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Green coal mining technique integrating mining-dressing-gas draining-backfilling-mining

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A B S T R A C T

Aiming to address the following major engineering issues faced by the Pingdingshan No. 12 mine: (1) difficulty in implementing auxiliary lifting because of its depth (i.e., beyond 1000 m); (2) highly gassy main coal seam with low permeability; (3) unstable overlying coal seam without suitable conditions for implementing conventional mining techniques for protective coal seam; and (4) predominant reliance on "under three" coal resources to ensure production output. This study proposes an integrated, closed-cycle mining-dressing-gas draining-backfilling-mining (MDGBM) technique. The proposed approach involves the mining of protective coal seam, underground dressing of coal and gangue (UDCG), pressure relief and gas drainage before extraction, and backfilling and mining of the protected coal seam. A system for draining gas and mining the protective seam in the rock stratum is designed and implemented based on the geological conditions. This system helps in realizing pressure relief and gas drainage from the protective seam before extraction. Accordingly, another system, which is connected to the existing production system, is established for the UDCG based on the dense medium-shallow trough process. The mixed mining workface is designed to accommodate both solid backfill and conventional fully mechanized coal mining, thereby facilitating coal mining, USCG, and backfilling. The results show that: The mixed mining workface length for the Ji_{15}-31010 protected seam was 220 m with coal production capacity 1.2 million tons per year, while the backfill capacity of gangue was 0.5 million tons per year. The gas pressure decreased from 1.78 to 0.35 MPa, and the total amount of safely mined coal was 1.34 million tons. The process of simultaneously exploiting coal and draining gas was found to be safe, efficient, and green. This process also yielded significant economic benefits.

1. Introduction

Highly gassy mines and collieries are found all over China. These mines and collieries are mainly concentrated in Guizhou, Sichuan, Heilongjiang, Shanxi, Henan, and Anhui provinces. The Chinese statistics for 2010 has indicated that 2197 highly gassy mines account for approximately 17% of all collieries in the country. Consequently, mining levels have been extended with the increase in coal production. This development has resulted in a gradual increase in the proportion of highly gassy coal seams with low permeability. More than 95% of the coal seams in China's highly gassy mines actually have low permeability. Their permeability coefficients are less than 0.1 $m^2/(MPa^2{\cdot}d)$, which makes coal exploitation and gas draining a very challenging process.

The most common mining method presently employed for highly gassy coal seams with low permeability is used in mining the protective seam, to achieve pressure relief and gas drainage before extracting protected seam [1–3]. However, this method has limitations, and requires the existence of coal or parting thin seam that can act as the protective seam. The positions of the protective and protected seams must also be aligned relative to each other. Finding suitable methods of relieving gas pressure and increasing drainage rate before seam extraction is a major challenge in mining highly gassy coal seams without the requisite protective seams. This approach can facilitate simultaneous coal exploitation and gas draining, which would lead to safe and efficient coal production.

The Pingdingshan No. 12 mine, named as No. 12 mine for short, is owned by the Pingdingshan Tianan Coal Mining Co., Ltd. The Ji_{15} coal seam of the mine is highly gassy, has low permeability, and does not have a protective seam, which is the requisite condition

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for conventional mining. This study proposes a coal mining technique that integrates the processes of mining-dressing-gas draining-backfilling-mining (MDGBM) to address the previously mentioned challenges. This framework includes various processes, including the mining of protective seam in the rock stratum, underground dressing of coal and gangue (UDCG), development of a system for exploiting coal and draining gas, and using a mixed mining technique that combines solid backfill and conventional, fully mechanized coal mining. The MDGBM technique was successfully implemented in the Ji_{14}-31010 and Ji_{15}-31010 workface, which are located in the third level of the No. 12 Mine. This result proves that the approach is safe, efficient, and green for simultaneously exploiting coal and draining gas.

2. Project overview

2.1. Background

The No. 12 mine, which is buried at a depth of 1100 m and has a production capacity of 1.3 Mt/a, is located in the Henan province. Its mining depth extends from −150 to −800 m. The remaining recoverable reserves of the mine currently amount to 23.849 Mt, 12.343 million tons (51.75%) of which is classified as "under three" coal resources. "Under three" refers to pressure-relieved coal buried under railways, waterbodies, or buildings. The first and second levels of the No. 12 mine have been fully mined. The third level has total reserves amounting to 32.323 million tons, 21.253 million tons (65.75%) of which is recoverable. The third level is also a single mining area with two wings. It is presently used as the main mining area with main coal seams belonging to the Ji group. The Ji_{15} coal seam, which has a permeability coefficient of 0.0776 m^2/MPa^2·d, specifically contains 15.256 m^3/t of raw gas at a pressure of 1.78 MPa. This seam is overlaid by the 0.5 m-thick Ji_{14} seam, which is a non-outburst seam with inherent instability and a gas pressure of 0.26 MPa.

Mining of the Ji_{15} seam is faced with the following challenges:

(1) The implementation of auxiliary lifting and other deep mining processes is difficult because the mining depth exceeds 1100 m.
(2) The Ji_{15} seam is highly gassy, but has low permeability and poor drainage efficiency. These characteristics pose serious potential risks and make safe mining very difficult to achieve.
(3) The overlying Ji_{14} coal seam is inherently unstable, too thin for mining, and does not have the requisite technical conditions for conventional mining of protective seams. On the one hand, abandoning the seam will result in serious resource wastage. On the other hand, designating it as the protective seam will involve mining it in the rock stratum, which will inevitably cause the coal flow to contain a high proportion of gangue (i.e., as much as 73.7%). The protective seam workface will create approximately 8.1 million m^3 of gangue, the surface discharge of which will significantly increase underground transportation and lifting costs. Secondary issues include choosing either lifting the gangue for surface discharge or treating them underground.
(4) The mine is predominantly reliant on "under three" coal resources, especially those under buildings. Therefore, its production output cannot be guaranteed. Accordingly, the engineering issue to be resolved is how to mine the J_{15} seam safely and efficiently.

2.2. Concept behind the integrated MDGBM technique

The Backfilling Mining Task Force from the China University of Mining and Technology has proposed the integrated MDGBM technique to address the engineering issues in the No. 12 mine. The basic concept behind this integrated technique is a green and cyclical mining system targeting the highly gassy Ji_{15} seam with low permeability. The MDGBM technique is entirely implemented underground and comprises the following processes: coal (rock) seam mining, UDCG, pressure relief, and gas drainage before extraction, and development of a mixed mining technique that combines solid backfill and fully mechanized conventional coal mining.

