Determination of Mixing and Conveying Parameters in a Phosphate Rock Filling System

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Abstract. A phosphorus mine in Hubei Province adopts the roof cutting room pillar method of non rail equipment layered mining. With the extension of exposure time, the stress in the goaf further changes and the pillar has begun to damage, and the failure rate has a trend of increasing. In order to avoid large-scale goaf caving, the mine decided to adopt concrete cemented filling method to mine unstable pillars. In filling material preparation and filling system, mixing technology, equipment and conveying system play an important role. In this paper, according to the actual situation of the mine, we have carried out investigation, analysis and calculation, finally, the slurry transportation and mixing process, the pipeline transportation model and main pipeline transportation parameters has been determined. It provides a theoretical basis for the application of filling method.

Keywords: Mine fill; Conveying parameters; Filling system; Stability.

1. Introduction
A phosphorus mine is located in Hubei Province. The stope adopts the roof cutting, room and pillar mining method with trackless equipment. The mining area has been exploited for 3 years, and the stoping work of the room has been completed. The roof and pillar are instable and the joints are developed. Temporary support with seam pipe anchor and hanging net, and then the anchor cable is used for permanent support.

The pillar left in the underground ore body is the support system of the mined out area, and the ore amount of ore pillar accounts for 32\% of the ore amount of the panel. With the extension of exposure time, the stress in the goaf has further changed, the pillar has begun to be damaged, and the failure rate has a trend of increasing. With the continuous destruction of pillars, there is a risk of large-scale goaf caving. If the goaf caving occurs, the surface will collapse, cut the upper fault, produce large-scale landslide and causing serious disaster. Therefore, the management of goaf is imminent, and the remaining pillars are also recovered, otherwise, the opportunity of management will be lost.

As the surface of the mining area is not allowed to collapse, through comprehensive analysis, it is decided to adopt the cemented filling method of concrete, with cement as the gelling agent and tailings and gravel as the filling aggregate to recover the unstable pillars.

2. Application Status of Filling Technology
The development of cemented filling technology has gone through the following stages: from dry filling to hydraulic conveying cemented filling, the pipeline conveying of filling materials has been realized; from low concentration hydraulic filling to high concentration filling, the filling materials
will not be separated; from high concentration filling to paste filling, no dewatering in the stope\cite{1}. Cementitious agent has developed from ordinary portland cement to fly ash cement and high percentage of water rapid materials, etc.\cite{2,3} The utilization of aggregate has developed from graded tailing to full tailing, mountain sand, river sand, bar grinding, fine-grained gravel (-2mm) and other inert materials.

In the early 1960s, China took the lead in the application of graded tailings filling in Xi Kuangshan, Feng Huangshan, Huang Shaping and other mines. In the 1960s and 1970s, Jin Chuan nickel mine and Fan Kou Lead Zinc Mine began to study the cemented filling of coarse aggregate. In the 1980s, Beijing General Research Institute of mining and metallurgy, Northeast Institute of technology and so on carried out the research on the physical and chemical characteristics and mix proportion of tailings, and promoted the application of graded tailings filling technology in a large number of nonferrous and gold mines in China. In the 1990s, Jin Chuan Group carried out the experimental research on the new technology of all tailings paste pumping and filling, while Fankou Lead Zinc Mine carried out the experimental research on the new technology of high concentration all tailings gravity filling\cite{4-6}.

3. Mixing and Conveying System of Filling Slurry

3.1. Selection of Mixing Process of Crushed Stone Filling Slurry

Mixing technology and equipment play an important role in filling preparation and filling system. Mixing effect is one of the key technologies to determine filling quality and smooth pipeline transportation. Macadam filling slurry belongs to the category of concrete. For concrete, there are complex changes in the mixing process. In addition to strong physical effects, there are also certain chemical effects. Not only the total volume of the mixture has changed, but also its state and performance have also changed. Even if it reaches homogeneity in the macro level, there are still 10% - 30% cement particles under the microscope Granular aggregates. Therefore, concrete mixing must provide not only macro homogeneity, but also micro relative homogeneity. In a word, as a key process in the production and transportation of waste rock filling slurry, mixing directly affects the quality and level of waste rock filling slurry production, the stability of pipeline transportation and the strength of filling body.

