

Research Article

Gas Distribution Law for the Fully Mechanized Top-Coal Caving Face in a Gassy Extra-Thick Coal Seam

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Mine gas overflow is a serious threat to the safe and efficient longwall mining of gassy coal seams. Based on the field mining conditions and gas extraction of the fully mechanized top-coal caving face of a gassy coal mine, the space volume fraction distribution and emission (extraction rate) of gas in the face were tested by an arrangement of measuring points in the stereo grid. The isograms of gas volume fraction distribution for each measurement section and air direction in the face are drawn. The research shows that each measurement section gas volume fraction distribution is presented for an asymmetric concave curve along the vertical direction of the coal wall in the air-inlet side and the air-return side of the face; on the working face air-return side, the determination of gas volume fraction distribution of the section appears as falling straight line along the vertical direction of the coal wall. Before the first weighting, the absolute quantity of gas emission in the working face increased with the advancing of the working face, reached the maximum at the time of the first weighting, and then remained stable.

1. Introduction

Mine gas overflow is one of the main factors detrimental to the intensive production of coal mines in China. With the deepening of mining exploring, the number of gassy mines and coal and gas outburst mines accidents is increasing, resulting in frequent gas disasters and major losses [1–3]. According to statistics, in 2016, the number of coal mine gas accidents amounts to 13 in China, killing 170 people. The death rate per million comes in at 0.156, and death rate dropped 3.7 percent year-on-year. Although the number of coal mine gas accidents has dropped dramatically in recent years, the gas accidents in total are still large and major gas accidents have not been effectively curtailed, and measures of preventing and controlling coal mine gas are still not sufficient. Due to the large amount of coal falling from the working face during the mining process, the amount of coal left in the goaf area, and the influence of large-scale mining activity, the fully mechanized top-coal caving face in the

thick coal seam produces a large amount of gas emission from the working face. It is easy for the gas and air-return way to exceed the limit, which poses a great threat to safe production.

Domestic and foreign researchers have conducted a series of studies on gas migration and extraction in coal seams. To reduce the coal seam gas emission into the working space, various measures including predrainage and postdrainage strategies have been developed [4]. Taking advantage of the computational fluid dynamics (CFD) longwall models, the gas distribution along the longwall face and in the immediate goaf was investigated under six different mining conditions to reveal the gas dispersion and flow characteristics [5, 6]. Sander et al. [7] presented a review of experimental methods that could be applied to determining the permeability of low to ultralow permeability gas reservoirs. The feasibility of individual techniques depends on many factors, including permeability, porosity, and adsorption capacity of the porous rock. In order to investigate the permeability variation

during the gas drainage process, Wang et al. [8, 9] established a coal permeability variation model based on the Kozeny–Carman equation, the theories of surface physical chemistry and effective stress of the coal containing gas. The results indicate that the gas flow with the characteristics of anisotropy and the permeability anisotropy degree are dynamic with the stress loading. To raise the gas flow rate and concentration from a mining seam and reduce the suction pressure loss in the pipeline, Qin and Xu [10] established an opportunity election model of secondary borehole sealing and also developed a dynamic secondary borehole-sealing device. Wang et al. [11] presented gas permeability evolution mechanisms and gas seepage rules of protected seams close to protective seams and applied comprehensive gas extraction technologies to creating a favorable environment for the safe mining of coal and gas outburst seams. The existence of truly undesorbable residual gas in coal seams and its impacts on the sorption model and gas drainage efficiency were studied [12]. Hu et al. [13] presented a technique useful for the extraction of goaf methane from abandoned mines through surface vertical drainage wells. Liu et al. [14] studied coal seam gas occurrence and the pressure-relief range and presented a new approach to calculate the gas emission quantity.

