Application of Gravity-flowed Convey Technology by Pipeline at Great Times Line for High Concentration Backfill Slurry

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Abstract. In order to realize the gravity-flowed convey of high concentration backfill slurry of aeolian sand at 15 times line, the industrial test on convey by high concentration slurry backfill pipeline is carried out based on the calculation and analysis of backfill pipeline with respect to the design of the backfill pipeline and the critical velocity of slurry in Yuyang Coal Mine. The calculation and test results show that the high concentration aeolian sand backfill slurry has good fluidity, which drops markedly when the slurry concentration exceeds 72%. In order to achieve gravity-flowed convey of backfill slurry, it must be subject to an upper limit of concentration of 75%; The critical velocity of backfill slurry convey in Yuyang Coal Mine is 1.19m/s, with an operating velocity of 4.19m/s, which is 3.5 times of the critical velocity. With a maximum conveying capacity of backfill pipeline of 396m³/h, and high reliability in the pipeline convey of slurry, the great times line gravity-flowed convey of high concentration backfill slurry with aeolian sand as aggregate is achieved.

1. Introduction
The ecological environment in Shaanxi-Mongolia region of northwest China is vulnerable. In order to effectively protect the local ecology during high-intensity mining of coal resources, the backfill mining technology shall be adopted as one of the key approaches to realize water-preserved mining, control of surface subsidence and protection of the ecological environment in the mining areas of Western China [1-4]. In consideration of the feature in the ecologically vulnerable mining areas in Northwest China with widespread presence of aeolian sand on the surface, together with the urgent needs for water-preserved mining and ecological protection, it gives a great edge in terms of cost efficiency to use the aeolian sand that is widely distributed in the area as backfill material to achieve backfill mining, which can effectively solve the problems of unbalanced supply and demand of backfill materials and unbalanced benefits and costs. In recent years, some achievements have been made in the research of aeolian sand as backfill material [5]. Among them is the calculation method for local resistance loss in pipeline convey of high concentration aeolian sand backfill slurry proposed by Liu Pengliang and Sun Kaihua et al, which, through gravity-flowed convey test, determines the inner diameter of great times line gravity-flowed convey pipeline[4], and verifies the backfill performance through industrial test. At present, researches are rare on gravity-flowed convey technology by pipeline for high concentration backfill slurry with aeolian sand as aggregate under the condition of great times line, with the related research results as follows [6]: In consideration of the law in pipeline convey of high concentration backfill slurry, Zhou Xu and Wang Peixun adopted approaches marked with low velocity, low flow rate and large pipe diameter under the condition of...
great times line to achieve gravity backfill under the condition of extra great times line; Lan Wentao, Wu Aixiang et al. conducted research on the rheological parameters and gravity-flowed convey of paste slurry to demonstrate from the perspective of backfilling line that the critical gravity-flowed times line of paste backfill slurry is related to the plastic viscosity coefficient and yield stress. Therefore, the critical gravity-flowed backfilling times line of paste backfill slurry with different velocity and different pipe diameters can be derived based on rheological parameters. The foregoing related tests and research results have certain reference significance for the research and field application of high concentration backfill slurry of aeolian sand under the great times line gravity-flowed convey condition.

2. Overview of Backfill System and Fluidity of Backfill Materials

2.1. Overview of Backfill System

The paste-like backfill technology of aeolian sand in fully-mechanized coal mining is to use aeolian sand as aggregate, mixed with a large amount of fly ash, with alkali materials such as quicklime, cement and admixture as auxiliary materials, which are processed into high concentration backfill slurry with a mass concentration of 66% - 75% through the surface backfill station. The backfill slurry is then conveyed to the fully-mechanized coal mining working face by gravity through the backfill pipeline, where the coal mining and backfill processes are carried out alternately. After the slurry is solidified, backfill induration will be formed in the goaf, which, as a supporting and controlling system of overlying strata, can effectively control the damage and movement of overlying strata, realize water-preserved mining and protect the ecological environment of mining areas, while achieving the green mining method and technology that enable utilization of aeolian sand as resources.

