Regularity of Mine Gas Flow Disaster Induced by Gas Natural Ventilation Pressure after Coal and Gas Outbursts

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ABSTRACT: The gas pressure generated during a coal and gas outburst is an important factor affecting the stability of mine ventilation systems. The gas released from an outburst flows and diffuses in the mine, leading to an uneven distribution of the air in the mine ventilation system and the formation of natural wind pressure. Because of the effect of the gas pressure, the mine ventilation system becomes disordered, leading to a counterflow in the roadway. This increases the complexity of the gas movement, extends the influence range of the gas, enlarges the disaster area in the mine, and exacerbates the destructiveness. In this study, the TF1M simulation program was applied to simulate a coal and gas outburst accident that occurred in the 1747 heading roadway of the Sizhuang Coal Mine, in a bid to reproduce the entire process of the diffusion flow of the counter current and outburst gas in the mine roadway. Moreover, the dynamic influence of the gas pressure on the entire ventilation network was analyzed. An experimental device was set up to test the relationship between the natural wind pressure and the height difference of the roadway and density of the gas flow, and the formation and mechanism of the natural wind pressure were explored. By analyzing the experimental and numerical results, the variation law of the air flow and the law of gas movement under the influence of gas pressure were summarized. The movement law and influencing factors of the gas during the mine outburst period were studied, the influence range of the gas was determined, the distribution law of the gas concentration after the outburst was obtained, and further expansion of the gas was prevented. This study has theoretical and practical significance in enhancing our understanding of the development process of mine gas disasters, which can help establish effective emergency response strategies and reasonably implement postdisaster relief measures.

1. INTRODUCTION

Coal plays a pivotal role in China’s energy structure, and coal and gas outbursts are one of the main threats to its safe production.1–5 A coal and gas outburst is a complex dynamic phenomenon6,7 capable of causing a significant degree of damage with a wide influence range and easily inducing other major accidents and secondary disasters.8–13 For example, in 2011, the ”11-10” coal and gas outburst accident in Sizhuang Coal Mine (Shizong County, Qujing City) resulted in 43 deaths,14 and in 2009, the “11-21” coal and gas outburst in Xinxing Coal Mine (China Longmei Group Hegang Branch) resulted in 108 deaths.15 In 2004, the “10-20” coal and gas outburst in Daping Coal Mine (Zhengzhou Coal Group) caused a gas explosion, killing 148 people.16 Therefore, it is necessary to study the gas flow process following a coal and gas outburst in mines. The main reason for secondary disasters after an outburst is the turbulence of the air flow in the ventilation system generated by the expanding power of the gas. This turbulence makes it difficult to predict the gas flow direction and gas concentration changes in the mine ventilation network. In the event of a coal and gas outburst in a mine, the direct expansion power of the outburst...
gas can make the air flow in the ventilation system countercurrent.17,18 Through a combination of similarity experiments and numerical simulation, Wei19 systematically studied the laws of migration and diffusion of a large amount of gas flowing along the roadway and its influence range in the mine. The expanding gas and air-mixed flow continuously change the air flow density in the roadway and the natural wind pressure of the mine system or local area, which is called the gas natural ventilation pressure. The change in the natural wind pressure in mines due to the outburst gas has been studied experimentally.20 Wang et al. studied the air flow stagnation accident that occurred in an inclined roadway in Tangshan Coal Mine, China, and attributed this disaster to the pressure of the gas diffusing after the outburst.21−25 Yang26 studied the diffusion and migration laws of outburst gas in a ventilation system and simulated the ventilation network under an unsteady state. The author combined the two to establish a calculation model for the wind network and gas distribution under the unsteady state and on this basis developed a set of online identification and emergency decision-making software to simulate coal and gas outbursts in mines. Li et al.27−29 developed a simulation program called TF1M for a mine ventilation system based on the active wind network theory and numerically simulated the entire process of a coal and gas outburst. The dynamic wind pressure of the expanding source was found to have a significant impact on the ventilation system: it reduced the air volume of the inlet shaft or caused a reverse flow and simultaneously increased the air volume of the return shaft. The authors obtained the catastrophic law of the ventilation system under the influence of the expanding gas and dynamic wind pressure.

