New integrated monitoring and control system for disaster gas application in coal mine

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Abstract. This paper introduces the composition, working principle and characteristics of the new gas monitoring system, which are used to monitor the gas in the gob area and working face of the mine in real time. According to the oxygen concentration, the spontaneous combustion of gob area “three zones” was determined and divided. In order to carry out disaster early warning, the methane and carbon monoxide super gas concentration changes were studied and analyzed. And the variation law of gas concentration in gob area and coal face in coal mining was obtained. This study provides reference for the follow-up fire prevention and production.

1. Introduction
Coal contains a variety of harmful gases. During the process of coal mining, the oxidation, spontaneous combustion of coal itself, and heat, combustion of a variety of materials will produce a variety of toxic and harmful gases. Therefore, the detection and analysis of coal mine gas is the basis of coal mine safety production, and is the fundamental basis for coal mine disaster prevention, management and disaster relief decision-making. And so, the coal-seam methane-induced gas monitoring, the development and use of the new disaster-proof gas comprehensive monitoring system are particularly important [1-4]. This paper will introduce the application of new disaster-prone gas integrated monitoring system in mine disaster prevention.

2. Presentation of new integrated monitoring and control system for disaster gas

2.1. Composition of new integrated monitoring and control system for disaster gas
Based on the existing KJ352 mine monitoring system, combined with JSG6-F beam tube sampling and analysis system, the new integrated monitoring system for disaster-causing gas is developed with the functions of tube sampling, infrared analysis of underground gas sample, seamless information transmission and equipment control with other monitoring systems. Its structure is shown in Figure 1.

2.2. Principle of new integrated monitoring and control system for disaster gas
When the system works, the pump is started, the tube forms a negative pressure which is less than the underground pressure outside the beam tube, then the gas undermine was sucked into the beam tube and the analysis unit, where it is analysed real-time; at the same time undermine staff can monitor the
gas concentration of sample points. The analysis unit transmits the results of the analysis to the ground via a communication line. Ground workers can simultaneously monitor the gas concentration of the measuring points in the ground monitoring room. The early warning software provided analysis to make early warning.

**Figure 1.** Schematic diagram of the new integrated monitoring and control system for disaster gas

**Figure 2.** Schematic diagram of measuring points

2.3. Features of new integrated monitoring and control system for disaster gas

Compared with other tube monitoring systems, the system uses infrared chromatography instead of gas chromatography. Infrared chromatograph can be used underground without explosion danger, as it does not need H2 as a carrier gas. The gas chromatograph is flawed because it needs carrier gas, long beam tube pipeline, and much maintaining work. During the period of gas transfer from the underground to the ground, pipeline leakage or pipeline clogging often occurs due to the great length of the pipeline and the existence of a middle connector. It will lead to erroneous analysis results if troubleshooting cannot be detected in time [5-9]. Monitoring system puts the analysis unit in the chamber underground close to the sampling point. The analysis unit directly analyzes the gas sample collected in the beam tube underground, and then transmits the analysis result to the ground center station by the electric signal, realizing the rapid prediction of the harmful gas disaster.

Sending and analyzing gas samples will take some time so that the monitoring results cannot be punctual. Therefore, during data analysis, the gas analysis time should be advanced depending on the specific conditions used in the system. According to the gas sample transmission time T and time required for each single sample analysis T1, the time forward (T + T1) is the exact time of the gas sample analysis.

The transmission time T can be calculated by the following formula,

\[ T = \sum L / v \]  

Where, \( L \) is the length of the tube and \( v \) is the average velocity of the fluid in the pipe, the average velocity can be calculated by the following formula.

\[ v = Q / A \]  

Where, Q is the gas flow rate and A is the pipe cross-sectional area.

