Gas explosion characteristics and its control technologies in closed fire zone

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Abstract

The closure measures of fire zones are taken after gas explosion in the working face, which can bring two problems: whether closure measures will lead to a secondary gas explosion in closed fire zones or not, and what will be the rough time interval between taking measures and gas explosion occurrence. To solve these problems, gas accumulation characteristics, oxygen concentration characteristics and fire sources in the fire closure process were analysed, and then the characteristics and rules of gas explosion were acquired, in addition, the pressure change and gas accumulation model in closure zones under three conditions (the temporary closure wall only in air inlet laneway, only in air return laneway, or both in air inlet laneway and air return laneway) were obtained. Finally, the measures and technologies to prevent and control gas explosion were introduced in the fire closure process of working face.

Keywords: Closed Fire Zone, Gas Explosion Characteristics, Gas Accumulation Model, Fire Sources, Control Technologies

1 Introduction

With the increase of coal mining scale and the extension of production level, gas emission quantity increases gradually and mine fires occur more and more frequently. In high gas area, once fire happens, regardless of an internal fire, an external fire or a secondary fire caused by gas explosion, the improper handling measures can result in gas explosion, which can bring the injuries and deaths of disaster relief personnel [1, 2]. When high-temperature and high-pressure smoke produced by gas explosion flows through the over-limit area of gas concentration, two scenarios may appear: one is that a secondary gas explosion or a fire is resulted in, thus directly threatening the workers' lives; the other is that a secondary gas explosion or a fire is not brought, but a large number of harmful gases (such as high concentration CO_2, high temperature water vapour, CO, H_2S) generated by gas explosion seriously threaten the workers' lives. The CO_2 with the concentration above 5 % or the CO with the concentration above 0.5% can result in workers to death; in addition, the high temperature water vapour can scald the internal organs.

Whether gas explosion can cause secondary disasters or not, the diffusion of harmful smoke is the main factor on threatening the lives of underground workers. A large number of gas explosion accidents show that the poisoning and suffocation caused by the harmful smoke are the main reasons for the casualties. In addition, the smoke produced by gas explosion can reduce the visibility and block the sight, thus affecting the safety evacuation of personnel and the success of disaster relief work. Generally speaking, the decision-making and operations for disaster relief always follow gas explosion accidents. Therefore, for high gas coal mines with fire zones, the measures, such as closing fire zones and injecting inert gases, are often taken in order to prevent the disaster expansion, which can bring the changes of ventilation pressure and gas concentration in closed fire zones. Meanwhile, two problems can be brought [3]: the one is whether closure measures will lead to a secondary gas explosion in closed fire zones or not, the second is what will be the rough time interval between taking measures and gas explosion. Consequently, oxygen concentration characteristics, gas accumulation characteristics and fire characteristics in closed zones are analysed in this paper. The study results can reduce many uncertain factors in disaster relief process to a minimum range and increase science and correctness of disaster relief decision.

2 Gas explosion characteristics in closure process of fire zone

Gas explosion occurrence must be provided with the following three conditions at the same time [4]: the gas concentration is within the explosion limits (i.e. 5-16%), the oxygen concentration of the mixed gas is not less than 12%, and the ignition source has sufficient energy.

In the closure process of fire zone, if the oxygen concentration is more than 10%, the heat released by the oxidization reaction of coal and oxygen can maintain the constant coal temperature. Thus, the coal temperature will not decrease significantly (namely, the coal

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temperature can be assumed to be constant). As long as the coal temperature does not drop below the minimum temperature of gas explosion, there are fire sources in combustion zones. In closure process of fire zones in the working face, the fire sources are the main factors on causing gas explosion. According to the practical experience in coal mines, after the fire zone is closed, the methods, such as gel injection to fire zones, can usually be taken to make the temperature drop below the lower limit of gas explosion temperature. If the cooling measures are not taken, the fire sources in fire zones exist for a long time. The main fire sources resulting in gas explosion in the gob are the spontaneous combustion of residual coal and rock friction (collision) sparks during roof caving. Therefore, the changes of oxygen concentration and gas concentration in the fire zone were mainly analysed.