The conditions for protective seam mining are specifically created based on the basic requirements for protected seam mining. These requirements indicate that mining of the Ji_{14} protective coal (rock) seam should free the underlying highly gassy Ji_{15} seam with low permeability. The previous process produces raw coal with high gangue contents. This raw coal goes through the UDCG system. The resultant gangue is simultaneously transported to the underlying Ji_{15} seam workface, where mixed mining (i.e., solid backfill and conventional fully mechanized coal mining) is conducted. The backfill mining technique is subsequently used for goaf backfilling [4–15]. Protective seam mining increases the protected

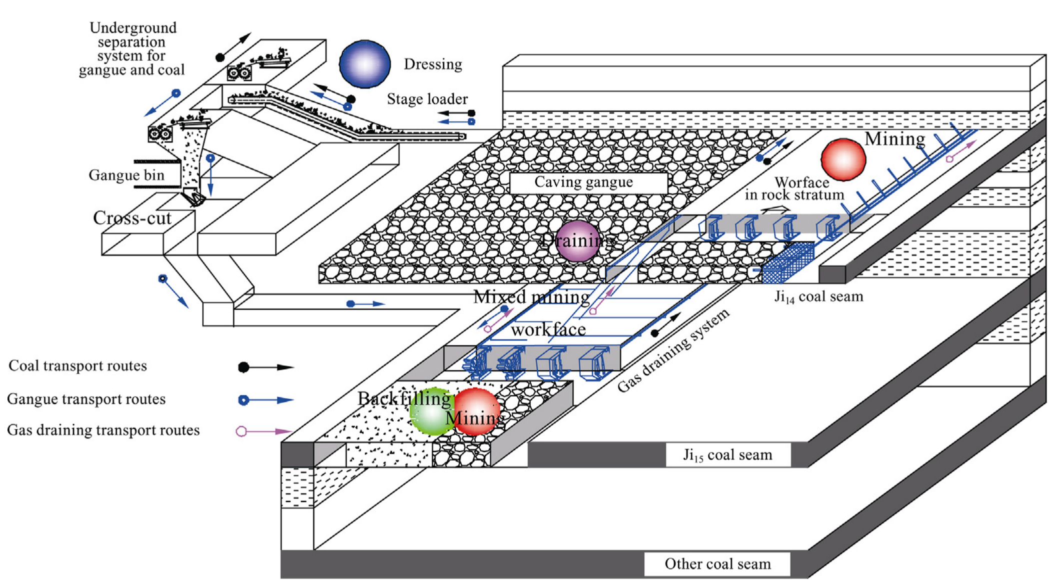


Fig. 1. Overall concept behind the integrated MDGBM technique.

permeability of the seam. Therefore, the gas in the latter can be extracted using a gas drainage system installed between the protective and protected seams. Consequently, simultaneous coal exploitation and gas drainage from the highly gassy Ji_{15} seam can be safely and efficiently realized. Fig. 1 shows the overall concept behind the integrated MDGBM technique for coal mines.

2.3. Geological mine conditions

The third level, which has a strike length of 2250 m, sloping width of 1800 m, and a mining depth ranging between 800 and1240 m, is located in the northern region of the No. 12 mine. The elevations of its upper bound and ground level range from −620 to −840 and +180 to +400 m, respectively. The Ji group, which is mined at the third level, comprises the Ji_{14}, Ji_{15}, Ji_{16}, and Ji_{17} seams arranged downward from the top. The Ji_{14} seam cannot be mined, while the Ji_{15} seam is isolated. The Ji_{16} and Ji_{17} seams are combined to form the $Ji_{16\text{-}17}$ seam.

The Ji_{15} seam, which produces high-quality coking coal, is the main seam being currently mined. This seam has an average thickness of 3.2 m, a dip of 6–10°, and consists of an 8.5–16.5 m-thick grayish black sandy mudstone roof. It has a Protodyakonov's hardness coefficient (*f*) of 2–5 and a vertical compressive strength of 29.4–45 MPa. The main roof is 25–30 m thick, and grayish white coarse-grained sandstone with a Protodyakonov's hardness coefficient of 6–10 while a vertical compressive strength of 53.9–186.2 MPa. The direct floor of the Ji_{15} seam is the immediate roof of the $Ji_{16\text{-}17}$ seam. This roof is 0.6–1.8 m thick, and consists of dark gray mudstone with a Protodyakonov's hardness coefficient of 0.8–3 and a compressive strength of 8.6 MPa.

Fig. 2 presents the synthetical stratum histogram of the Ji_{15} seam. The first mining face of the protective seam is the Ji_{14}-31010 workface, which has a strike length of 571.9, 150 m sloping width of 150 m, average dip of 5.5°, and average seam thickness of 0.5 m. The Ji_{14}-31050 protective seam workface is located in the north and is adjacent to the Ji_{14}-31010 workface. It has a strike length of 1040 m and a sloping width of 150 m. The first mining face of the protected seam is the Ji_{15}-31010 workface, which has a face length of 220 m, strike length of 929 m, depth of 1005–1166 m, and an average dip of 5°. Fig. 3 shows the plane layout of the test mining area.

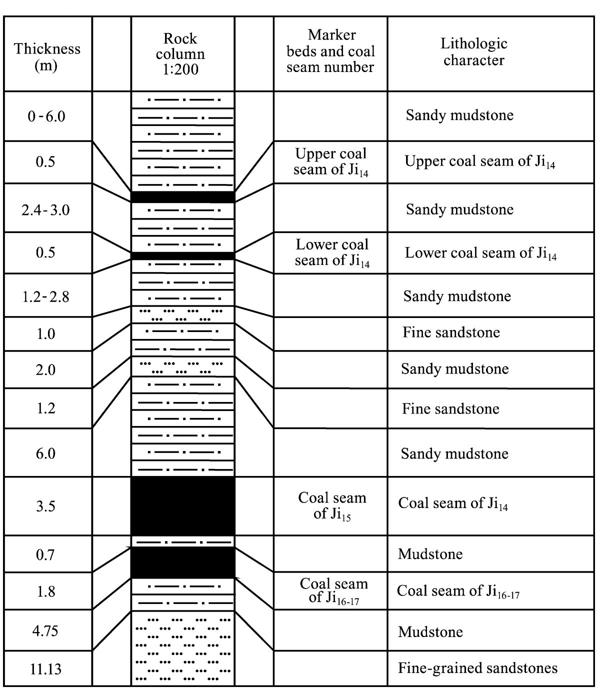


Fig. 2. Synthetical stratum histogram of the Ji_{15} seam.

3. Mining method for protective seams in rock strata

3.1. Method contents

The workface generally involve mining a rock stratum with a particular thickness before the protective seam can attain the ideal pressure relief effect. Therefore, the desired effect cannot be achieved if the mining of the thin coal seam is designed solely on the pressure relief principle. The technique of mining the protective seam in a rock stratum is intended for highly gassy coal seams with low permeability, which necessitates implementing pressure relief mining of the protective seam. However, a suitable protective seam is not available. The technique requires mining the thinner coal seam located near the outburst seam and portions or even the entirety of the nearby rock stratum to create the requisite protective seam. This step ensures the realization of the pressure relief effect during protective seam mining, thereby eliminating the risk of coal seam outbursts.

