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Friction losses of classified tailings slurry based on loop pipe testing

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Abstract

In this paper, a full-scale pipe loop test for the backfill mixes of classified tailings collected from a copper mine was conducted in JCHX Paste Backfilling Lab. The process flow, main equipment and measuring instruments were introduced. Based on the data analysis, the transport characteristics and pipe friction losses under different work conditions were determined. The research results indicated that: the more suitable transporting concentration of the non-cemented slurry is 66 to 68wt%, and the corresponding friction losses is 3 to 3.5 MPa/km (pipe diameter: 100 mm, flow velocity: 1 m/s). As to the cemented tailings slurry, the optimal transporting concentration is within the range of 72 to 74wt%, and the friction losses is 2.2 to 2.4 MPa/km. The friction losses in R600 elbow was 1.3 times as much as that in R1500 elbow, and was approximately 7 times as much as that in the horizontal pipe.

1 Introduction

As a key technology in mine backfilling, pipeline transportation directly affects the operation state and efficiency of mine filling system. In the study of pipeline transportation, the friction losses of slurry flowing in pipe is considered to the basis for the design of pipeline layout, equipment selection and identification of process parameters. The friction losses of traditional filling slurry with lower concentration can be estimated through empirical formulas based on solid-liquid two-phase flow theory, such as the R. Durand formula, Jinchuan formula, and so on (Han, 1985). However, the flow pattern gradually changed from the two-phase flow to the structural one with the increase of backfilling slurry concentration, and is characterized by an obvious behavior of non-Newtonian fluid flow. To study the flow characteristics of structural fluid, rheology theory is considered to be the most effective means (Wu and Liu 2014), from which a few calculation models for friction losses can be derived, such as the Bingham model, the Herschel-Bulkley model and so on (Hallbom, 2008). Nevertheless, with the significant mismatch between the calculation results and the actual situations in practical application processes, the loop pipe testing is still the most reliable method to obtain the flow characteristics.

At present, cooper mines in China are in transition from open-pit mining to underground mining that features an upwards cut and fill method. The waste rock and uncemented classified tailings were filled in the underpart of open stope to support the hanging wall and foot wall of the ore body. However, high-strength cemented classified tailings were used for the fill top surface, as high short-term strength must be achieved for each fill to support both mining equipment and personnel (Belem and Benzaazoua, 2008). Therefore, in order for a comprehensive filling system design, a loop test was carried out for both uncemented and cemented classified tailings and the pipe friction losses under different work conditions were obtained.

Process parameters such as pipe diameter, concentration and critical flow rate of backfilling pipeline transportation were also designed.

2 Experimental equipment

The loop pipe test was conducted in the JCHX Paste Backfilling Lab affiliated to JCHX Mining Management Co, LTD. In the test, backfilling materials such as tailings, cement, and water are added into a twin-shaft mixer at the designed ratio for primary mixing. In order for the mixture to be more homogeneous, the materials are then sent to a twin screw mixer for secondary mixing, pumped into the test pipes by a KOS s-tube piston pump, and produced in Putzmeister Solid Pumps GmbH (PM). The test pipes encircle the lab and eventually return to the twin screw mixer to form a closed circuit. For better simulation of the field production, four pipes, fabricated with 16 Mn steel, are in use, with a diameter of 50, 100, 150 and 200 mm, respectively. Each test pipeline features five laying directions, namely, the inclined upward, inclined downward, upstream, downstream, and horizontal. In addition, two long radius elbows (R1500 and R600) are also included in this loop pipeline. Three hydraulic diverter valves are installed to realize automatic switching control between test pipes, thirty-six diaphragm pressure transmitters are installed to detect the real-time pressure values in different positions of the pipeline, and an electromagnetic flow meter is used to measure the flow rate. The testing data are collected and recorded by the Distributed Control System (DCS) in the control room. Figure 1 shows the monitor interface of the auto-control system.