At present, the mixing process of mine filling material is divided into intermittent mixing process and continuous mixing process. The intermittent mixing technology is only used to prepare paste slurry in mine filling system, and its application is limited. However, the measurement of intermittently stirred materials is accurate and reliable, and the mixing quality is good. It can be compared with the paste with the same viscosity calibrated in advance by the force and energy consumption of the agitator. It can be found that the unqualified paste can be adjusted by adding materials of different particle sizes or clear water, or it can be discarded.

The continuous mixing process is to feed all kinds of materials into the mixer quantitatively, simultaneously and continuously according to the design requirements, and add water continuously and quantitatively\cite{7}. After continuous mixing, mixing and discharging by continuous mixer, it enters the receiving hopper of paste delivery pump\cite{8}. According to the requirements of uniformity, difficulty and material ratio, the slurry continuous mixing preparation process is generally divided into one-stage continuous mixing and two-stage continuous mixing.

Only one continuous mixer is used for the first stage mixing. At present, the second stage mixing method is mainly used for the paste mixture slurry mixing, especially when adding coarse aggregate, the second stage mixing must be used\cite{9}. According to the requirements and process characteristics of gravel filling in the mining area, and considering the coarse aggregate, in order to ensure the filling quality and improve the filling efficiency, the two-stage continuous mixing process is adopted.

3.2. Preparation of Filling Aggregate

According to the design of filling scheme, it is necessary to crush and rod grinds the quarrying samples. The required particle size of crushed stone is about 20mm, and the particle size of rod grinding is - 3mm with continuous grading\cite{10}.
The test crushing process is as follows: the quarry is evenly supplied to XPC 150×200 jaw crusher for coarse crushing (Figure 1a), a section of crushed waste rock (-150mm) is sent to XPC -60×100 jaw crusher for medium crushing, the crushed material is screened by SZZ 1500×4000 vibrating screen, the large material (+20mm) on the screen is sent to impact crusher for re-crushing, and the lower material (-20mm) is sent to XPS - Ф250×150 roller crusher for fine crushing (Figure 1b), the crushed materials are screened through stainless steel standard screens with different particle sizes.

![Figure 1](image1.png)

(a) (b)

Figure 1. Crushing and grinding process.

The crushed and screened gravels meet the transportation requirements.

3.3. Pipeline Transportation Model and Determination of Main Parameters

Gravel filling slurry is high concentration slurry. In the normal filling stage of mine, it can be approximately considered that the pipe transportation movement of gravel slurry belongs to stable flow, the movement factors such as velocity, pressure and concentration do not change with time. Therefore, Bernoulli equation can be derived according to the quasi homogeneous fluid, and its pipeline transportation model is shown in Figure 2.

![Figure 2](image2.png)

Figure 2. Pipeline transportation model.

According to the layout characteristics of the filling pipeline, the filling pipeline system is divided into vertical pipe and horizontal pipe. The horizontal pipe is the converted total length of the pipeline. Then the balance equation of the mine filling pipeline is as follows:

\[ \rho g H = (1 + k) f H + (1 + k) f L_0 \]  

(1)

In the formula:

- \( f \) - Average pipe friction resistance coefficient, PA/M;
L₀ - The total length of the converted horizontal pipeline from the bottom of the filling vertical pipe to the filling and discharging point (curved pipe, slope pipe, horizontal pipe, etc.), m.

\( P \) - Density of waste rock filling slurry, kg/m³;

\( g \) - Acceleration of gravity, 9.8m/s²

\( k \) - Local resistance loss coefficient, \( k = 0.05 \sim 0.15 \)

So,

\[
H = \frac{(1 + k)f}{\rho g - (1 + k)f} L₀
\]

(2)

The calculation of the average pipeline friction resistance loss refers to the resistance model along the road obtained from the semi industrial test of gravel tailing filling in similar mines:

\[
f = a + bv^c
\]

(3)

In the formula:

\( a, b \) and \( c \) - statistical constant of slurry rheology. \( a, b \) and \( c \) are function of slurry component, concentration, conveying system, etc. which can be measured by test. Substitute \( f \) to the above formula, we can get:

\[
H = \frac{(1 + k)(a + bv^c)}{\rho g - (1 + k)(a + bv^c)} L₀
\]

(4)

The average flow rate of slurry at a specific pipe diameter is \( v = \frac{4Q}{\pi D^2} \). By substituting it into the above formula, we can get:

\[
H = \frac{(1 + k)[a + b\left(\frac{4Q}{\pi D^2}\right)^c]}{\rho g - (1 + k)[a + b\left(\frac{4Q}{\pi D^2}\right)^c]} L₀
\]

