Distribution and Prevention of CO in a Goaf of a Working Face with Y-Type Ventilation

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ABSTRACT: In recent years, the mining technology of “roof cutting and pressure releasing” has appeared in China. It is called China’s third mining revolution. The technology of “roof cutting and pressure releasing” has changed the traditional working face ventilation system and the boundary conditions of a goaf. The law of air leakage in the goaf has changed, resulting in changes in the distributions of CO and other disaster gases. In order to ensure the promotion of this advanced mining technology safely, research on the distributions of CO and other disaster gases is very necessary. By installing CO sensors in the air intake lanes, gob-side entry retaining, and goaf, the distribution of CO in the goaf during the advancement of the working face under the “roof cutting and pressure releasing” mining method is studied. The concentration of CO in the upper corners of the working face under the traditional mining method and the “roof cutting and pressure releasing” mining method was compared and analyzed. The results show that the CO in the experimental working face mainly comes from the oxidation of the residual coal; after analysis, the CO concentration in the goaf is divided into three areas: the slowly increasing area, sharply increasing area, and attenuation area; the CO concentration in the upper corner of the working face of Y-shaped ventilation with “roof cutting and pressure releasing” mining is much lower than that in the upper corner of the working face of U-shaped ventilation in the traditional mining. In order to prevent the oxidation and heating of the residual coal in the goaf to produce CO, comprehensive prevention measures for CO escape in the goaf have been adopted. After actual production verification, the prevention and control measures show good effects to ensure the safe and effective production of the working face.

1. INTRODUCTION

The fuel industry is an important part of economic development of all countries in the world. The sustainable development of the coal industry is directly related to the development and safety of the fuel industry in countries that extract coal and even affects politics and economy.1–7 Many of the existing coal mines in the world are underground mining.8 In China, with the improvement of mining mechanization and centralization, the coal production has been increasing continuously. Meanwhile, due to the increase of the mining depth, complicated geological conditions, and the relatively backward technical equipment, coal dust, gas explosions, fires, floods, rock bursts, roof fall, and other disasters occur frequently, with China being one of the countries with serious mining disasters. These disasters also exist in other countries in the world that extract underground coal. Among the underground disasters, the over-limit CO has become more and more prominent, which seriously threatens the safe production of coal mines and the lives of workers. CO is a colorless, odorless, flammable, highly toxic, and suffocating gas.9 It is also a sensitive indicator of whether coal seams are oxidized and spontaneously combusted.10,11 Moreover, spontaneous combustion of coal is not the only or main source of CO. CO that is not related to spontaneous coal combustion seriously interferes with early prediction of spontaneous coal combustion. Therefore, studying the source and distribution of CO in mines and proposing targeted control methods are of great significance to the safe and efficient production of mines.

In general, the CO in the coal mining face mainly includes the following sources: the gas in the original coal seam,12,13 the gas produced in the mining face, the gas produced by oxidation of residual coal in goafs,14–16 and the gas produced by underground blasting and mechanical operation.17–20 At present, the oxidation of residual coal in the goaf is generally considered to be the main source of CO in underground mines.21

The distribution of CO in coal mine goafs is closely related to the mining method and ventilation method. At present,
most of the existing coal mines in the world adopt the traditional longwall mining method. Under this mining method, it is necessary to excavate two lanes for one mining face. At the same time, a coal pillar should be reserved to balance the stress transmitted from the roof of the mining face. This coal pillar is difficult to recover, causing serious loss of resources. The maximum loss can reach 40% of the recoverable reserves. This kind of working face generally adopts the "U"-shaped ventilation method. As shown in Figure 1, this goaf is a closed goaf because the roadway and the goaf are not directly adjacent to each other.