It is generally believed that the gas source in the fully mechanized top-coal caving face is mainly the coal wall, caved coal, and goaf [15, 16]. Among them, the coal wall gas source includes the working face coal wall, belt haulage roadway coal wall, and air-return roadway coal wall; mining coal gas sources include the cutting of coal by a shearer and its transportation by a scraper conveyor from front to rear. Gas sources in the goaf include waste coal in the goaf, adjacent floors, and surrounding rocks. Due to the control of the airflow field on the working face, these gas outflows will form a certain gas distribution characteristic. Numerical simulation and field measurement methods can be used to study these gas emissions [17, 18]. In recent years, a unit method has been proposed to measure gas emission proportion in the stope face using [19–21]. Due to the influence of air leakage, different pumping conditions, and the complexity of gas emission, it is very difficult to determine the gas emission component of gas source in the working face.

2. Engineering Background

2.1. Geological Conditions. Xiagou Mine is a key production mine located in the southeast of Binchang Mining Area. The recoverable coal seam in the mine field is #4 coal seam. The coal seam has thickness of 16.7 m on average and a bulk density of 1.32 t/m^3 . Topped with a sandy mudstone and fine siltstone, the coal seam structure is simple and stable with an average thickness of 5 to 7 meters, and the basic roof is made of gray coarse sandstone. The bottom of the coal seam is aluminous mudstone, with an average thickness of 3 to 10 m, which is easily inflated with water. #4 coal seam belongs to the type II spontaneous combustion coal seam. Coal dust is explosive, and the mine is a high-gas mine. ZF301 working face is the first working face of 403 mining area, with a strike

length of 2916 m, a prone length of 180 m, an average coal thickness of 16.7 m, which is roughly in the east-west direction and northward inclination, a west dip of $0^\circ\text{--}8^\circ$, and an east dip of $15^\circ\text{--}18^\circ$. The layout of ZF301 working face is shown in Figure 1. The northern area is ZF302 longwall face (unmined) and the southern area is a 100 m width coal pillar, next to the goaf of Shuilian Coal Mine.

After sampling, the original maximum gas content in the coal seam was $5.05 \text{ m}^3/\text{t}$, the detachable gas content was $3.64 \text{ m}^3/\text{t}$, and the residual gas content was $1.41 \text{ m}^3/\text{t}$, belonging to the high-gas face. The working face adopts the approach of fully mechanized top-coal caving mining technology. The mining height is 3 m, and the mining-caving ratio is 1:3. As a result, the mined coal seam thickness is 12 m, and the reserve-protected coal is 4.7 m. To reach the goaf of safe and efficient longwall mining, a series matched equipment has been applied in the field mining conditions, as listed in Table 1. The working face adopts “one enter and one back” U-type ventilation.

2.2. Gas Drainage Conditions. Three gas drainage systems were designed in ZF301 working face: (1) the first two alternate gas drainage pumps are fixed on ground, and the pump type is CBF810-2BG3 with a rated flow rate of $500 \text{ m}^3/\text{min}$ through a seamless steel pipe of $\Phi 720 \text{ mm}$, which is mainly used for drainage in the dedicated gas drainage lane; (2) the second two gas drainage pumps, type of 2BEC100 with a seamless steel pipe of $\Phi 377 \text{ mm}$, are mainly used for the buried pipe drainage at the upper corner of the working face; (3) the third two alternate gas drainage pumps are moveable underground, and the pump type is ZWY260/315 with a rated flow rate of $260 \text{ m}^3/\text{min}$ through a seamless steel pipe of $\Phi 377 \text{ mm}$, which is mainly used for predrainage in the belt conveyor roadway. In the first 300 m section of the belt conveyor roadway, horizontal predrainage boreholes have been drilled with 1.0 m space. For the rest section, 36 drill sites have been designed with a space of 50 m and 25 predrainage boreholes for each drill site.