The surface of Yuyang Coal Mine is featured with desert beach and semi-fixed dune landform, with little topographic relief, and with an average thickness of about 40m. The 2307 experimental face for fully-mechanized coal mining backfill is located in the southwest of the mine, with a 1,149m-long and 150m-wide working face strike, at an average mining thickness of 3.5 m and an inclination of 0.28°.

The paste-like fully-mechanized coal mining backfill system of aeolian sand in Yuyang Coal Mine mainly consists of three parts, namely: surface backfill station, slurry convey pipeline and fully-mechanized coal mining backfill working face. The backfill station is responsible for monitoring the entire backfill system and preparing the backfill slurry. The preparation of backfill slurry is divided into two steps, namely: preparing primary slurry and preparing slurry, mixing water and fly ash above Grade III as per corresponding ratio to obtain primary slurry, and mixing aeolian sand, cement and auxiliary materials with the primary slurry as per a certain ratio to obtain the backfill slurry. The slurry is prepared and temporarily stored in a slurry tank, and then is mixed intensively at a high speed from top to bottom with a stirrer, through which the continuous preparation and output of the slurry are realized by uninterrupted stirring; The slurry is conveyed to the backfill working face by geopotential energy through the pipeline convey system with flow control and filtering functions. The backfill system achieves production and backfill capacity of 360m³/h through two slurry making systems with design capacity of 180m³/h respectively.

The horizontal distance between the backfill station and backfill working face in Yuyang Coal Mine is rather large (see Fig. 1), with the total length of the farthest pipeline up to L=2,616m, the height difference between the starting point and the ending point of backfill pipeline up to H=175m, and the backfilling times line of pipeline up to N=15, which is far greater than the 4 - 6 times line commonly used in mine backfilling at present, and also higher than the great times line backfilling pipeline which is 10 times higher than that used in common mine backfilling at present. There are two main pipeline convey modes for backfill materials, namely: gravity-flowed convey and pumping. Relatively speaking, the former is of low operation cost and low risk of pipeline blockage, and paste-like slurry has better fluidity than paste backfill materials, so gravity-flowed convey mode should be preferred.
Requirements on the fluidity of slurry and the conveying capacity of pipeline are extremely high in order to achieve great times line gravity-flowed convey at 15 times line, while there is no proved design and engineering experience available for reference. After calculating and analyzing the critical velocity of slurry, in combination with the experience in backfill industry test, the pipeline is designed and selected, and a set of "high concentration gravity-flowed convey great times line" process system is developed to meet the backfill process requirements of Yuyang Coal Mine.

2.2. Fluidity test of high concentration backfill slurry

Slurry concentration is one of the key factors affecting the fluidity of backfill slurry. The law for fluidity of high concentration backfill slurry of aeolian sand subject to changes in concentration can be demonstrated by experiments using NXS-1A coaxial cylinder upward-spinning viscometer to prepare the sample slurry at a mix ratio of W (cement) : W (auxiliary material) : W (fly ash) : W (aeolian sand) = 1:2:10:10 in solid material. The relationship between apparent viscosity and shear stress of slurry with different concentrations at shear rate of 28 s⁻¹ is shown in Fig. 2:

![Fig. 2 Relationship curve of slurry concentration v.s. apparent viscosity and shear stress](image)

It can be seen from Fig. 2 [2] that the shear stress and apparent viscosity of slurry increase synchronously with the concentration of slurry at the same shear rate; When the slurry concentration exceeds 72%, the shear stress and apparent viscosity increase more significantly, which demonstrates that the fluidity of slurry will obviously decrease when the concentration of slurry exceeds 72%. In order to realize long-distance gravity-flowed convey free of pump pressure under the condition of great times line, reasonable concentration shall be adopted as the main factor to ensure good fluidity of slurry. In consideration with the experience in gravity-flowed convey by pipeline of mine backfilling slurry, it is determined that the initial shear stress of backfill slurry should be 11Pa, and the apparent viscosity should generally be kept within1,500 MPa.s. Therefore, the 75% concentration is taken as the upper limit of the concentration of high concentration backfill slurry of aeolian sand.

