# THE INFLUENCE LAW OF PIPE-LINE TRANSPORTATION FLOW OF MULTI-SOURCE COAL-BASED SOLID WASTE FILLING MATERIALS

by

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*Aiming at the problem of long-distance transportation of multi-source coal-based solid waste filling materials, combined with the physical characteristics of multi-source coal-based solid waste filling materials, the reliability of the simulation results is verified by comparing the numerical simulation with the measured data of the ring pipe experiment. The straight pipe conveying characteristics of multi-source coal-based solid waste filling slurry were studied by numerical simulation, and the variation law of resistance along the pipe during the flow of slurry in the pipe was obtained.*

Key words*: coal-based solid waste, numerical simulation, frictional resistance*

## Introduction

Multi-source coal-based solid waste cementing material is used for underground filling in coal mines as an innovative green mining technology [1, 2], which is of great significance to absorb coal-based solid waste, protect the surface ecological environment, alleviate the mine pressure of underground working face and control the surface subsidence. However, different from the traditional belt conveying method of solid filling, the underground filling of solid waste filling materials requires long-distance pipe-line transportation of multi-source coal-based solid waste filling materials. The precipitation, segregation and solidification of materials in the process of pipe-line transportation have an important influence on the transportation efficiency and economy [3, 4]. It is urgent to carry out the research on the flow characteristics of multi-source coal-based solid waste filling materials in pipe-line transportation.

Many scholars at home and abroad have studied the problem of pipe-line transportation of materials and obtained many useful results: Feng *et al.* [5] found that the flow rate of backfill slurry directly affects the transportation performance during pipe-line transportation, which in turn affects the blockage and wear of the pipe-line. Wang *et al*. [6] carried out the numerical simulation study of the resistance characteristics and local resistance characteristics, and studied the influence of filling material concentration, fine gangue rate, flow rate, pipe inner diameter and elbow curvature radius on the pipe flow of filling material. In the process of pipe-line transportation, Liu *et al.* [7] coarse-grained tailings deposition and fine-grained tailings suspension formed

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three regions: the velocity along the cross-section of the pipe-line is arched, the velocity near the middle of the pipe-line is high, and the velocity near the pipe wall is low.

This paper mainly focuses on the numerical simulation of the physical characteristics of multi-source coal-based solid waste filling materials such as gangue, desulfurization gypsum, fly ash, gasification slag and bottom slag, and provides theoretical support for the long-distance transportation of multi-source coal-based solid waste.

## Numerical simulation reliability verification

To verify the correlation between the numerical simulation and the real situation, we carried out a scale experiment (the loop pipe experiment), and used the numerical simulation method (1:1) to restore the pipe-line transportation of the loop pipe experiment, as shown in fig. 1.


**Figure 1. Loop tube experiment process and re-engraved in FLUENT**

The experimental conditions of the ring pipe are input into ANSYS FLUENT for simulation. The corresponding observation sections *Numerical simulation reliability verification*, *Simulation scheme design*, and *Numerical modeling* are arranged at the position of the ring pipe pressure gauge.

The measured data and numerical simulation results of the loop pipe experiment are shown in tab. 1. The error between the simulation results and the actual measured data of the loop tube experiment is less than 5.1%, so we believe that the numerical simulation part of this study is a correct simulation in line with the actual situation.

**Table 1. Comparison of experimental and numerical simulation data of loop pipe**

| Data sources | Pressure gauge 1 [Pa] | Pressure gauge 2 [Pa] | Pressure gauge 3 [Pa] | Frictional resistance [kPam$^{-1}$] |
|---|---|---|---|---|
| Experiment | 51293.530 | 46563.930 | 27328.110 | 0.797 |
| Simulation | 54050.391 | 44591.851 | 27400.000 | 0.887 |

## The influence law of pipe-line flow performance of multi-source coal-based solid waste filling materials

According to the results of the experiment and simulation, ANSYS FLUENT software was used to study the influence of coal-based solid waste filling material on the flow performance of pipe-line transportation.

