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# Study on filling mining technology for gently inclined thin to medium thick phosphorus deposits

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This study is grounded in research conducted at the Kunyang Phosphate Mine No. 2, a Chinese open-pit phosphate mining enterprise owned by the Yunnan Phosphate Group Co., Ltd. Due to the small inclination angle and the presence of weak interlayers in the middle of the gently inclined thin to medium thick phosphate ore layer, mining such ore bodies cannot rely on self weight migration, making roof management difficult and mining costs high technical challenges. The methods utilized on-site research, engineering comparisons, and theoretical analysis experiments to address the gently inclined phosphorus deposits. Based on the actual technical and economic conditions of current phosphorus mines, the advantages, disadvantages, and practical conditions of upward horizontal layered filling mining method, upward horizontal layered drift filling mining method, and pseudo inclined segmented strip filling mining method are compared. Priority should be given to using the pseudo inclined segmented strip method as the main method for mining, supplemented by the upward horizontal layered filling method in the panel area. And theoretical calculation methods were applied to obtain various numerical values of the filling capacity of the 2 million t/a mine filling test section, providing technical support for the mining design and equipment selection of the filling test system. The relevant research results can provide guidance for the selection of mining methods for gently inclined thin to medium thick phosphate deposits with an average inclination angle of 15°. The theoretical calculation method used can provide technical guidance for the filling system and filling equipment.

## KEYWORDS

gently inclined phosphate rock, filling technique, underground-mining, filling system, technical guidance

## 1 Introduction

Phosphate ore is a crucial strategic resource for China due to its diverse applications across various industries, including agriculture, energy, materials, chemical engineering, and national security. Phosphate ore is primarily produced in sedimentary rock, with phosphorite accounting for 85% of such rock. Smaller amounts of this ore can also be found in metamorphic and igneous rock formations. With few exceptions, phosphorus in minerals predominantly occurs as orthophosphate, with apatite as its primary mineral source. The phosphate rock layers in China generally have a state of “gently inclined,

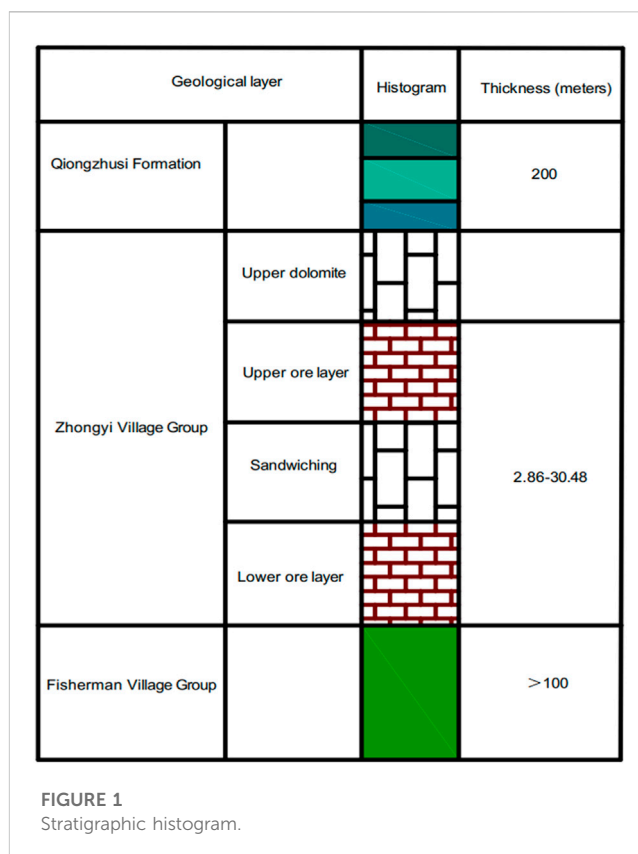
medium to thin layers, and multiple interlayers". There are technical challenges such as high ore loss and dilution rate, layered mining, and stability of roof and pillar. Therefore, in order to solve the problems in underground mining of phosphorus mines, the research on underground mining methods and filling techniques is of great significance.

The characteristics of China's phosphate ore can be described as follows: firstly, the ore is predominantly middle to low-grade, with only a few rich ores available. The average grade of  $P_2O_5$  in China's phosphate ore is approximately 17%. The second characteristic is relatively fewer easily processable ores and sedimentary rock boasts the highest proven reserves. However, most of the ores are of medium to low grade. As a result, most of the ores must be sorted to meet the high-concentration phosphorus compound fertilizer industry's production requirements, with only a select number of rich ores meeting these requirements. Thirdly, the mining of phosphorus ore presents several challenges. Due to the lengthy mineralization history, deep burial, strong rock formation, and densely packed cement, most phosphate mines are difficult to mine either through open-pit or underground methods, resulting in high loss and dilution rates and low mining rates.

In China, three main mining methods are employed for phosphate ore: single open-pit mining (Erdenv, 2022; Wei et al., 2022), underground mining (Gong, 2022; Li, 2022), and combined open-pit and underground mining (LI et al., 2019; Li et al., 2021; Jiang et al., 2022; Li et al., 2022; Li et al., 2023).