![Figure 1. Traditional longwall U-shaped ventilation mining.](image1)

In order to reduce the waste of coal resources, no-pillar mining technology emerges with the development of the mining industry. The representative is the mining technology of "retaining lanes along the goaf". This technology maintains a roadway along the boundary of the goaf during the mining process of the working face and fills a supporting wall on the side of the goaf behind the working face. The filling materials include concrete, flexible mold materials and paste materials, and high-water materials and make the hardened wall support the roof pressure, excavation disturbance pressure, and roof cycle pressure. In fact, the function of this supporting wall is mainly to replace coal pillars, and the working face has realized "Y"-type ventilation. This technology is effective for the shallow mining. As the depth of mining increases, coal roof pressure, excavation disturbance pressure, and roof cycle pressure increase exponentially, and a series of problems such as stress concentration of the surrounding rock of the roadway will occur to make it difficult to maintain the roadway. In this mining method, both the goaf and roadway are located behind the working face, and the roadway and goaf are separated by a filling wall, resulting in a closed goaf (see Figure 2).

![Figure 2. Filling support no-pillar Y-type ventilation mining.](image2)

The working principle of the technology is as follows: When the working face is recovered, the inner surface and the side of the goaf are supported by the constant-resistance and large-deformation anchor cable, and the working face is advanced by a certain distance. Along the direction of the trough, the directional blasting technology can precrack the roof, forming a slit surface along the goaf side of the retaining roadway. After mining, the dense single pillars are arranged close to the precracked line to support the roadside. The roof of the goaf is automatically degraded along the slit surface due to its self-weight and mine pressure; thus, a slot in the working surface is formed, and the mined-out area is open (see Figure 3).

The application of roof cutting and pressure releasing technology in coal mining is bound to bring about a series of new problems. This paper focuses on the problem of CO exceeding the limit in coal mine production. At present, most of the coal mine’s prevention and control technologies for CO are based on the traditional long-walled "U"-shaped ventilation mining face. Many scholars have concluded that the working face using the traditional long-wall "U"-shaped ventilation mining method is easier to form a disaster gas accumulation area in the upper corner, including CO. Liu and Chen established a fully coupled model of CO generation and migration in a long-walled goaf. They studied the migration of CO in the goaf during spontaneous combustion and found that the high carbon monoxide concentration area is associated with the oxidized self-heating zone of the oncoming wind in the goaf overlaps with the high temperature zone. Pan et al. using a numerical simulation method determined that the concentration of O2 and CO goaf spontaneous combustion can
be divided into three zones using simulation results and observations. Based on the study of three zones, they also point out that the location of the CO concentration peak can represent the most severe position of coal oxidation as well as the position where the spontaneous coal combustion starts, according to the position of governance, which is an effective and efficient governance approach. Zhuo et al. took the Branta mine as the background and used Fluent to simulate the oxygen concentration field, carbon monoxide concentration field, and wind velocity field in the goaf and concluded that for the shallow coal seam goaf, mining the distribution of CO concentration in the upper part of the goaf is mainly affected by air leakage from the ground, and the distribution of CO concentration in the lower part of the goaf is mainly affected by air leakage from the working face.

Some scholars have also studied the distribution of CO in the working face of "Y"-type ventilation mining with reserved roadways along the goaf. They have made some comparisons between "U"-ventilation and "Y"-ventilation. Tutak et al. compared the gas concentration under "U"-type ventilation and "Y"-type ventilation and through statistical data and test results, it was found that the "Y"-type long-walled ventilation system can better reduce the gas concentration. The concentration of gas at the same time will increase the risk of spontaneous combustion of coal. Li et al. used the numerical simulation software Comsol Multiphysics to numerically simulate the goaf and revealed the law of air leakage and gas distribution in the goaf of a fully mechanized mining face under the condition of "Y" ventilation, compared with the "U"-type ventilation, the "Y"-type ventilation can reduce the gas concentration in the upper corner and the working face. The three-dimensional space distribution law of the gas in the goaf is similar to the "O" circle theory of mining cracks. Wei et al. selected CO and CH4 as coal seam spontaneous combustion index gases and compared the "U"-type ventilation and "Y"-type ventilation working face, and the results showed that the heat dissipation area of the "Y"-type goaf and the depth and width of oxidation are slightly increased compared to the "U" type.