The workface may involve part of or even the entire rock stratum when its coal line is relatively thin and the rock stratum being mined is thick. Under these circumstances, the conventional, fully mechanized coal shearer cannot achieve the ideal rock-cutting effect. In other words, specialized mining processes, such as upgrading the coal shearer and related equipment, water-infused softening of the stratum, and pre-splitting blasting, are needed for workface mining in a rock stratum. We developed a coal-rock cutting method for the workfaces in rock strata after considering a comprehensive study of the methods used for mining parting thin seams proposed by researchers from China and overseas [16–19]. The method is applicable to the workfaces of protective seams in rock strata with different characteristics with regard to coal-rock thickness. Table 1 presents the specific features of the various cutting methods.

3.2. Production system for protective seams in rock strata

The first protective seams to be mined in the rock strata are the Ji_{14}-31010 and Ji_{14}-31050 workfaces (Fig. 3). The average coal seam thickness at these workfaces is only 0.5 m, while the designed mining height is 1.9 m. The workface stratum, which has a Protodyakonov's hardness coefficient of 7–9, is thicker than 0.8 m for more than 80% of the entire protective seam. Considering the varying workface stratum thickness, the shearer model is changed from MG320/710-WD (original) to MG500/1130-WD and then combined with pre-splitting blasting. The shearer is specifically used for direct cutting of coal rock when the rock stratum is thinner than 0.6 m. Meanwhile, pre-splitting blasting is executed prior to shearer cutting when the rock stratum is 0.6 m or thicker.

The boreholes for blasting are designed for real-time adjustment according to variations in the thickness of the rock stratum. A single row of boreholes at an elevation of 10° is laid out when the rock stratum is 0.6–0.8 m thick. On the contrary, a tri-petal layout is used for boreholes at elevations of 15° and dips of 15°-20° when thickness exceeds 0.8 m. The interval of boreholes for both layouts is the same at 0.5–0.7 m, while the depth of each borehole is 1.2–1.5 m. Figs. 4 and 5 show the cutting methods for the protective seam in a rock stratum of varying thickness and the blasting borehole layouts, respectively.

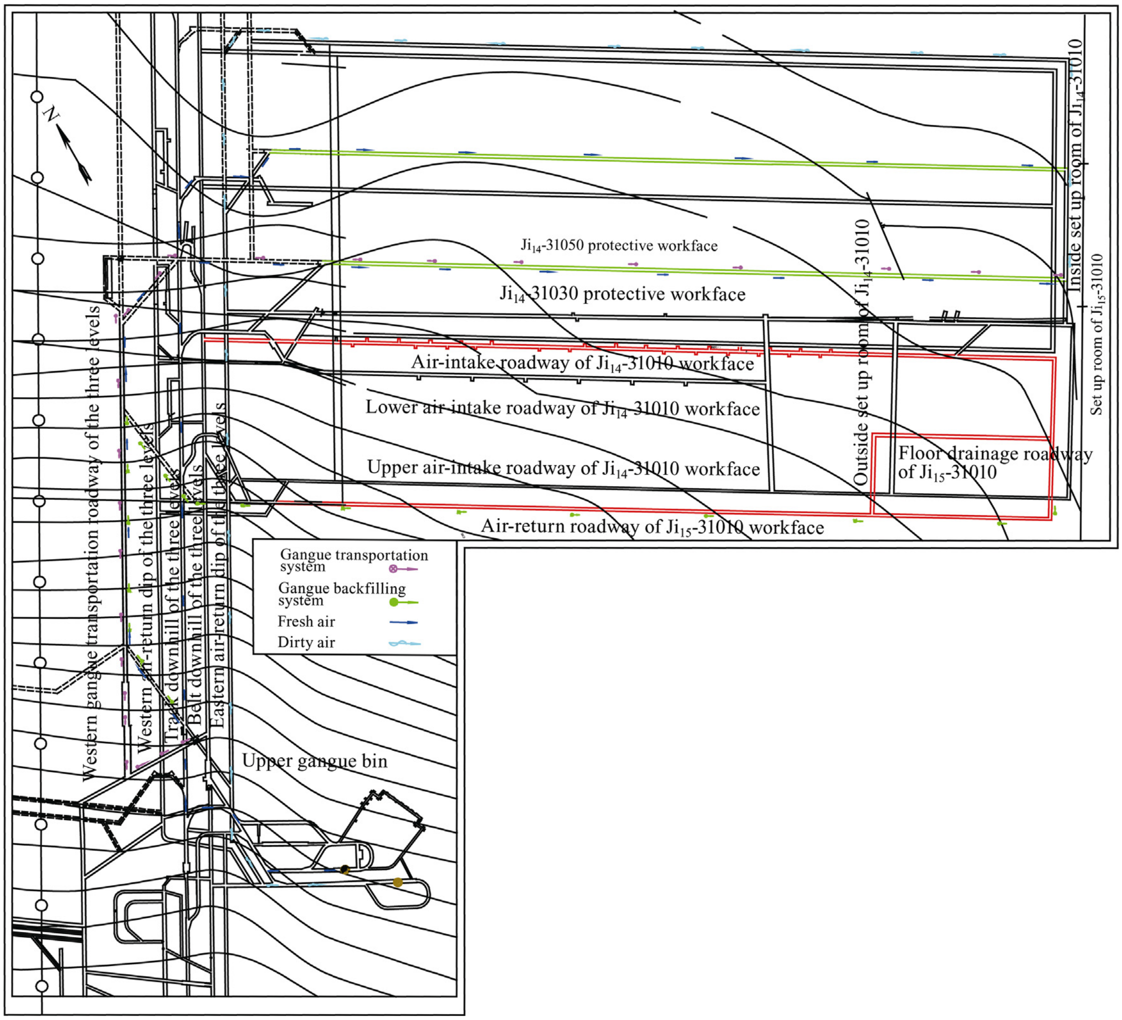


Fig. 3. Plane layout of the test mining area.

Table 1
Coal-rock cutting methods for protective seams in rock strata.

Cutting methods	Condition of use	Process flow	Main disadvantage
Conventional, fully mechanized mining	Rock stratum that lacks hardness and thickness	Mining that combines high-powered coal shearers and high-strength picks	Pick damage rate is high; maintenance cycle is short
Blasting mining	Rock stratum with good hardness or recovery of resources in irregular blocks or segments	Coal blasting, mechanized coal transportation, and roof propped up with support units	Labor-intensive, potential safety hazards, and low efficiency
Fully mechanized mining combined with water-infusion softening	Rock stratum with moderate hardness	Hole drilling to facilitate water-infusion softening of the rock stratum, followed by fully mechanized mining	Softening effect is very gradual and causes serious water accumulation
Fully mechanized mining combined with pre-splitting blasting	Rock stratum with moderate hardness and large-scale operations	Localized pre-splitting blasting of hard rocks, followed by cutting using a coal shearer	Equipment is easily damaged during rock blasting

4. UDCG

4.1. Main UDCG method

Present UDCG methods are mainly based on the existing processes and techniques used by aboveground coal preparation plants. The equipment used above ground for the dressing the coal and gangue are basically redesigned and reconstructed before being transported underground, where a dressing chamber is set up for the UDCG. The most commonly used UDCG methods are selective crushing, movable sieve jig, and dense medium-shallow trough (DM-ST) [20–24]. Table 2 summarizes the advantages and disadvantages of these methods.