The gas in the goaf area is pumped through the dedicated gas drainage for the roof gas. The dedicated gas drainage roadway is driven along the roof of the coal seam and is offset 20 m from the horizontal level of the return airway. The section is rectangular in shape, with a width of 3.8 m and a height of 3.1 m. The roadway mouth is sealed by a closed wall, and the pipeline equipment, such as pumping pipes, observation pipes, grouting pipes, and discharge pipes, is installed. The extraction pipelines are connected to ground pump stations for gas extraction. In addition, a high negative pressure underground moving gas drainage system is arranged downhole for gas predrainage in the coal seam. The coal body of the coal seam is arranged with a rectangular drilling field at intervals of 50 m (Figure 2) at the working belt conveyor roadway. Three-layer fan-shaped vertical staggered drilling is arranged in the drilling field to form a three-dimensional drainage system. The borehole is connected with the underground mobile pumping station through a gas gathering pipeline to form a high negative pressure gas drainage system.

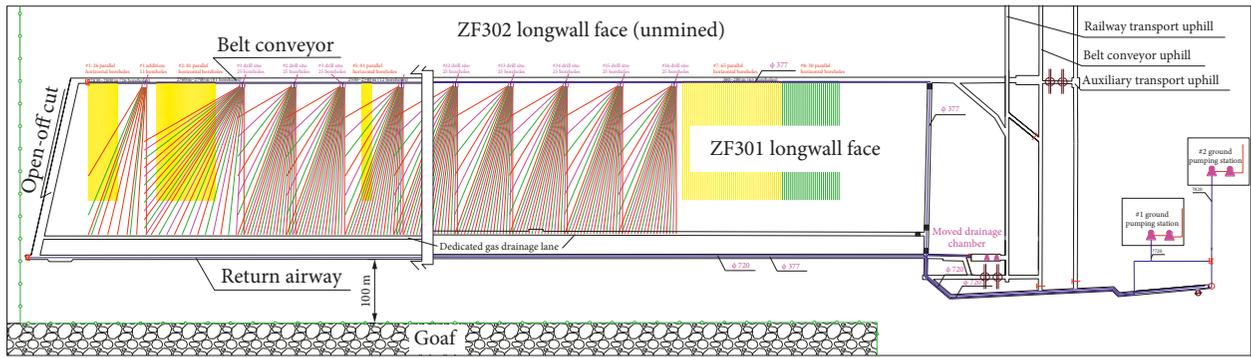


FIGURE 1: Layout of ZF301 working face and gas drainage borehole.

TABLE 1: Working equipment for ZF301 longwall face.

No.	Equipment name	Equipment type	Quantity
1	Coal mining machine	MG300/730-WD1	1
2	Transition hydraulic support	ZFG10000/20/38H	6
3	Middle hydraulic support	ZF10000/20/38	117
4	Ends hydraulic support	ZFTZ13000/23/38	1
5	Front scraper conveyor	SGZ800/800	1
6	Rear scraper conveyor	SGZ800/800	1
7	Loaders	SZZ900/400	1
8	Crusher	PCM250	1
9	Emulsion pump	BRW550/31.5	4
10	Atomizing pump	BPW315/6.3	2
11	Extendable belt conveyor	DSJ120/150/2×315	2
12	Air compressor	MLGF-20/8-132G	1
13	Endless rope winch	SQ-120/132B	1