However, the "Y" ventilation mode under the emerging roof cutting and pressure releasing mining is different from the general "Y" ventilation mode. Due to the change of the boundary conditions of the goaf, the air leakage will increase, which will aggravate the oxidation of the leftover coal in the goaf, resulting in an increase in the amount of CO generated and the risk of coal spontaneous combustion; on the other hand, it will inevitably lead to changes in the distribution of CO and other disaster gases and at the same time bring a series of production problems. At present, there are no scholars on the related research of CO prevention and control in open goaf and working face under the "Y"-type ventilation mining technology of roof cutting and pressure releasing. Therefore, in order to ensure the safe production and subsequent promotion of the working face using the roof cutting and pressure releasing technology, it is very necessary to carry out research on the CO distribution law and prevention measures in the goaf of the working face under the "Y"-shaped ventilation mode.

The purpose of this article is to explore the law of CO concentration distribution in the "Y"-shaped ventilated goaf under the new roof cutting and pressure releasing mining mode and to provide basic support for preventing CO disasters under the new mode of roof cutting and pressure releasing mining. In this study, based on engineering practice, this article monitors the CO concentration in real time by installing CO sensors in the working face’s air intake lane, working face support, and goaf. In this paper, a comprehensive analysis of the source of CO in the working face was carried out, and the CO concentration in the upper corner under the mining mode of a "Y-shaped" ventilation system under the roof cutting and pressure releasing mining method and a "U-shaped" ventilation system under the traditional longwall mining method was compared. The study obtained the change law of CO concentration as the working face advances. On this basis, the prevention and control measures of CO overrun in the goaf of the "Y" ventilation system under the roof cutting pressure releasing mining method are proposed.

2. MATERIALS AND METHODOLOGY

2.1 Overview of the Engineering Background. The Halagou Coal Mine is located in Daliuta town, Shenmu country, Shanxi province, China. The mine belongs to the...
Shenhua Shendong Coal Company. The mine length is 8.4–11 km, the width is 8.3–10 km, and the area is 85 km². The approved production capacity of the mine is 16 million t/a. There are eight layers of recoverable and locally recoverable coal seam. The main mining coal seam is 2–2 coal, 3–1 coal, and 4–2 coal, which are nearly horizontal. The mine has been identified as a gas mine. The coal seam has a spontaneous combustion grade in the Jingtian area of class I, and the spontaneous combustion period is 1–3 months, indicating that spontaneous combustion is easy. Additionally, coal dust in this seam is an explosive hazard. The 1–2 coal seams mined at the experimental working face 12,201 have a low metamorphism degree, mainly long flame coal. Under traditional “U-shaped” ventilation, the CO concentration in the upper corner of the 12,202 working face is always in a state of exceeding the limit. Therefore, it is necessary to conduct a study on the 12,201 working face was pushed to the cutting hole 12,202 and the second mined face 12,201.

The 12,201 fully mechanized coal face is the first mined face of coal seam 1–2. The thickness of the coal seam is 0.8–2.2 m with an average seam thickness of 1.92 m. The depth is 60–100 m, and the roof is siltstone with a thickness of 0.52–3.9 m (~1.84 m). The top of the roof of the coal seam is the upper corner of coal seam 1–2 (1–2 up) with a thickness of 0.0–2.75 m (~1.56 m). 1–2 up is mudstone with a thickness of 2.14–0.55 m (~1.35 m), and the old roof is composed of fine sandstone (thickness: ~3.34 m) and siltstone (thickness: ~4.05 m). The floor of the coal seam is siltstone with an average thickness of 3.67 m. In accordance with the Shendong Coal Group regulations, during the mining of the 12,201 face of the Halagou Coal Mine, when the coal seam thickness is less than or equal to 1.9 m, high cutting mining techniques may be used; however, when the coal thickness is more than 1.9 m, fully mechanized techniques should be used. It is speculated that the goaf of coal seam 1–2 contains less coal. As it is unstable and cannot be mined, the complete 1–2 up coal seam is left in the goaf of working face 12,201. However, coal seam 1–2 up is only 1.84 m away from coal seam 1–2 and it is completely within the mining range. The coal in the goaf is shown in Figure 4.