When tube diameter is 8mm, flow rate is 0.6L / min, \( v \) can be calculated \( v = 1.99m / s \). When ordinary monitoring system analyzer is placed on the ground, the distance from the ground through the wellbore to the sub-station of the monitoring system generally is increased by at least about 3.5 km or more. The new integrated monitoring system is at least 6 minutes faster than the ordinary system. According to the above, the accurate time required to move forward is calculated as at least 35min for the general monitoring system. The present monitoring system can issue the disaster warning 35min earlier than ordinary monitoring system. This time is critical for security.
3. Measurement of gas concentration

We arranged two measuring points into air inlet and outlet ends in the +518B4-6 coal face. With the normal mining work, oxygen, carbon monoxide, methane and other gas concentrations of gob area are monitored continuously. The measuring point arrangement is shown in Figure 2.

1 pipeline laying: B6 roadway is located 0.5m away from the north wall, 0.3m away from the roadway floor; B4 roadway is located 0.5m away from the south wall, 0.5m away from the roadway floor; The beam tube laying length of the tunnel is 80m, it is protected D50 by steel pipe.

2 Gas collection: the system conducts a gas composition data analysis every 30 minutes, while recording the scale of the daily coalface and the distance of probe from the coalface.

3 monitoring cycle: With the normal mining work proceeding, the system stopped monitoring until the beam tube all go deep within the gob area.

4. Data analysis of new integrated monitoring and control system for disaster gas

4.1. Determination of spontaneous combustion “three zones” in gob area

According to the oxygen concentration, the area of coal oxidation and spontaneous combustion of gob area can be divided into three zones (Table 1). They are cooling zone, spontaneous combustion zone and suffocation zone.

Table 1. Oxygen concentration standard of the three zones [3]

|                        |        |
|------------------------|--------|
| Cooling zone           | >18%   |
| Spontaneous combustion zone | 10%~18% |
| Suffocation zone       | <10%   |

Figure 3 reflects the oxygen concentration changes in the coalface with the advance of B4 roadway embedded beam tube probe. The beam tube probe is 0~14.8m away from the coalface, the oxygen concentration remained above 18%. This is the cooling zone; the gob area oxygen concentration gradually decreases from 14.8m. Beam tube probe is 14.8~22.6m away from the face area, and the oxygen concentration is 10%~18%, thus the region is the spontaneous combustion zone; With the coalface continues to advance, the compaction of top-coal coal and air leakage disappears, the oxygen concentration quickly is reduced to 10% or less, which is the suffocation zone. Gob area belongs to the suffocation zone when the beam tube probe is more than 22.6m away from the coalface.

Figure 4 reflects the oxygen concentration changes in the coalface with the advance of the B6 roadway embedded beam tube probe. The beam tube probe is 0~11.2m away from the coalface, the oxygen concentration remains above 18%, and the gob air oxygen concentration is relatively high. This is the cooling zone; although the oxygen concentration at 11.2m suddenly rises to 20.84%. It is estimated to be due to air leakage caused by gob area. But the overall curve is still in a downward trend; the gob area oxygen concentration gradually decreases from 11.2m. Beam tube probe is...
11.2~16.6m away from the face, the oxygen concentration is 10% -18%, thus the region is spontaneous combustion zone. When the beam probe is more than 16.6m away from the coal face, the oxygen concentration drops rapidly. That is suffocation zone. Spontaneous combustion danger zone comprehensive division shows in Figure 5 and Table 2.

| measuring point | Cooling zone | Spontaneous combustion zone | Suffocation zone |
|-----------------|--------------|----------------------------|------------------|
| B4 roadway      | 0~14.8m      | 14.8~22.6m                 | >22.6m           |
| B6 roadway      | 0~11.2m      | 11.2m~16.6m                | >16.6m           |

Figure 5. Spontaneous Combustion Hazard Zone

In the spontaneous combustion zone, the temperature of the floating coal increases; however, if the coalface advances rapidly to the suffocation zone before the coal temperature rises to the critical temperature, spontaneous combustion will not occur, otherwise, the spontaneous combustion will occur. Accordingly, the minimum advancing speed of the coalface can be calculated by the following formula.

$$V_{\text{min}} = \frac{L}{T}$$  \hspace{1cm} (3)

Where, L is the length of the coal seam and T is the mining time.

The +518B4-6coal is a high volatile long flame coal; the fire period is generally 3 to 6 months, the shortest fire period is only 27 days.