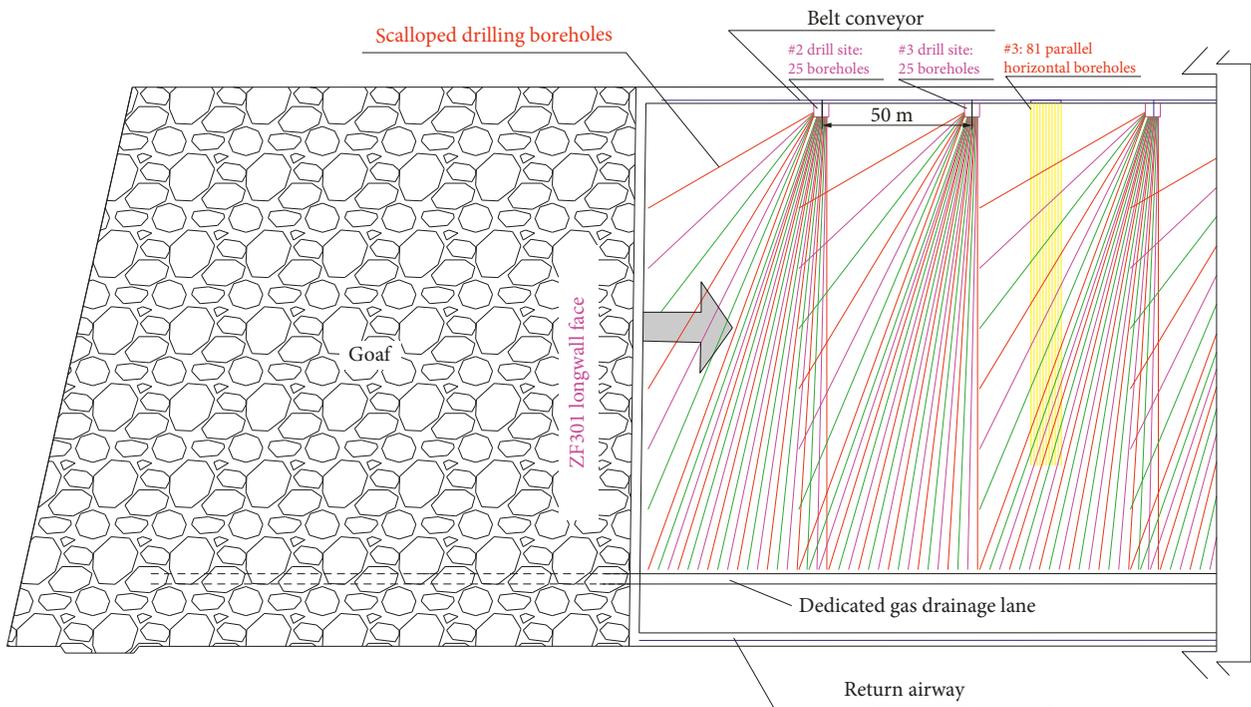


FIGURE 2: Gas drainage borehole layout in the working face.

3. Gas Distribution Characteristics

3.1. Working Face Gas Measurement Method. There are many factors that affect the amount of gas emission and source of gas emission in the fully mechanized top-coal caving face. Factors such as the gas content, permeability, and attenuation coefficient of the coal seam affect them directly; furthermore, there are many factors such as the recovery process, recovery rate, mining intensity, propulsion speed, air volume at the working face, and air leakage from the goaf. The distribution of gas emission in the working face and the magnitude of gas emission are changed with time and space, with multidimensional dynamics. Therefore, when measuring and analyzing the gas distribution and the magnitude, it is necessary to measure not only the distribution of gas in the three-dimensional space of the analysis face, but also the gas emission dynamics in the dimension of time.

Using the unit determination method divides working face into units; in the space along the air direction of the working face, seven measurement cross sections are laid at the #15, #35, #55, #75, #95, #105, and #115 supports, respectively (Figure 3). The measuring section arranged the middle and lower three rows of measuring points at equal intervals for each measurement of the cross-sectional gravity direction, five measuring points (numbers 1, 2, 3, 4, and 5) are arranged at equal intervals from the coal wall to the boundary of the goaf area for each measurement point, belt conveyor roadways, air-return roadways, and dedicated gas drainage roadways setup layout station, and the air volume and gas volume fraction were measured for each measurement point. The measuring equipment includes calibrated electronic air meters, portable gas detectors, stopwatches, and dust masks.

3.2. Gas Distribution in Working Face. It is determined that the gas volume fraction of the conveyor belt in the ZF301 fully mechanized top-coal caving face is 0.02%, the air-inlet rate is 1811 m³/min, the gas volume fraction in air-return roadway is 0.38%, the volume in air-return roadway is 1180 m³/min, the gas volume fraction of gas-specific drainage roadway is 10.75%, and the pump amount is 617.68 m³/min.