There are few studies on the outburst gas flow process in a mine network system related to the superposition of outburst gas flow and ventilation dynamics. Previously, the passive wind network theory was applied to simulate gas outbursts. It is necessary to perform an in-depth study on the secondary disasters due to coal and gas outbursts, the influence of gas natural ventilation pressure on wind flow after the formation of natural wind pressure, and the time and scope of the action. Studying these influencing factors can help provide a theoretical basis for a rational utilization of the gas natural ventilation pressure in actual production. A coal and gas outburst process is complex, and the analysis of the outburst coal power and the formation process of the gas natural ventilation pressure have been ignored in existing research. Therefore, our main focus was on the influence of the gas natural ventilation pressure on the air flow in roadways.

In this study, through a combination of numerical simulation and experiments, the diffusion and migration of gas in the entire ventilation network during the catastrophic outburst period were explored to analyze the dynamic impact of the gas natural ventilation pressure on the air flow in the roadway and to study the generation of gas natural ventilation pressure after the outburst power source disappears. We studied the movement and propagation laws of the gas in the roadway to provide a scientific guidance for accurately grasping the mechanism of disaster occurrence and for disaster control.

2. FORMATION AND CHARACTERISTICS OF GAS NATURAL VENTILATION PRESSURE DURING THE CATASTROPHIC PERIOD

The gas natural ventilation pressure is a form of natural wind pressure. When analyzing this pressure, the influence of temperature on the air flow density in the mine is not considered. The gas natural ventilation pressure is affected by the gas density of the ventilation system and the height difference of the roadway. The gas has a lower density than air. During the disaster period of a coal and gas outburst, the outburst gas accumulates in the mine ventilation system, which changes the natural wind pressure in the entire mine ventilation system, thereby generating a natural wind pressure.

The active wind network theory is applied to solve the problem of outburst sources of gas in mine ventilation systems during the catastrophic period. The time step method is used to discretize the unsteady process of the flow of the salient source in time, assuming that the wind flow movement in each time step is expressed as a steady flow. The unsteady convection—diffusion process of the prominent gas in the mine is solved using a 1D finite element method. The gas natural ventilation pressure, wind pressure balance, air volume balance, and ventilation resistance of the gas are adjusted and calculated. The following assumptions are made: (1) the temperature of the mine system does not change during the outburst; (2) the change in the wind flow density is only due to gas mixing; (3) the outburst gas source is on the network node; (4) the change in the mine system does not affect the strength of the gas source.

The steady-flow mass balance equation for an active wind network is as follows

\[ \mathbf{A} \mathbf{Q} = \mathbf{D} \]  

where \( \mathbf{A} \) is an independent node correlation matrix; \( \mathbf{Q} = [Q]_{n \times 1} \) is the air volume vector, \( Q \) is the air volume in the \( j \)th branch, \( m^3/s \); \( \mathbf{D} = [D]_{(m-1) \times 1} \) is the external wind source vector, where \( D_i \) is the \( i \)-th-node wind source, that is, the gas volume flow of the prominent source, \( m^3/s \); \( m \) and \( n \) are the number of nodes and number of branches, respectively.

In a mine ventilation system, the algebraic sum of the branch position pressure difference in any loop is the natural wind pressure. During the catastrophic period of coal and gas outbursts, the density of the gas flow or the air containing the gas wind flow is significantly reduced, and the natural wind pressure change due to the outburst gas is the gas natural ventilation pressure. The wind pressure balance equation for an active wind network containing gas outburst sources is

\[ \mathbf{B} \mathbf{H} = \mathbf{B} \mathbf{H}_f + \mathbf{B} \mathbf{H}_e \]  

where \( \mathbf{B} \) is the basic loop matrix; \( \mathbf{H} \) is the wind pressure vector, \( \mathbf{P}_a; \mathbf{H}_e = [h_{e,j}]_{n \times 1} \) is the potential pressure difference vector, where \( h_{e,j} \) is the potential pressure difference of the \( j \)th branch, \( h_{e,j} = (Z_{e,1} - Z_{e,2}) \rho g a \). Here, \( \rho a \) is the density distribution function of branch \( j \), kg/m³; \( Z_{e,1} \) and \( Z_{e,2} \) are the elevations of the beginning and end nodes of branch \( j \), m.