The selection of filling mining method and the study of filling mining technology have always been the focus of research as the main technical means of deep ore body mining. Qu Liping et al. Zhang Runda et al. (2021) (Qu and Wang, 2021) chose the staggered upward horizontal layered filling mining method, which achieved a production capacity of 2,745 t/d and increased the economic benefits of the mine. Bai Yang (2023) et al. (Zhang et al., 2021) optimized the traditional upward horizontal layered filling mining process to address the technical challenges encountered in the mining process of steeply inclined thin ore bodies, and proposed an upward horizontal layered graded tailings filling mining method suitable for steep and gently inclined thin ore bodies. Deng Gaoling et al. (2023) (Bai et al., 2023) conducted research on the mining method and process optimization of steeply inclined and fractured thin ore veins using the downward drift filling mining method. Yan Hui Feng (2023) (Deng et al., 2023) introduced the basic concept, application advantages, and application strategies of different types of backfill mining technologies of paste filling technology. Hao Yingjie et al. Zeng Jialong (2022) et al. (Yan, 2023) used FLAC<sup>3D</sup> and Midas GTS software to compare and analyze the stress disturbance and displacement changes under the pseudo inclined segmented strip filling mining method, providing a theoretical basis for selecting structural parameters of the same type of mining site, which has certain guiding significance.

Kunyang Phosphate Mine No. 2 is a large open-pit to underground phosphorus mine under Yunnan Phosphate Group. The research on underground mining technology and filling technology can provide important significance for the filling technology mining of gently inclined mines containing soft armor layers that are currently undergoing the process of open-pit to underground mining.



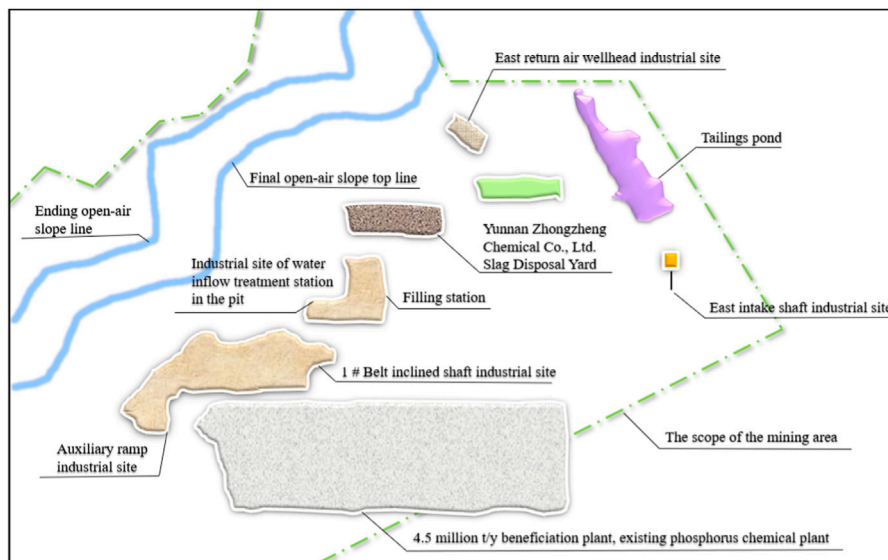
## 2 Project overview

### 2.1 Mine location and rock mass overview

The Kunyang Phosphate Mine No. 2 is located in the southwest region of the Dianchi Phosphate Accumulation Zone, adjacent to Kunyang Phosphate Mine in the east and Xiaojiaying Phosphate Mine in the west. The northern part of the region is Haikou Phosphate Mine, situated in Erjie Town, Jinning District. The mining area is 44.5 km away from Kunming City and 9 km away from Jinning City. The exploration line extends from Dawei Mountain in the east to Erming Road in Erjie Town in the west, between 56 and 74. Its east-west length is around 4.5 km, north-south width is around 1.7 km, and the total area is 7.66 km<sup>2</sup>. The northern end of the mining area is near 320 National Highway, Kunming Kunyang Yuxi Railway and Highway, Gaohai Expressway, Anjin Expressway in the east, and the Bajie Erjie Haikou Highway in the south. The internal road network of the mining area spans approximately 13 km, and there are approximately 62 km to Kunming City and approximately 10 km to the nearest train station, Zhongyi Village Station, making transportation exceptionally convenient (Qu and Wang, 2021; Zhang et al., 2021).