- B4 roadway return air side: $V_{\text{min}} = 0.8m/d$
- B6 roadway inlet air side: $V_{\text{min}} = 0.6m/d$

Therefore, +518B4-6 coal face advances at a minimum speed of 0.8m/d, in fact, +518B4-6 coal face advances 2.4m/d. Comprehensive analysis shows that: spontaneous combustion will not occur.

4.2. Disaster prevention and control

Figure 6 reflects the curves of CH4 and CO concentration in B4 roadway. According to the curve, the CH4 concentration is kept below 0.04% within 15m range of the gob area. The concentration of CH4 increases gradually, and the CH4 concentration reaches 0.97% at 23.8 m in gob area, but it does not reach the explosion limit of 5% -16%, and 23.8m position has been in the suffocation zone, so CH4 in the gob area will not explode.

From the curve of CO concentration in Figure 6, it can be seen that the CO on the return air side cannot be detected, but it does not indicate that the coal in this area has not been oxidized. On the one hand, due to the high negative pressure on the return air side, the air leakage intensity of the gob area is large. On the other hand, the oxygen concentration monitored on the return air side shows that the products of coal oxidation are CO2. Based on the oxygen concentration monitored at the return air side, it is assumed that the product of coal oxidation is basically CO2, so the CO concentration on the return air side is substantially 0. Although the CO concentration rapidly increases to 73 PPM at 20.2 m position, it was due to a sudden spill of gas in the abandoned mine. Therefore, there was no evidence of ignition in roadway return air side.
Figure 7 reflects the curves of CH4 and CO concentration in B6 roadway. According to the curve, the CH4 concentration is kept 0 within the 13.6m range of the gob area. The concentration of CH4 increases gradually, and the CH4 concentration reaches 0.63% at 17.2m in gob area. Although this concentration is in the gob spontaneous combustion zone, it does not reach the explosion limit of 5% -16%, so CH4 in the gob area cannot explode. According to the trend of the curve, although CH4 concentration is in the ascending stage, but the oxygen concentration with the CH4 concentration gradually decreases, and it greatly reduces the possibility of CH4 explosion.

For CO, coal oxidation of the product is basically CO2, due to the fresh air, gob air leakage, higher O2 concentration, so the CO concentration is zero. With the coalface advancing, it gradually moves into the spontaneous combustion zone with the advance of the coalface. Gob air leakage is very small, and coal and O2 produces CO gas; and at the same time, due to top coal cave off strict and the accumulation of CO, the CO concentration reaches a maximum of 24ppm at 16.6m position. Then it moves into the suffocation zone, where due to O2 concentration decreasing, CO concentration decreases rapidly. Therefore, there was no possibility of ignition in roadway return air side.

5. Conclusion
1. The range of “three zones” in gob area was obtained by dividing the spontaneous combustion danger zones in the gob area by the concentration of O2. ① The range of cooling zone: it is less than 11.2m away from the coalface the in inlet air side and less than 14.8m away from the coalface in the return air side; ② The range of spontaneous combustion zone: it is within 11.2 ~ 16.6m away from the coal face in the air inlet side and it is within 14.8 ~ 22.6m away from the coal face in the return air side. ③ The range of suffocation zone: it is behind the edge of the spontaneous combustion zone in the air inlet-side wind and the return air side and direct to the gob area.

2. Although the CO concentration reaches 24ppm, 73ppm in the air inlet side and the return air side of gob area, respectively, as long as the daily advancing speed of coal face is greater than 0.8m, spontaneous oxidation zone will go to the suffocation zone, quickly. The gob area will not combust spontaneously.

3. The CH4 concentration in the air inlet side and the return air side of gob area is 0.63% and 0.97%, respectively, which does not reach the critical value of 5% ~ 16%. Therefore, the possibility of CH4 explosion in gob area was eliminated.

The new integrated monitoring and control system for disaster gas can detect the hidden danger of coal spontaneous combustion, and determine whether the hidden danger of spontaneous combustion occurs. In the process of fire control, it can provide a reliable basis for fire prevention and disaster prevention, ensuring the timeliness of fire prevention and control work. Aspects about correlation, maintenance and viability issues of the monitoring system will be studied in the future.
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