sustainability

MDPI

Article

Innovative Extraction Method for a Coal Seam with a Thick Rock-Parting for Supporting Coal Mine Sustainability

Meng Li, Jixiong Zhang *, Kai Quan and Nan Zhou

State Key Laboratory of Coal Resources and Safe Mining, School of Mines, China University of Mining & Technology, Xuzhou 221116, China; limeng1989@cumt.edu.cn (M.L.); quankai1206@163.com (K.Q.); zhounanyou@126.com (N.Z.)

* Correspondence: zjxiong@163.com

Received: 30 September 2017; Accepted: 25 October 2017; Published: 30 October 2017

Abstract: As thick rock partings delay the efficient mining of coal seams and constrain the sustainable development of coal mines, an innovative extraction method for a coal seam with thick rock parting was proposed. The coal seams were divided into different sub-zones according to the thickness of rock parting and then the sub-zones were mined by separately using three mining schemes involving full-seam mining, combined mining using backfill and caving (CMBC), and reducing height mining. Afterwards, the study introduced the basic mechanism and key devices for the CMBC and analysed the working state of the backfill support in detail. Moreover, the method for calculating the length of the backfill zone was proposed to design the length of backfill zone and the influences of four factors (including bulking coefficient) of rock parting on the length of the backfill zone were also explored. By taking the No. 22203 panel, Buertai mine, Inner Mongolia, China as an example, the mined coal resource by using the CMBC extraction method will increase by 1.83×10^6 tons and the recovery ratio will rise from 56.2% to 92.4% compared with mining of the 2-2 upper coal seam alone. Moreover, by applying CMBC, a series of environmental and ecological problems caused by rock parting is reduced, which can improve the environment in mined areas. The research can provide technological guidance for mining panels of a coal seam with a thick rock parting and the disposal thereof under similar conditions.

Keywords: thick rock parting; sustainability; backfill and caving mixed mining; high-efficient mining; environment protection

---

1. Introduction

Coal seams with thick rock parting indicate that there is a layer of thick rocks between coal seams in which the rock stratum is called a rock parting [1,2]. The coal seam is divided into upper and lower coal seams due to the existence of such a rock parting. In China, a large number of coal resources exist with thick rock parting, which restricts the sustainable development of the coal mine. The mined coal contains much crushed rock if the coal seam is directly mined. With the rapid development of the economy, high-quality coal resources are essential for the coal mines. The rock parting will be bound to reduce the coal price and influence the sale of coal. If the coal and rock parting are mined at the same time, they will be mixed together. The separation of coal and crushed rock is expensive and also haulage costs increase thereafter [3]. Additionally, the crushed rocks are piled on the ground to form a gangue dump, risking landslides and explosions, which not only encroaches on valuable land, but also heavily pollutes the environment [4–7]. There is a low recovery ratio of coal if only the thick upper or lower coal seams are mined, resulting in the waste of coal resources and a high cost for mining the coal. Therefore, the thick rock parting heavily influences coal mining yields and efficiency, and has negative effects on the production benefits of coal mines [8]. However, there are few effective methods to solve the problems caused by a coal seam with thick rock parting.

At present, scholars concentrate on separation of coal from rock partings [9–11] when investigating the mining of such coal seams. They illustrate that coal is isolated from rock partings by using multiple methods, such as increasing the number of devices used in its transportation, and then the rock parting is transported to the ground after being stored in a storage bin. By doing so, coal quality can be improved only to a certain extent, with low mining efficiency and high cost. Meanwhile, in order to ensure safe mining, Singh et al. [2,12] studied the stability of the parting between coal pillar workings and obtaining the factors affecting parting stability. These research results contributed to the mining of coal seams with rock parting. However, it can be seen that the extraction of coal seams with thick rock partings and the disposal of rock partings still remain difficult. Solid backfill mining [13,14] is a green mining method used to solve the problems related to mining under buildings, water bodies, and railways, as well as coal gangue accumulation on the surface [15–17]. Using solid backfill mining, solid wastes, including gangues, coal ash, and slag, can be directly filled into goaf [18,19]. An innovative extraction method for coal seams containing thick rock partings was proposed on the basis of solid backfill mining. By taking the No. 22203 panel in Buertai mine as an example, the coal seams were divided into different sub-zones according to the thickness of the rock partings therein and the sub-zones were mined by separately using three mining schemes involving full-seam mining, combined mining using backfill and caving (CMBC), and reducing height mining. Afterwards, the study introduced the basic mechanism, and key devices, of CMBC to further propose a method for designing the length of the backfill zone. Finally, the benefit of the mining method was analysed to give technological guidance to those seeking to mine panels in coal seams containing thick rock partings and dispose of rock partings under similar conditions.

2. Geological Conditions and Existing Problems

Buertai mine is located in Inner Mongolia, China, in which a 2-2 coal seam was mined in the No. 22203–22215 panels. According to drilling data, the average thicknesses of 2-2 upper and lower coal seams were 2.2 and 1.2 m, respectively and a thick rock parting with the thickness ranging from 0.2 to 7.2 m was found between the coal seams. Moreover, most of the thickness of the rock parting was within 2 m and the average thickness was 1.1 m, as shown in Figure 1.

Generally, only the 2-2 upper coal seam was mined without mining of the 2-2 lower coal seam, resulting in a waste of coal resources. The thick rock parting constrained the recovery ratio, and influenced the sustainable development of the mine. Meanwhile, the crushed rock parting was transported to the surface, then, the rock parting was accumulated to form the gangue piles. Thus, Buertai mine is facing economic and environmental challenges. To solve this problem, the No. 22203 panel was investigated by seam sub-division according to the thickness of the rock parting and then the 2-2 coal seam was mined by using different mining schemes. Moreover, the crushed rock parting was filled into the goaf to dispose of the rock parting and improve the recovery ratio of coal resources. The isolines of the thicknesses of the rock parting in the No. 22203 panel are shown in Figure 2.

