TRANSPORTATION CHARACTERISTICS OF PASTE FILLING MATERIAL IN CURVED PIPE-LINE

by

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Aiming at the problem of long-distance transportation of paste filling materials in underground pipe-lines, combined with the physical characteristics of paste filling materials, the transportation characteristics of paste filling materials in curved pipe-lines were studied by numerical simulation. The relationship between the flow resistance of paste filling materials in curved pipe-lines and the geometric size of curved pipe-lines was obtained, and the location of pipe-line damage was predicted.

Key words: *paste filling, pipe-line transportation, geometrical dimension*

Introduction

The coal-based solid waste paste filling technology is to mix and stir a series of solid waste materials such as coal gangue, fly ash and gasification slag into paste materials through cementitious materials, and pump them to the underground filling area through pipe-lines. While consuming solid waste, it can effectively control ground pressure, prevent surface subsidence, protect the ecological environment, and achieve the purpose of *one waste cures two hazards* [1, 2]. The coal-based solid waste paste needs to be transported by long-distance pipe-line from the ground preparation yard to the underground filling area. During the transportation process, it is found that the pipe-line wear or even rupture often occurs in the elbow area [3]. It seriously affects the stability of the filling process, causing environmental pollution and economic losses. It is urgent to carry out research work on the bending pipe-line transportation characteristics of paste filling materials.

Domestic and foreign scholars have done a lot of research on the pipe-line transportation of materials. Belem *et al.* [4]. Based on the rheological model, the stress state of slurry with different concentrations in the pipe-line is analyzed, and the calculation model of resistance along the pipe-line is proposed for the design of paste filling material conveying pipe-line system. Zhou *et al.* [5] studied the influence of slurry velocity, aggregate particle size and mass concentration on pipe-line corrosion and wear through the ring pipe test. Zhang *et al.* [6] used CFD-DEM method to study the influence of velocity, bend direction and bend angle on the wear location of bend during concrete conveying, and proposed a new collision strength model based on time-average impact force. Wang *et al.* [7] used CFD to model and analyze the slurry flow and wall impact information, and studied the effects of particle concentration, straight pipe length between elbows and inlet conditions on erosion behavior.

In this paper, the numerical simulation of the flow characteristics of curved pipe-line transportation is carried out for the physical properties of coal-based solid waste filling paste

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material, which provides theoretical support for the long-distance transportation of paste and the reinforcement of the vulnerable position of underground filling pipe-line.

The model introducing

The ANSYS FLUENT software was used for numerical simulation. The geometric model of the pipe-line was established by Space claim and the grid was divided to study the flow characteristics of the paste filling material in the elbow.

The simulation program

Aiming at the study of the influence law of the flow performance of the paste filling material in the elbow, the form of *straight pipe-bend pipe-straight pipe* was established, respectively. Six horizontal elbow transportation models with a total length of about 100 m and *a* diameter of ∅150 mm were used to analyze the influence of the elbow turning angle (90°, 60°, and 30°) and the curvature radius of the elbow (500 mm, 1000 mm, 1500 mm, and 2000 mm) of the multi-source coal-based solid waste filling material on its pipe-line flow characteristics. Six simulation schemes were designed by single factor rotation method. The simulation parameters were determined as follows: concentration 76%, gasification slag accounted for 20% of gangue, fly ash accounted for 40% of gangue, desulfurization gypsum accounted for 20% of gangue, bottom slag accounted for 20 % of gangue, Reynolds number Re = 163.30, density 1718, viscosity 2525, and the material was transported in the pipe-line in a laminar flow state.

The 3-D pipe model is a horizontal bend pipe with a bend angle of 90°, 60°, and 30°, as shown in fig. 1. Considering the boundary effect, the distance from the inlet to the outlet of the model is about 100 m, and the resistance generated by the filling material transported from the section 1-1 to the section 1-2 with the flow rate, v, is the resistance along the bend. The pipe curvature R = 0.5 m, 1.0 m, 1.5 m, and 2.0 m. Figure 1 shows the axial and cross-section element meshing of the elbow part with the inner diameter of the pipe ∅ = 150 mm and the curvature radius of the pipe R = 0.5 m.

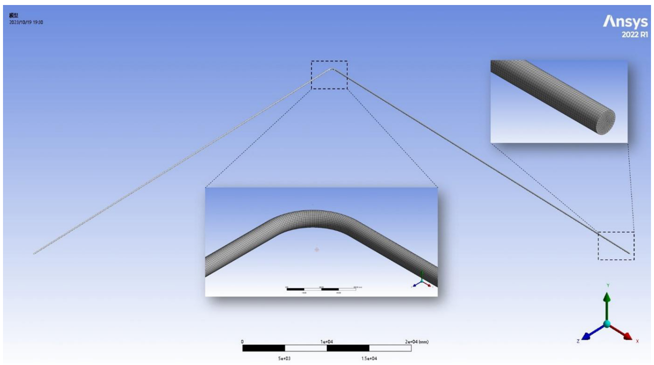

Figure 1. Pipe-line model grid graph

According to the physical properties of the paste filling material, the following assumptions are made for the model:

- *Continuity*. The material is continuous in the tube.
- *Isotropic*. The material is isotropic.
- *Incompressibility*. The material is incompressible.