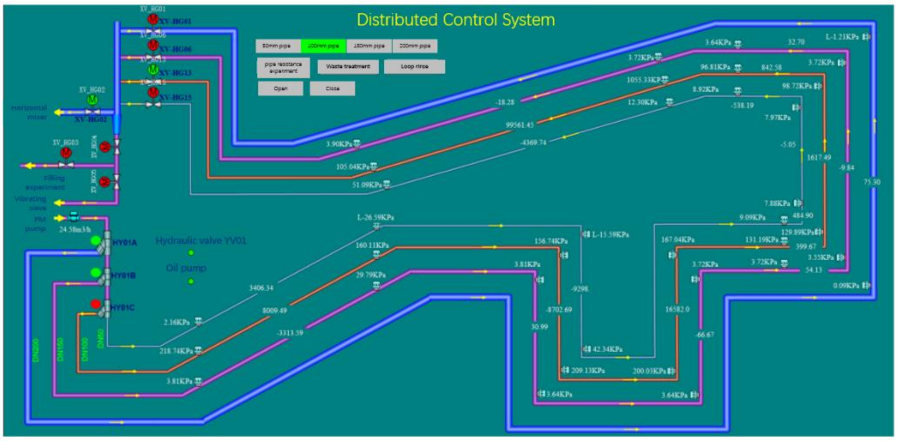

Figure 1 Monitor interface of the auto-control system

The technical parameters of the main equipment are as follows:

- rated flow of KOS pump: 40 m^3/h.
- maximum working pressure of KOS pump: 7.5 MPa.
- processing capacity of twin-shaft mixer: 60 m^3/h.
- processing capacity of twin screw mixer: 70 m^3/h to 90 m^3/h.
- inner diameter of test pipe: 50, 100, 150, 200 mm.
- length of pipelines: 150 m (each diameter), 600 m (total length).

The photographs of the pipe loop test plant are shown in Figure 2 and Figure 3

Figure 2 KOS pump and hydraulic diverter valve

Figure 3 Loop pipe test plant

3 Test material

Samples of classified tailings were collected from an on-site tailings facilities concentrator in a copper mine in China and were sent to the JCHX Lab. The specific gravity of this material is 2.92 and its porosity is 47.5wt%. The distribution of particles coarser than 150 µm is determined using the mechanical vibration sieve method, and for the particles finer than 150 µm, a laser particle size analyzer was used. The test results are shown in Table 1. It is found that the size distribution of particles is narrow and concentrated, with the fine particle (-20 µm) accounting for no more than 5wt% and as much as 44% of particles coarser than 150 µm. The average grain diameter d_{50}=130 µm, and size non-uniformity coefficient C_u=3.3, which is likely to cause severe segregation in backfilling slurry. The binder used in this test was 425 Portland cement, the addition of which could ease the settlement of coarse particles.

Table 1 Particle size distribution of the tested classified tailings

Size(µm)	-20	+20-38	+38-45	+45-74	+75-106	+106-150	+150
Proportion	4.37	1.42	0.045	15.35	7.88	26.14	44.8
Accumulation	4.37	5.79	5.835	21.18	29.01	55.2	100

The slump test for cemented classified tailings (with a binder content of 15wt%) was carried out, and the results show that: when the mass concentration of slurry is lower than 70wt%, the segregation problems are particularly serious. While the concentration is 76wt% and the slump height is 26~28 cm, the slurry has better homogeneity and achieve a flowability for pipe transportation. Consequently, the mass concentration for cemented slurry should be in the range of 70~76wt%.

4 Results and discussion

4.1 Test results

The pipe loop tests were conducted using pipes with a diameter of 100 mm. Figure 4 shows the change of pipe pressure and flow rate within a certain time period at different detection points, with a sampling interval of 10 s. It can be seen that because of the pulse effect of piston pump, the test values also shows cyclical fluctuations. As the pump speed decreases from 85 to 50wt%, the flow rate and pressure change accordingly.