The gangue contents in the coal flow from the Ji_{14} protective seam in the rock stratum can be as high as 73.7%. Accordingly, 35.4% of these sieved substances consists 0–13 mm particles, while the remaining 61.5% consists of ash contents. The dressing density is 1.7 kg/L. This composition requires a very high degree of discrimination during the coal and gangue dressing process. Considering the aforementioned features and the actual conditions in the

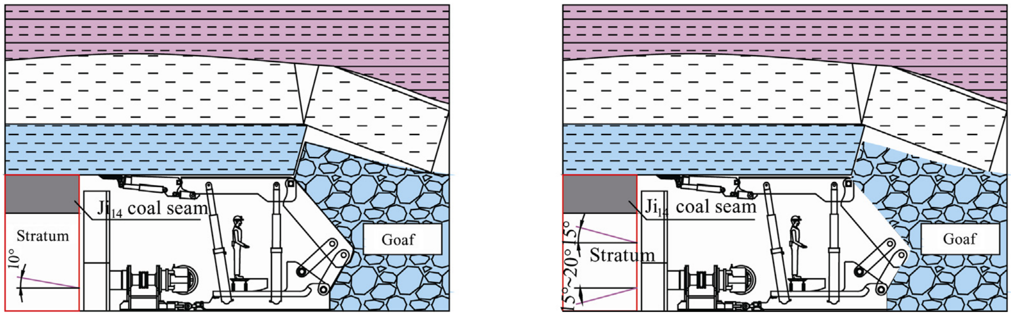


Fig. 4. Cutting methods for the protective seam in a rock stratum with varying thickness.

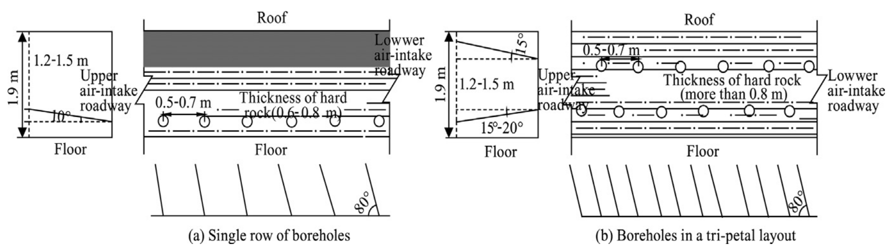


Fig. 5. Blasting borehole layouts.

Table 2
Comparative analysis of the UDCG methods.

Dressing methods	Key dressing equipment	Advantage	Disadvantage
Selective crushing	Selective crusher	Simple system and processing layout and small equipment investment	Low gangue recovery efficiency and limited applicability
Movable sieve jig	Jig, separator, crusher	Amount of gangue transported out of the mine is reduced, thereby saving aboveground space; simple processing system; and gangue recovery efficiency up to 85%	Difficulty of setting up tall and bulky equipment, and the particle size range that can be separated is limited
DM-ST	DM-ST separator, crusher, sculpting sieve	Amount of gangue transported out of the mine is reduced; raw coal quality is improved; savings on various costs; and dressing efficiency up to 98%, among others	Huge equipment investment, large space needed for bulky equipment, and high production costs

No. 12 mine, a 13, 250 mm three-product toothed roller sieve is used to initially separate gangue in the coal flow based on the particle diameter. A DM-ST separator is then utilized to execute the final dressing process based on the substance density.

4.2. DM-ST dressing system

The UDCG method is mainly composed of the following two components: the DM-ST discharging system and the slurry treatment system. These two components are utilized in the coal and gangue dressing process. The overall process flow of the dressing system is described below. First, a roller sieve with an appropriate mesh size is used to sieve the run-of-mine coal from the Ji_{14} protective seam in the rock stratum. This step aims to reduce the amount of ash contents, with small particle sizes, to a certain level. Second, the DM-ST separator is employed for the recovery treatment of substances remaining in the sieve before the slime recovery system conducts another round of slime washing. Fig. 6 shows the process flowchart of the DM-ST dressing system.

After evaluating the actual mine conditions, a dressing chamber is then set up in the connecting area between the third level's west wing gangue transportation and the inclined gangue transportation lanes. The UDCG chamber is 49.7 long, 8.8 tall, and 4 m wide along the horizontal direction. Immediately adjacent to the UDCG chamber is another chamber holding the conveyor head of the third level's west wing refuse transportation lane. This chamber is 60 m long, 6 m tall, and 8.4 m wide along the horizontal direction. The dressing chamber contains the key equipment, a three-product toothed roller sieve (Type of XCG-16/28), a roller crusher, and a DM-ST separator (Type of XZQ1525). The separator is suitable for segregating 13–250 mm coal and gangue particles with a dressing capacity of 2.2 million tons per yeart/a. Fig. 7 shows the UDCG chamber and the key equipment.

5. Gas drainage methods

Gas drainage is carried out underground. Accordingly, a 3D drainage pattern is set up to execute pressure relief mining and gas draining. Previous studies and experiments have successfully implemented various gas drainage methods for the working and adjacent seams and goaf combined with the use of an upper (lower) roadway or stay lane. These techniques have been used until now, and include the following aspects: (1) roadway on the protected seam floor along with upward-facing crossing boreholes, (2) pressure relief during multiple mining of a coal group, (3) roadway on the roof of the first mining (protective) seam, (4) removal of outbursts from the workface through coal seam bedding drilling, (5) drilling along the roof strike of the protective seam, (6) buried pipes in the goaf of the protective seam workface, (7) pressure relief of goaf, and (8) gas drainage through the upper workface corner [25–29].