In the closed zones, the gob and other fractures, because of oxygen consumption or lack of oxygen supply conditions, the oxygen concentration may be less than 12%. In other laneways and workplaces, the oxygen concentration is not less than 12%. In the fire closure process, because the oxygen is consumed by the reaction between coal and oxygen, the oxygen concentration decreases gradually in the closed fire zone [5]. When the oxygen concentration drops below 12%, the gas loses its explosive capability. In the fire closure process, if the gas concentration increases to 5-16%, the oxygen concentration is still more than 12%, and the temperature is still high, then gas explosion may happen [6]. In order to make calculation easy, the reaction between coal and oxidation is assumed to be the simple gas-solid reaction after fire closure. According to the principle of chemical reaction kinetics, the reaction rate is proportional to the oxygen concentration. Consequently, as long as several groups of oxygen concentration data are measured in different time, the curve equation of oxygen concentration varying with time in the actual conditions can be obtained by using relational expression of oxygen concentration varying with time, and then the oxygen concentration at any given moment can be obtained after fire closure.

In the fire closure process, gas emission is from working face (coal laneway wall) and fallen coal (residual coal) [7], the gas concentration increases rapidly and the local gas accumulation is formed around the gas emission place [8]. According to the gas sources and accumulation time, the gas accumulation during fire closure has four types: the gas accumulation due to normal emission from the gob and blind laneway, the gas accumulation due to geological condition change, such as the connection between fault and gob, the gas accumulation due to the roof caving in the gob, and the gas accumulation due to gas outburst. In fact, in the fire closure process, gas explosion in the gob is mainly affected by four factors [9]: the properties of the exothermic oxidation of coal, the thickness and fragment of residual coal in the gob, the air leakage in the gob after fire zone closure, and the original temperature of the surrounding rock in the gob. Due to the comprehensive effect of the above four factors, the spontaneous combustion process of residual coal in the gob shows dynamic change. Therefore, the occurrence of gas explosion in the closed fire zone mainly depends on oxygen concentration and gas concentration.

In the fire closure process, gas accumulation caused by the undesirable gas drainage results in gas explosion accidents mainly in the working face, secondly in the laneway. Therefore, reasonable gas drainage can effectively control gas explosion [10]. Gas explosion in working face is mostly because much gas emits into the working face for roof caving. Thus, the measures on controlling roof caving should be taken to prevent sudden gas emission and avoid gas explosion. In addition, strengthening the management and implementing operation instruction strictly can effectively reduce gas accumulation to avoid gas explosion accidents.

3 Gas accumulation model in fire closure zone

In the fire closure process, first, the auxiliary or temporarily closure is often built fast in the air inlet laneway and the air return laneway of zones, which will be closed. After the closure, zones are stability for a period of time, and then other disaster relief measures are taken. In the closure process, the closure measures can increase the local wind resistance of the air inlet laneway and air return laneway of closure zones, thus changing the atmospheric pressure distribution in the fire closure zones, which makes changes of the gas emission and migration rule in the fire closure zone.

According to facts, the spontaneous combustion in working face is most frequently, at the same time, the possibility that the gas concentration reaches the explosion limits due to gas accumulation is largest, thus the working face is analysed. Gas migration of a typical working face is described in Figure 1, if spontaneous combustion appears in the gob, the working face must be closed, there are three methods for the fire closure (or constructing temporary closure places): the temporary closure walls are only constructed in air inlet laneway, the temporary closure walls are only constructed in air return laneway, and the temporary closure walls are constructed in air inlet laneway and return laneway.

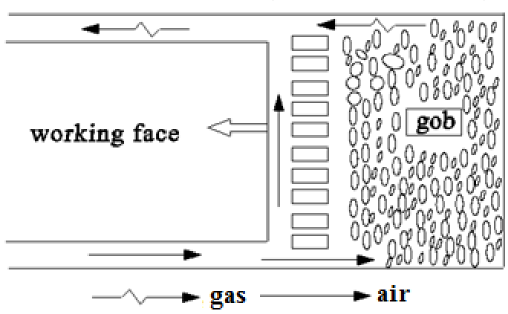

FIGURE 1 Gas migration of typical working face

3.1 GAS PRESSURE MODEL IN CLOSED ZONES

When the temporary closure walls are constructed in air inlet laneway and return laneway (or only in air inlet laneway, or only in air return laneway), at temporary closure places, the closure wall cuts off airflow in the closed zones, at the same time, it also changes and adjusts wind pressure distribution. The pressure changes at the temporary closure wall can result in the pressure change in the closed zone. The static air pressure increases in the air inlet side of temporary closure wall, while the static air pressure decreases in the air return side of temporary closure wall. The effect of the temporary closure wall on static air pressure in closed zone and laneway is determined by its gas tightness, which depends on the wall thickness, material properties and construction quality, etc.