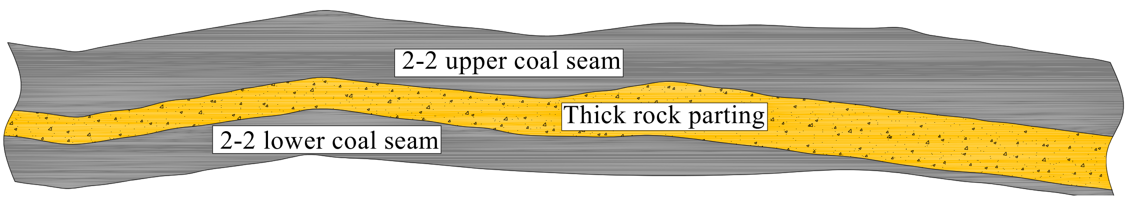

Figure 1. Locus of the coal seams and rock parting.

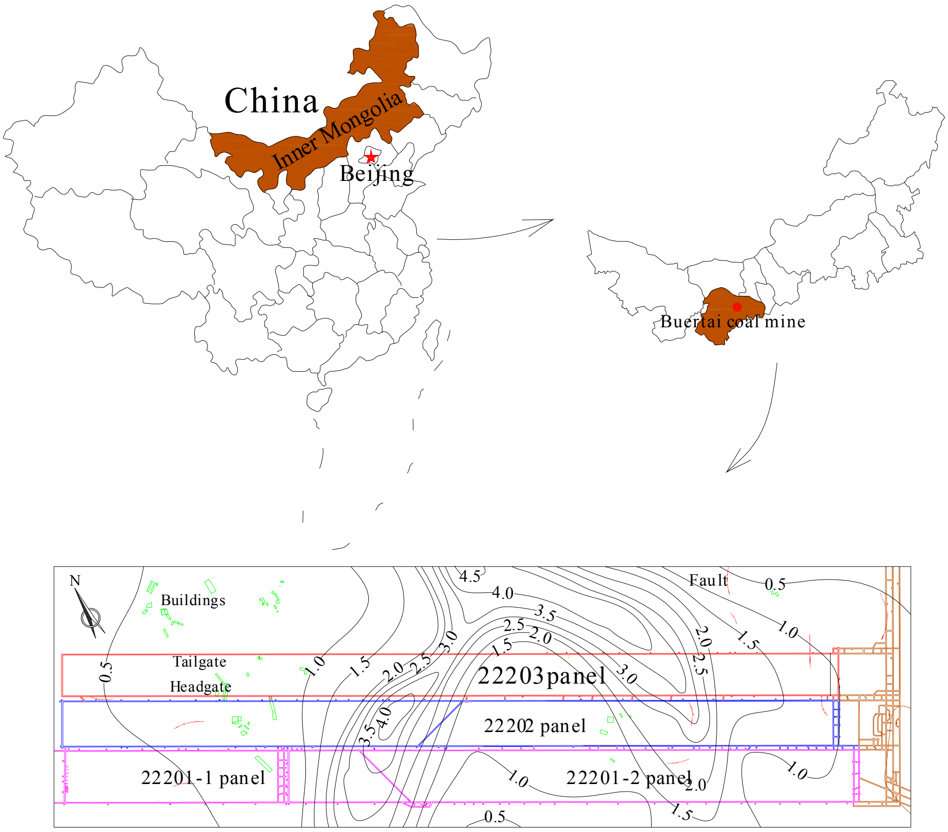

Figure 2. Location of the Buertai mine and isolines of the thicknesses of rock parting.

The advance length and length of the No. 22203 panel are 4527 and 240 m, respectively, and the coal reserve and the total amount of rock parting are 5.172×10^6 and 2.39×10^6 tons, respectively. After the experiment, the density, tensile strength, and compressive strength of the rock parting were 2240 kg/m^3, 1.7 MPa, and 24.6 MPa, respectively (Figure 3). The firmness coefficient f of the rock represents the relative value of its crushing strength. The rocks show the largest strength, such that 1/10 of the uniaxial compressive strength of rocks is considered as representing the firmness coefficient of the rocks, namely:

$$f = \frac{\sigma_c}{10} \tag{1}$$

where σ_c denotes the uniaxial compressive strength of the rock.

(**a**) (**b**)

Figure 3. Mechanical property testing of rock parting samples. (**a**) Tensile strength; and (**b**) compressive strength.

Equation (1) shows that the rock parting was a soft-semi-hard rock, with a firmness coefficient of 2.46. The shearer used in Buertai mine can be applied to cut rocks whose firmness coefficients are lower than 4, so this rock parting can be cut and crushed by using this shearer.

3. Methodology

3.1. Extraction Method for a Coal Seam with a Thick Rock Parting

To decrease the rock content, reduce the haulage cost, and improve the coal recovery ratio, the coal seams are divided into sub-zones according to the thickness of rock parting. Moreover, the different sub-zones were mined using different mining schemes. The areas where the thicknesses of rock parting are separately lower than 0.5 m, in the range of 0.5 to 2 m, and greater than 2.0 m are denoted by A, B, and C (Figure 4).

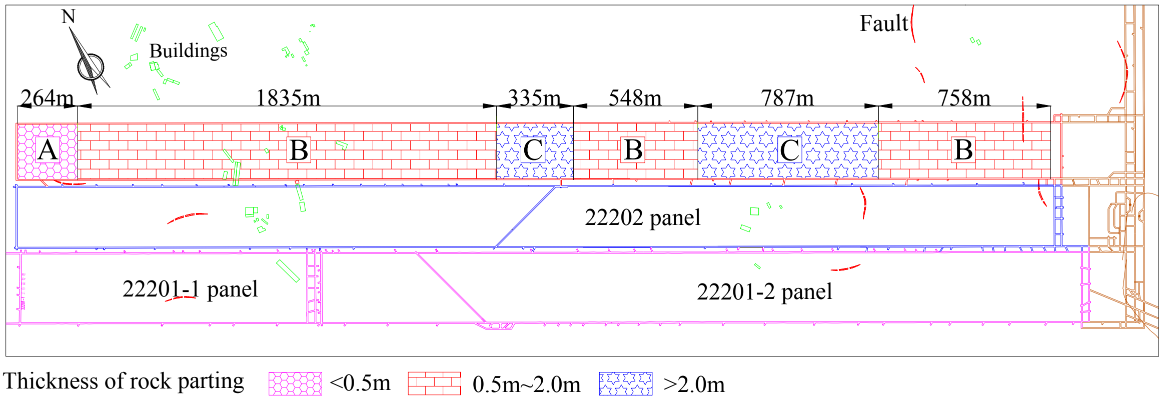

Figure 4. Sub-zones based on the thickness of the rock parting.