3.2.1. Characteristics of Gas Distribution on Each Section. According to the measured data, the contour maps of the gas volume fraction at the #15, #55, #95, and #105 support surfaces in the working face are plotted, as shown in Figure 4. The gas volume fraction at a certain point on the cross section of the working face is determined by the action of the gas source (coal wall, coal mining, and goaf) on this point and the air speed at that point. The distribution of flow velocity at the cross section is uneven; the flow velocity at the center of the cross section is the maximum.

In Figure 4, the following can be seen:

- (1) At the air-inlet side of the working surfaces (such as the #15–#55 supports), the gas volume fractions above and below the cross section in the working

face are significantly larger than those in the middle. The reasons for this is, firstly, with the progress of the coal mining process in the working face, the top coal and the bottom coal in the working face are continuously exposed, and the gas therein and the gas in the falling coal are continuously desorbed and flocked to the working face; secondly, the upper and lower sections are affected by the increase of the ventilation resistance due to the support in the working face and the arrangement of the mining equipment, which reduces the air speed. The combined influence shows that the distribution of the gas volume fraction in the cross section of the working face characterizes large, small, and large distribution.

- (2) At the air-return side in the working faces (such as #95 support), the gas from the coal wall and the caved coal accumulates with increases of the airflow route. The impact of accumulated gas at the site and the gas emission from the goaf become the dominant factors in determining the size of the gas in the area. In contrast, the nonuniform distribution of the air speed at the cross section has little effect on the gas volume at the site. Therefore, the distribution of the gas volume fraction shows large and small distribution characteristics in the cross section of the working face in the direction of gravity, and the gas volume generated by the gas outflow in the goaf area at the upper right corner of the section shows an increase in the fan-shaped region.
- (3) At the air-outlet side of the working faces (such as #105 support and later), the gas from the coal wall and the mining coal accumulates with increases of the airflow route. The cumulative effect of gas production at the site has become a major factor in determining the volume of gas at the site. Compared with the nonuniform distribution of air speed at the cross section and the gas emission from the goaf, the impact on the gas value at the site is very small. Therefore, the gas volume fraction of the cross section in the direction of gravity is almost a constant value.

In order to further reflect the characteristics of the gas distribution in the measured area, the three points of the upper, middle, and lower sections are taken on average. The average value of the five gas volume fractions in the vertical coal wall direction measured section is shown in Figure 5.

In Figure 5, the following can be seen:

- (1) At the air-inlet side and return air side in the working faces (such as #15–#95 supports), the distribution of gas volume fractions along the vertical coal wall measured section shows an asymmetric concave curve. This shows that, on these routes, volume of the gas is determined by the gas accumulation in the coal wall and fulling coal, the gas emission in the goaf area, and the velocity of the air in the goaf effect.
- (2) At the return air side in the working faces (such as #105 and #115 supports and later), the distribution of

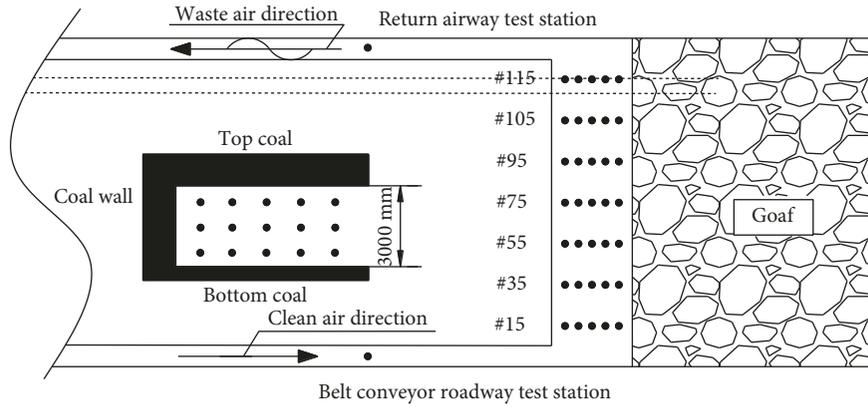


FIGURE 3: Measuring point arrangement of the face in the shape of the stereo grid.