3. Paste-like Slurry Convey Technology by Pipeline at Great Times Line and Equipment

3.1. Pipeline convey parameters and pipeline selection
3.1.1. More complex tables. According to the design ratio of backfill slurry and laboratory test results, the basic parameters of backfill slurry are determined as follows:

- Slurry density: \( \rho_s = 1.70 \text{t/m}^3 \);
- Carrier density: \( \rho_c = 1.20 \text{t/m}^3 \);
- Density of mixed solid materials: \( \rho_s = 2.45 \text{t/m}^3 \);
- Average particle size of solid materials: \( d_{av} = 0.14 \text{mm} \);
- Median particle size of solid materials: \( d_{50} = 0.12 \text{mm} \);
- Mass concentration of slurry: \( m_s = 72\% \);
- Bulk concentration of slurry: \( \rho_b = 50\% \);
- Water-sand ratio: \( X = 1.0 \);
- Backfilling times line: \( N = 15.0 \).

It is determined according to the production capacity requirements, slurry ratio parameters and coal mine labor organization system that the conveying capacity of backfill slurry must reach \( Q = 180 \text{m}^3/\text{h} \).

3.1.2. Pipeline pressure. The maximum pressure and minimum pressure of pipeline during normal operation shall be calculated according to the following formula:

\[
\begin{align*}
P_{\text{max}} &= \Delta H \cdot \gamma \\ 
P_{\text{min}} &= \Delta H \cdot \gamma - L \cdot i 
\end{align*}
\]

Wherein, \( \Delta H \) is the height difference between the inlet and outlet of the pipeline, which is taken as 175m; \( \gamma \) is the bulk density of backfill material, which is taken as 17kN/m\(^3\); \( L \) is the total length of pipeline (including drilling pipeline), which is taken as 2,616m; \( i \) is hydraulic gradient, which is taken as 0.6kPa/m.

By introducing the above-mentioned parameters into formulas (1) and (2) respectively, it can be calculated that \( P_{\text{max}} = 2.98 \text{MPa} \) and \( P_{\text{min}} = 1.41 \text{MPa} \).

Backfill pipeline blockage is one of the most probable accidents in backfill system. By installing an emulsion pump (or fresh water pump) at the top of the backfill riser in the surface backfill station, the pipeline blockage accident can be handled promptly and quickly by pressurizing the pipeline, with the pressure range of 5-10MPa on the pipeline at the borehole bottom. Therefore, the nominal pressure of trunk pipeline and fittings shall not be less than 10MPa.

![Fig. 3 Schematic diagram of slurry pressure in backfill pipeline](image)

3.1.3. Pipeline selection. The downhole backfill pipelines in Yuyang Coal Mine are pressurized pipelines, with a pressure generally within 5MPa and a downhole temperature generally between 10\(^\circ\)C and 30\(^\circ\)C. The humidity in some areas downhole is relatively high, so the steel pipe material should be adapted to meet the environmental conditions. Commonly used pipes include carbon steel seamless pipes, alloy steel seamless pipes, stainless steel seamless pipes, nickel-titanium alloy pipes, aluminum alloy pipes and cast iron pipes. Material selection for backfill trunk pipeline should ensure sufficient plasticity, toughness, strength and good stability. Considering the cost efficiency factor and other cemented backfill pipelines in coal mines, the 16Mn carbon steel seamless pipes with tensile strength \( \sigma_b = 490 \text{MPa} \) and yield strength \( \sigma_s = 320 \text{MPa} \) is selected with the minimum allowable stress of
163MPa at 20°C according to *Specification for Pressure Pipeline -Industrial Pipeline-Part II: Materials* (GB/T 20801.2-2006). By referring to the experience in pipeline design with the equivalent backfill mine convey capacity at home and abroad, and in consideration with the requirements of backfill system for convey capacity, it is determined that the inner diameter of the pipeline is temporarily taken as D=180mm. The wall thickness of backfill pipeline is calculated as follows:

\[ \delta = \frac{P_{\text{max}}D}{2[\sigma]_t} + \delta_1 + \delta_2 \]  