The total area of the No. 22203 panel is 1.08648×10^6 m^2, where the areas of sub-zones A, B, and C are 6.336×10^4, 7.5384×10^5, and 2.6928×10^5 m^2, respectively, which separately account for 5.8%, 69.4%, and 24.8% of the total area. The specific conditions are summarised in Table 1.

Table 1. Distribution of rock partings.

Sub-Zone	Thickness of Rock Parting (m)	Length (m)	Area (m^2)	Proportion (%)
A	<0.5	264	63,360	5.8
B	0.5 to 2.0	3141	753,840	69.4
C	>2.0	1122	269,280	24.8

In sub-zone A, the thickness of the rock parting is less than 0.5 m. Moreover, the rock parting occupies a lower proportion of the panel area than the coal and the haulage cost is low, so the 2-2 coal seam was directly mined, and then the mined coal transported to the surface to improve the recovery ratio and mining efficiency. In sub-zone B, the thickness of the rock parting ranged from 0.5 to 2.0 m. The rock parting occupied a larger proportion than the coal and the haulage cost was high, so the rock parting was directly cut with the shearer. Afterwards, the coal was transported to the surface, while the crushed rock parting is filled into the goaf after separation. In sub-zone C, the thickness of the rock parting was greater than 2.0 m and occupied the largest proportion compared with coal and the costs of separating the coal and rock parting, and hauling it were high, so the thick 2-2 upper coal seam was mined without mining the 2-2 lower coal seam. According to the above analysis, the No. 22203 panel is mined by using the following mining schemes (Figure 5):

Scheme 1: When the thickness of the rock parting is less than 0.5 m (sub-zone A), the 2-2 coal seam is mined by using full-seam mining.

Scheme 2: When the thickness of the rock parting is between 0.5 and 2.0 m (sub-zone B), the 2-2 coal seam is mined by using CMBC (see Section 3.1).

Scheme 3: When the thickness of the rock parting is greater than 2.0 m (sub-zone C), only the thick 2-2 upper coal seam is mined and the 2-2 lower coal seam is untouched.

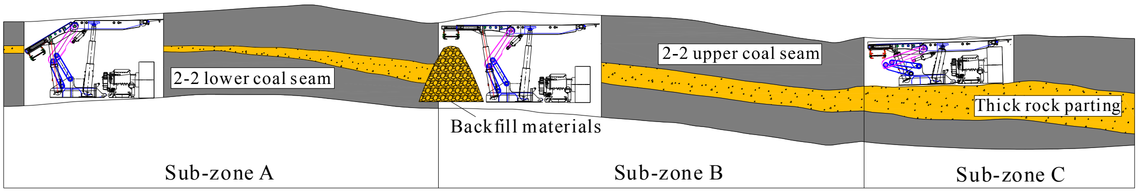

Figure 5. Schematic diagram of three mining schemes.

3.2. CMBC

3.2.1. Basic Mechanism

The CMBC is proposed by combining solid backfill mining and traditional caving mining. The backfill and caving zones are both designed in the same panel and the two zones share the same set of mining systems; however, the roofs are supported by separately, using hydraulic supports with different structures in the two zones to guarantee that the coal mining and backfilling of the panel are synchronous (Figure 6).

The roofs in backfill and caving zones are supported by separately employing backfill supports and fully-mechanised supports. The coal and rock parting are transported to a separation device by belt-conveyor after they are cut and crushed by the shearer and then the crushed rock parting and coal are separated. After separation, coal is transported to the surface while the crushed rock parting is further crushed to suit the backfill requirements of the panel. Afterwards, the crushed rock parting is transported to the panel passing the backfill conveyor hanging at the back of the backfill support. There is a discharge hole in the backfill conveyor so that the crushed rock parting can be filled into the goaf.