During the catastrophic period, the effect of outburst gas flow on the mine ventilation system can be divided into two stages. The first stage is the direct effect of the outburst power on the tunnel airflow, and the second stage is the dynamic influence of the gas natural wind pressure on the air flow in the roadway after the outburst source power disappears. With the gas flow movement, the migration and diffusion of the gas induce a gas natural wind pressure, which is a dominant factor having a significant impact on the mine ventilation system. Based on the assumption that the air flow in the roadway cannot be compressed and combined with the theory of convection and diffusion, the unsteady change process of the air flow in the roadway under the influence of natural gas
pressure and the diffusion and migration process of the outburst gas flow in the entire mine were analyzed.

For branch $j$ in the wind network, the air flow and gas concentration and mass transfer equations can be expressed as follows

$$\frac{\partial c_i}{\partial \tau} + v \frac{\partial c_i}{\partial t} = \frac{\partial}{\partial t} \left( \lambda \frac{\partial c_i}{\partial t} \right)$$

where $v$ is the wind speed in the branch $j$, m/s; $\tau$ is the time variable, s; $c_i$ is the gas concentration in the wind flow in the $j$ branch, %; $\lambda$ is the gas mechanical dispersion coefficient, m$^2$/s.

In each step of the time cycle, the gas concentration at each node in the network is continuously updated and calculated. Each node in the network constitutes the starting point and boundary value of the downstream branch, and the gas concentration at each node is formed by the upstream branch confluence. Thus, the gas concentration (external source gas) after mixing at the $m$ node can be expressed as follows

$$c_m = \sum_{k=1}^{l} Q_k c_k + W_k \sum_{k=1}^{l} Q_k + W_k$$

where $k$ represents the inflow branch of node $m$; $l$ is the number of inflow branches of node $m$; $c_m$ is the inflow-mixed concentration of node $m$ (boundary value); $c_k$ is the concentration of the external source gas in the $k$ branch; $W_k$ is the external gas in the $k$th branch.

3. CASE ANALYSIS OF TURBULENCE IN THE VENTILATION SYSTEM DUE TO GAS NATURAL VENTILATION PRESSURE

Sizhuang Coal Mine is located in Xiongbi Town, Shizong County, Qujing City, Yunnan Province. The mine employs inclined shaft development and is divided into three horizontal mining areas. There are two mining areas in the south and north wings. The south and north mining areas are connected by 1780 horizontal transportation lanes. The mine ventilation system simulation program TF1M was used to construct a ventilation system for a private village. As shown in Figure 1, the mine adopts a central boundary ventilation method. The ventilation system sends air from the second auxiliary shaft and the main inclined shaft and returns it from the boundary air shaft located in the south wing. The draw-out-type ventilation method is used. The BD-II-6-No18 fan is selected, the fan speed is 740 rpm, the air volume is 19.48 m$^3$/s, the external air leakage volume is 2.18 m$^3$/s, the wind pressure is 211.23 Pa, and the natural wind pressure is $-32.63$ Pa. In the branches shown in the figure, the symbols "●" and "•" express the wind flow direction, where "●" represents the front of the wind flow direction, and "•" represents the back of the wind flow direction; the higher the wind speed, the greater the distance between the two. The wind flow and wind speed in the figure are separated by commas, the unit of air volume is m$^3$/s, and the unit of wind speed is m/s.