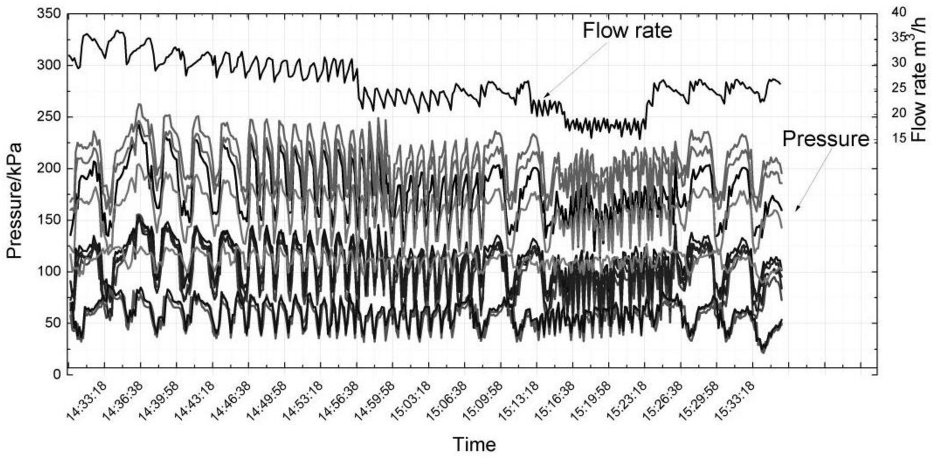

Figure 4 Time variation curve of pipe pressure and flowrate over time

4.2 Influences of mass concentration on friction losses

Figure 5(a) illustrates that friction losses change with the changing concentration of uncemented tailings slurry. When the mass concentration is below 66wt% and the flow velocity is greater than 1 m/s, friction losses rapidly increases as concentration rises. For the tailings slurry with a same mass concentration, as the flow velocity is less than 1 m/s, the friction losses is two times what it is with higher flow velocity,. While the mass concentration exceeds 66wt%, the friction losses features a less obvious increase.

Figure 5(b) presents the increase of friction losses with that of the concentration of cemented tailings slurry. When concentration is below 74wt%, friction losses has a less obvious increase. When it is above 74wt%, friction losses rapidly increases, with an inflection point at slightly higher than 74wt%. Therefore, for cemented backfilling, once concentration passes the critical point at 74wt%, the friction losses will be greater, hence causing higher energy consumption in field production.

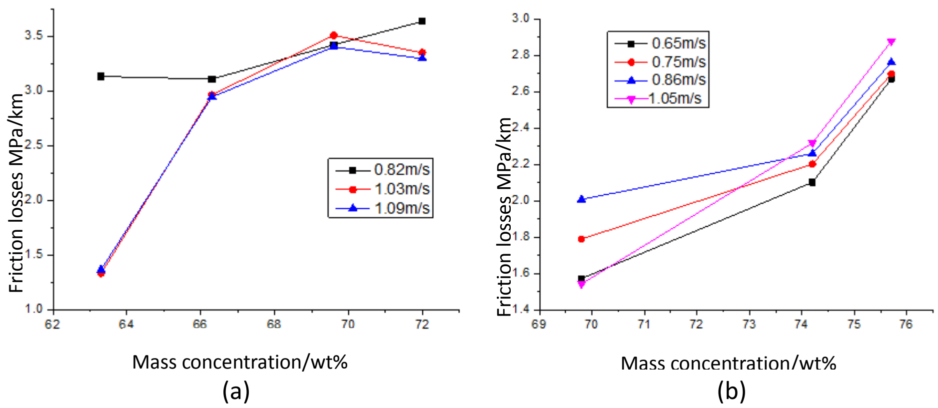

Figure 5 The curves of friction losses changed with concentration; (a)uncemented tailings slurry; (b) cemented tailings slurry