## Simulation scheme design

Aiming at the research on the influence law of the flow performance of the filling material under the straight pipe model, four horizontal straight pipe transportation models with a length of 100 m and a diameter of ∅100 mm, ∅150 mm, ∅200 mm, and ∅250 mm were established, respectively. The mass concentration of coal-based solid wastes the filling material. The mass ratio of gasification slag to gangue (the ratio of gangue) *a*, the ratio of fly ash to gangue *b*, the ratio of desulfurization gypsum to gangue *c*, the ratio of bottom slag to gangue *d*, the flow rate of filling slurry and the inner diameter of filling pipe-line are analyzed. The influence law of seven factors on the flow characteristics of pipe-line transportation is analyzed. The factor level of the simulation scheme is shown in tab. 2.

**Table 2. The level setting of factors affecting the flow performance of filling materials**

| Level | Concentration [%] | *a* [%] | *b* [%] | *c* [%] | *d* [%] | Flow rate [ms$^{-1}$] | Inside diameter [mm] |
|---|---|---|---|---|---|---|---|
| 1 | 0.74 | 10 | 30 | 10 | 10 | 1.4 | 100 |
| 2 | 0.75 | 15 | 40 | 20 | 20 | 1.6 | 150 |
| 3 | 0.76 | 20 | 50 | 30 | 30 | 1.8 | 200 |
| 4 | 0.77 | 25 | 60 | 40 | 40 | 2.0 | 250 |
| 5 | 0.78 | 30 | – | – | – | – | – |

## Numerical modelling

The geometric model uses Spaceclaim to establish the pipe-line geometric model and mesh it. Considering the boundary effect, the distance from the inlet to the outlet of the model is 100 m, and the resistance generated by the filling material flowing through the whole pipe-line at the flow rate v is the resistance along the way. Take the inner diameter of the pipe ∅100 mm, ∅150 mm, ∅200 mm, and ∅250 mm. According to the characteristics of the flow of filling materials in the pipe-line, the following assumptions are made as: The flow of materials in the pipe-line is continuous and no gap. The mechanical properties of materials in all directions are consistent. The material is incompressible in the pipe-line. The material satisfies the stable flow hypothesis. The material has no heat exchange with the outside world. The energy loss of the filling material occurs during the flow process. The energy loss from the inlet to the outlet is calculated by the energy loss equation (the Bernoulli equation):

$$\frac{p_1}{\gamma}+\frac{{v_{z1}}^2}{2g}=\frac{p_2}{\gamma}+\frac{{v_{z2}}^2}{2g}+h$$

where $p_1$ is the pressure of the fluid at the inlet, $p_2$ – the pressure of the fluid at the outlet, $\gamma$ – the bulk density of filling material, $v_{z1}$ – the speed at the inlet, $v_{z2}$ – the speed at the outlet, and $h$ – the resistance generated by the fluid moving from the inlet to the outlet.

## Result and analysis

Figure 2 shows the variation curve of the resistance along the way with the concentration of the multi-source coal-based solid waste filling material. It can be obtained that the resistance along the way increases linearly with the increase of the concentration. When the concentration is 74%~77%, the increase rate of resistance along the way is gradually accelerated; when the concentration increased from 77%-8%, the rate of resistance increase began to slow down. This is because as the concentration increases, the viscosity of the filling material increases. The viscous force between the filling materials and the friction force between the filling material and the pipe wall are related to the viscosity. The viscosity increases, the friction force increases, and the resistance along the way increases. When the concentration of the filling material rises to a certain extent, the increase in viscosity is slowed down.

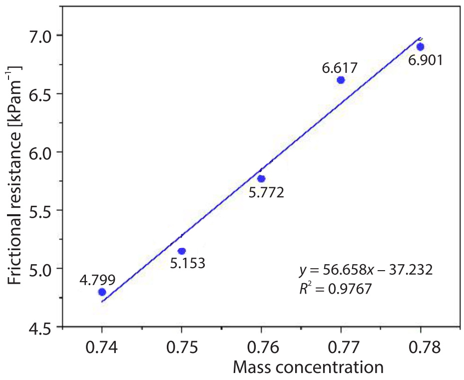


**Figure 2. The effect of mass concentration on the resistance characteristics along the path**

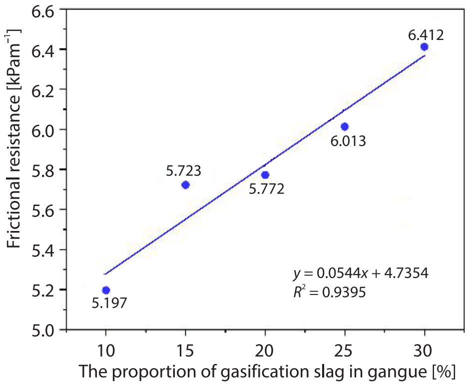


**Figure 3. The influence of the proportion of gasification slag to gangue on the resistance characteristics along the path**