The TF1M simulation program was used to simulate the entire process of coal and gas outburst and the outburst gas dispersion flow process in the mine system. The main and auxiliary shafts are counter-current. Figure 2 shows the mine gas distribution diagram at a certain time during the simulation outburst process. At this time, the gas flows back from the air inlet lane of the auxiliary shaft no. 2 and diffuses to the return air lane. When a coal and gas outburst occurred in the 1747 driving face, the outburst gas directly flowed up the no. 2 auxiliary shaft until it filled the entire no. 2 auxiliary shaft roadway.
Under the action of the ventilation, the expanding gas enters the 1727 maintenance work area with the wind flow through the depot and is discharged from the south air shaft. The loop formed by the return air tunnel and the no. 2 auxiliary well is affected by the gas natural ventilation pressure. Figure 3 records the air volume change curve of the roadway, where the 1727 inspection point is located during the simulation process. During the expansion process, the air volume first increases and then decreases, and when it decreases to the lowest point, the air volume gradually increases. At the 120th second of the simulation, the outburst process ends. As the gas diffuses into the mine ventilation system, it flows back from the air inlet tunnel and fills the return air tunnel. The gas is unevenly distributed in the ventilation system, resulting in a gas natural ventilation pressure. The gas natural ventilation pressure and the ventilation force have a combined effect on the ventilation system. In the upwardly ventilated roadway, the gas natural ventilation pressure and the ventilation force are in the same direction, thus facilitating the ventilation process. In the downward ventilation tunnel, the gas natural ventilation pressure and the ventilation pressure have the opposite effect, which hinders the ventilation. In the entire ventilation system, the natural wind pressure plays a more complicated role. The gas natural ventilation pressure and ventilation pressure act in the same direction in the 1727 tunnel to promote ventilation. The air volume increases, and at the 385th second of simulation, the air volume in the roadway reaches its lowest end of the air inlet pipe, oxygen sensor 2 at the lowest end of the air inlet, oxygen sensor 3 at the outlet of the air inlet, oxygen sensor 4 at the exit of the return air outlet. Flow sensors 1 and 2 are located at the outlet end of the air inlet pipe, with opposite directions. Flow sensor and oxygen sensor with a mass flow sensor and oxygen sensor with a mass flow meter in opposite directions were set in the return air tube. The lower branch was designed as a protruding end, and the mass flow sensor installed on the protruding branch records changes in the expanding flow during the simulation. To ensure safety, helium was used instead of gas in the experiment. Helium is less dense than gas. The gas natural ventilation pressure is related to the gas density. The experiment using helium gas can reflect the density difference in the gas in the tunnel without affecting the experimental results. The experimental phenomenon could be captured using a mass flow sensor and oxygen sensor with a fast response time, and the experimental data were transferred to a computer through a data acquisition card. The gas sensors in the experiment were all oxygen sensors, and the changes in the mixed gas concentration were reflected by testing the changes in the oxygen concentration. Figure 5 shows the schematic of the experiment. Using this platform, it is possible to study the laws of wind turbulence in different forms of ventilation networks due to the gas natural ventilation pressure. Mass flow meters can record data only in one direction; therefore, two mass flow meters in opposite directions were set in each lane, and the data in the opposite directions were recorded and analyzed during the data analysis. Figure 6 shows the arrangement of the measuring points. Oxygen sensor 1 is located at the outlet of the air inlet, oxygen sensor 2 at the lowest end of the air inlet pipe, oxygen sensor 3 at the lowest end of the return air pipe, and oxygen sensor 4 at the exit of the return air outlet. Flow sensors 1 and 2 are located at the outlet end of the air inlet pipe, with opposite directions. Flow sensors 3 and 4 are located at the outlet end of the return air pipe, with opposite directions.

4. EXPERIMENTAL RESEARCH ON AIR FLOW TURBULENCE IN THE ROADWAY DUE TO GAS NATURAL VENTILATION PRESSURE

Physical experiments were conducted to study the change in the air flow and gas movement in the presence of the gas natural ventilation pressure in the mine ventilation network. The formation process of the gas natural ventilation pressure is not considered, and the influence of the dynamics before the formation of the gas natural ventilation pressure is ignored. The focus is on the factors influencing the natural wind pressure on the wind flow. When the gas natural ventilation pressure affects the wind flow changes, it is necessary to start with a simple specific wind network to analyze its effect more clearly.