(5)

From the above formula, it can be seen that the right half of the equation contains four important parameters of pipeline transportation, namely, the converted length of horizontal pipe \( L₀ \), pipe diameter \( D \), flow \( Q \), and the resistance coefficient along the pipeline transportation of slurry. These four parameters can be changed independently. In the actual production, if the four active parameters are not properly selected, the vertical pipe from the ground to the underground will be insufficient. In this way, there will be serious erosion and wear at the liquid level of the vertical pipeline, which will reduce the service life of the vertical pipeline and affect the normal production. Therefore, it is necessary to maintain full pipe flow in the stable stage. In order to achieve the above purpose, we can adjust these four active parameters according to the specific situation in production to achieve full pipe, so that \( H = H₀ \).

According to the minimum pressure of the filling pump required by the pressure pipeline transportation system of the gravel filling pump in theory, and the combined formula, it can be seen that the existence of \( H/H₀ \) value is a necessary condition for the realization of pipeline transportation, when \( H/H₀ \lesssim 1 \), the filling can realize self flow transportation, when \( H/H₀ \gtrsim 1 \), the filling must adopt pump pressure transportation, and the existence of \( H/H₀ \) value must meet the following conditions:

\[
\rho g - (1 + k)k_ε[a + b\left(\frac{4Q}{\pi D^2}\right)^c] > 0
\]

(6)

At the same time, it can be concluded that:
As:

\[ D > \left( \frac{4Q}{\pi} \left[ 1 \left( \frac{\rho g}{b^{1+k}} - a \right) \right] \right)^{-\frac{1}{2k}} \]  

(7)

According to the relationship between the velocity and rate flow of slurry in the pipeline, it can be concluded that:

\[ \nu < \left( \frac{1}{b} \left[ \frac{\rho g}{1+k} - \alpha \right] \right)^{\frac{1}{2k}} \]  

(9)

Let:

\[ \nu_{\text{max}} = \left( \frac{1}{b} \left[ \frac{\rho g}{1+k} - \alpha \right] \right)^{\frac{1}{2k}} \]  

(10)

Then, only \( \nu < \nu_{\text{max}} \) and \( D > D_{\text{min}} \) can meet the above conditions.

According to the ratio, concentration and pipeline transportation test results determined by relevant mine experience, the pipeline transportation results of gravel filling slurry are calculated as Table 1:

| Proportion of crushed stone to bar sanded | Concentration | Resistance loss along the way | \( \nu_{\text{max}} \) | D_{\text{min}} (mm) | Q (m³/h) | Slurry density (t/m³) |
|-----------------------------------------|---------------|-------------------------------|----------------|------------------|--------|---------------------|
| 5:5                                     | 75%           | 1.96                          | 94            | 50               |        |                     |
|                                         |               |                               | 99.5          | 55               |        |                     |
|                                         |               |                               | 104           | 60               |        |                     |
|                                         |               |                               | 108           | 65               |        |                     |
|                                         |               |                               | 113           | 70               |        |                     |

According to the theoretical conditions of the minimum pressure of the filling pump required for the pressure pipeline transportation system of the gravel filling slurry pump, based on the relevant mine experience, it can be seen from the calculation that:

Under the condition of gravel bar grinding ratio of 5:5 and slurry concentration of 75%, the maximum flow rate of slurry shall be less than 1.96m/s; the minimum inner diameter of pipeline required for the flow of 50-70m³/h shall be 94-113mm. Therefore, 125mm should be selected to determine the inner diameter D of filling pipeline.

4. Conclusion
(1) After crushing, grinding and screening, the filling aggregate can meet the requirements of filling pipeline transportation.
(2) As the aggregate grade in the crushed stone filling slurry is -20mm and has continuity, 125mm steel pipe with inner diameter is adopted, which conforms to the practical experience that the pipe diameter should be 5-6 times larger than the particle size in industrial application.
(3) The flow rate of slurry is 1.23-1.72m/s, which is less than 20% of the maximum theoretical flow rate. Theoretically, the pipeline transportation can be realized. At the same time, according to the
laying situation of a phosphorus filling pipeline in Hubei Province, when $H/H_0 \geq 1$, pressure transportation should be adopted.

Acknowledgments
This research was financially supported by the National Key Research and Development Project of China (No. 2018YFE0123000).

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