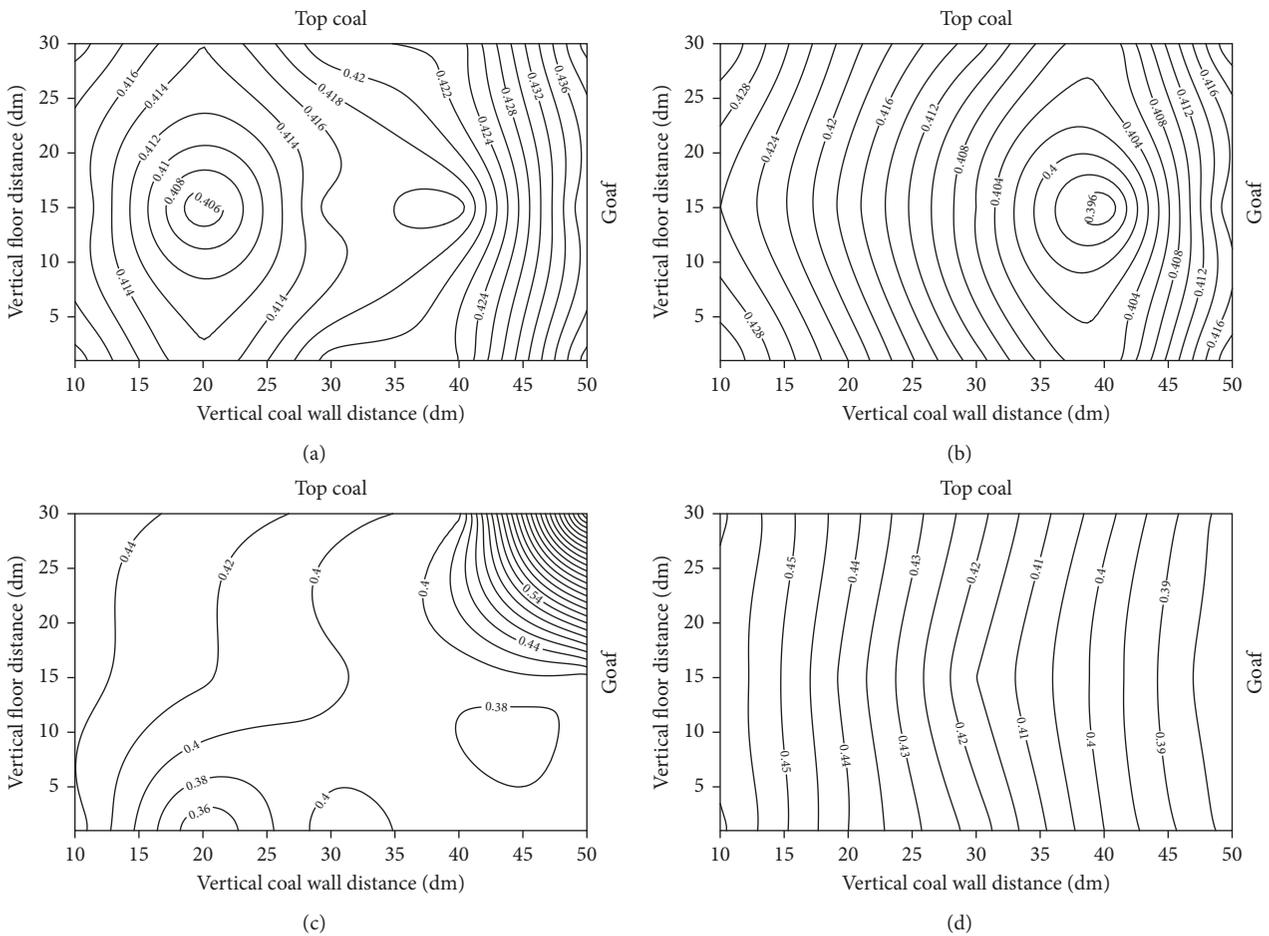


FIGURE 4: Isograms of gas volume fraction at sections of the face. (a) #15 support measurement section. (b) #55 support measurement section. (c) #95 support measurement section. (d) #105 support measurement section.

the gas volume fraction along the vertical coal wall measured cross section is presented as a decreasing straight line. It indicates that, on these routes, the accumulation of gas extracted from the coal wall and fulling coal is the main factor affecting and determining the volume of gas at the site. The uneven distribution of cross-sectional air speed and gas

emission from the goaf has little effect on the gas volume at the site.

3.2.2. Gas Distribution Characteristics in the Air Direction. Taken the average of the upper, middle, and lower measuring points of each vertical section, the contour of the gas volume fraction is shown in Figure 6.

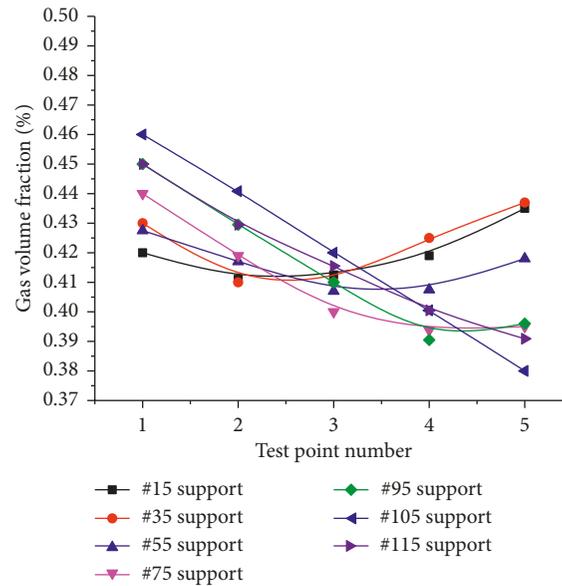


FIGURE 5: The gas volume fraction distribution curves of every section along the vertical coal wall line.

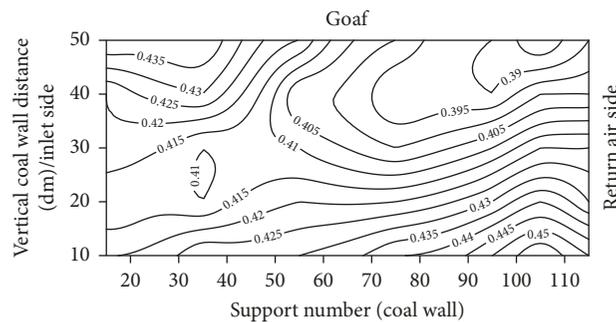


FIGURE 6: Isograms of gas volume fraction along the air direction in the working face.

In Figure 6, the following can be seen:

- (1) At the air-inlet side and air-return side in the working faces (such as #15–#95 supports), the gas volume fraction of the section has the lowest value, and its position gradually increases from about 2 m from the coal wall to about 4.5 m from the coal wall. This shows that the effect of gas accumulation from the coal wall and fulling coal increases in proportion with the increase in the airflow route, while the influence of the airflow velocity at this site and the gas emission from the goaf declines gradually.
- (2) At the air-inlet side in the working faces (such as #15–#55 supports), the gas volume near the goaf side is higher. The reason is that gas accumulations from coal wall and fulling coal on these routes and the gas emission from the goaf have little effect on the cross-sectional gas.
- (3) At the air-return side of the working faces (such as 105[#], 115[#] supports and its subsequent supports), the gas volume near the coal wall is higher. The reason is that the gas accumulation of the coal wall and fulling coal on these routes has a great influence on the cross-sectional gas and the air velocity at this site and the gas emission from the goaf have little impact on the cross-sectional gas.
- (4) The volume fraction of gas at the air-return side is significantly higher than that at the air-inlet side. This is because the gas emission from the coal wall, caved coal, and goaf area is superimposed along with the increase of the airflow route in the working face.

