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Measuring Technology of Ventilation Leakage in the Goaf of False-inclined Flexible Shield Support Working face by Using Multi- element Tracer Gas

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Abstract. According to the characteristics of the high steep coal seam mining with false-inclined flexible shield support method such as high tunneling ration, multi air leakage channels and easy spontaneous combustion, the technology of multi-element tracer gas was proposed to measure ventilation leakage in the goaf. With its application in the No.13111 working face of a certain mine in the Huainan Mining Group, the realization methods were described in detail. This technology is advantageous to the improvement of scientific and accurate detection of the air leakage in the complicated goaf. It may be stated that the method can master the division of air leakage areas and provide the scientific references to the prevention and control of the coal spontaneous combustion in the goaf.

1. Introduction

The high steep coal seam reserves are abundant in China, which accounts for 4% of the country's proven reserves. There are more than 70 coal fields mining high steep coal seams [1]. It's an innovation that the false-inclined flexible shield support method is adopted to mine the high steep coal seam [2]. The flexible shield supports are used to isolate the goaf, and under the push of self-weight and upper caving rock pressure, supports are lowered down along the coal seam. The working face is false obliquely advanced along the direction. However, there are some drawbacks to the steep inclined seam mining, high tunneling ration, multi air leakage channels, slow working face speed, large amount of lost coal and so on. As a result, it's easier to spontaneous fire than gently inclined seam mining. Once spontaneous combustion occurs in the goaf, it's hard to isolate the fire source and eliminate the disaster. Accordingly, it's particularly important to study the prevention of the coal spontaneous combustion in the goaf to the false-inclined flexible shield support method [3].

Air leakage is one of the necessary conditions that cause spontaneous combustion of coal left in the goaf. Therefore, some important ways must be taken to prevent or control the spontaneous combustion of the coal lost in the goaf for the false-inclined flexible shield support method, including detecting the air leakage distribution in the goaf, eliminating or controlling air leakage from the flammable wind speed and so on[4]. In order to understand the distribution law of air leakage in the goaf accurately, the technology of multi-element tracer gas for air leakage distribution detection was firstly used in the 13111 working face of a certain mine in the Huainan Mining Group, which is a typical false-inclined flexible shield support working face. Through the experiment, the distribution law of air leakage in the goaf is known well. It provides a reliable basis for the prevention of spontaneous combustion of coal in the goaf.

2. Basic thought of tracer technology for air leakage detection

The goaf is not accessible, and the application of tracer to study the internal gas flow traces and their laws owns its unique advantages [5]. According to the different requirements for the air leakage detection, the method of tracer technology for air leakage can be divided into instantaneous release and continuous quantitative release. The instantaneous release method is simple and easy to implement. But it's difficult to master the time of sampling. If the highest concentration point is missed, the analysis will result in an error. The continuous quantitative release method can avoid it. Additionally, its sampling time is easy to master, measurement relative error is small, and the air leakage can be detected quantitatively.

When the continuous quantitative release is taken to measure air leakage, the quantitative tracer gas is released continuously and stably in the intake airway. Then the gas sample is collected at the sampling point set in the direction of the wind flow. If there is no leakage or outward air leakage along the way, the concentration of tracer in the wind flow remains unchanged. Otherwise, tracer gas concentration in the roadway shows a downward trend. According to the variation of the tracer gas concentration from the sampling points, the concentration distribution of tracer in space can be got. As a result, the law of air leakage will be found out [6].

3. Selection of tracer

Tracer technology is a special one for the use of tracers to study the flow traces and their laws of fluid (gas or liquid). And the selection of tracer is very important to the application of tracer technology. As identifying gas, the tracer gas is used to detect air leakage in a coal mine. The selected tracer gases should have the following requirements [7-9]:

(1) Nontoxic, non-corrosive, non-flammable, non-plosive, insoluble in water, and harmless to people.

(2) Chemically inert, resistant to degradation, no chemical reaction to matter.

(3) Low natural content in the mine and usually below $4.46*10^{-11}mol/m^3$, easily detected.

(4) Low cost and easy to get, high measurement accuracy (The sensitivity of chromatographic analysis can reach above $4.46 * 10^{-8}mol/m^3$), simple detection means.

(5) The density is close to the air. It can be quickly mixed with air and does not produce stratification with air.

(6) When multiple tracers are used, it is better to have a high response value to the same chromatographic column and the chromatographic detector.

The Varian CP3380 chromatograph was used for the test, which was equipped with electron capture detector and 5A molecular sieve chromatographic column. Considering all of above, three kinds of tracer gases with higher response value on the electron capture detector were selected, namely, SF6, R-600a, HCFC-22.

4. On-site application

The No.13111 working face of a certain mine in Huainan Mining Group was located in an area of steep coal seam, about 1500m along the strike and 40m along the dip. The coal seam in this section was about 303 ~ 305° along the strike with dip angle 25° and the thickness reached to 3.2m. The coal seam had spontaneous combustion danger, the shortest coal spontaneous combustion period of which was only about 15 days. The No.13111 working face was mined with false-inclined flexible metal shield support method. And the -250~-140m goaf was located below the No.13111 working face. There were three root board coal pillars in the goaf, where existed air leakage and material base of spontaneous combustion. During the machinery tunnel driving working at the No.13111 working face, gas samples were got from the upper and lower boreholes in it. The analysis showed the presence of CO with varying concentrations. The results showed that the residual coal oxidation exists in the lower goaf. To prevent spontaneous combustion and find out air leakage law in the goaf, the test of multi-element tracer gas to detect air leakage was performed on the No.13111 working face.