(3)

Wherein, \([\sigma]_t\) is the minimum allowable tensile stress, taken as 163MPa; while D, the inner diameter of pipeline, is taken as 180mm; \(\delta_1\) is the additional thickness for dealing with factors such as unevenness and corrosion, which is taken as 4 mm; \(\delta_2\) is the reserved wear thickness, which is taken as 3 mm; \(P_{\text{max}}\) is the maximum pressure.

Introducing \(P_{\text{max}}=2.98\)MPa into formula (3), it is derived that \(\delta = 8.65\) mm. Considering the safety factor, the wall thickness of trunk backfill pipeline is taken as 10mm.

Where the pipeline pressure is taken as 10MPa,

\[ P_{\text{max}}D = \frac{2[\sigma]_t}{\delta} \]

5.5mm<10mm; the calculation results show that the pipeline still operates safely with a certain margin when the pipe wall is pressured up to 10MPa.

According to *Definition and Selection of DN (Nominal Size) of Pipeline Components* (GB/T 1047-2005), the corresponding nominal diameter DN=200mm. The selection of trunk pipeline is consistent with that of vertical borehole pipeline, with a nominal diameter of 200mm.

With reference to *Varieties of Hot Rolled Seamless Steel Pipes* (GB8163, GB17395) and based on the above calculation results, the backfill pipeline made of standard seamless steel pipes with diameter close to the theoretical diameter is selected as the downhole trunk pipeline, which is of the variety of \(\phi 203 \times 10\) 16Mn seamless steel pipes with effective inner diameter \(D_I=183\)mm. The high-pressure quick coupling is selected as the coupling between pipelines, with an outer diameter of 203mm and a nominal pressure \(\geq 10\)MPa.

### 3.1.4. Critical velocity \(v_c\) and operating velocity \(v\)

The slurry velocity of backfill pipeline is an important basis to determine whether pipeline selection is reasonable or not. At a fixed flow rate, if the conveying velocity is too high, the slurry will be turbulent in the pipeline, and the hydraulic gradient that slurry flow needs to overcome will also be significant, which will cause a sharp rise in pipeline convey resistance, pipe wall abrasion and convey energy consumption, preventing it from achieving pipeline design economy; Where the velocity is low, the inner diameter of the pipeline needs to be increased, significantly driving up the corresponding pipeline material cost and installation cost. Meanwhile, where the velocity is too low, the solid particles such as aeolian sand in slurry will be subject to an obvious subsidence trend, resulting in the unstable flow phenomenon where the slurry changes with time, or even causing pipeline blockage. Therefore, the slurry in the pipeline should be conveyed within a reasonable velocity range, so as to realize the balance between economic efficiency and safety of pipeline convey. The lower limit of the reasonable velocity range of slurry in the pipeline is expressed as the critical velocity \(v_c\), which determines the lower limit of safety for the pipeline convey velocity of paste-like slurry of aeolian sand.

Where the inner diameter of pipeline is less than 200mm, the critical velocity \(v_c\) can be calculated with Durad formula.

\[ v_c = F_1 \sqrt{\frac{2gD}{\rho_1 - \rho_j} \rho_j} \]  

(4)

Wherein, \(F_1\)-- Velocity coefficient related to particle size and concentration, is taken as 1.05; \(g\)--Gravity acceleration, 9.81m/s²; \(D\)--Inner diameter of pipeline: 183mm; \(\rho_j\)--Slurry density, 1.70t/m³; \(\rho_1\)--Carrier density, 1.25t/m³;
By introducing the corresponding parameters into the formula, the critical velocity of slurry is calculated to be \( v_c = 1.19 \text{ m/s} \).