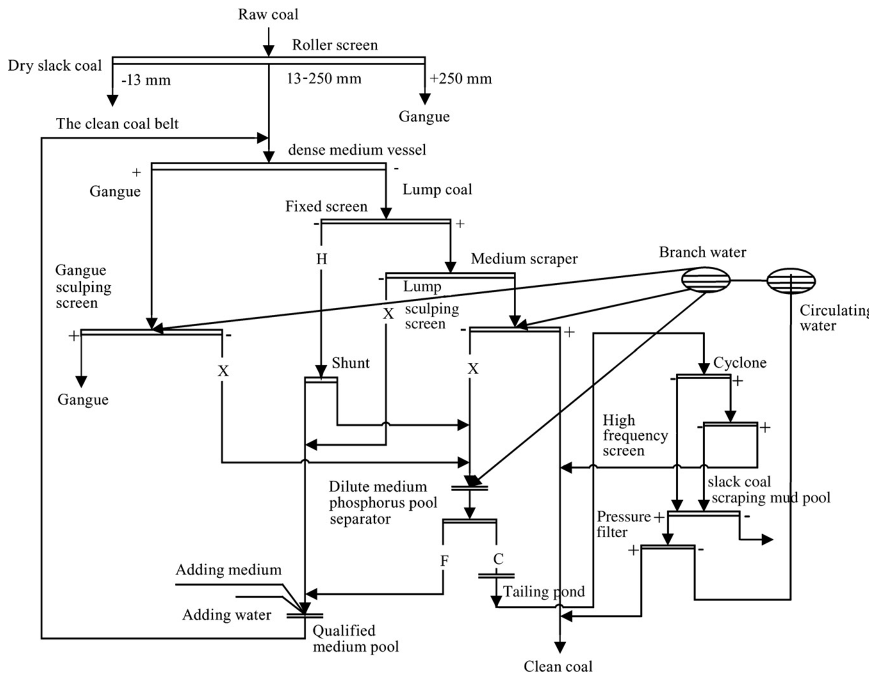
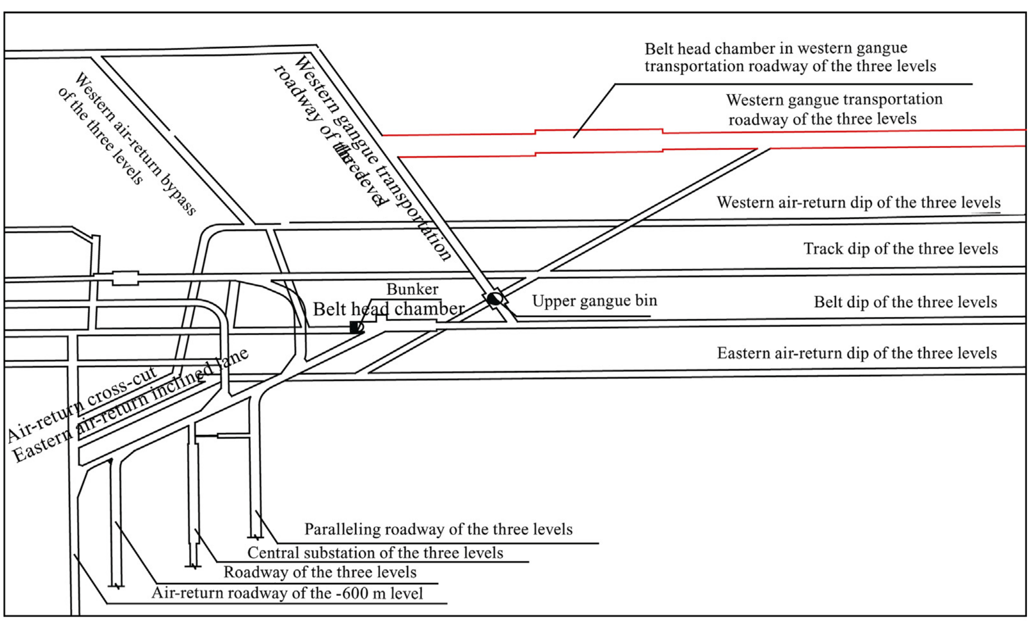
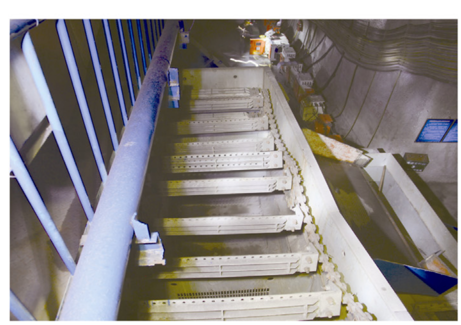


Fig. 6. Overall processing flow of the DM-ST dressing system.



(a) Plane layout of the underground dressing chamber

(b) Underground dressing chamber

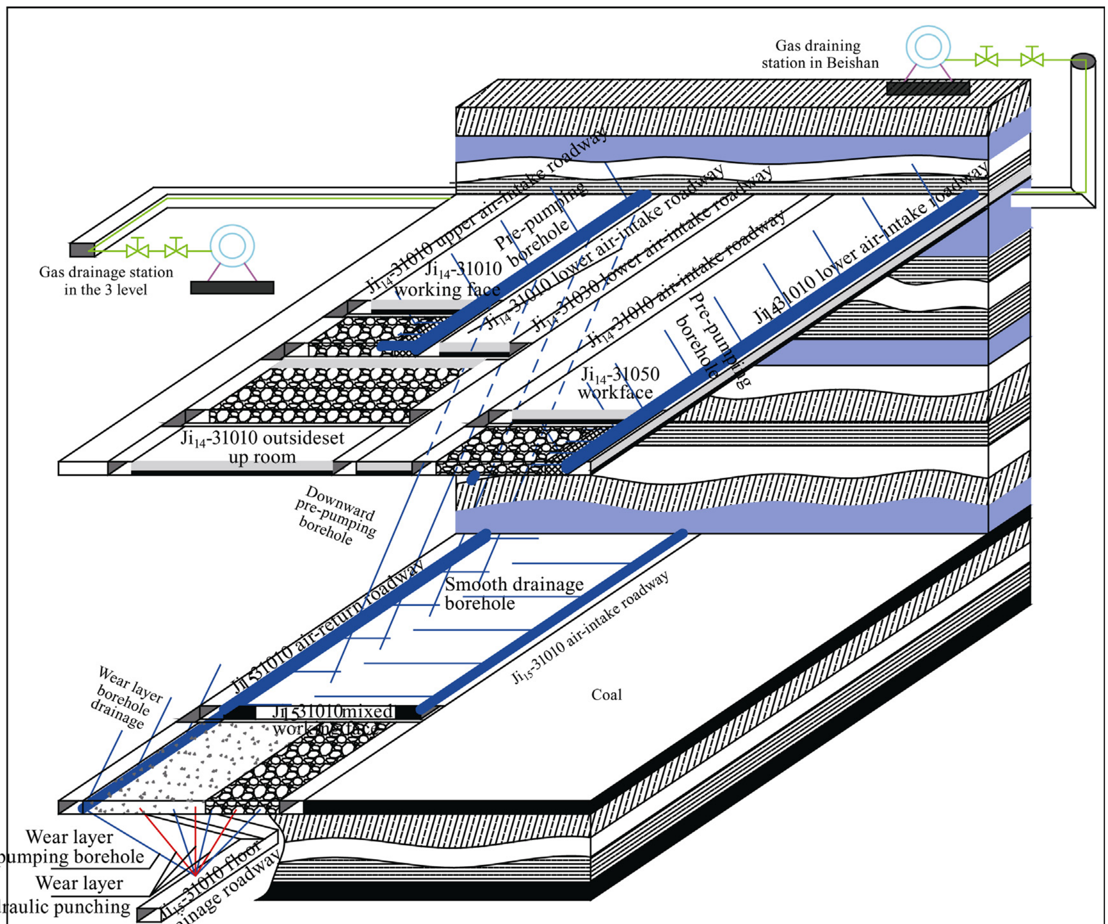


(c) DM-ST separator (plan view)

Fig. 7. UDCG chamber layout and key equipment photographs.