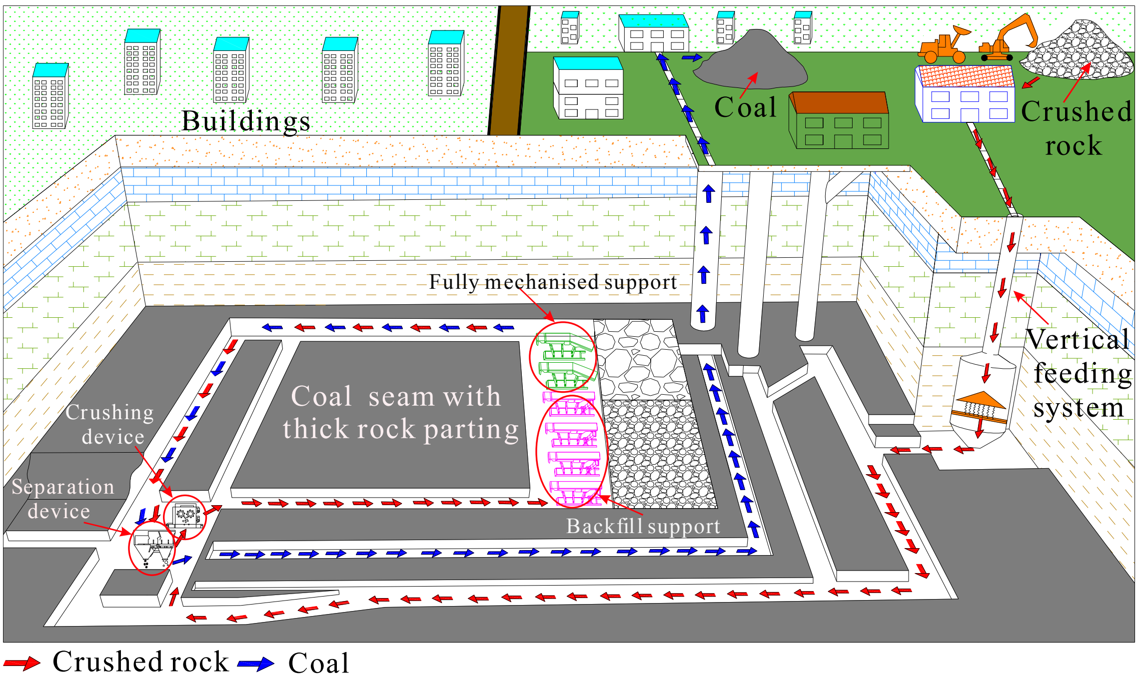

Figure 6. Basic mechanism of CMBC.

3.2.2. Key Devices

The kit includes mining and backfill devices. The mining device includes: a shearer, a scraper conveyor, a fully-mechanised support, and a coal belt, while the backfill device includes: a backfill support, a transfer machine, and a backfill belt. Moreover, the backfill support is mainly composed of a front top beam, a back top beam, a column, a four-bar linkage, a backfill conveyor, and a base. The backfill conveyor hangs on the back top beam while there is discharge hole in the lower part of the backfill conveyor (Figure 7).

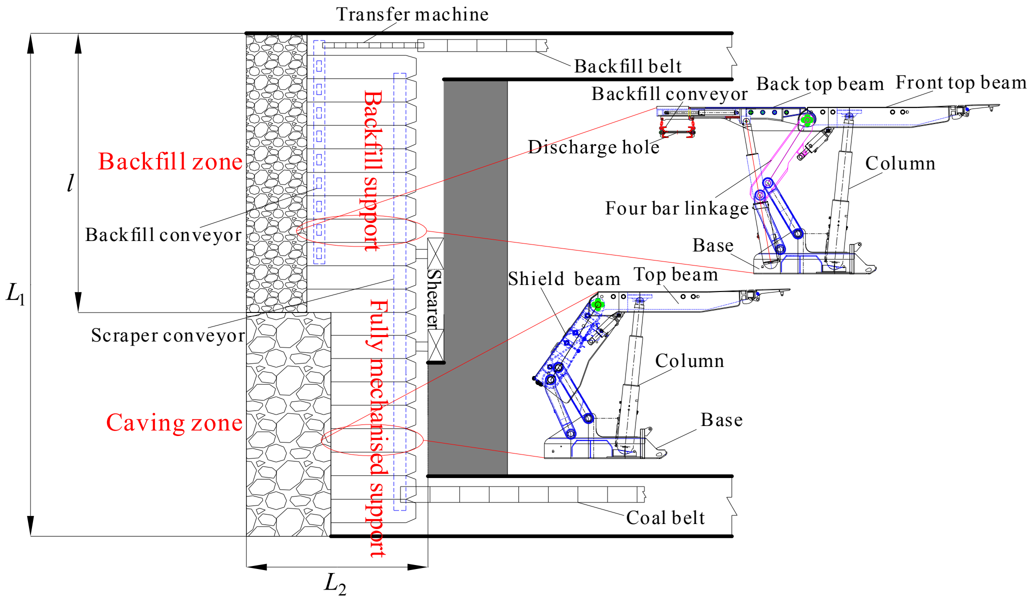

Figure 7. Distribution of devices within the panel.

3.3. *Working State of Backfill Support*

The 2-2 coal seam is mined by using three schemes based on different thicknesses of rock parting. For each mining scheme, it is unnecessary to adjust the working state of the fully-mechanised support while it is necessary to constantly adjust the working state of the backfill support according to the mining scheme used.

When the thickness of the rock parting is less than 0.5 m (sub-zone A), the 2-2 coal seam is mined by using full-seam mining and it is unnecessary to fill the goaf with crushed rock parting. Therefore, the back top beam of the backfill support is used as a shield beam (Figure 8).

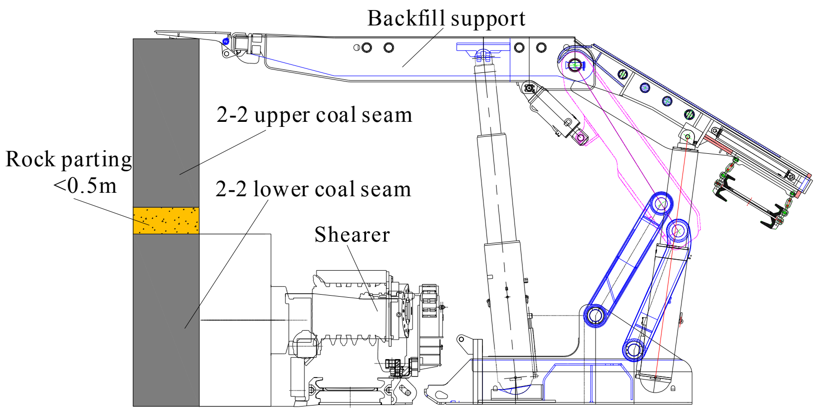

Figure 8. The corresponding working state of the backfill support in Scheme 1.

When the thickness of the rock parting ranges from 0.5 to 2.0 m (sub-zone B), the 2-2 coal seam is mined by employing CMBC and in this context, it is necessary to fill the crushed rock packing into the goaf and the backfill conveyor lifts to backfill the crushed rock packing (Figure 9).

