho_i \mathbf{u}_i \mathbf{u}_i \right) = -\alpha_i \nabla p + \nabla \tau + \alpha_i \rho_i g + M_i
\] (2)

In the middle, \( i = f, p \) represents liquid phase and particle phase, \( p \) express static pressure, \( \tau \) express shear stress, \( M \) Means the exchange of momentum between two phases.

2.3. Discrete phase governing equation
The particles start to move in the pipeline due to the action of the fluid. The forces acting on the particles mainly have dragging force and buoyancy.

The buoyancy formula of the particles is

\[
F = \rho_f V g
\] (3)

In the middle, \( \rho \) is liquid density, \( g \) is acceleration of gravity, \( V \) is the volume that the particles are discharged from the liquid.

Drag force is

\[
F = \frac{1}{8} C_d \rho \pi d^2 \left| u_f - u_p \right| \left| u_f - u_p \right|
\] (4)

According to the external force of the particles, the equation of motion of the particles can be obtained according to Newton's second law.
\[ m \frac{du_p}{dt} = \sum F \]  

(5)

3. Model establishment

3.1. Particle model establishment

In order to determine the motion characteristics of different shapes of particles in the pipeline, five models with the same volume and different particle shapes were established for comparative analysis. For the simple calculation period, the single-ball, double-ball, three-ball and four-ball combination were used respectively.

| Table 1 Basic parameters |
|--------------------------|
|                          | Symbol | Unit   | Value |
| Particle density         | \( \rho_0 \) | Kg/m³ | 1500  |
| Particle-particle static friction coefficient | \( f \) | 1     | 0.3   |
| Young's Modulus of Particles | \( Y_0 \) | Pa     | 1.2e+10 |
| Poisson's ratio of particles | \( \mu_0 \) | 1     | 0.25  |
| Density of the pipe      | \( \rho_1 \) | Kg/m³ | 7800  |
| Young’s modulus of pipe material | \( Y_1 \) | Pa     | 2.0e+10 |
| Poisson's ratio of pipe  | \( \mu_1 \) | 1     | 0.3   |
| Particle-particle dynamic friction coefficient | \( \lambda_0 \) | 1     | 0.2   |
| Particle-particle recovery factor | \( e_1 \) | 1     | 0.01  |
| Particle-pipe static friction coefficient | \( \lambda_1 \) | 1     | 0.2   |
| Particle-pipe dynamic friction coefficient | \( \lambda_2 \) | 1     | 0.545 |
| Particle-pipe recovery factor | \( e_2 \) | 1     | 0.01  |
| Particle surface energy  | \( K \) | J      | 5     |
| Gravity acceleration    | \( G \) | m/s²  | 9.81  |

Figure 1. Particle model.
4. Simulation and results analysis using EDEM and Fluent coupling

4.1. Pipeline model

![Figure 2. Pipe model.](image)

In the mud-water circulation system of the shield machine, the pipe is cut as shown in the figure. The length of the pipe is 5 meters, the pipe angle is 15 degrees, the particle production speed is 2000 per second, and the simulation time is 5 seconds. The movement of the above five kinds of particles in the pipe was used to study the difference between the collision and wear of the particles with the pipe wall due to the difference in shape.

4.2. Simulation results

At the bottom of the pipeline, the movement attitudes of the five different shapes of the particles are quite different. The first and second types of particles mainly dominate the translational motion, and the third, fourth and fifth particles move in the tumbling and jumping manner. There are two main reasons for the above two different modes of motion: 1 at the bottom of the pipe, close to the pipe wall, the flow velocity of the fluid is small, and the pressure is strong. When the particles move at the bottom of the pipe, the pressure difference is generated due to the difference in flow velocity between the upper and lower parts of the pipe. To make the particles have a large lift; 2 due to the different shape of the particles, when the spherical particles move at the bottom of the pipe, a stable pressure difference can be formed, and the non-spherical particles are turned over by the flow rate, and the ratio of the upper and lower surfaces of the particles is constantly changing, the lift generated by the pressure, is also constantly changing, causing the particles to move in the fluid and collide with the wall of the pipe.

![Figure 3. Number of collisions between particles](image)
Figure 4. Tangential energy loss between particles and pipes

After the EDEM simulation is completed, the collision data of the particles in the pipeline for 1~5s can be obtained through software post-processing. Contrasting and analyzing the collision times of five different shapes of particles in the pipeline, within 0~1s, the fluid motion in the pipeline has not stabilized, the number of collisions of particles is less, and the collision times of particles with different shapes and pipelines have little change. After 1 s, the movement of the fluid is stabilized, and the number of collisions caused by the difference in particle shape varies greatly. Among them, the third and fourth types of particles have the most collisions.

The Figure 4 shows the loss of tangential energy of particles and pipes. The greater the loss of tangential energy, the more serious the wear of the pipes. After 1 s, the movement of fluids and particles in the pipeline is stabilized, and the tangential energy loss of the 3rd, 4th, and 5th shaped particles is the largest. The reason is related to the movement pattern of the particles in the pipeline. The first and second kinds of particles are mainly in the translational movement in the pipeline. 3, 4, and 5 kinds of particles mainly advance in a hopping manner, and the tangential energy loss caused by collision with the pipeline is large.

5. Conclusion
Contrasting and analyzing the movement of five different shapes of particles in the pipeline, the lower the sphericity, the more complex the movement posture of the particles, and the more collisions at the bottom of the pipeline, the greater the energy loss. The more the collision wear on the pipe is.

References
[1] Lu Huilin, Liu Wentie, Zhao Broadcasting, et al. Numerical simulation of dense gas-solid two-phase flow in pipe: particle dynamics method [J]. Journal of Chemical Industry and Engineering (China), 2000(01): 31-38.
[2] Lin Jiang. Study on gas-solid two-phase flow characteristics in accelerating zone in pneumatic conveying system [J]. Journal of Zhejiang University (Engineering Science), 2004(07): 100-105.
[3] Kuo H P, Knight P C, Parker D J, et al. The influence of DEM simulation parameters on the particle behaviour in a V-mixer [J]. Chemical Engineering Science, 2002, 57(17): 3621-3638.
[4] GIDASPOW D. Multiphase flow and fluidization [M]. Boston: Academic Press, 1994.