Table 3
Technical parameters of the boreholes for the Ji_{14}-31010 workface.

Borehole	Diameter (mm)	Depth (m)	Inter-borehole distance (m)	Dip angle (°)	Type	Location
1	89	30	15	−22	Crossing boreholes for gas drainage	Through cut of the Ji_{14}-31010 workface
2	89	60	30	−11	Crossing boreholes for hydraulic fracturing	
3	89	90	15	−8	Crossing boreholes for gas drainage	
4	89	30	50		Crossing boreholes for gas drainage along the roof strike	Lower head entry for the Ji_{14}-31010 workface
5	89	40	10		Crossing boreholes along the floor	



(a) Gas drainage system

(b) Drainage pipes

(c) Interconnecting pipes

(d) Board documenting drainage parameters

Fig. 8. Gas drainage system layout and drainage pipe photographs.

The aforementioned gas drainage methods have been referenced for designing a system for the Ji_{14} and Ji_{15} seams. The crossing boreholes for gas drainage and hydraulic fracturing are specifically set up at the through cut of the Ji_{14}-31010 workface for pressure relief and gas drainage of the Ji_{15} seam. The crossing boreholes are drilled along the roof strike at the lower head entry for the Ji_{14}-31010 workface. Concurrent drilling of crossing pre-drainage boreholes is also conducted on the floor for relieved gas drainage from the Ji_{15} seam. Table 3 presents the technical parameters of the boreholes. Subsequently, 300-mm-diameter drainage pipes are buried along the lower head entry and the gob-side entry wall at 10 m intervals. Doing this drains the gas accumulated at the upper goaf portion.

Boreholes are also drilled in the bedding order on the vertical coal walls of the head and tail entries of the Ji_{15}-31010 workface for gas drainage from the working seam. The boreholes have a diameter of 89 mm, depths of 70 and 140 m, and are located at 2 m intervals. At the same time, upward-facing crossing boreholes are drilled in the Ji_{15}-31010 tail entry to drain gas that had dissipated upward from the Ji_{15} seam to the fracture belt on the protec-

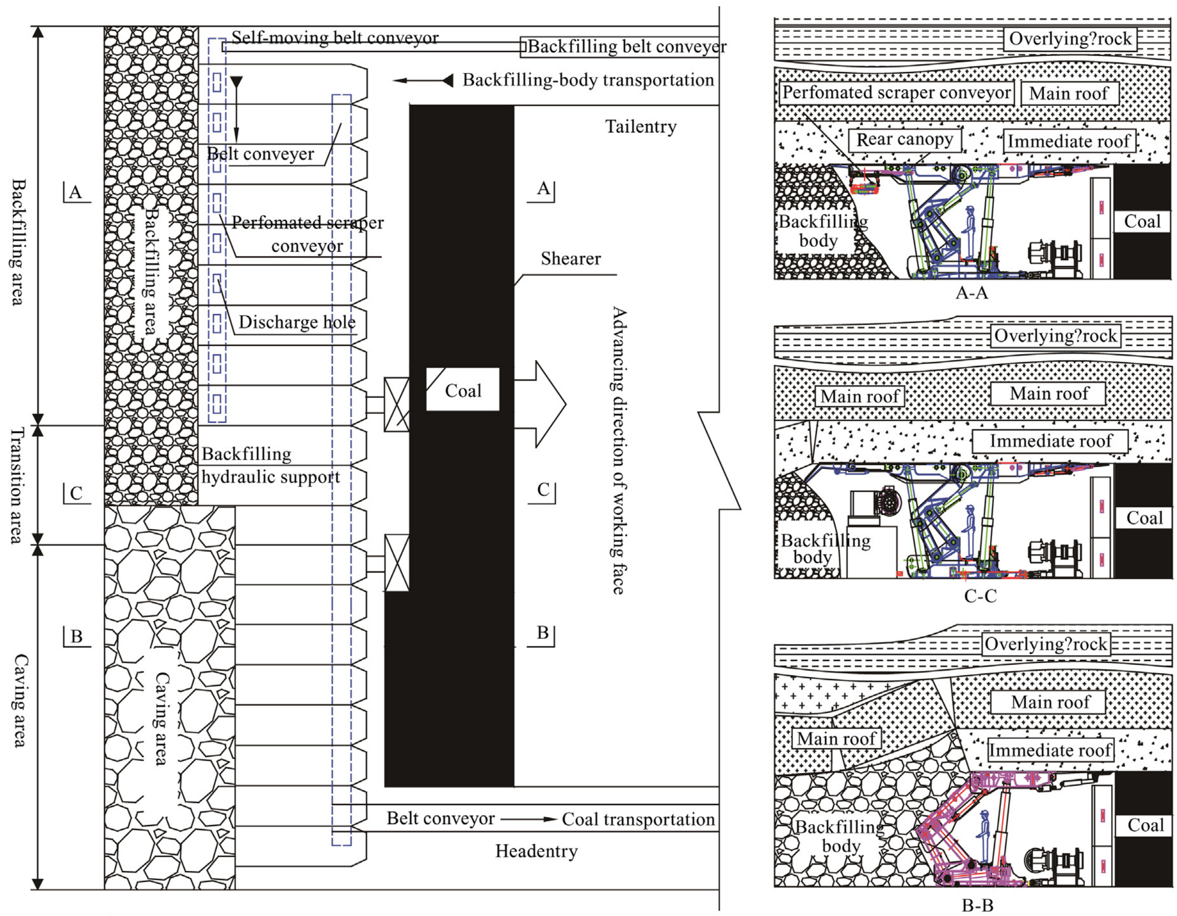


Fig. 9. Mixed mining workface and equipment layout with solid backfill and conventional fully mechanized coal mining.

Table 4
Selected equipment models for the mixed mining workface.

Index No.	Equipment name	Model No.	Quantity
1	Coal shearer	MG400/940 WD	1
2	Front scraper conveyor	SGZ-800/800WS	1
3	Stage loader for coal transportation	SZZ764/200	1
4	Dual-column fully mechanized mining support	ZY6800/20/40	76
5	Backfilling support	ZC5200/20/40	66
6	Backfilling transition support A	ZCGa5200/20/40	2
7	Backfilling transition support B	ZCGb5200/20/40	1
8	Backfilling transition support C	ZCGc5200/20/40	1
9	Rear scraper conveyor	SGZ764/2 × 200	1
10	Belt conveyor	DTL80/50/30	1

tive seam roof. The boreholes have a diameter of 75 mm and are located at 10 m intervals.