Figure 3 shows the variation curve of resistance along the way with the ratio of gasification slag to gangue of multi-source coal-based solid waste filling material. It can be seen from fig. 3 that the resistance along the path increases approximately linearly with the increase of the ratio of gasification slag to gangue. This is due to the increase of the ratio of gasification slag to gangue, the viscosity of the filling material increases, the friction between the filling material and the pipe wall increases, and the resistance along the way increases.

Figure 4 shows the variation curve of the resistance along the way with the ratio of fly ash to gangue in the multi-source coal-based solid waste filling material. From fig. 4, it can be seen that when the proportion of fly ash to gangue increases by 10% from 30%-60%, the resistance along the way increases by 21.54%, 11.88% and 2.1%, respectively. If the proportion of fly ash to gangue reaches 50%, the resistance along the way changes little. This is because with the increase of the proportion of fly ash in the gangue, the influence on the increase of the viscosity of the filling material is gradually reduced, the friction between the filling material and the pipe wall is limited, and the resistance along the way is increased, but the increase is limited.

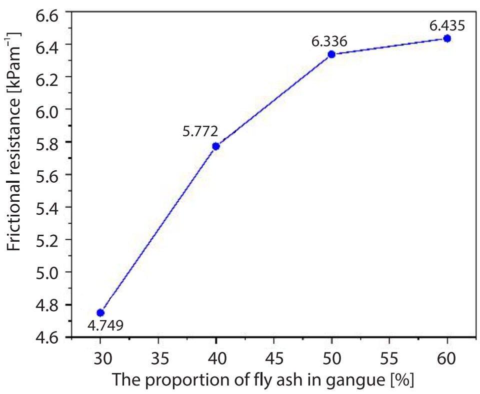


**Figure 4. The influence of the proportion of fly ash to gangue on the resistance characteristics along the way**

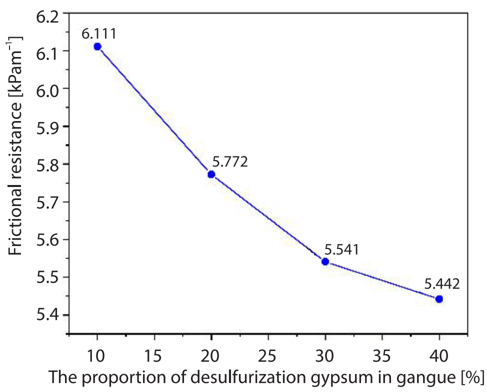


**Figure 5. The influence of the proportion of desulfurization gypsum to gangue on the resistance characteristics along the way**

Figure 5 shows the variation curve of the resistance along the path with the ratio of desulfurization gypsum to gangue of multi-source coal-based solid waste filling material. It can be seen from fig. 5 that the resistance along the path decreases with the increase of the ratio of desulfurization gypsum to gangue, and the rate of decrease gradually decreases. This is because with the increase of the proportion of desulfurization gypsum, the viscosity of the filling material decreases, the friction between the filling material and the pipe wall decreases, and the resistance along the way decreases. However, with the increase of the proportion of desulfurization gypsum, the viscosity of the filling material decreases, and the resistance along the way decreases.

Figure 6 shows the variation curve of resistance along the way with the ratio of bottom slag to gangue of multi-source coal-based solid waste filling material. It can be seen from fig. 6 that the resistance along the path decreases linearly with the increase of the ratio of bottom slag to gangue. This is because with the increase of the ratio of bottom slag to gangue, the viscosity of the filling material decreases, the friction between the filling material and the pipe wall decreases, and the resistance along the way decreases.