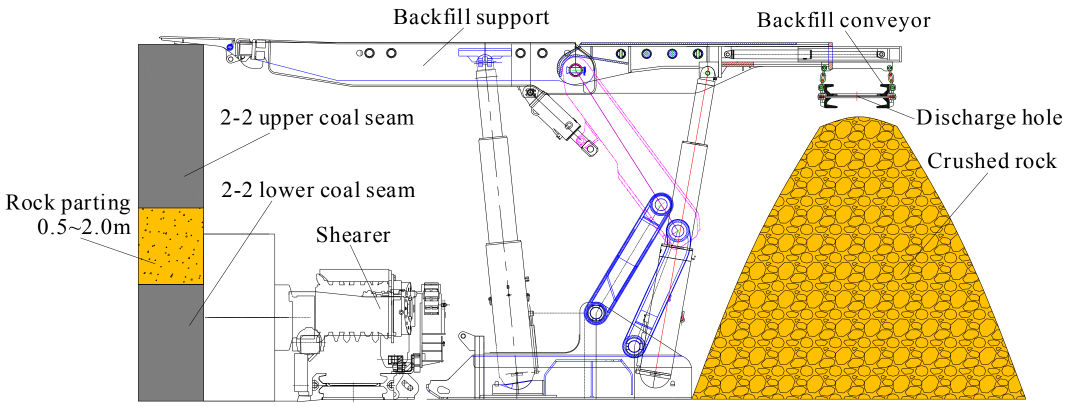

Figure 9. Corresponding working state of the backfill support in Scheme 2.

When the thickness of the rock parting is greater than 2.0 m (sub-zone C), only the 2-2 upper coal seam is mined and it is necessary to decrease the height of backfill support (Figure 10).

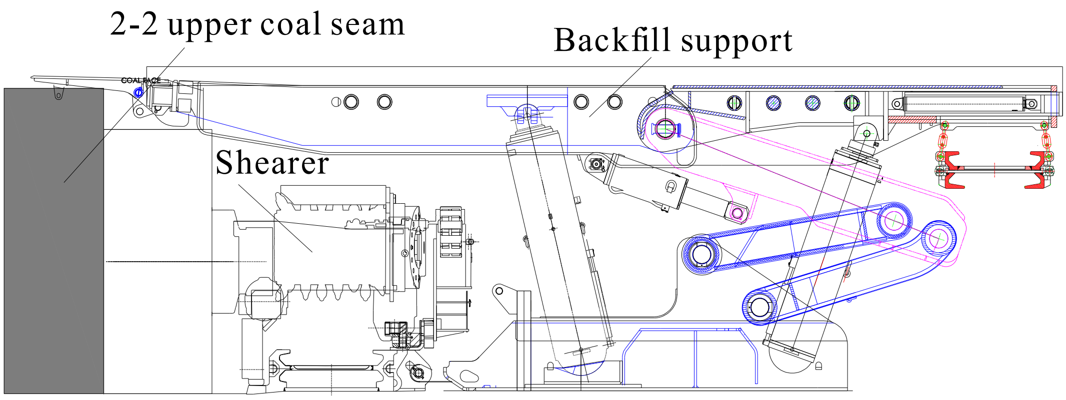

Figure 10. Corresponding working state of backfill support in Scheme 3.

3.4. Design of the Length of the Backfill Zone and Analysis of Influencing Factors

3.4.1. Design of the Length of the Backfill Zone

When the thickness of the rock parting is between 0.5 and 2.0 m (sub-zone B), it is necessary to crush the rock parting and then fill them into the goaf. Thus, the volume of crushed rock parting cannot be lower than the backfill space in the goaf. It is assumed that the thicknesses of 2-2 upper and lower coal seams, as well as that of the rock parting, the distance between bottom and roof of backfill conveyor, the bulking coefficient of rock parting, the length of the panel, advance length, and the length of backfill zone are M_1, M_2, H, h, k, L_1, L_2, and l, respectively (Figures 7 and 11).

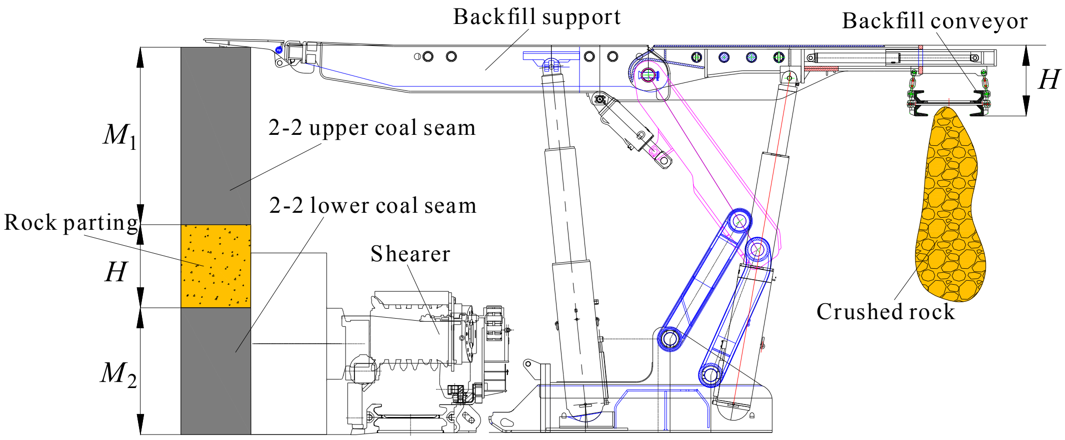

Figure 11. The working state of supports backfilled using crushed gangues.

The rock parting is crushed after being cut before backfilling into the goaf, while the crushed rock parting shows a certain bulking coefficient. Moreover, the backfill conveyor hangs on the lower part of back top beam of backfill support, taking up part of the backfill height. Therefore, the following expression is acquired:

$$L_1 L_2 H k = (M_1 + M_2 + H - h) L_2 l \tag{2}$$

The length of the backfill zone can be obtained by simplifying Equation (2):

$$l = \frac{L_1 H k}{(M_1 + M_2 + H - h)} \tag{3}$$

Section 1 tells us that the thicknesses of the 2-2 upper (M_1) and lower (M_2) coal seams, the distance (h) between bottom and roof of backfill conveyor, the bulking coefficient (k) of the rock parting, and the length (L_1) of the panel are 2.2 m, 1.2 m, 0.8 m, 1.5, and 240 m, respectively. By substituting the above parameters into Equation (3), the relationship between the length l of the backfill zone and the thickness H of the rock parting can be obtained (Figure 12).