The simulation procedure

The model is imported into FLUENT software. The specific simulation process is as: Check the grid, and view the specific grid information. Select the flow state as the laminar flow state, define the physical properties of the fluid, and use the laminar flow model in FLUENT. The inlet of the pipe model is set as the velocity inlet boundary, and the flow rates are 1.4 m/s, 1.6 m/s, 1.8 m/s and 2.0 m/s, respectively. The outlet is set to the pressure outlet. Considering the laminar flow state, the influence of wall roughness on the calculation is 0. The outside of the pipe-line is set to standard atmospheric pressure. The relaxation factors of pressure, density, volume force and momentum in the control parameters are set to 0.5, 1, 1, and 0.5, respectively. The flow field velocity is set and initialized. The number of storage iterations in the residual monitor is set to 1000. The number of iterations is 1000, and the iterative calculation is started until the model calculation reaches equilibrium. Get the numerical simulation results. The pressure difference at the inlet and outlet can be viewed through the area-weighted average pressure.

Results and analysis

Table 1 shows the numerical simulation results of elbow pressure. According to the pressure at Section 1-1 and Section 1-2 in Section 1, the pressure loss, ΔP, of the elbow is calculated, and then the local resistance, h, of the fluid-flowing through the elbow per unit length is calculated according to the energy loss equation:

$$h = \frac{\Delta P}{\gamma} + \frac{v_2^2 - v_1^2}{2\text{g}}$$

where ΔP is the pressure loss at the bended pipe position, γ – the bulk density of filling paste, v_1 – the speed at the entrance, and v_2 – the speed at the exit.

Table 1. Results of simulation scheme

Number	Turn angle	Curvature radius	Length	Pressure 1-1	Pressure 1-2	Frictional resistance
	[°]	[mm]	[mm]	[Pa]	[Pa]	[MPam^{-1}]
1	90	500	785	291208	285284	7.55
2	90	1000	1571	292979	282050	6.96
3	90	1500	2356	294681	278988	6.66
4	90	2000	3142	296299	275981	6.47
5	60	1000	1047	291934	284917	6.70
6	30	1000	524	299471	296189	6.26

Figure 2 shows the variation curve of the resistance along the bend with the turning angle of the bend. It can be seen from fig. 2 that the resistance along the bend increases gradually with the increase of the turning angle of the bend. When the bend angle increases from 30-60°, the resistance increases by 7.03%, and when the bend angle increases from 60-90°, the resistance increases by 4.15 %. From the analysis of the test results, it can be seen that the larger the turning angle of the elbow, the greater the shear stress and the greater the local resistance.

Figure 3 shows the variation curve of the resistance along the bend with the curvature radius of the bend. It can be seen from fig. 3 that the resistance along the elbow part gradually decreases with the increase of the curvature radius of the elbow, but the decreasing trend grad-

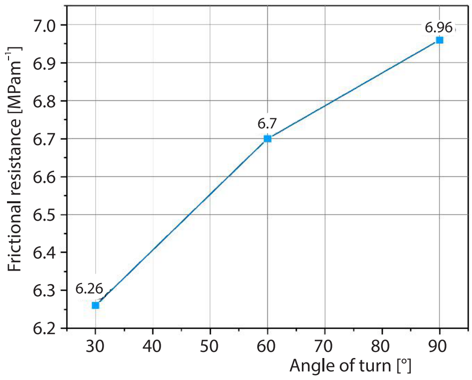

Figure 2. The influence of turning angle on the resistance along the way

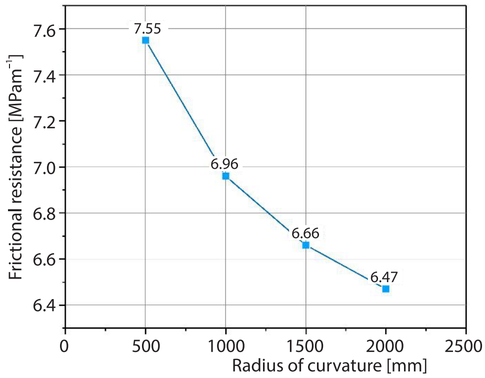

Figure 3. The influence of curvature radius on the resistance along the path

ually becomes smaller. For every 500 mm increase in the curvature radius of the elbow from 500 -2000 mm, the resistance along the elbow decreases by 7.81%, 3.97%, and 2.52%, respectively. From the analysis of the test results, it can be seen that the larger the curvature radius of the elbow, the smaller the shear stress and the smaller the local resistance.