The inclination and strike lengths of the working face 12,201 are 320 and 747 m, respectively. During production, the working face was pushed to the cutting hole 12,202 and the roadway was reserved. The technique of roof cutting and pressure releasing was used for working face 12,201. The length of the reserved roadway was 580 m. The ventilation system was adjusted from U-type to Y-type. The working face ventilation system is shown in Figure 5. (Two air intake lanes, one return air lane, Y-shaped ventilation).

2.2. Analysis and Monitoring of the Source of CO Emission. In order to grasp the distribution and sources of CO in the Halagou coal mine, the CO concentration measurement points were arranged at intervals in the wind tunnel of Yunshun 12,201, and the CO concentration measurement points were arranged at the upper corners of the working face.

2.2.1. Monitoring of CO Concentration in the Inlet Roadway and Working Face. One CO measurement point is arranged at every 200 m interval of the 12,201 transportation air inlet lane, and the CO concentration change in the air inlet lane of the working face is monitored by the mining KGS CO sensor (KGS CO sensor, made in Shandong, China, working voltage: 9–24 V, measuring range: 0–1000 ppm, response time: less than 30 s, size: 280 mm × 150 mm × 60 mm, weight: 1 kg, see Figure 6). The professional staff will record data every 8 h.

A CO measuring point is installed on the support of the working face, and the CO concentration change during mining of the working face and the CO concentration change of the upper corner are monitored by the mining KGS CO sensor.

2.2.2. Monitoring of CO Concentration in the Goaf. In the mining process of the 12,201 working face, one measuring point is arranged every 50 m or so, and the carbon monoxide in the mined-out area is simultaneously monitored by the JSG4 mine fire beam monitoring system (see Figure 7). The JSG4 mine fire tube monitoring system is mainly composed of three parts: the underground gas sampling and analysis system, ground chromatography analysis workstation, and ground data processing shared subsystem (see Figure 8). The system error is less than 1.5%, and the CO detection range is 0–1000 ppm (resolution: ~0.1 ppm). In order to avoid sampling errors and make the monitoring data representative, the average value of the monitoring data over 1 day is used as the measurement data.

3. RESULTS AND DISCUSSION

3.1. Analysis of CO Source under the Roof Cutting and Pressure Releasing Mining Method. From the analysis and summary of the monitoring data, the concentration of CO in the inlet air lane of the working face is 0–1 ppm, which is mainly generated when the rubber wheel transport vehicle transports goods. 1–2 ppm CO will basically exist in the working face during the maintenance shift, and 1–2 ppm CO will also exist in the working face during the night shift and the production shift. A large concentration of CO was detected in the goaf, far exceeding the current coal mine CO concentration of 24 ppm stipulated in China’s current safety regulations. The main reason for the excess was residual coal oxidation. In other words, the CO in the mine mainly comes from the oxidation of residual coal in the goaf, and a small amount comes from the rubber wheels used for transportation and coal cutting. Therefore, the paper focuses on the analysis of CO distribution in the goaf.

3.2. Variation of CO Concentration in the Goaf with the Advance of the Coal Mining Face. The measuring points 22, 72, 133, and 175 m away from the cutting hole of working face 12,202 were numbered as no. 1, no. 2, no. 3, and no. 4, respectively. The positions of each measuring point are shown in Figure 5. The change curve of CO concentration at
each measuring point, while advancing the coal mining face, is shown in Figure 9.

It can be seen that the CO concentration in the goaf gradually increased in the first 50 m, but the rate of increase was low. The monitoring data show that the CO concentration reached 40–60 ppm (∼50 ppm) when the working face was pushed to 50 m. When the working face advanced farther than 50 m, the concentration of CO in the goaf area began to increase sharply. When the working face was pushed to approximately 110 m, the CO concentration in the goaf rose above 200 ppm. When the working face was pushed past 110 m, there was a vibration trend of the CO concentration in the goaf, and some of the measuring points within the shock attenuation area showed a trend of concentration decay. According to the measurements, the CO concentration in the goaf side of the working face can be divided into three zones: a slowly rising area, a rapidly rising area, and a shock attenuation area. The three zones are shown in Figure 10.