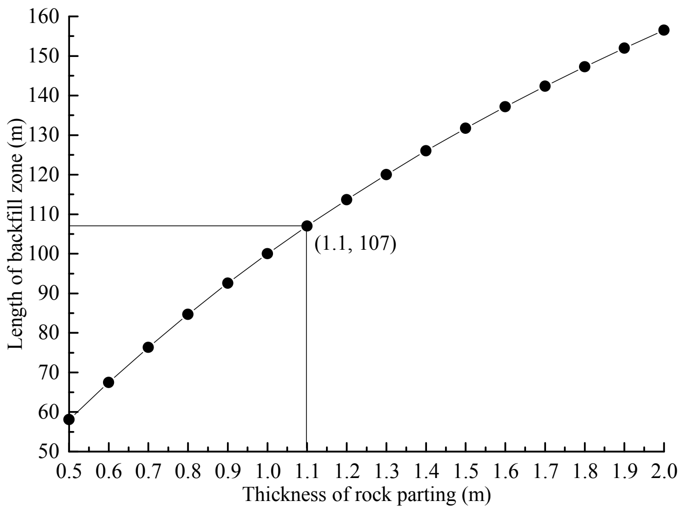

Figure 12. Relationship between the length of the backfill zone and the thickness of the rock parting.

Figure 12 shows that the length of the backfill zone gradually increases with the growing thickness of the rock parting because the thicker the rock parting, the larger the yield therefrom, and the more crushed rock arisings accumulate for disposal, and the longer the backfill zone required. When the thickness of the rock parting is 1.1 m, the length of backfill zone reaches 107 m and the length of the backfill zone is 115 m, while there is a distance of 5 to 10 m occupied by the connection between the backfill conveyor and the transfer machine: the length of the caving zone is, thus, set to 125 m.

3.4.2. Analysis of Influencing Factors

The influence of bulking coefficients of the rock parting on the length of the backfill zone is calculated by separately substituting variable bulking coefficients (k = 1.3, 1.4, 1.5, and 1.6) into Equation (3), as shown in Figure 13.

As shown in Figure 13, the length of the backfill zone gradually increases when the bulking coefficients increase from 1.3 to 1.6. On the precondition that there is a certain yield of rock parting, the larger the bulking coefficient, the larger the backfill space of crushed rock parting taking up in the goaf and, therefore, the longer the zone to be backfilled. When the thickness of the rock parting is 1.1 m, the corresponding lengths of the backfill zone are 93, 100, 107, and 114 m when bulking coefficients are 1.3, 1.4, 1.5, and 1.6, respectively. Moreover, the length of backfill zone exhibits a similar trend with increasing bulking coefficient.

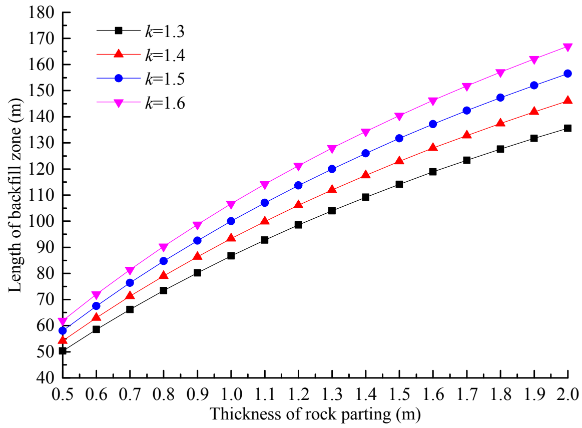

Figure 13. Influence of bulking coefficient of rock parting on the length of the backfill zone.

By separately substituting the lengths of a panel (L_1 = 100, 200, 300, and 400 m) into Equation (3), the influence of the length of the panel on the length of the backfill zone is obtained (Figure 14).

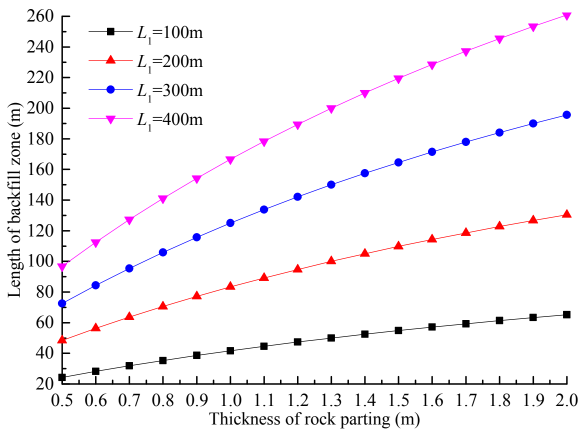

Figure 14. Influence of the length of the panel on the length of the backfill zone.

As indicated in Figure 14, the length of the panel exerts a significant influence on the length of the backfill zone and the length of backfill zone gradually increases as the length of the panel increases from 100 m to 400 m. The longer the panel, the larger the yield of rock parting produced during coal mining and, therefore, it is necessary to allow more space for filling gangues. When the thickness of the rock parting is 1.1 m, the corresponding lengths of the backfill zone are 45, 89, 134, and 178 m for panel lengths of 100, 200, 300, and 400 m, respectively. The length of the backfill zone shows a similar trend as the length of the panel gradually increases.

The influence of the thickness of the 2-2 upper coal seam on lengths of backfill zone is calculated by separately substituting the thicknesses of the 2-2 upper coal seam (M_1 = 1.0, 1.5, 2.0, and 2.5 m) into Equation (3), as shown in Figure 15.

Figure 15 shows that the length of backfill zone gradually decreases as the thickness of the 2-2 upper coal seam increases from 1.0 m to 2.5 m. When there is a certain yield of the rock parting, the thicker the 2-2 upper coal seam, the larger the backfill volume of crushed gangues and, therefore, the shorter the backfill zone. When the thickness of the rock parting is 1.1 m, the corresponding lengths of the backfill zone are 158, 132, 113, and 99 m when the thicknesses of the 2-2 upper coal seam are 1.0, 1.5, 2.0, and 2.5 m, respectively. The decrease in length of the backfill zone gradually decreases with increasing upper coal seam thickness.