The experimental platform is mainly composed of three rubber pipe branches, which are connected by three links, and the branch diameter is 20 mm. A small electric air pump was installed on the top of the experimental system to simulate extraction ventilation. Each branch was equipped with a valve that could adjust the air resistance of the pipeline, and a drawout-type air pump was used to adjust the air extraction capacity through a fan speed regulator. The lower branch was designed as a protruding end, and the mass flow sensor installed on the protruding branch records changes in the expanding flow during the simulation. To ensure safety, helium was used instead of gas in the experiment. Helium is less dense than gas. The gas natural ventilation pressure is related to the gas density. The experiment using helium gas can reflect the density difference in the gas in the tunnel without affecting the experimental results. The experimental phenomenon could be captured using a mass flow sensor and oxygen sensor with a fast response time, and the experimental data were transferred to a computer through a data acquisition card. The gas sensors in the experiment were all oxygen sensors, and the changes in the mixed gas concentration were reflected by testing the changes in the oxygen concentration. Figure 5 shows the schematic of the experiment. Using this platform, it is possible to study the laws of wind turbulence in different forms of ventilation networks due to the gas natural ventilation pressure. Mass flow meters can record data only in one direction; therefore, two mass flow meters in opposite directions were set in each lane, and the data in the opposite directions were recorded and analyzed during the data analysis. Figure 6 shows the arrangement of the measuring points. Oxygen sensor 1 is located at the outlet of the air inlet, oxygen sensor 2 at the lowest end of the air inlet pipe, oxygen sensor 3 at the lowest end of the return air pipe, and oxygen sensor 4 at the exit of the return air outlet. Flow sensors 1 and 2 are located at the outlet end of the air inlet pipe, with opposite directions. Flow sensors 3 and 4 are located at the outlet end of the return air pipe, with opposite directions.
5. RESULTS AND DISCUSSION

5.1. Height Effect. In the experimental system, by changing the elevation difference of the roadway, the initial gas natural ventilation pressure in the experiment was varied, and the influence of the height on the experimental phenomenon was analyzed. We kept the position of the protruding source unchanged, made the two branches of the pipeline system parallel, adjusted the console height, and conducted experiments with height differences of 0, 6, 10, and 14 m.

Figure 7 shows the wind speed change curve at the outlet of the air inlet pipes with different height differences. A flow sensor was used, with a unit of SLPM. Figure 8 shows the oxygen concentration changes recorded by the oxygen concentration sensor at the outlet of the air inlet duct with different height differences. Here, we analyze the changes in the air flow and oxygen concentration in the air inlet tunnel. The wind speed change curves corresponding to different height differences highlight the influence of the dynamic pressure of the power source on the air flow of the air inlet pipe, which leads to a decrease in the air volume of the air inlet pipe or a reverse flow. When the height difference is 0 m, the wind speed in the air inlet duct decreases first and then remains constant after decreasing to the minimum value. As the protrusion ends, the wind speed in the air inlet duct increases to the initial air volume value, and normal ventilation is restored. When the height differences between the two ends are 6, 10, and 14 m, the change trend in the wind flow in the air inlet duct is the same, and because of the expansion power of the outburst itself, the wind flow in the air inlet duct exhibits different degrees of reverse flow. With the disappearance of the expanding source power, the gas migrates and diffuses in the pipeline, resulting in an uneven gas distribution in the pipeline system and generating a gas natural ventilation pressure. The greater the height difference, the greater the gas natural ventilation pressure. The combined effect of the natural wind pressure in the air inlet tunnel and the ventilation pressure gradually increases the speed in the air inlet tunnel, and the gas counterflow in the air inlet tunnel disappears. When the air flow in the air inlet tunnel ends, the gas flows back. The gas natural ventilation pressure in the air inlet tunnel still acts on the air inlet tunnel and reaches the maximum value. The most evident feature is that the peak air flow velocity of the air inlet tunnel at this time is higher than the normal ventilation air flow speed. Subsequently, the gas natural ventilation pressure gradually weakens and becomes negligible, and the air flows in the inlet and return air ducts return to normal. The influence of gas natural ventilation pressure on the air inlet tunnel is also reflected in the oxygen concentration change at the air inlet outlet. Oxygen sensor 1 was arranged at the upper outlet of the air inlet pipe. Figure 8 shows the data recorded by the oxygen sensor 1. When the pipeline is filled

Figure 7. Wind speed change curves of roadways with different height differences.