At a carrier density \( \rho_1 = 1.20 \text{ t/m}^3 \), the reasonable operating velocity should be that which ensures stable convey and large capacity, which is related to backfilling times line, pipeline diameter and slurry resistance loss, etc., and can be estimated through the following formula:

\[
v = 3.3 \sqrt{gD \cdot \frac{(1 + N)^2}{XN^2}}
\]

Wherein, \( N \)--Backfilling times line: 15.0; \( g \)--Gravity acceleration, 9.81 m/s\(^2\); \( D \)--Inner diameter of pipeline: 183 mm; \( X \)--Water-sand ratio: 1.0.

By introducing the corresponding parameters into the formula, the operating velocity of slurry is calculated to be \( v = 4.19 \text{ m/s} \). The operating velocity \( v \) is 3.5 times of the critical velocity \( v_c \). Therefore, the pipeline convey of slurry is reliable.

It is shown by the calculation results from the formula above that compared with aggregates such as gangue and river sand, the particle size of aeolian sand is smaller, which ensures a relatively low critical velocity with respect to the size of suspended particles, thus facilitating convey through the pipeline. This is one of the reasons that enable great times line gravity-flowed convey of the paste-like slurry of aeolian sand.

3.1.5. Verification of conveying capacity. Reasonable conveying capacity is to maximize the backfilling capacity of the system on the basis of making full use of the effective pressure head, which is calculated with the following formula:

\[
Q = \frac{\pi v D^4}{4} \]

Wherein, \( D \)--Inner diameter of pipeline: 183 mm;

\( v \)--Operating velocity: 4.19 m/s.

It is derived through calculation that the conveying capacity of the pipeline conveying system is \( Q = 396 \text{ m}^3/\text{h} \), which fully meets the requirements of backfilling capacity.

3.2. Principle of high concentration gravity-flowed convey technology at great times line

Paste-like backfill is a type of high concentration cemented backfill. At present, the coal mines applying high concentration gravity-flowed backfill technology in China include Suncun Mine, Wangzhuang Mine, Bucun Mine, Caitun Mine, Aiyou Mine and Daming Mine. Most of them have a backfilling times line of 4 - 8, such as Suncun Mine operated by Shandong Energy Xinwen Mining Group, which has a backfilling times line of 3.9 and a slurry concentration of 72%; The backfilling times line of Wangzhuang Mine in Shandong Province is 13.1, while its slurry concentration is rather low, only at 65%; The backfilling times line of Aiyou Mine of Liaoning Fuxin Mining (Group) Co., Ltd. is 3, with a slurry concentration of 57%; At present, in mine backfilling projects with slurry concentration exceeding 70% at home and abroad, pumping-based backfilling technology is basically adopted where the backfilling times line exceeds 10. Whereas the maximum concentration of slurry in Yuyang Coal Mine is 75%, with a maximum backfilling times line of 15. At high concentration, the backfilling times line is much larger than that in other coal mines, which enables high concentration gravity-flowed backfill at high flow rate and great times line. When slurry flows in a pipeline under pressure, it has to overcome the interlayer resistance produced by turbulence and the frictional resistance produced by the pipe wall at the same time, which are collectively referred to as frictional resistance loss, i.e. hydraulic gradient. The small hydraulic gradient is the main reason for enabling high concentration gravity-flowed convey in Yuyang Coal Mine at great times line.
3.2.1. Influencing factors of hydraulic gradient.

1. Cement-sand ratio
   Cement-sand ratio is an important factor affecting the gradation and fluidity of slurry. The slurry contains a large amount of ultrafine materials such as fly ash and cement, especially with the presence of fly ash with a microstructure featured with spherical particles, which improves the fluidity of slurry, and at the same time, forms a lubricating layer on the inner wall of pipeline under pressure, reducing the friction resistance of pipeline. In general, the cement-sand ratio (or the ratio of ash to coal gangue) in paste-like backfilling of coal mines is 1:2 - 1:3, while the cement-sand ratio of paste-like material of aeolian sand is 1, which is high, with small hydraulic gradient. Meanwhile, the particle size of aeolian sand as aggregate is relatively smaller than that of river sand and gangue, which ensures lower critical velocity, therefore beneficial to gravity-flowed convey of slurry.