Figure 2 describes the closure model of a working face with U type, M_1 and M_2 are the temporary closure walls in air inlet laneway and in air return laneway respectively, R_1 is the local wind resistance in M_1, Q_1 is the air leakage in M_1, P_{1n} and P_{1w} are the internal static air pressure and external static air pressure of M_1 respectively, R_2 is the local wind resistance in M_2, Q_2 is the air leakage in M_2, P_{2n} and P_{2w} are the internal static air pressure and external static air pressure of M_2 respectively, P_g is the static air pressure in the gob, Q_g is gas emission quantity from the gob to working face. As shown in Figure 2, when the temporary closure walls are constructed in the air inlet laneway and the air return laneway, with the increase of gas tightness of M_1 and M_2, the air leakage reduces, so P_g and Q_g increase. When the temporary closure wall is constructed only in the air inlet laneway, with the increase of gas tightness of M_1, the air leakage reduces, so Q_g increases, but P_g is constant. When the temporary closure wall is constructed only in the air return laneway, with the increase of gas tightness in M_2, the air leakage reduces, so P_g and Q_g increase.

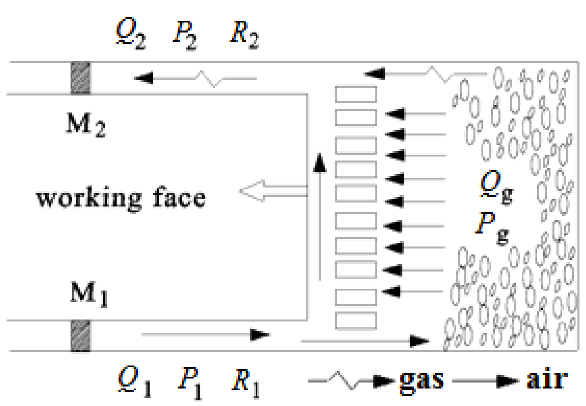

FIGURE 2 Closure model of U-type working face (The temporary closure walls constructed in air inlet laneway and return laneway)

3.2 CALCULATION MODEL OF GAS CONCENTRATION WITH TIME IN CLOSED ZONE

As shown in Figure 2, when the temporary closure walls are constructed in air inlet laneway and air return laneway, the assumptions are as follows. (1) When there is little or no wind in the working face, gas emission in air inlet laneway, air return laneway and working face are uniform [11]. (2) When the temporary closure walls are constructed in air inlet laneway and return laneway, the effect of ventilation pressure changes in working face on gas emission is negligible, namely, the gas emission is constant.

When the temporary closure walls are constructed in the air inlet laneway and air return laneway, the assumptions are as follows: the air leakage is Q (m^3/s), gas emission from coal laneway is b (m^3/s), the gas emission from working face is a (m^3/s), the laneway volume is V (m^3), the gas concentration at time t is x, the gas concentration at time t+dt is x+dx, the initial gas concentration in the laneway is x_0. Thus, when the time increment is dt, in the closed zone, the gas increment is (a+2b)dt (m^3/s), the gas reduction due to air leakage is $Qxdt$ (m^3/s), the change of gas concentration is Vdx (m^3/s).

Taking the closed zone as the research object, according to the law of conservation of mass, the change of gas concentration in closed zone is equal to the difference between gas increment and gas reduction due to air leakage, namely:

$$Vdx = (a+2b)dt - Qxdt \quad (1)$$

Then we can derive formula:

$$\frac{dx}{dt} + \frac{Q}{V}x = \frac{a+2b}{V} \quad (2)$$

Solving for equation (2), we obtain:

$$x = Ce^{-\frac{Q}{V}t} + \frac{(a+2b)}{Q} \quad (3)$$

Where C is a constant. Putting the boundary conditions (t=0 , x=x_0) into equation (3), we get $C = x_0 - \frac{a+2b}{Q}$

Putting C into equation (3), we get

$$x = \left(x_0 - \frac{a+2b}{Q}\right)e^{-\frac{Q}{V}t} + \frac{a+2b}{Q} \quad (4)$$

The formula (4) is the calculation model of gas concentration varying with time when the temporary closure walls are constructed in air inlet and air return laneway. Similarly, when the temporary closure wall is constructed only in the air inlet laneway or in the air return laneway, the law of gas concentration varying with time can be obtained.