3.3. Variation of CO Concentration at the Upper Corner of the Working Face. In the mining process of the 12,201 working face, the CO concentration at the upper corner of the working face was tested. The measured data is shown in Figure 11.

It can be seen that the CO concentration of working face 12,201 was generally 0 ppm. The maximum concentration of the upper corner was 13 ppm, and the average value was 2.82 ppm, far below the 24 ppm limit of the coal mine safety regulations.

To compare the CO concentration difference between the roof cutting and pressure releasing technique and traditional mining method, the CO concentration in the upper corner of the working face was tested in the adjacent working face 12,202. The measured data are shown in Figure 12.
From Figure 12, we can see that, in the production process of working face 12,202 using the traditional mining method, the upper corner had a concentration of CO consistently within extreme conditions. The maximum concentration was 214 ppm, which is 9 times greater than the maximum allowable concentration of 24 ppm. The average measured concentration was 85 ppm, which is 3.5 times higher than the 24 ppm.

The upper corner CO concentrations of working face 12,201 using the Y-type ventilated mining system for roof cutting and pressure releasing were compared with those of working face 12,202, which used the traditional U-type ventilated mining system. Under the Y-type ventilation system with roof cutting and pressure releasing, compared to the same location with the traditional mining method, the maximum CO concentration of the upper corner was lower by 94% and the average concentration was lower by 97%, suggesting that the technique of roof cutting and pressure releasing completely eliminated the high CO concentration in the upper corner. In addition, the coal cutting area of the shearer is the gathering area for workers. When using the traditional mining method, the CO concentration near the end bracket often exceeds 24 ppm; however, under the technique of roof cutting and pressure releasing, the head of the shearer is in fresh air; the CO concentration in this region was only 5 ppm, eliminating the threat of high CO concentration for the operating personnel.

3.4. Prevention and Control Technology. According to the above research, the CO concentration distribution law is

![Figure 9. Variation of CO concentration relative to the working face advancing distance.](image)

![Figure 10. Distribution of CO concentration in the goaf.](image)

![Figure 11. Concentration of CO in the upper corner of the working face 12,201.](image)
obtained. On this basis, the following prevention and control measures were implemented.

1. Leakage prevention technology for ground cracks. Due to the shallow burial depth of the working face, a large number of cracks have occurred in the ground after mining, see Figure 13. In order to prevent air leakage through the cracks into the mined-out area, which intensifies the oxidation of the remaining coal, generating more CO, in the process of mining the face, professional workers are arranged to block the ground cracks every day.

2. Construction of walls in air corners. There is a significant difference in air pressure between the inlet angle and the retaining road. Under this pressure drop and inertia, some air flow enters into the goaf through the air inlet angle, which exacerbates the air leakage in the goaf and expands the possible poisoning area. To prevent air leakage at the corner, Halagou Coal Mine built walls at the upper corner of the inlet.

3. Speed up the working face. In the goaf, the area of CO formation was mainly distributed in the cooling zone and the oxidation elevation zone, and the increment of the advancing speed of the working face advancement would reduce the amount of CO in the goaf. Therefore, Halagou Coal Mine accelerated the speed of working face advancement. The maximum daily advancing distance reached 13 m.

4. Pre-treatment of coal left over in goaf. Because working face 12,201 is directly on top of the occurrence and coal seam 1−2 has an average thickness of 1.56 m, the coal seam occurrence is not stable and, therefore, unworkable. However, the upper coal seam of no. 1−2 is only 1.84 m away from coal seam no. 1−2 and within the mining caving range. Therefore, the 1−2 up coal seam was left in the goaf of working face 12,201, which leads to a high amount of residual coal in the goaf of 12,201.

5. Spray plugging technology in the left lane. The retaining lane of Halagou coal mine was blocked by the shotcrete spraying method. Two applications created a total thickness of 80 mm. The effect of shotcrete is shown in Figure 14.

6. Grouting plugging technology. To reduce the air leakage into the goaf further, grout was applied from the side of the gravel with a grouting bolt. The depth of the grouting hole was 2.0 m, and the distance between the drill holes was 800 mm × 800 mm. Grouting was divided into three to five holes with 0.05 m³ of grouting per hole.