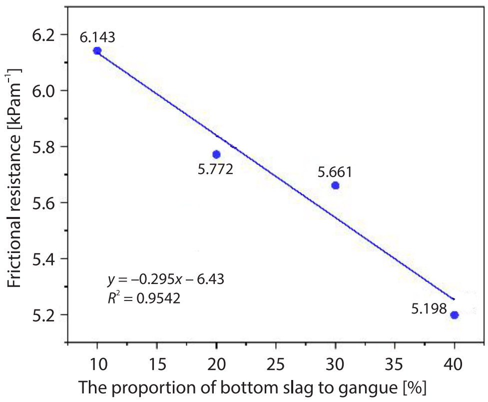


**Figure 6. The influence of the proportion of bottom slag to gangue on the resistance characteristics along the path**

The pressure distribution of the slurry in the horizontal straight pipe is as shown in fig. 7. The slurry has the highest pressure at the inlet of the horizontal pipe. As the slurry is pumped and pushed forward, the pressure reaches the minimum at the outlet. At the same cross-section in the tube, the slurry pressure in the 80% area near the core is constant, almost 0. Near the pipe wall, the pressure increases sharply from the core to the outside, as shown in fig. 8.

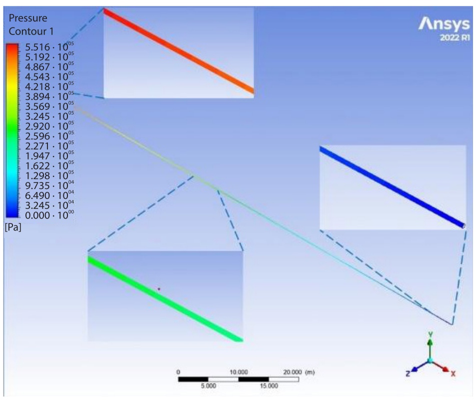


**Figure 7. Pressure distribution of slurry in horizontal straight pipe**

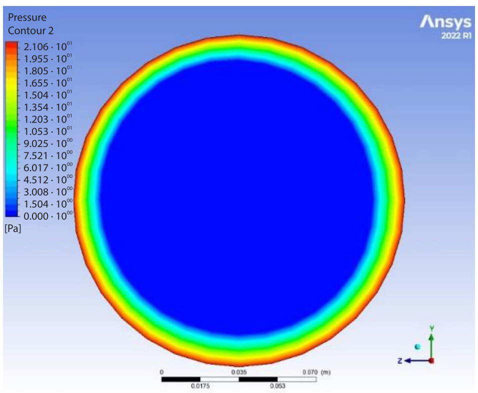


**Figure 8. Pressure distribution of slurry radial section in straight pipe**

## Conclusion

In this study, aiming at the problem of long-distance transportation of multi-source coal-based solid waste filling materials, combined with the physical characteristics of multi-source coal-based solid waste filling materials, the straight pipe transportation characteristics of multi-source coal-based solid waste filling slurry were studied by means of numerical simulation, and the variation law of resistance along the pipe during the flow of slurry in the pipe was obtained. The specific conclusions are as follows. By comparing the numerical simulation results with the results of the scale experiment (the loop experiment), it is verified that the error between the simulation results and the experimental results does not exceed 5.1%, and the simulation results can reflect the real situation a large extent. Through the numerical simulation of the straight pipe form, it is found that the resistance along the path increases with the increase of concentration, gasification slag ratio and fly ash ratio. It decreases with the increase of the ratio of desulfurization gypsum to gangue and the ratio of bottom slag to gangue. From the inlet to the outlet of the horizontal pipe-line, the slurry pressure gradually decreases. Within approximately 80% of the cross-sectional area near the core region of the pipe-line, the slurry pressure remains nearly constant and close to zero, while it increases sharply in the vicinity of the pipe wall.

## Nomenclature

$h$ – resistance generated, [Pa]
$p_1$ – pressure of the fluid at the inlet, [Pa]
$p_2$ – pressure of the fluid at the outlet, [Pa]
$v_{z1}$ – speed at the inlet, [ms$^{-1}$]
$v_{z2}$ – speed at the outlet, [ms$^{-1}$]

*Greek symbol*

$\gamma$ – bulk density of filling material, [Nm$^{-3}$]

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