### 2.2 Selection principles and scope of filling test area

As a permanent facility in mines, the selection of filling stations is one of the key factors affecting the investment, operating costs,



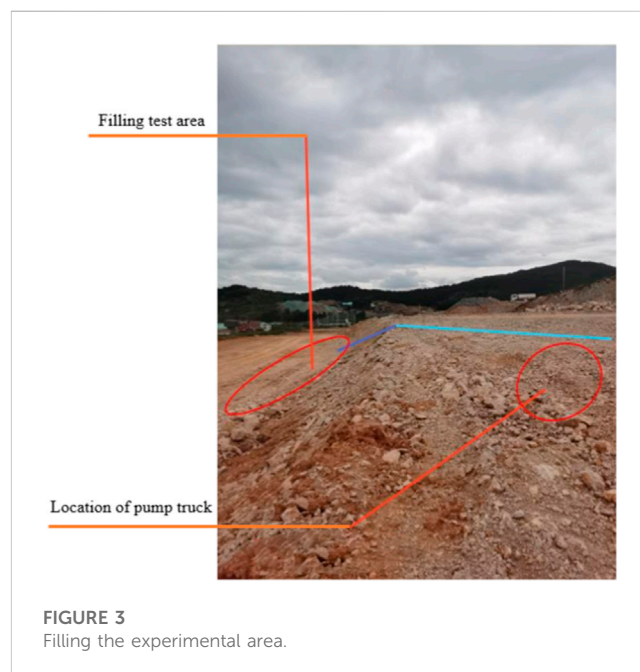
**FIGURE 2**  
Site selection diagram of the filling station.

and reliability of the filling system (Ren Q., 2021). Therefore, the selection principles and scope of the filling test area should follow the following principles.

- 1) The station site is not affected by underground mining activities;
- 2) Having suitable filling lines;
- 3) Facilitate the transportation of materials from the beneficiation plant to the filling station;
- 4) Having sufficient industrial sites and stable water and electricity supply;
- 5) Try not to acquire new land;
- 6) There are tunnel projects in corresponding underground locations, which are convenient for filling and drilling construction, and reduce the number of new projects;
- 7) It meets the current filling requirements for the middle stage of production and the filling requirements for deep ore bodies.

The filling test is situated in the Kuyang Phosphate Mine No. 2, with an average inclination angle of 15°. It is typically gently sloping thin to medium-thick ore body with a soft protective layer, making it highly representative. The stratigraphic column is shown in Figure 1. The 63-67# exploration lines' outcrop area in Kuyang Phosphate Mine No. 2 and the northern side of the 62-59# exploration lines in the northern part of the mining rights are undergoing open-air terrace mining. The lowest step in the middle has been recovered to nearly 2,100 m. The western mining area has excavated 1.1600 million tons, with a local minimum altitude of 2,000 m. At 2,050 m in the eastern mining area, the maximum horizontal resistance is 38 times the maximum geometric filling line. By contrast, at 1,860 m in the western mining area, the horizontal resistance varies considerably and has a maximum geometric filling line of 16.1.

Based on the selection principles and scope for the filling test area mentioned earlier, a location near the high-level water tank



**FIGURE 3**  
Filling the experimental area.

has been chosen for the filling test area. The station is located on the south side of the east return air shaft, with a surface elevation of 2,161 m for the filling station. Two independent filling systems are installed at the filling station site. When the filling station is located there, the tailings from the 450 beneficiation plant are transported to the filling preparation station through a 2.1 km tailings conveying pipe, and then prepared into filling slurry through the filling station. It can be directly transported to various underground mining sites through the filling boreholes in the station, and then flow to each underground mining site through the filling boreholes, achieving the “self flow”

transportation of the filling slurry. The site selection of the filling station is shown in [Figure 2](#).

## 2.3 Geological conditions of the filling test area

The test area is positioned in the center of Kunyang Phosphate Mine No. 2. The filling test area is shown in [Figure 3](#). The mining area is generally a tilted structure that slopes from south to east, and due to the gentle production of the ore layer, the open-air shape is relatively complicated. The distribution is from the south to the north of the mountains. The sedimentary-type phosphorus rock bed was formed, resulting in the production status of the mine layer being relatively stable, remaining consistent with the upper layer. Typically, the mine's production status moves towards the northeast to the southwest and inclines at an angle ranging from 2° to 31°, tending towards the southeast.

The upper layer of ore is distributed between exploration lines 58–74, with an average thickness of 6.88 m and an average P<sub>2</sub>O<sub>5</sub> content of 21.8%. The minimum thickness of the upper ore layer is 2.62 m, while the maximum thickness is 12.69 m. On average, the thickness measures 6.7 m, and the variation coefficient for thickness is 33%, indicating this layer is stable. Regarding its P<sub>2</sub>O<sub>5</sub> content, the average grade is 22%, and the grade change coefficient is 17%, indicating that it is uniform. This layer contains I–III grade ores, distributed in a spatial pattern that gradually becomes richer from the upper poor to the middle lower. The ore layer is relatively continuous and stable along the strike and dip. The interlayer mainly occurs in the southwest of the mining area (between exploration lines 63–74), while it is scattered in the east. The lithology consists of gray, white, and yellow clay, with a thickness ranging from 0 to 3.08 m. The rock thickness varies between 0 and 3.15 m, with an average thickness of 1.08 m. The lower ore layer is distributed between exploration lines 58–74. The average thickness of the ore layer is 5.65 m, and the average content of P<sub>2</sub>O<sub>5</sub> is 27.66%. The minimum thickness of the lower ore layer is 0.34 m, the maximum thickness is 12.77 m, the average thickness is 5.67 m, and the thickness variation coefficient is 36%, belonging to the stable type. The average content of P<sub>2</sub>O<sub>5</sub> is 26.9%, and the grade change coefficient is 15%, belonging to the uniform type. I–III grade ores are distributed in this layer and have a spatial distribution pattern of upper rich and bottom poor.