2. Concentration
   Concentration has obvious influence on hydraulic gradient, where the greater the concentration, the greater the pressure loss of fluid. The increase of concentration implies an increase in the proportion of solid materials. To ensure the suspension of all solid materials, the energy consumed should be increased to overcome the gravity of solid materials, so the hydraulic gradient has to increases accordingly; The viscosity of the material increases with the increase of concentration, and the friction resistance increases accordingly. The slurry concentration in Yuyang Coal Mine is basically 70% - 75%, which is lower than that of other paste-like backfilling (concentration of 72% - 78%), which is also one of the reasons for achieving small hydraulic gradient and long-distance convey.

3.2.2. Calculation of hydraulic gradient.

The hydraulic gradient of slurry is generally calculated through a formula factoring in yield stress, relative density, velocity, pipe diameter, slurry viscosity and other parameters. These parameters have large measurement errors and are different from the actual ones, so it is generally calculated with the relevant data provided in pipeline design scheme. The calculation process is as follows:

The energy equation at constant total flow is:

$$Z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = Z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + h_{l1-2}$$

(7)

Wherein, $Z_1, Z_2$-- Elevation of any point on the selected section 1 and section 2 relative to the selected reference plane; $p_1, p_2$--Intensity of pressure at the same selected point on the corresponding section; $v_1, v_2$--Average velocity of corresponding sections; $h_{l1-2}$-- Average unit head loss between sections 1 and 2, including frictional loss and local loss.

According to theoretical calculation and corrected in consideration with the operation condition and parameters of backfill pipeline system, the hydraulic gradient of pipeline convey in Yuyang Coal Mine is obtained as $i=0.6\text{KPa/m}$.

The maximum allowable backfilling times line $N_{\text{max}}$ is calculated based on slurry density and actual pressure, and can be estimated using following formula in practical application:

$$N_{\text{max}} = \frac{K_1 \cdot \gamma}{K_2 \cdot i}$$

(8)

Wherein, $K_1$--Full-pipe coefficient of vertical pipe section, taken as 0.9; $K_2$--Local resistance coefficient of pipeline, taken as 1.1; $\gamma$--Slurry density, 1.70t/m$^3$; $i$--Hydraulic gradient, 0.6KPa/m.

It can be derived through calculation that $N_{\text{max}}$ is 22.7, which is much higher than the actual backfilling times line of Yuyang Coal Mine, which is 15, that is, the downhole horizontal convey distance reaches 3,798m at a vertical depth of 175m, which enables the long-distance gravity-flowed convey of high concentration backfill slurry at great times line.
4. Installation and Application of Backfill Pipeline System
The backfill pipeline consists of two parts: borehole riser and downhole drift horizontal pipeline.

4.1. Borehole riser
The backfill pipeline in Yuyang Coal Mine consists of two independent pipelines, with a single set of riser having a length of 145m and a single sectional length of 10m. A φ219mm×19mm pipeline (16Mn seamless steel pipe with a length of 150m for each borehole pipeline) is installed in the two backfill boreholes respectively in the backfill station. The two pipelines are connected by threads, and changed into horizontal pipelines through an elbow at the bottom of each borehole.

4.2. Horizontal pipeline in downhole drift
The backfill pipeline leading from the bottom of the borehole to the entrance of the working face serves as the downhole horizontal pipeline, which serves the fully-mechanized coal mining backfill working face. Each set of downhole pipeline is 2470m long, and the horizontal pipeline is selected as φ203mm×10mm (made of 16Mn seamless steel pipe). The single set of pipeline is made of a single steel pipe with a length of 4m or 6m (short connected locally), provided with 25X90° elbows and 2X135° elbows. The two pipelines are connected by high-pressure quick coupling. Two downhole pipelines are arranged on the backfill working face through special backfill drifts and return airway. The end of seamless steel pipe is externally connected with DN200 high-pressure hose, which is used to backfill the goaf.