A set of crossing pre-drainage boreholes is drilled on the Ji_{15} seam on the floor drainage gateway of the Ji_{15}-31010 workface at 5 m intervals. Each set comprises 11 boreholes at 5 m intervals. These boreholes facilitate gas pre-drainage from the Ji_{15} seam. Fig. 8 shows the overall layout of the gas drainage system for the Ji_{14}-31010 protective seam, Ji_{14}-31050, and Ji_{15}-31010 workfaces.

6. Mixed method of combining solid backfill and conventional fully mechanized mining

6.1. Method contents

The most commonly used mixed mining methods are as follows: (1) high-grade, conventionally mechanized mining mixed with blasting mining, (2) fully mechanized mining mixed with blasting mining, (3) fully mechanized mining mixed with longwall top coal caving, and (4) solid backfill mixed with conventional fully mechanized mining [30–33]. The fourth method refers to the concurrent equipment setup for both fully mechanized solid backfill and conventional fully mechanized mining at the same workface. The different equipments have coordinated operations, which jointly completes the coal and solid backfill mining processes. The mixed mining workface comprises three areas, namely, backfilling, transition, and caving. At the backfilling area, the solid backfill method is used for coal mining. A backfilling hydraulic support and a perforated scraper conveyor are used to backfill the goaf with gangue. At the caving area, the conventional, fully mechanized coal mining method is employed. This area is equipped with a conventional, fully mechanized hydraulic support. Furthermore, the mine roof is allowed to naturally collapse. The transition area is located

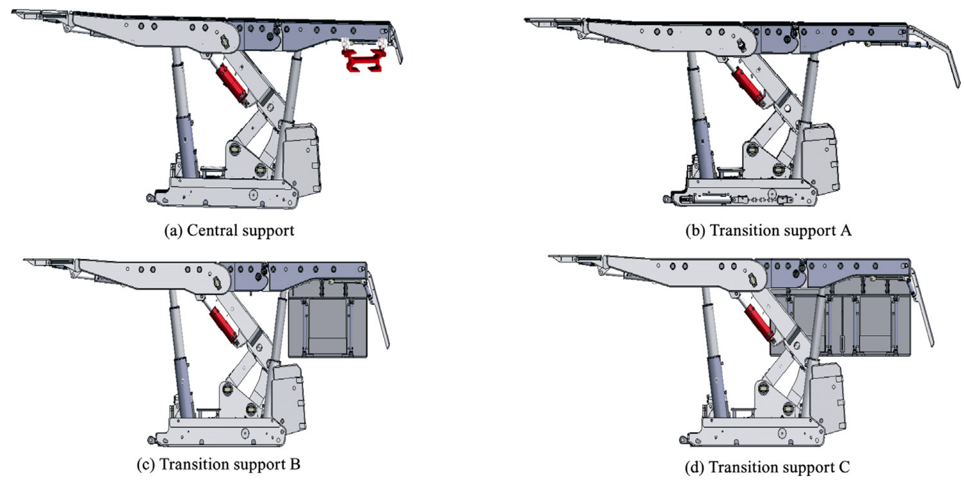


Fig. 10. Basic structure of the backfilling hydraulic support.

between the two previously mentioned areas. It also consists of a backfilling transition support and a perforated scraper conveyor head.

A coal shearer and a scraper conveyor for coal transportation are subsequently installed at the front of the mixed mining workface. The crusher, stage loader, belt conveyor, and other equipment are located within the coal transportation lane. The gangue transportation lane holds a separate gangue belt conveyor and a gangue stage loader. The total length of the mixed mining workface exceeds 200 m. It is capable of processing gangue for workface solid backfilling. It also has the ability to overcome the disadvantages of a plain backfilling workface, including low production capacity and poor efficiency. Therefore, the requirements of production capacity of the mine can be satisfied with a single workface. Fig. 9 shows the production system of the mixed mining workface and the equipment layout.

6.2. Key technical parameters and equipment selection for the Ji$_{15}$-31010 mixed mining workface

The first mining face of the Ji$_{15}$ seam in the third level is the Ji$_{15}$-31010 mixed mining workface (Fig. 9). The Ji$_{15}$-31030 will be its replacement face. The Ji$_{15}$-31010 mixed mining workface is designed based on the requirements of production capacity of the mine, processing gangue from the Ji$_{14}$ protective seam in the rock stratum, and the stress distribution characteristics of the transition area. The workface has a total length of 220 m, of which the lengths of the backfilling, caving, and transition areas correspond to 120, 94, and 6 m, respectively.

The following matching principles must be considered in selecting the equipment for the mixed mining workface: (1) compatibility between backfilling and coal mining capabilities, (2) parallel backfilling and coal mining operations, and (3) safety management of the transition zone. The finalized list of selected key equipment includes MG400/940 WD coal shearer, SGZ-800/800WS scraper conveyor, ZC5200/20/40 backfilling hydraulic support, SZZ764/200 self-moving belt conveyor, and SGZ764/2 × 200 perforated scraper conveyor.

The coal shearer and the scraper conveyor are standard equipment used for conventional, fully mechanized coal mining. The basic support chosen for the transition area, which has been selected after considering ventilation management, conveyor head layout, and requirements for refuse blocking, is similar to that for the backfilling area. The transition support rear is fixed with a holder that connects to the lifting platform of the conveyor head, as well as the equipment at the rear and side for refuse blocking. Table 4 presents the equipment models for the mixed mining workface. Fig. 10 shows the basic structure of the backfilling hydraulic support used in the backfilling and transition areas.

7. Implementation results

7.1. Integrated MDGBM technique

The concept of an integrated MDGBM technique successfully brings together several systems. These systems include underground mining of the protective seam in the rock stratum, underground low coal and high gangue contents dressing, gas drainage from seams with low permeability, and combination of extended solid backfill with conventional, fully mechanized mining. These various production systems are mutually coordinated with a temporally sequential and spatial matching of the rock mining, dressing, drainage, backfill, and coal mining processes. This coordination ensures a safe and efficient operation of the integrated MDGBM system. Fig. 11 shows the overall process flowchart of the system.