Based on the classification of ore products, the first-grade products (P<sub>2</sub>O<sub>5</sub> content ≥25%) are located on the phosphorus ore's intermediate and upper mine layers. Second-grade products (P<sub>2</sub>O<sub>5</sub> content between 15% and 25%) are mainly located in the upper mine layer with phosphorus-containing layers. Third-grade products (P<sub>2</sub>O<sub>5</sub> content between 8% and 15%) are situated in the middle and lower portions of the phosphorus ore layer.

The phosphate rock deposit in the experimental area is continuously deposited between rich and poor ore layers, with gradual changes in material composition and gradual transition in ore grade. The ore layer in the experimental section has good stability with continuous and stable strike and dip, with an average dip angle of 15°, making it highly suitable for filling in the experimental area.

## 3 Implementation plan for underground mining engineering

### 3.1 Overall plan and mining scale

This experiment is an industrial test project focused on underground mining and mining methods. Its primary objective is to seek effective mining methods suitable for underground mining, optimize the mineral structure parameters of the mining method, analyze and determine the safety hazard factors associated with underground mining, and conduct mining testing calculations—Economic Indicators. The mining method test will use the field's production capacity as the assessment indicator. The mining production capacity is 2 million tonnes annually, with a filling capacity of 2.67 t/m<sup>3</sup>. As the mine scale is related to mining scope, methods, and equipment level ([Bai et al., 2023](#)), this trial will primarily evaluate the field's production capacity, transportation capacity, and economic indicators during the test period.

### 3.2 Optimization of mining methods

Green mining is an inevitable trend in mining development ([Deng et al., 2023](#); [Hao et al., 2023](#); [Yan, 2023](#)). The filling mining method can greatly improve the mining recovery rate while the dilution rate is minimal. Additionally, this method provides the ability to mine the ore body under the principles of “Three underminings.” The filling mining method provides a high resource utilization rate and allows for effective control over ground pressure. Furthermore, this method significantly reduces water inflow into the mine and helps prevent geological disasters such as ground collapse, cracking, and mountain collapse. The filling mining method can fill the empty areas with waste rock and tailings. This eliminates the need for large waste rock dams and tailings ponds on the ground, which can significantly improve the surrounding environment of the mining areas and prevent potential conflicts between enterprises and local communities ([Zeng et al., 2022a](#); [Liu, 2022](#); [Shen and Ning, 2022](#)).

In this experiment, if the upward horizontal layered drift filling method is utilized by arranging ore rooms along the strike ([Ren Q., 2021](#); [Cui and Qi, 2023](#); [Wu and Wang, 2023](#)), it has good safety; Additionally, a larger number of ore rooms can be arranged in each panel, thereby improving production capacity. Nonetheless, the design does not deem this method suitable due to the complex process and poor ventilation environment. The upward horizontal layered filling method (with a vertically oriented layout of the ore house) can protect the roof via anchor bolts and reserve ore pillars and adjust to layered drift filling mining based on the ore body and surrounding rock conditions. When the panel slope is arranged outside of the vein, it exhibits good adaptability to the technical mining conditions of the ore body. However, it has a low recovery rate after reserving ore pillars and presents multiple constraints on the panel production capacity ([Wang, 2023](#)). The pseudo-inclined segmented strip-filling method ([Zhang, 2014](#); [Wang et al., 2022](#); [Zeng, 2023](#)) has the advantages of large panel production capacity, long service life, good safety, and good economy ([Ren Y. D., 2021](#)). The comparison of this experimental mining method is shown in [Table 1](#).

TABLE 1 Advantages and disadvantages of mining plans.

Indicator name	Mining plan			
	Pseudo-inclined segmented strip-filling mining method	Upward horizontal slicing and filling mining method (vertically arranged mining rooms)		Upward horizontal slicing and filling mining method
		Extravenous sampling	Intravenous sampling	
Advantages	1. Arranging mining rooms along the inclined direction can more efficiently separate the upper and lower layers of ore	Used when the inclination angle of the ore body is greater than 15°	1. The mining room is arranged vertically along the direction of the ore body, with high equipment efficiency	1. Many mining rooms can be arranged in each panel
	2. The production capacity of the panel is large			
	3. High recovery rate			
Disadvantages	1. Poor ventilation environment in the mining area		1. High mining costs	1. Poor ventilation in the mining area
	2. The equipment operation efficiency is low		2. Low pillar recovery rate	2. There are many process steps
Conclusion	Recommend			