4.3. Pipe fittings and accessories
Valve: mainly used for pipeline conversion, slurry discharge and flow control; There are two types of nominal pressures, namely 10MPa and 5MPa, gate valves and ball valves, most of which are connected to the surface PLC for centralized control.

Flowmeter: the surface slurry tank is installed along with the borehole riser chamber and the downhole horizontal pipeline, and connected to the surface PLC.

High pressure gauge: with a measuring range of 0 - 16MPa, which displays readings locally and remotely and provides pressure data recording function; it is connected to the surface PLC, with a supply voltage of 127V.

Tee: used to connect pipelines and fittings, with nominal pressure not less than 10MPa, including straight tee and reducing tee. The backfill pipeline and valves are shown in Fig. 4.

4.4. Pipeline monitoring and rapid treatment of pipeline blockage
During the backfill operation, some quality problems may occur which will affect the efficiency of backfill operation, such as impurities mixed in slurry, excessively high slurry concentration or setting too fast, and certain production accidents, such as solidification caused by long standing time of slurry in the pipeline, pipeline blockage and even pipeline leakage caused by unthorough cleaning of the filling pipeline. Therefore, it is necessary to monitor the backfill pipeline, establish a monitoring...
system for the backfill pipeline, and formulate an early warning and rapid treatment plan targeting pipeline blockage. Measures are developed to mainly address the following three aspects:

1. Electric control and monitoring system: electric valves are used as main valves, which can quickly realize pipeline switching, sewage discharge and other operations; Pipeline pressure, flow rate, slurry backfill status, etc. are also monitored in real time by local and surface remote monitoring systems. The pipeline monitoring system is incorporated into the backfill automatic control system.

2. Pipeline monitoring: an online pressure monitoring system for backfill pipeline is established, and pressure sensors are installed in low-lying areas and elbow sections to monitor pipeline pressure and give early warning of accidents such as pipeline blockage.

3. Flow control of pipeline backfill slurry: in order to ensure that the backfill slurry flows within a reasonable velocity range and to prevent slurry from segregation or sedimentation, thus causing pipe blockage accidents, it is necessary to install a flow control valve and use a hydraulic valve to control the flow rate of slurry to ensure that the backfill slurry is conveyed in a stable and full-pipe manner in the pipeline.

After the installation of backfill pipeline, the industrial test of pipeline convey was carried out with test slurry concentration at 72%, slurry flow rate at 200 - 400m³/h, and slurry ejection distance at the downhole slurry outlet of about 2 m. It demonstrates high reliability in pipeline convey of slurry and proves the feasibility of long-distance gravity-flowed convey of high concentration backfill slurry at great times line.

5. Conclusions
(1) The high concentration backfill slurry of aeolian sand has high fluidity. Experiments show that the fluidity will markedly drop when the slurry concentration exceeds 72%. To enable gravity-flowed convey of backfill slurry, the initial shear stress of backfill slurry must be 11Pa and the apparent viscosity generally must not exceed 1500 mPa·s, subject to a corresponding upper limit of slurry concentration of 75%.

(2) The calculation and analysis show that the critical velocity and operating velocity of high concentration backfill slurry at a backfilling times line of 15 are 1.19m/s and 4.19m/s respectively. The operating velocity is 3.5 times of the critical velocity, with maximum conveying capacity up to 396m³/h, and the pipeline conveying of slurry has high reliability. According to the backfill pipeline conditions in Yuyang Coal Mine, the maximum feasible backfilling times line is 22.7, that is, the horizontal convey distance downhole can reach 3,798m at a vertical depth of 175m, thus achieving the long-distance gravity-flowed convey of high concentration backfill slurry at great times line.

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