7. Pressure leak proof technology. To reduce the working face crossheading air flow into the goaf, Halagou Coal Mine adopted wind and pressure ventilation measures. That is, air volume facilities at the 12,202 main retreat were constructed to adjust the air volume and pressure of the 12,201 transport and air troughs. This technique reduced the gas pressure difference between the goaf and the mining space and adjusted the wind window to simultaneously control the air pressure in the 12,203 transport along the chute and the 12,204 transport along the trench.

According to the CO concentration distribution law, we have implemented a series of technical measures, including ground crack plugging technology, the prevention technology of the wall at the corner of the air inlet to prevent air leakage, speeding up the advancement of the working face, pretreatment of leftover coal in the goaf, shotcreting prevention technology for retaining lanes, grouting plugging technology, and equalizing pressure prevention technology. During the advancing process of the 12,201 working face, the CO concentration in the retaining lane where the constructors...
were located was tested to verify the effect of prevention and control measures. The measured data is shown in Figure 15.

![Figure 15. Concentration distribution of CO in lane.](https://dx.doi.org/10.1021/acsomega.0c02853)

Figure 15 shows that the highest concentration of CO in the left lane was only 15 ppm. The CO concentration in the left lane (near the working face end support office) was 2 ppm. At a greater distance from the working face, the concentration of CO increased. At up to 150 m from the working face, the CO concentration rose from 2 to 12 ppm. CO concentration increased from 12 to 15 ppm in the range of 150 to 450 m. Through analysis, the reason is that the CO in the goaf is continuously discharged through the return airway with the leakage air, and the CO concentration in the retained lane will increase with the increase of the distance from the working surface, but the CO concentration will not be too high. It can be seen that after taking comprehensive prevention measures, CO did not adversely affect the mining safety.

3.5. Discussion. From the above research, it can be seen that in the roof cutting and pressure releasing mining method, the CO concentration in the upper corner is not high, and the main CO occurrence area exists in the goaf. According to the difference of the CO concentration in the goaf, it is divided into three areas: slowly rising area, sharply rising area, and shock (attenuation) area; the area with the highest CO concentration represents the starting area where coal spontaneous combustion may occur. Knowing the distribution of CO concentration can prevent the occurrence of coal spontaneous combustion in a timely and effective manner.

These three areas have many connections with the three zones of spontaneous combustion in the goaf. Chen determined the specific length of the three spontaneous combustion zones in the goaf under the traditional longwall mining mode and the roof cutting and pressure releasing mining mode based on the O₂ concentration through field measurement. The specific distribution distance is shown in Figure 16.53 The study found that the goaf under the roof cutting and pressure releasing Y-type ventilation mode has a significantly larger range of influence than the traditional longwall mining oxidation heating zone, which greatly increases the possibility of coal spontaneous combustion. Combined with the research in this paper, it can be analyzed that the CO slow rising area is in the scattered tropical zone of the goaf spontaneous combustion zone. In this area, although heat was generated by the oxidation of the residual coal, further oxidation was hindered by the leaking air; thus, CO formation was prevented, resulting in a small increase in the CO concentration. The rapidly rising area was in the back of the scattered tropical zone, and the front of the oxidation heating zone. The air leakage in the area was less, and the wind speed was low. The heat produced by the residual coal could not be brought out by the wind in time. The accumulated heat promoted further oxidation of the coal, resulting in a sharp increase in CO concentration. With the advance of the working face, the amount of air leakage was gradually reduced and the O₂ required for the oxidation was not sufficiently supplied, thus weakening the oxidation reaction and resulting in a significant decrease in CO production, exhibiting a shock phenomenon. When O₂ was exhausted, the oxidation reaction stopped, and the CO concentration gradually oscillated until it decayed. Combining the three areas of CO concentration distribution and the three zones of spontaneous combustion in the goaf, we can take better and more accurate measures to prevent the spontaneous combustion of coal left in the goaf.