After analyzing and studying 88 boreholes within the designated mining area, the following conclusions can be drawn: Approximately 33.70% of individual projects have an upper ore bed thickness of  $\leq 6$  m, with an average thickness of 4.29 m. On the other hand, thicknesses greater than 6 m account for 66.30%, with an average thickness of 7.92 m. Additionally, individual projects with a thickness of  $\leq 6$  m in the lower seam represent 59.55%, with an average thickness of 4.39 m, while 40.45% are thicker than 6 m, with an average thickness of 7.56 m. A calculated approach has been implemented to enhance the recovery rate of the lower seam, mitigate inclusions, and maintain stable roof conditions in the upper seam. The pseudo-inclined segmented strip-filling mining method (I) is applied primarily to ore bodies with a thickness of  $\leq 6$  m, comprising 40% of the total, while the pseudo-inclined segmented strip-filling mining method (II) is utilized mostly for ore bodies with a thickness of  $>6$  m, accounting for 50%. The remaining 10% of the mine is reserved for the upward horizontal layered filling method (Peng, 2022).

### 3.3 Filling system design

The process flow of the filling station is to transport the tail mortar produced by the flotation plant to the thickener of the filling station (Wang, 2020; Zeng et al., 2022b; Xu, 2022) and then pump the thickener to the mixer of the filling station through a slurry pump. The internally purchased crushed stones are stored in the crushed stone pile shed. Materials are loaded into the feed bin using a scraper and transported to the mixer via the belt when filling. Cementitious material is delivered to the filling station by a cement tanker and discharged through a soot-blowing pipe into the cement silo. The screw feeder at the bottom of the silo feeds the mixture to the mixer according to the required filling strength. They enter the filling pump after fully mixing the tail mortar, crushed stone, and cementitious materials. They are transported along the surface through the filling pipeline to the borehole near the east return air shaft before reaching the goaf for filling. The filling test

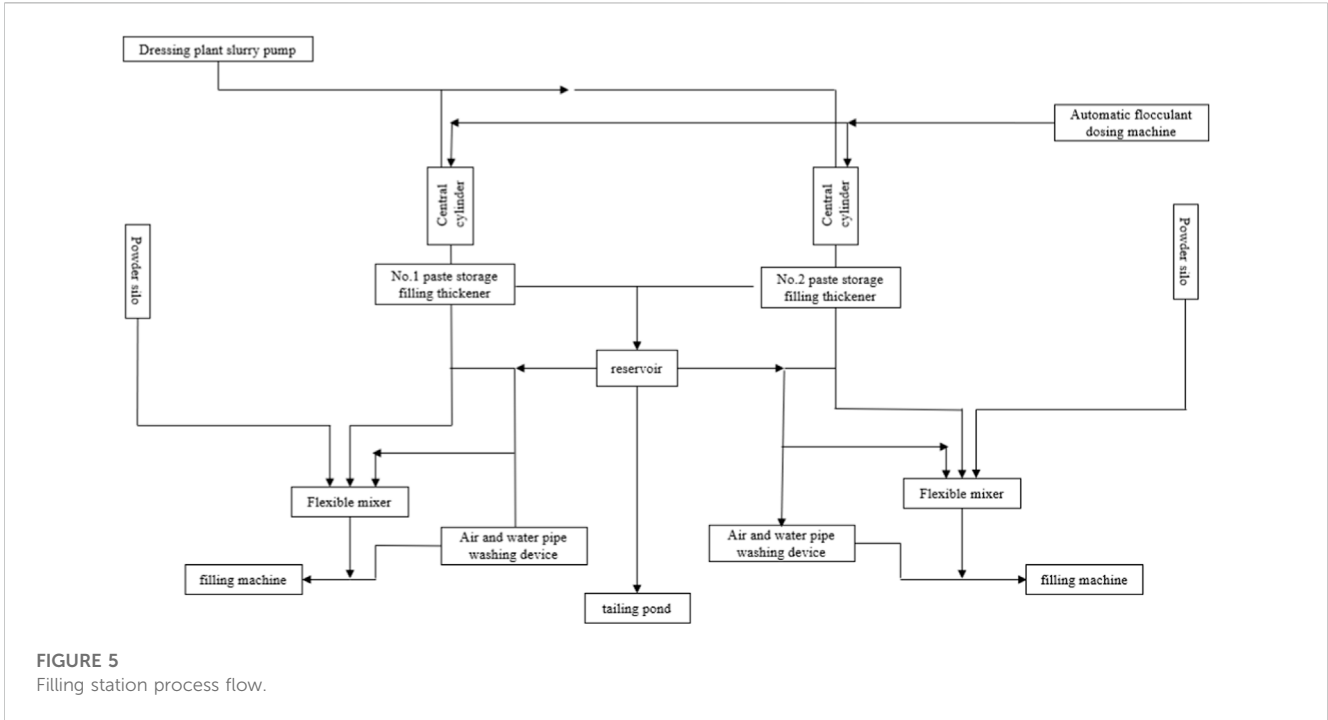


FIGURE 4 Filling test equipment.

equipment and filling station process flow are shown in Figure 4, 5. The station has three sets of filling pumps, two for normal operation and one for standby. Accident waste slurry and production wastewater are collected in the sewage collection tank, while clarified water is discharged to the high-level water tank. The accumulated waste sand is regularly cleared out. Apart from receiving overflow water, the sand return tank can also discharge the tailings deposited in the thickener to the sand return tank in case of a system failure.