4.3 Influences of flow velocity on friction losses

As seen in Figure 6(a), the friction losses of uncemented slurry decreases gradually with the increase of flow velocity and is also closely related with concentration. When the concentration is below 63.3wt%, as the flow velocity increases, friction losses decreases linearly. When the flow velocity is above 1 m/s, friction losses becomes stable. When the concentration is greater than 66wt%, friction losses slowly declines with the increase of flow velocity, and fluctuates within the range of 3~3.5 KPa/m. It is likely because the settlement of coarse particles generates a sliding bed in the pipe bottom, where slurry is transported through the interaction between the solids and turbulent eddies within the pipe, so the particles are conveyed at higher pressure gradient. At velocities high enough, the high turbulence level randomly lifted particles across the entire pipe cross section and formed a pseudo-homogenous suspension, which decreases the friction losses of slurry flowing (Pullum, 2007).

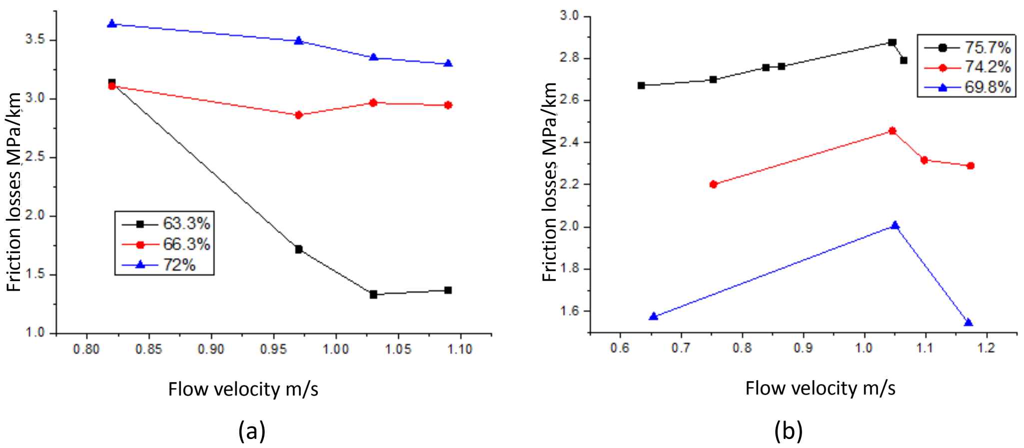

Figure 6 The change of friction losses with flow velocity; (a) uncemented tailings slurry; (b) cemented tailings slurry

Figure 6(b) shows that for cemented tailings, when flow velocity is less than 1.05 m/s, friction losses slowly increases with that of flow velocity, until it reaches a peak value at a flow rate of 1.05 m/s. As flow velocity passes 1.05 m/s, friction losses decreases. In conclusion, with the critical flow rate being 1.05 m/s, it is suggested that the velocity should be greater than 1.05 m/s in order to ensure the low energy consumption in backfilling system.

4.4 Influences of flow direction on friction losses

The analysis of comparison of the friction losses in different flow directions shows that: other conditions being equal, the friction losses in R600 elbow was 1.3 times as much as that in R1500 elbow, and was approximately seven times as much as that in horizontal pipe. In addition, the friction losses in upstream pipe was slightly greater than that in downstream pipe.

Conclusions

This full-scale pipe loop test system is advantageous in terms of more optional test pipes with different diameters and laying directions, more pressure monitoring points, and higher degree of automation. Hence, it serves to more effectively simulate the field production and obtain more accurate experimental data. Studies such as flow mode, resistance characteristics, and optimum flow rate for different slurry pipeline transportation can be conducted in this test plant, which is conducive to the design and optimization of the filling station.

Both uncemented and cemented classified tailings are settling slurry. For the non-cemented slurry, the suitable transporting concentration is 66~68wt% and the corresponding friction losses is 3~3.5 MPa/km in the pipes with a diameter of 100 mm and flow velocity of about 1 m/s. For the cemented tailings slurry, the optimal transporting concentration is within the range of 72~74wt%, and the friction losses is 2.2~2.4 MPa/km.

The friction losses in R600 elbow was 1.3 times as much as that in R1500 elbow, and was approximately 7 times as much as that in the horizontal pipe.

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