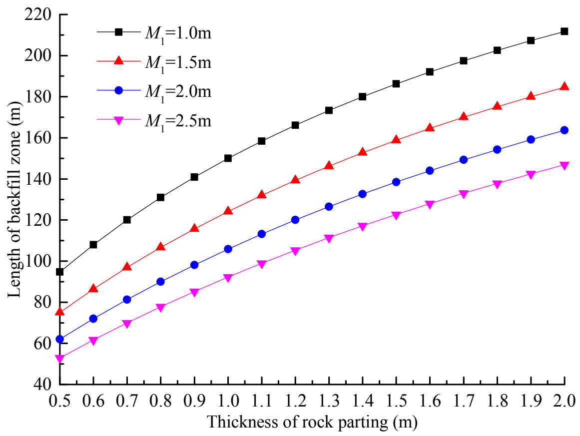

Figure 15. Influence of the thickness of the 2-2 upper coal seam on the length of the backfill zone.

The influence of the distance between the bottom and roof of the backfill conveyor on the length of the backfill zone is calculated by substituting the distance (h = 0.6, 0.8, 1.0, and 1.2 m) into Equation (3), as displayed in Figure 16.

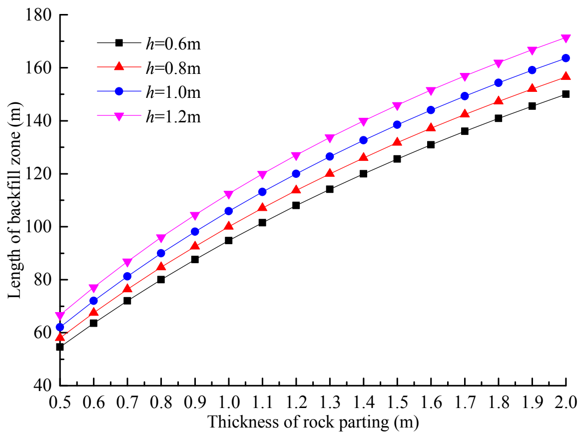

Figure 16. Influence of the distance between the bottom and roof of the backfill conveyor on the length of the backfill zone.

As shown in Figure 16, the length of backfill zone gradually increases as the distance between the bottom and roof of the backfill conveyor increases from 0.6 m to 1.2 m. When there is a certain yield of the rock parting, the larger the distance between the bottom and roof of the backfill conveyor, the smaller the backfill volume of crushed gangues and, therefore, the longer the backfill zone. When the thickness of the rock parting is 1.1 m, the corresponding lengths of the backfill zone are 103, 107, 113, and 120 m when the distance between the bottom and roof of the backfill conveyor are 0.6, 0.8, 1.0, and 1.2 m, respectively. Moreover, the increase in the length of the backfill zone gradually increases as the distance between the bottom and roof of the backfill conveyor increases.

4. Social and Economic Benefits

4.1. Economic Benefits

Before using the extraction method for a coal seam with a thick rock parting, most of the coal in the 2-2 coal seam can be mined, thus improving the coal recovery ratio. By taking the No. 22203 panel as an example, the mined coal resource using the new extraction method will increase by 1.83×10^6 tons and the recovery ratio will rise from 56.2% to 92.4%, compared with only mining the 2-2 upper coal seam, the details are listed in Table 2. Moreover, the mined coal resource can increase by 2.37×10^7 tons after the extraction method is applied over the whole experimental area: by applying the new extraction method, the cost of transporting and storing rock partings decreases to good economic benefit.

Table 2. Rough comparison of the economic benefits in the #22203 panel.

Mining Area	Recovery Ratio (%)	Production (10^6 t)	Benefits (Million Yuan)
Full seam	92.4	4.78	2389
2-2 upper seam	56.2	2.95	1476

4.2. Social and Environmental Benefits

There is a layer of the rock parting in the 2-2 coal seam with a thickness of 0.2 to 7.2 m that impairs the high-efficiency and high-yield production pattern of the panel and decreases the coal recovery ratio. To solve the above problems, an extraction method for a coal seam with a thick rock parting was proposed. The method:

(1) Can improve the coal recovery ratio, increase the yield of coal, and decrease the pressure on washing systems thereafter.
(2) Allows the mined rock parting to be directly filled into the goaf, thus reducing the pressure on subsidiary transportation systems and haulage costs.
(3) Decreases the accumulation and discharge of rock parting on the surface can be decreased to reduce a series of environmental problems in mined areas.
(4) Can, by filling the rock parting arisings into the goaf, decrease subsidence in overlying strata as induced by coal mining.
(5) Can provide technological guidance for those mining panels in a coal seam with thick rock partings and help in their disposal of rock parting.

5. Conclusions

To realise high-yield, high-efficiency mining of coal seams with thick rock partings, an innovative method for extracting the coal from a seam with a thick rock parting was proposed and trialled on the No. 22203 panel, Buertai mine. The coal seams were sub-divided according to the thickness of their rock partings and different sub-zones were mined by using three mining schemes involving full-seam mining, CMBC, and by mining only the thick upper coal seam.

For each mining scheme, it is unnecessary to adjust the working state of the fully-mechanised support while the working state of the backfill support has to be constantly adjusted according to the mining scheme selected. Therefore, the study analysed the working states of the backfill support system by separately employing different mining schemes and also proposed a method with which to design the length of the backfill zone required. Moreover, the influences of various factors, including the bulking coefficient of the rock parting, the length of a panel, the thickness of the upper coal seam, and the distance between the bottom and roof of the backfill conveyor, on the length of the backfill zone were analysed.

Most coal resources in the 2-2 coal seam can be mined to improve the coal recovery ratio after using this extraction method. By taking the No. 22203 panel as an example, the mined coal resource, using the proposed extraction method, increased by 1.83 million tons and the recovery ratio rose from 56.2% to 92.4% compared with the case involving the mining of the 2-2 upper coal seam alone. The use of CMBC could reduce the accumulation of rock parting arisings on the surface, which further minimises a series of associated environmental problems. The method can consequently improve the environment in mined areas, showing favourable economic, social, and environmental benefits.