The designed mining production scale is 2 million t/a, with 330 working days per year. The specific gravity of ore is 2.67 t/m<sup>3</sup>, and the filling system is also based on 330 working days per year. We need to meet the current production demand and consider that there should be a certain margin in filling system production capacity.

- (1) Annual volume of empty space to be filled



**FIGURE 5**  
Filling station process flow.

$$V = \frac{T_y}{u} \times Z \times K_1 = 74.16 (10000\text{m}^3/a)$$

$$Q_{hmax} = \frac{Q_{dmax}}{n_1 t} = \frac{2830}{2 \times 6} \approx 240 (\text{m}^3/h)$$

In the formula:  $T_y$ —Annual filling mining capacity  
 $u$ —Ore weight  
 $Z$ —Mining and filling ratio  
 $K_1$ —Unbalance coefficient, taking  $K_1 = 1.1$

In the formula:  $Q_h$ —Hourly slurry preparation capacity of filling station,  $\text{m}^3/h$

$Q_{hmax}$ —Maximum hourly slurry preparation capacity of the filling station,  $\text{m}^3/h$

$n_1$ —Number of daily work shifts, taking  $n_1 = 2$ ;

$t$ —Filling time per shift, taking  $t = 6h$

(2) The annual consumption of full tailings cemented filling slurry volume is:

$$V_m = K_2 K_3 V = 1.02 \times 1.03 \times 74.16 \approx 78 (10000\text{m}^3/a)$$

Design 2 sets of filling slurry with a separate preparation capacity of  $100 \text{ m}^3$ /The filling system of H, with two sets of systems operating in parallel (two shifts) or a separate filling system operating continuously for 24 h, can meet production needs. The filling capacity calculation is shown in Table 2.

In the formula:  $K_2$ —Compression settlement coefficient, taking  $K_2 = 1.02$   $K_3$ —Loss coefficient, taking  $K_3 = 1.03$

We calculated that the maximum daily filling slurry volume in the experimental area was  $2,830 \text{ m}^3/d$ , and the average daily filling slurry volume was  $2,360 \text{ m}^3/d$ . The filling system has two sets of filling pumping systems, comprising filling pumps, feeding belts, tailings feed pumps, paddle mixers, screw mixers, cement slurry, filling pumps, off-site gravel storage yards, and tailings deep cone thickeners.

(3) Average daily filling volume required

$$Q_d = \frac{V_m}{T} = \frac{780000\text{m}^3/a}{330} \approx 2360 (\text{m}^3/d)$$

In the formula:  $V_m$ —Annual average demand for filling slurry,  $\text{m}^3/a$   $T$ —Filling workday, 330d/a

The filling station has an aggregate storage yard and cement warehouse to meet the daily filling material volume. For this experiment, tailings and crushed stones serve as the main filling aggregates, and bulk cement is stored in a 300 t cement silo, which can provide materials for filling buffer for approximately 3 days. The gravel filling dosage is between 70–80 tons/hour, and each shift dose ranges from 420 to 480 t. One shift per day is worked, calculated based on an eighth shift. The gravel pile shed stores 3 days' worth of filling materials, and the lattice screen on top of the feeding bin controls the size of the aggregate entering it. Three ZL50 loaders are configured for filling and loading. The filling system is equipped

(4) Maximum daily filling volume

$$Q_{dmax} = KQ_r \approx 2830 (\text{m}^3/d)$$

In the formula:  $Q_m$ —Daily filling capacity of the mine,  $\text{m}^3/d$   $K$ —Uneven coefficient of filling operation,  $K = 1.2$

(5) Hourly slurry preparation capacity of filling station

$$Q_h = \frac{Q_d}{n_1 t} = \frac{2360}{2 \times 6} \approx 200 (\text{m}^3/h)$$

TABLE 2 Calculated values of filling capacity.

Serial number	Parameter	Unit	Number
1	mine production capacity	10,000 t/a	200
2	Annual working days	d/a	330
3	Ore weight	t/m <sup>3</sup>	2.67
4	Annual production gap	10,000 m <sup>3</sup> /a	74.16
5	Annual filling of empty areas	10,000 m <sup>3</sup> /a	74.16
6	Annual preparation amount of filling slurry	10,000 m <sup>3</sup> /a	78
7	Annual filling operation days	d/a	330
8	Daily average filling slurry volume	m <sup>3</sup> /d	2,360
9	Imbalanced coefficient of filling		1.2
10	Maximum daily filling slurry volume	m <sup>3</sup> /d	2,830
11	Daily filling time of filling station	h/d	12
12	Hourly filling slurry volume	m <sup>3</sup> /h	200–240
13	Required number of filling coefficient sets	Cover	2
14	Filling capacity of a single system	m <sup>3</sup> /h	100

with two cement silos, and the storage capacity of each silo should be no less than the demand for 3 days. The maximum daily consumption of cement is 400 t, so the storage capacity of each cement silo should be no less than 300 t, with an effective volume of 250 m<sup>3</sup>, which can meet the cement consumption needs for 3 days. A transmission pipeline has been constructed from the concentrator to the tailings pond, with a branch pipe connected starting from pipeline stake No. PN11 leading to the filling station. The pipeline is utilized for filling purposes after concentration.