Figure 8. Oxygen concentration change curve at the exit of the air inlet tunnel with different height differences.
with helium, the pressure in the pipeline increases, and the oxygen concentration increases temporarily, and there are slight fluctuations in the four curves in the figure. When the elevation difference is 0 m, there is no natural wind pressure of the gas and only slight fluctuations. At this time, only the power of the expanding source is exerted. With the end of the expansion, the oxygen concentration returns to normal. At altitudes of 6, 10, and 14 m, the natural wind pressure reduces the oxygen concentration in the air inlet pipe, and the oxygen volume fraction increases gradually. The rate at which the oxygen concentration decreases is evidently greater than the rate at which it increases. The greater the height difference, the lower the minimum oxygen concentration. The lowest oxygen concentrations corresponding to height differences of 14, 10, and 6 m are 13, 2.4, and 1.83%, respectively. The change trend in the oxygen concentration is the same under different height differences. The natural gas wind pressure makes the helium discharge time and rate different from that in the pipeline. The greater the natural wind pressure, the shorter the time taken by the air inlet pipe to restore normal ventilation.

5.2. Influence of Density. Another important factor influencing the gas natural ventilation pressure is the difference in the air density in the ventilation system. Therefore, equal amounts of air and helium were filled in the protruding end for comparison and analysis. The height difference between the protruding end and the inlet-return air outlet was set to 14 m, the flow velocity in the control tunnel was 25 SLPM, and the other variables were the same.

The air velocity variations in the inlet-return duct are recorded in Figure 9 under two conditions. When the air is filled, the wind speed in the inlet tunnel decreases, and the wind speed in the return tunnel increases under the dynamic action of the outburst source. The air velocity in the inlet duct decreases to the minimum value, and the wind speed remains unchanged after the air velocity in the return air duct increases to the peak value. With the end of the inflation at the outburst end of the experiment in this process, the pipe has only air, the gas is evenly distributed in the pipe, and there is no gas natural ventilation pressure. However, because of the difference in height, in addition to the outstanding power, there is an additional force, and the air flow in the inlet and return air ducts is disturbed. When helium is filled, the air flow in the return air duct increases first, then decreases, and then increases. The variation in the wind velocity in the air inlet and return ducts filled with helium can be divided into four stages. In the first stage (T1), under the pressure of the fan, normal ventilation is performed, and the inlet and return air ducts have the same wind speed. In the second stage (T2), the wind speed in the inlet air duct decreases, whereas that in the return air duct increases under the prominent dynamic action. In the third stage (T3), the outburst power gradually disappears, and the gas pressure and fan power combine to increase the air velocity in the air inlet pipe and decrease the air velocity in the air return pipe. The gas pressure in the air inlet pipe helps with the ventilation, whereas the natural air pressure of the gas in the return air duct hinders the ventilation. Under the combined action of the gas pressure and fan power, the peak wind speed in the inlet duct is greater than that during normal ventilation, and the minimum wind speed in the return duct is lower than that during normal ventilation. The natural wind pressure gradually reduces, and this type of phenomenon disappears. In the fourth stage (T4), under the fan pressure function, normal ventilation is gradually restored, and the inlet and outlet wind speeds are the same.

Oxygen sensors 1 and 2 are arranged at the top and bottom of the inlet duct as shown in Figure 6, and oxygen sensors 3 and 4 are arranged at the top and bottom of the return duct. Figure 10 shows the four sensors recording the oxygen concentration changes as helium is pumped in. During the experiment, the oxygen concentration recorded by the four oxygen sensors decreased evidently, and the recorded change curve trends were the same, which showed that the prominent gas flowed into the air duct, diffused into the return air duct, and filled the entire pipe system at an instant. The minimum oxygen concentrations recorded by oxygen sensors 1, 2, 3, and 4 were 19, 3.99, 0.04, and 4.36%, respectively. This shows that the closer the distance to the outburst site, the greater the peak concentration of the outburst gas; the farther the distance from the outburst site, the lower the peak concentration. There is a linear relationship between the outburst gas diffusion distance and the roadway length. The curve of the oxygen concentration in the air inlet pipe fluctuates twice, that is, the air flow in the air inlet pipe exhibits the phenomenon of “countercurrent backflow” because of the gas natural ventilation pressure. This is consistent with the flow phenomenon of gas outburst reported by Cui through experimental monitoring, indicating the complexity of the natural wind pressure of the gas in inclined roadways.