3.2.3. *The Law of Gas Emission in Working Face.* The work surface has moved forward by an average of 3.2 m per day since the working face was resumed on February 29, 2016.

When the basic roof is falling until March 16 (that is, when the working face experienced first weighting), the absolute gas emission volume and gas drainage volume change with working face progress, as is shown in Figure 7.

As can be seen from Figure 7, before the working face experienced roof weighting for the first time (March 16), the absolute gas emission amount in the working face gradually increases with the working face advancement, along with the amount of gas scavenging and gas extraction volume, with small fluctuations in the local area. The absolute gas emission peaked at $52 \text{ m}^3/\text{min}$ ($\pm 3 \text{ m}^3/\text{min}$) for the first time during the initial roof pressure on the working face. This occurred because of basic roof caving and weighting, which caused pressure relief of the adjacent layer and surrounding rock into the goaf. After the initial pressure, the absolute emission volume and drainage volume of working face gas tend to be stable, and the fluctuation range is between 43 and $52 \text{ m}^3/\text{min}$ and 37 – $45 \text{ m}^3/\text{min}$, respectively, and it shows strong regularity with the direct top cyclical slump. The daily average gas drainage rate of the working face is similar to the regularity of the daily gas drainage volume; it tends to be stable after the initial pressure, and it has been maintained at more than 85%.

4. Conclusions

- (1) The influencing factors of gas emission quantity and gas emission source in fully mechanized top-coal caving face have the characteristics of coal seam gas content, gas permeability, attenuation coefficient, and other coal seam, along with mining process technology, recovery rate, mining intensity, propulsion speed, and air volume at the working face. The distribution of gas emission in the working face and the magnitude of gas emission vary with time and space and have multidimensional dynamics.
- (2) The gas volume fraction at a certain point on the cross section of the working face is determined by the action of the gas source (coal wall, caved coal, and goaf) on the point and the air speed at that point. Therefore, the gas distribution of the working face presents different characteristics on the air-inlet side and air-return side of the working face.
- (3) Before the first weighting, the absolute amount of gas outflow in the working face increases with face advancement, and gas drainage scalar and extraction rate also increase. After the initial pressure, the absolute emission volume and pumping volume of gas peak for the first time and gradually stabilize.

Data Availability

The data used to support the findings of this study are included within the article.

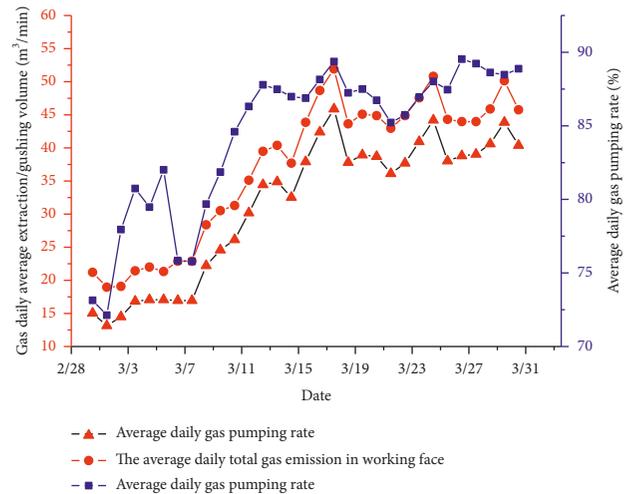


FIGURE 7: Curves of gas emission and extraction rate of the working face.

Conflicts of Interest

The authors declare there are no conflicts of interest regarding the publication of this paper.

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