4 Control measures and technologies of fire closure zone with explosion risk

Based on the theoretical analysis, if the fire zone has explosion risk and must be closed, explosion-proof treatment in fire zone is necessary before fire closure. When the closure sequential is chosen according to the actual situation and the underground fire characteristics, the change of wind pressure and the effect of each laneway closure on the wind road of fire zone should be considered carefully. When many laneways need to be closed, the laneway without great impact on the system should be firstly closed.

1) When the fire zone with explosion risk must be closed, the problem on explosion proof should be first considered. Generally speaking, the closure should be constructed in the air inlet laneway firstly, the explosion proof methods (such as setting sandbags) should be used to prevent explosion, and the ventilation window should be reserved to ensure certain air into fire zone. After the explosion proof work is over, the ventilation window should be block off. If there is no problem within 24 hours, the closure in the air return laneway can be constructed.

2) When the fire zone is closing, the specific persons should be arranged to closely monitor the change of air compositions in fire zone. The gas sample should be obtained in the top, the middle and the bottom of the laneway. The best way is to carry out beam tube monitor by installing beam tubes once, which can avoid entering fire zones repeatedly.

3) The change of atmospheric pressure should be monitored during the fire closure process, the time that atmospheric pressure rises is the best time to build a firewall, which can help to prevent gas in the fire zone from flowing outward and eliminate the threat to disaster relief personnel.

4) The working face with high gas generally has the gas drainage system. After the working face is forced to close due to fire, to prevent gas accumulation and gas explosion, the gas drainage should continue until there is no explosion risk in the closed zone.

5) When closure conditions in fire zone are good and it can ensure no air leakage, the method that the temporary closure walls are constructed in the air inlet laneway and air return laneway can be considered, which can shorten time as possible and quickly cut off oxygen supply conditions. The injection of the gelatine, CO_2, N_2 can further enhance the safety of fire zone closure. The gelatine injection can reduce the temperature in fire zone below the low limit of gas explosion temperature [12].

6) In the fire closure process, the temperature and CO concentration in fire zone are very high, so workers cannot work near the fire zone. If conditions are permitted, the nitrogen injection from the ground into the fire zone can be adopted to reduce oxygen concentration and coal temperature, thus ensuring the safety in working face.

5 Conclusions

1) When high-temperature and high-pressure smoke produced by gas explosion flows through the over-limit area of gas concentration, two scenarios may appear: one is that a secondary gas explosion or a fire is resulted in, thus directly threatening the workers' lives. The other is that a secondary gas explosion or a fire is not brought, but a large number of harmful gases (such as high concentration CO_2, high temperature water vapour, CO, H_2S) generated by gas explosion seriously threaten the workers' lives.

2) The gas explosion characteristics in closure process were obtained by analysing the time-space relationship of oxygen concentration, temperature, and gas concentration.

3) In the fire closure process, gas accumulation caused by the undesirable gas drainage results in gas explosion accidents mainly in the working face and laneway. Therefore, reasonable gas drainage can effectively control gas explosion. Gas explosion in working face is mostly because much gas emits into the working face for roof caving. Thus, the measures on controlling roof caving can be taken to prevent sudden gas emission and avoid gas explosion.

4) According to gas sources and accumulation time, strengthening the management and implementing operation instruction strictly can effectively reduce gas accumulation to avoid gas explosion.

5) When the temporary closure walls are constructed in the air inlet laneway and return laneway (or only in the air inlet laneway, or only in the air return laneway), at temporary closure places, the closure wall cuts off airflow in the closed zones, at the same time, it also changes and adjusts wind pressure distribution. The pressure changes at the temporary closure wall can result in the pressure changes in the closed zone. According to the law of conservation of mass, the law of gas concentration varying with time was obtained.

6) The measures and technologies such as laneway closure sequential, gas drainage in closed zones, measures of gel injection into the fire zone, and dilution of gas and oxygen by injecting inert gas (i.e. N_2) are introduced.

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