The horizontal mixing system used in this design boasts several advantages, such as low equipment and small building height requirements, mature equipment with high performance, and convenient installation and maintenance. For each system, we recommend using two stages of mixing: double shaft blade mixer and double screw mixer, with a mixing capacity of 100–120 m<sup>3</sup>. During mixing, the tail mortar is first diluted in a central barrel and then mixed evenly with the flocculant. It is then concentrated and settled before being metered and batched by the weighing system. Crushed stone is transported to the main material hopper by a belt conveyor, while bulk cement is stored in a weighing hopper through a cement weighing system. The water used for filling the slurry comes from the production water of the concentrator. A proper proportion of full-tail mortar, cement, and concentrated water is measured and added to the mixer to mix evenly. The filling material should be thoroughly stirred to create a slurry with a moderate concentration and excellent fluidity, ensuring that it can be easily supplied to the filling material delivery pump or the lower hopper of the filling borehole.

A concrete pump then transports the mixed filler slurry. Before feeding the concrete delivery pump, it is important to ensure even mixing of the concrete. During feeding, unloading should be carried out uniformly in conjunction with pumping while maintaining the concrete above the height mark line in the aggregate hopper. A mesh screen should also be placed on the

concrete pump feed hopper, and someone should be assigned to monitor the feeding process carefully to prevent excessive particle size aggregate or foreign matter from entering the pump and causing a blockage.

In order to make the filling slurry transportation system adopt self flow transportation, it is necessary to calculate the pipe diameter and theoretical thickness of the self flow transportation system separately.

- (1) Calculation of the pipe diameter of the self flow transportation system:

Many filling mines at home and abroad use seamless smooth pipes and pipeline steel as filling pipelines. This time, pipeline steel is used as filling pipelines. According to the flow rate of the filling slurry in the semi industrial test section, which is 1.4–18 m/s, the minimum inner diameter of the filling pipeline is:

$$D_T = \sqrt{\frac{4Q_h}{3600\pi v}} = 132.9mm$$

In the formula:  $Q_h$  is the hourly filling capacity requirement of the filling system, taking 100 m<sup>3</sup>/h;  $V$  is the working flow rate designed for the filling system,  $V=1.6$  m/s= $5,760$  m/h

- (2) Theoretical thickness calculation of pipeline:

$$\delta = \frac{P \cdot D}{2[\sigma]} + K$$

In the formula:  $P$  is the maximum pressure that the pipeline can withstand, MPa; The maximum weight of the slurry is 1.96 t/m<sup>3</sup>, The maximum pressure exerted on the pipeline is approximately 11 MPa  $[\sigma]$  is the allowable tensile stress of the steel, with a value of 160 MPa for 16 Mn seamless steel pipes

TABLE 3 Main power equipment of the filling system.

Serial number	Name	Number	Technical parameter	Power and level
1	Filling industrial pump	3	100 m <sup>3</sup> ~120 m <sup>3</sup> , Working pressure, 10 MPa, 10 KV	560
2	Feeding tape machine	2	B=800 × 3400, 380 V	11
3	Belt conveyor	2	B=1,000 m, L=60 m, V=2 m/s, 380 V	55
4	Double shaft paddle mixer	2	Φ680, V=3.5 m <sup>3</sup> , Q=100 m <sup>3</sup> /h	2 × 37
5	Double axis spiral mixer	2	Φ750, V=5.1 m <sup>3</sup> , Q=100 m <sup>3</sup> /h	2 × 45
6	Cement silo	4	300 t, Φ5.5 m, Cement silo height 8.9 m, Cone height 3 m	
7	Current stabilizing device	4	15–70 m <sup>3</sup> /h, 1,000 m × 550 mm	2 × 7.5
8	Screw conveyor	4	Φ300 mm, L=4.5 m, Q=10–35 t/h	2 × 11
9	Deep cone thickener	1	Φ26 m	15
10	Slurry Pump	3	Q=100 m <sup>3</sup> /h, H=20 m, 380 V	37
11	clean water pump	2		18.5
12	Underarm slurry pump	2		45
13	Underarm slurry pump	2		11

K is the amount of wear and corrosion, taken as 4 mm.

After calculation,  $[\sigma] = 12$  mm, considering a certain margin, and using 16Mn steel, according to the steel pipe specifications, select a steel pipe with a wall thickness of no less than 14 mm for the high-pressure pipe section from the pump outlet to the vertical pipe area.