7.2. Pressure-relief effect of the Ji$_{15}$ protected seam

Fig. 12 shows change in gas pressure for the mixed mining workface of the Ji$_{15}$-31010 protected seam during protective seam mining. After mining the Ji$_{14}$-31010 protective seam in the rock

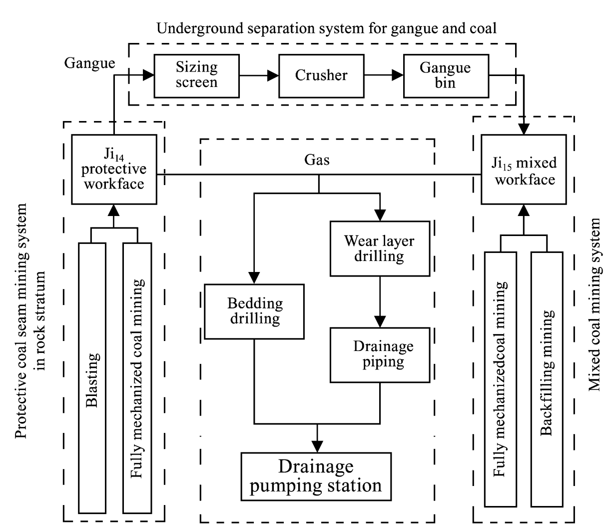


Fig. 11. Overall process flow of the integrated MDGBM system.

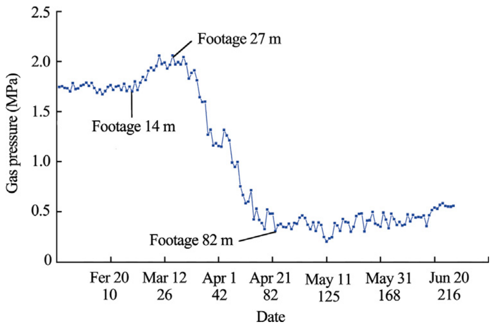


Fig. 12. Changes in the gas pressure of the Ji_{15}-31010 workface.

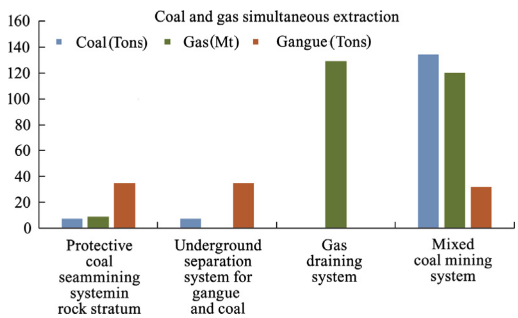


Fig. 13. Simultaneous coal exploitation and gas draining situation.

stratum, desorbed gas from the protected seam dissipates to the goaf of the protective seam through roof fractures. This dissipation leads to a sustained decrease in the gas pressure of the protected seam. The gas pressure of the Ji_{15}-31010 workface decreases by 80% from 1.78 to 0.35 MPa. This finding shows that protective seam mining is effective at pressure relief.

7.3. Effect of simultaneous coal exploitation and gas draining in the protective and protected seams

The Ji_{14}-31050 protective seam in the rock stratum was mined on October 23, 2014. The excavation reached 600 m by December 2015. The maximum footage capacity of the workface was 120 m/month. The amount of raw coal obtained was separated using the DM-ST system, which resulted in approximately 72,000 and 347,000 tons of coal and gangue, respectively. Accordingly, 9.6 million m^3 of gas was drained during the protective seam mining period. The length of the mixed mining workface of the Ji_{15}-31010 protected layer was 220 m, coal production capacity of 1.2 million ton per year, maximum unit production rate of 150,000 ton per month, and gangue processing capacity of 500,000.

This workface was mined on July 14, 2014, and was safely completed in November 2015. The cumulative amount of mined coal was 1.34 million tons, while that of gangue used for backfilling was 320,000 tons. The gas drained during that mining period amounted to 120 million m^3. Fig. 13 illustrates the simultaneous coal exploitation and gas draining.

7.4. Analysis of economic benefits

The integrated MDGBM system has the following major investments: (1) system for mining the protective seam in the rock stratum, (2) system for separating coal and gangue, (3) gas management system, (4) mixed system combining extended solid backfill and conventional fully mechanized mining, and (5) other expenses. Total investments amount to 337.474 million RMB, or the unit cost of coal mining at 240 RMB/t.

The main benefits obtained are as follows: (1) improved quality of produced coal owing to the use of the coal and gangue dressing system (2) cost savings obtained by eliminating the need for auxiliary lifting of coal for aboveground dressing (3) energy savings from using discharged gas for aboveground power generation and (4) use of discharged gas for preheating. The actual selling price of coal produced by the Ji_{15}-31010 workface is 500 RMB/t. The economic benefits from the first mining face would amount to 332.5 million RMB when the actual selling price was used as the basis. The total amount of coal obtained from all the workfaces in the third level was worth 11.715 million tons. Accordingly, the expected profit was 3.0381 billion RMB.

Table 5 lists the specific economic benefits. The aforementioned analysis indicated that the integrated MDGBM system was successfully implemented in the No. 12 mine. This system application resulted in significant technical and economic benefits.

Table 5
Analysis of benefits.

Category	First mining face only	All mining faces
Total investments (hundred million RMB)	3.375	
Coal capacity (10,000 t)	134.0	1,171.5
Total revenue (hundred million RMB)	6.700	58.575
Unit cost of coal mining (RMB/t)	240.0	
Profits (hundred million RMB)	3.325	30.381
Economic benefits (10,000 RMB/a)		
Improved coal quality	4040.8	
Savings from eliminating coal washing costs	1176.0	
Savings from eliminating transportation costs	586.2	
Comprehensive use of discharged gas	44.7	

8. Conclusions

The following conclusions are drawn from this study.

(1) Using the integrated MDGBM technique has successfully overcome the mining difficulties due to lack of a conventional protective seam for the Ji_{15} seam at the No. 12 mine. It also solved the challenges posed by the low permeability and highly gassy coal seam. The technique integrates mining of the protective seam in the rock stratum, UDCG method, gas drainage system, and mixed mining method combining solid backfilling and conventional, fully mechanized mining together.

(2) The proposed technique results in the following significant technical benefits: the gas pressure of the protected seam decreases from 1.78 to 0.35 MPa after mining the protective seam; a maximum footage capacity of 120 meter per month is attained for the workface for the Ji_{14}-31050 protective seam in the rock stratum; the mixed workface of the Ji_{15}-31010 protected seam is 220 m long, and a coal production capacity of 1.2 million t/a, gangue processing capacity of 0.5 million tons per year, cumulative coal production of 1.34 million tons, and processed gangue amounting to 0.32 million tons are achieved. Overall, the economic benefits are significant. Accordingly, the first mining workface amounts to 332.5 million RMB, while the total coal mined from all the workfaces in the third level is approximately 11.715 million tons, which could generate profits of 3.0381 billion RMB.

(3) Implementing the proposed technique has the following benefits: realizing the safe and efficient mining of the highly gassy coal seam with low permeability, improving the

mining rate for coal resources, establishing a method for outburst removal through pressure relief and permeability increase while mining a rock stratum, helping expand the technology for mining protective seams, building a completely new mixed mining method combining solid backfilling and conventional, fully mechanized mining, decreasing the environmental pollution associated with the aboveground discharge of gangue found within the coal flow, and fulfilling the important need for an integrated and green mining method to be used in deep resources.

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