On the whole, the roof cutting and pressure releasing mining method eliminates the upper corner CO high concentration distribution area: this is the advantage of all Y-type ventilation working faces, but it is different from the general filling-type Y-type. The boundary conditions of the roadway and the goaf have changed, leading to changes in the law of air leakage. The distribution of CO in the goaf has also changed significantly, resulting in three areas. Open mined-out areas increase the risk of excess CO concentration in the reserved lanes, which is quite different from the traditional mining mode. Combining the three-zone distribution law of spontaneous combustion in the goaf studied by previous studies, based on the analysis of

![Figure 16. Three zones of spontaneous combustion in the goaf under different mining methods.](https://dx.doi.org/10.1021/acsomega.0c02853)
the CO source in the mine, through the monitoring of the main source area of CO, the distribution law of CO inside the goaf is studied, the area is divided, and the establishment of targeted prevention and control technical measures have effectively prevented CO from exceeding the limit in the roof cutting and pressure releasing mining. This provides an idea for CO disaster management and prevention research under the roof cutting and pressure releasing mining. This idea can be applied to mines that also use the roof cutting and pressure releasing mining technology to ensure that the new technology of roof cutting and pressure releasing mining can be promoted safely and efficiently. The research results of this article point out the direction for the promotion of this new cutting roof pressure relief technology. With the successful promotion of the cutting roof pressure relief mining technology, for non-renewable coal resources, the coal recovery rate is greatly improved. This is not only benefiting China but also the common gospel of coal mining countries all over the world.

4. CONCLUSIONS

(1) Known as the third mining revolution, the mining technology of roof cutting and pressure releasing has fundamentally eliminated coal pillars and greatly reduced the waste of coal resources, but changed the ventilation system at the same time, resulting in changes in the migration of disaster gases.

(2) According to the CO monitoring results, the main source of CO is the oxidation of the residual coal in the goaf. During the advancement of the working face, the CO concentration in the goaf is divided into three zones according to the change trend of CO concentration. The CO concentration in the range of 0–50 m behind the working face changes little, and it is a slowly increasing area of CO concentration. The CO concentration in the range of 50–110 m behind the working face rises rapidly, and the change trend is obvious. It is defined as an area where the CO concentration rapidly rises. The CO concentration change trend in the area 110 m behind the working face is not obvious, but there is a certain range of oscillations, and some measuring points show an attenuation trend after the oscillation, which is defined as the CO concentration oscillation (attenuation) area.

(3) The “Y”-type ventilation mining mode of roof cutting and pressure releasing changes the CO distribution law. Compared with the traditional “U”-type ventilation mode, the “Y”-type ventilation mining mode with roof cutting and pressure releasing can eliminate the over-limit phenomenon of CO gas in the upper corner. The maximum CO concentration in the upper corner is 13 ppm, and the average is only 2.82 ppm. The maximum concentration in the corner was reduced by 94%, and the average concentration was reduced by 97%. However, the area of CO influence increases in the goaf, which brings a certain degree of danger to the reserved roadway workers.

(4) After adopting measures of leakage prevention technology for ground cracks, the prevention technology of the wall at the corner of the air inlet to prevent air leakage, speed up the advancement of working face, pretreatment of leftover coal in the goaf, The generation of CO was successfully prevented because of these effective measures. After adopting measures of shotcreting prevention technology for retaining lanes, grouting plugging technology, and equalizing pressure prevention technology, the diffusion of CO is effectively prevented. After implementing these prevention and control measures, the maximum CO concentration in the remaining lane (return air lane) is only 15 ppm. Comprehensive measures can reduce the CO concentration during the roof cutting and pressure releasing mining process and eliminate the harm caused by CO.

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Notes
The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This research was supported by the National Natural Science Foundation of China (51874122,51704100), the Program for Innovative Research Team of Henan Polytechnic University (T2019-4), the Key Research Projects of Henan Higher Education Institutions (18A440004, 15A440007), the State Key Laboratory Cultivation Base for Gas Geology and Gas Control (Henan Polytechnic University) (WS2019A06), the Key R & D and Extension Projects of Henan Province (202102310223), and the Doctoral Fund of Henan Polytechnic University (B2020-8). Constructive comments by anonymous reviewers and the editor are highly appreciated.

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