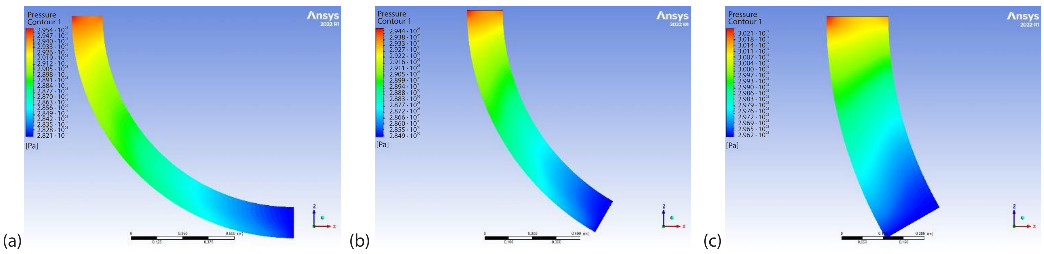

Figure 4. The influence of turning angle on the pressure distribution of filling slurry; (a) 90°, (b) 60°, and (c) 30°

The influence of the turning angle of the elbow on the pressure distribution of the filling slurry is shown in figs. 4(a)-4(c), and the influence of the turning radius, R, of the elbow on the pressure distribution of the filling slurry is shown in fig. 5. With the increase of turning angle, the pressure loss will increase, and the increase of turning radius will reduce the resistance along the way.

In general, the pressure of the slurry is the largest outside the inlet of the elbow, and the pressure reaches the minimum inside the outlet of the elbow as the slurry is pumped. Similarly, as shown in fig. 6, on the radial section of the pipe, the closer to the pipe wall, the smaller the slurry flow rate is, which is due to the boundary-layer effect between the slurry and the pipe wall. The outer edge pressure at the turning point of the pipe is greater than the inner edge of the same radial section. It can be

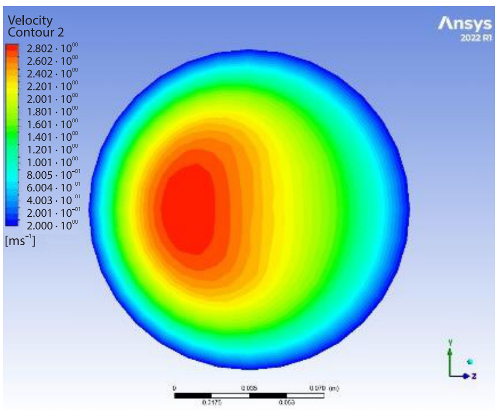

Figure 5. Bend pipe radial section slurry velocity distribution diagram

seen that the outer edge of the turning point of the pipe-line is more vulnerable than other parts in the pipe-line lay-out.

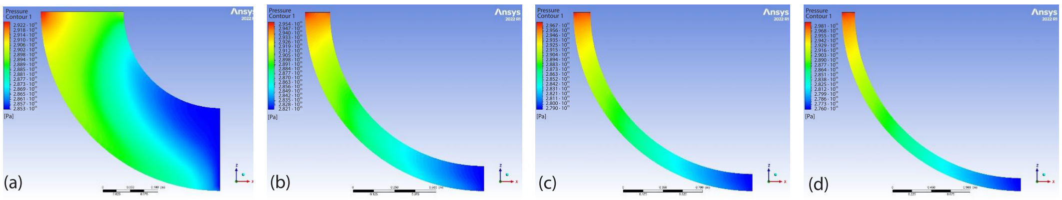

Figure 6. The influence of the curvature radius of 90° bending pipe on the pressure distribution of filling slurry; (d) *R* = 500 mm, (e) *R* = 1000 mm, (f) *R* = 1500 mm, and (g) R = 2000 mm

Conclusion

In this study, aiming at the problem of long-distance transportation of paste filling materials in underground pipe-lines, combined with the physical properties of paste filling materials, the numerical simulation method was used to study the transport characteristics of paste filling materials in elbows. The relationship between the flow resistance of paste filling materials in elbows and the geometric size of elbows and the prediction of vulnerable positions of pipe-lines were obtained. The specific conclusions are as follows. The resistance along the elbow increases with the increase of the turning angle of the elbow, decreases with the increase of the curvature radius of the elbow, and the decreasing trend decreases with the increase of the curvature radius. The inner wall of the pipe-line is vulnerable to wear. The outer side of the elbow inlet is the most seriously eroded, and the slurry pressure is the largest here, which is the most vulnerable and most vulnerable position.

Nomenclature

ΔP – pressure loss, [Pa]
v_1 – speed at the entrance, [ms^{-1}]
v_2 – speed at the exit, [ms^{-1}]

Greek symbol

γ – bulk density of filling paste, [Nm^{-3}]

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