The variations in the oxygen concentrations recorded by the four oxygen sensors, shown in Figure 11, are present when the protrusion is filled with air. During the experiment, the oxygen concentration at the four measuring points changed little, and the volume fraction varied from 18.72 to 21.38%. This shows that there was no natural wind pressure during the experiment, attributed to the slight change in the gas in the tunnel due to the outburst power.

5.3. Comprehensive Analysis. Through simulations and experiments, it was found that the gas natural wind pressure can cause air flow reversal or disorder in the tunnel ventilation system. The air flow reversal in the pipeline is affected by the gas density, height, wind speed, and size of the outburst source in the pipeline. When the height differences between the two ends are 6, 10, and 14 m, the change in the oxygen volume fraction at the inlet and outlet can be divided into two stages: an attenuation stage and an increase stage. Table 1 presents the oxygen growth curve data, oxygen volume fraction C, and its functional relationship with time t. The oxygen growth curve
Figure 10. Oxygen concentration curve (helium).

Figure 11. Oxygen concentration curve (air).
Table 1. Fitting of Oxygen Concentration Data after Outburst

| height difference (m) | fitting result | correlation coefficient | functional form |
|-----------------------|----------------|------------------------|-----------------|
| 6                     | $C = 0.20489 - 0.23835 \exp(−0.1669)$ | 0.9886 | exponential |
| 10                    | $C = 0.20657 - 0.18586 \exp(−0.13374)$ | 0.9799 | exponential |
| 14                    | $C = 0.20526 - 0.09582 \exp(−0.27566)$ | 0.9652 | exponential |

conforms to the exponential function, and the gas attenuation curve conforms to the exponential function.

Through an experimental analysis, the gas natural wind pressure $h_i$ is found to be affected by the height difference $\Delta Z$ and the gas density difference $\Delta \rho$ in the disaster period. The mathematical expression is $h_i = f(\Delta Z, \Delta \rho)$. The gas natural wind pressure is proportional to the height difference of the roadway, and the greater the height difference is, the greater the gas natural wind pressure is. The higher the gas concentration, the greater the density difference and the greater the gas natural wind pressure; when the tunnel is without gas, gas natural wind pressure does not exist.

6. CONCLUSIONS

(1) We established an experimental device for natural wind pressure-induced turbulence in a ventilation system of a coal mine during the catastrophic period of a coal and gas outburst. With this device, we verified the effects of the height difference of the roadway and density of the gas flow on the gas natural ventilation pressure and analyzed the influence of the gas natural ventilation pressure on the airflow movement of the ventilation system.

(2) Compared with the gas natural ventilation pressure and gas outburst power after a coal and gas outburst, the migration and propagation speed of the gas was found to be much lower, and the countercurrent migration speed of the gas in the air inlet lane was significantly higher than that in the return air lane. The greater the experimental height difference, the greater the inclination of the tunnel in the mine and the shorter the time required for the gas to flow through the inlet and return air tunnel and restore normal ventilation.

(3) In the process of a coal and gas outburst, the gas natural ventilation pressure of the gases varies dynamically. By combining experiments and simulations, we studied the changes in the wind flow and gas concentration and the forces in four stages of a coal and gas outburst process: fan pressure, outburst source power, and gas natural ventilation pressure. In the third stage of the catastrophic process, the combined action of the gas natural ventilation pressure and fan pressure caused turbulence in the inlet and return air tunnels, and the air flow in the air inlet tunnel showed a peak value, which was greater than the wind speed during normal ventilation.

(4) In this study, the physical experiment was based on a simple pipe research. In the future, there is a need to further improve the network for disaster wind flow experiments, study the natural gas pressure based on the gas flow dynamic change law of the disaster gas, and determine the effective range of the disaster gas.

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Notes

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