Acknowledgments: This research was supported by the Fundamental Research Funds for the Central Universities (2017XKZD13).

Author Contributions: All the authors contributed to this paper. Meng Li prepared and edited the manuscript. JiXiong Zhang provided theoretical and methodological guidance in the research process. Kai Quan partially participated in the literature search and data processing. Nan Zhou participated in revising the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wang, J.C.; Jiang, F.X.; Meng, X.J.; Wang, X.Y.; Zhu, S.T.; Feng, Y. Mechanism of Rock Burst Occurrence in Specially Thick Coal Seam with Rock Parting. *Rock Mech. Rock Eng.* **2016**, *49*, 1953–1965. [CrossRef]
2. Singh, R.; Singh, S.K.; Kushwaha, A.; Sinha, A. Stability of the parting between coal pillar workings in level contiguous seams during depillaring. *Int. J. Rock Mech. Min. Sci.* **2012**, *55*, 1–14. [CrossRef]
3. Zhang, J.X.; Zhang, Q.; Spearing, A.J.S.; Miao, X.X.; Guo, S.; Sun, Q. Green coal mining technique integrating mining-dressing-gas draining-backfilling-mining. *Int. J. Min. Sci. Technol.* **2017**, *27*, 17–27. [CrossRef]
4. Sun, Y.Z.; Fan, J.S.; Qin, P.; Niu, H.Y. Pollution extents of organic substances from a coal gangue dump of Jiulong Coal Mine, China. *Environ. Geochem. Hlth.* **2009**, *31*, 81–89. [CrossRef] [PubMed]
5. Skierszkan, E.K.; Mayer, K.U.; Weis, D.; Beckie, R.D. Molybdenum and zinc stable isotope variation in mining waste rock drainage and waste rock at the Antamina mine, Peru. *Sci. Total Environ.* **2016**, *550*, 103–113. [CrossRef] [PubMed]
6. Zhang, Y.Y.; Ge, X.L.; Liu, L.L.; Wang, X.D.; Zhang, Z.T. Fuel nitrogen conversion and release of nitrogen oxides during coal gangue calcination. *Environ. Sci. Pollut. Res.* **2015**, *22*, 7139–7146. [CrossRef] [PubMed]
7. Benvenuti, M.; Mascaro, I.; Corsini, F.; Lattanzi, P.; Parrini, P.; Tanelli, G. Mine waste dumps and heavy metal pollution in abandoned mining district of Boccheggiano (Southern Tuscany, Italy). *Environ. Geol.* **1997**, *30*, 238–243. [CrossRef]
8. Mandal, P.K.; Singh, R.; Maiti, J.; Singh, A.K.; Kumar, R.; Sinha, A. Underpinning-based simultaneous extraction of contiguous sections of a thick coal seam under weak and laminated parting. *Int. J. Rock Mech. Min. Sci.* **2008**, *45*, 11–28. [CrossRef]
9. Zheng, K.H.; Du, C.L.; Li, J.P.; Qiu, B.J.; Yang, D.L. Underground pneumatic separation of coal and gangue with large size (≥50 mm) in green mining based on the machine vision system. *Powder Technol.* **2015**, *278*, 223–233. [CrossRef]
10. Yu, X.D.; Luo, Z.F.; Li, H.B.; Yang, X.L.; Zhou, E.H.; Jiang, H.S.; Wu, J.D.; Song, S.L.; Cai, L.H. Effect of vibration on the separation efficiency of high-sulfur coal in a compound dry separator. *Int. J. Miner. Process.* **2016**, *157*, 195–204. [CrossRef]
11. Ghaffari, A.; Farzanegan, A. An investigation on laboratory Knelson Concentrator separation performance: Part 2: Two-component feed separation modelling. *Miner. Eng.* **2017**, *112*, 114–124. [CrossRef]
12. Singh, R.; Sheorey, P.R.; Singh, D.P. Stability of the parting between coal pillar workings in level contiguous seams. *Int. J. Rock Mech. Min. Sci.* **2002**, *39*, 9–39. [CrossRef]

13. Zhang, J.X.; Jiang, H.Q.; Deng, X.J.; Ju, F. Prediction of the height of the water-conducting zone above the mined panel in solid backfill mining. *Mine Water Environ.* **2014**, *33*, 317–326. [CrossRef]
14. Junker, M.; Witthaus, H. Progress in the research and application of coal mining with stowing. *Int. J. Min. Sci. Technol.* **2013**, *23*, 7–12. [CrossRef]
15. Li, H.Z.; Zha, J.F.; Guo, G.L.; Zhao, B.C.; Wang, B. Compression ratio design and research on lower coal seams in solid backfilling mining under urban areas. *Soil Mech. Found. Eng.* **2016**, *53*, 125–131.
16. Ju, F.; Huang, P.; Guo, S.; Xiao, M.; Lan, L.X. A roof model and its application in solid backfilling mining. *Int. J. Min. Sci. Technol.* **2017**, *27*, 139–143. [CrossRef]
17. Huang, J.; Tian, C.Y.; Xing, L.F.; Bian, Z.F.; Miao, X.X. Green and sustainable mining underground coal mine fully mechanized solid dense stowing-mining method. *Sustainability* **2017**, *9*, 1418. [CrossRef]
18. Ju, F.; Li, B.Y.; Guo, S.; Xiao, M. Dynamic characteristics of gangues during vertical feeding in solid backfill mining: A case study of the Wugou coal mine in China. *Environ. Earth Sci.* **2016**, *75*, 1389–1397. [CrossRef]
19. Li, M.; Zhang, J.X.; Deng, X.J.; Ju, F.; Li, B.Y. Measurement and numerical analysis of water-conducting fractured zone in solid backfill mining under an aquifer: A case study in China. *Q. J. Eng. Geol. Hydrogeol.* **2017**, *50*, 81–87. [CrossRef]