To improve the wear resistance of the filling pipeline, the main pipe adopts 16 Mn seamless steel pipes with strong wear resistance. Based on the above calculation results, the specifications of the main pipe are  $\Phi 168$  mm × 14 mm, actual effective inner diameter of pipeline DI=140 mm; Branch pipe, 8–4 MPa, steel pipe specification  $\Phi 168$  mm × 10 mm, effective inner diameter DI=148 mm; 4–0MPa, steel pipe specification  $\Phi 168$  mm × 8 mm, effective inner diameter DI=152 mm, and DN150 ultra-high molecular weight polyethylene pipes are used in the end segmented branch line and mining area.

When filling industrial pumps, it is essential to consider pipe plugging and outlet pressure fully. The pipes should be arranged in an S-shaped fashion to achieve optimal results. The flow rate for these industrial pumps should be set between 100 and 120 m<sup>3</sup>/h. When the distance is relatively close, the high-volume filling can be utilized.

The selection of the location of the filling station and the filling pipe in the well is complementary, and the combination of the two directly determines the filling of multiple lines of the pipeline. The filling pipe needs to be transported 400 m across the ground to reach the borehole for filling. Considering both surface topography and subsurface development, the east vertical air shaft was filled by drilling in the early stage, providing service to the mined-out areas above 1,890 m in the east. In the later stage, it fills the east and west mined-out areas below 1890m through the central air intake shaft.

Through research on mining technology and theoretical numerical calculation of the filling test section of Kunyang Phosphate Mine No. 2, preliminary Table 3 shows the power equipment of the filling system:

According to the above filling experimental calculation requirements, the main power equipment for the filling system is selected as shown in Table 3.

## 4 Problems that still exist during the filling process

Slightly inclined thin to medium-thick ore bodies have typical characteristics, such as slow dip angles, large changes in ore body shape, and unclear ore-rock boundaries. These features pose technical difficulties for both open-pit and underground mining, resulting in high loss rates, high dilution rates, and low resource recovery rates. These difficulties seriously restrict the development of phosphorus ore mining technology in China. Currently, the main problems in mining gently inclined thin to medium-thick phosphorus ore bodies persist, including.

- (1) The mechanical equipment, mining methods, and technology necessary for underground mining of these ore bodies have not been resolved yet.
- (2) The stability of the filling system operation and the overall filling process is relatively complex. The stability of each subsystem is particularly critical to the overall system, and any problem in the filling process can lead to the stoppage of filling work.
- (3) There are few studies on the underground mining of gently inclined thin to medium-thick phosphorous ore bodies, especially for fractured and unstable ones.
- (4) The research on the preparation and process of filling slurry is still imperfect. The filling effect's core issue lies in the filling slurry's preparation effect. If the filling effect is not good, it can lead to problems such as side chipping or large area collapse, increasing safety risks.
- (5) There are no significant breakthrough research results on the rock movement and surface subsidence caused by underground mining of phosphate mines, and the relevant theoretical system is far from mature and perfect. It is still in the preliminary research stage.



## 5 Conclusion

The gently inclined thin to medium thick ore body refers to an ore body with an inclination of 5°–30° and a 1.0–15 m thickness. The Kunyang Phosphate Mine No. 2 has an average inclination angle of 15°, typically a gently inclined thin to medium-thick deposit. Through research on phosphate mining and filling technology, the following conclusions are drawn.

- (1) Gently inclined thin to medium-thick phosphate ore deposits are mainly mined using the pseudo-inclined segmented strip drift filling method arranged along the ore room, supplemented by the upward horizontal layered drift filling method. This approach can increase the production capacity of coiled coils, improve the recovery rate, and separate the mining of upper and lower layers of ore, ultimately increasing the mining efficiency of phosphorus mines and extending the service life of the mine.
- (2) The selection of the filling station site for Kunyang Phosphate Mine No. 2 not only follows basic standards, but also meets the current filling requirements for the eastern part and the filling requirements for the western ore body. The filling slurry prepared by the filling station can be directly transported to various mining sites through the filling boreholes in the station, and then flows to various underground mining sites through the filling boreholes, achieving the “self flow” transportation of the filling slurry.
- (3) Based on the designed production scale of 2 million tons/a, the annual volume of the filling area required for the filling station, the annual consumption of all tailings cemented filling slurry volume, the daily average filling volume, the daily maximum filling volume, the hourly preparation capacity of the filling station slurry, as well as the calculation of the diameter of the gravity conveying pipeline and the theoretical thickness of the pipeline, were calculated through theoretical values. This provides technical and theoretical support and equipment selection for mine filling experiments. This paper focuses on Kunyang Phosphate Mine No. 2, under Yunnan Phosphate Chemical Group, and studies the filling mining technology after underground mining. The relevant research results are significant in guiding the underground mining and construction of difficult-to-mine phosphorous ore bodies in the Yunnan Dianchi region.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

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## Author contributions

DH: Conceptualization, Writing–original draft. MX: Validation, Writing–original draft, Writing–review and editing. XL: Investigation, Validation, Writing–review and editing. JW: Visualization, Validation, Writing–original draft. MW: Writing–original draft, Validation. SL: Validation, Writing–original draft.

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## Conflict of interest

Authors MX, MW, and SL were employed by Yunnan Phosphating Group Co., LTD.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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