4.1. Tracer gas release system

4.1.1 System design The tracer gas releasing system was arranged in the lower airway (I.E. machinery tunnel) of the No.13111 working face as shown in figure 1.

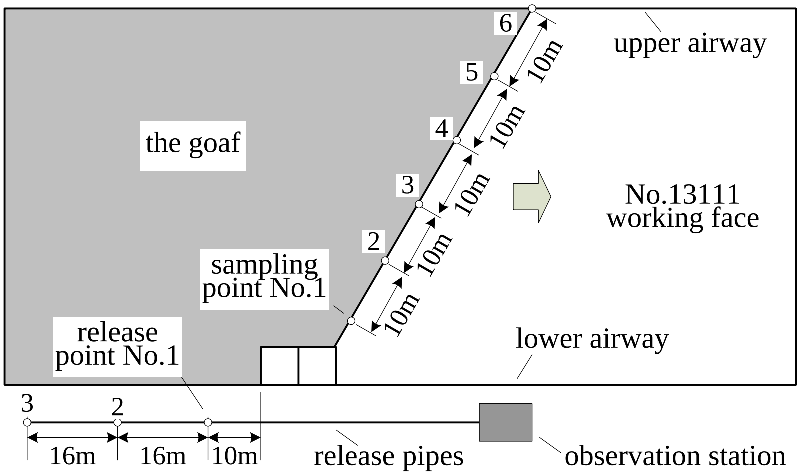

Figure 1. The layout of tracer gas releasing and sampling system.

The steel pipes, inserted by plastic pipes for releasing gas, were buried in the goaf of lower airway. Three release ports were designed on the pipeline. And the special branch pipe to be welded at the release port, connected to the main pipe through three connections. Outside of the branch pipe, a shield was put. There were 20 air permeability holes with a diameter of 10 mm evenly drilled on the shield.

4.1.2 Tracer gas release Tracer gas release was carried out when release port No.1 entered the goaf of 10 meters. The release parameters of the tracer gases were shown in table 1.

Table 1. The release parameters of the tracer gases.

release point	tracer gas	bleeding start time	bleeding end time
1#	SF6	9:54:45	9:58
2#	R600a	10:16	10:20:35
3#	HCFC-22	10:37:45	10:50

4.2. Tracer gas sampling system

4.2.1 System design 6 sampling points were laid at the inner frame top and upper corner of the No.13111 working face, 5 at working face and 1 in the upper airway, as shown in Figure 1. At each sampling point, the borehole with depth of 600 mm was drilled by the sleeve at the top of the working face towards the goaf. And on the upper side wall of the sleeve, 10 air vents 10 mm in diameter were drilled evenly. Then put in the homemade sampling tube, and joined up to a manual sampler through a plastic hose. And with the system, gas samples were extracted. To prevent the air from the face from leaking into the sampling tube, the 300 mm thick stemming was plugged between the outer of sleeve and the sampling tube.

4.2.2 Tracer gas sampling Before the tracer gas was released, the bulk gas samples were taken respectively from 6 sampling points. After the release, the gas samples were sampled at each test point every 15 minutes for 3 hours. The sampling location and time should be marked on the air sample bags.

4.3 Sampling analysis
In the lab, the Varian CP3380 chromatograph was used to analyze the gas samples taken from the No.13111 working face. And the results were shown in table 2.

Table 2. The sampling analysis results from the No.13111 working face.

sampling point	SF6 start time	R-600a start time	HCFC-22 start time
1#	10:05	10:35	——
2#	9:55	10:40	——
3#	9:55	11:40	——
4#	9:55	13:02	——
5#	10:30	10:40	10:40
6#	10:10	10:40	12:25

Based on the chromatographic analysis results in table 2 and the numerical simulation analysis of air leakage field in the goaf, the following conclusions were obtained.

(1) The tracer gas SF6, R-600a released by the release point No. 1 and 2, could be analyzed in the gas sample at the sampling points No.1-6. And SF6 appeared earlier at all sampling points. The HCFC-22 released by the release point No.3 could only be analyzed later in the gas sample at the sampling points No.5-6. It showed that the caving rocks in the goaf gradually turned from loose accumulation to compression and compaction. The porosity distribution of the caving rock was larger in the non-pressure zone. In the compression zone, the pores between the caving rocks gradually decreased, and the pores were extremely small in the compacted area. Moreover, the air-leaking drag was closely related to the porosity. Therefore, as the distance from the working face increased, the air-leaking drag increased gradually, and the air drag was almost constant after a certain distance from the working face.

(2) The tracer gases, SF6 and R-600a, appeared roughly at the same time at the 6 sampling points. It pointed out that in inclined direction, due to the large dip angle of coal seam and the effect of gravity, the rock or coal falling on the top of the goaf will sink to the bottom of the goaf, resulting in smaller porosity and larger wind resistance at the bottom of the goaf.

5. Conclusions

According to on-site application and laboratory analysis, it is feasible to detect the air leakage by using two or more tracer gases in the goaf of the false-inclined flexible metal shield support method. The applications are rare in China. It is of great significance to develop the technology of air leakage detection in coal mine.

(1) The chromatographic operating conditions of SF6, R-600a and HCFC-22 vary by the laboratory equipment. In the practical application, the appropriate chromatographic conditions should be found on the basis of conditions.

(2) The tracer gases have strong diffusivity, and it is necessary to prevent leakage when releasing and determining. Otherwise, it will pollute the air and affect the sampling analysis.

(3) When using the same sampler for continuous sampling, attention should be paid to rinsing the sampler with fresh air before the next sampling to remove the residual gas.

(4) When tracer gas is used for quantitative measurement of air leakage, there must be enough distance from the tracer gas release point to the sampling point to ensure that the tracer gas is completely mixed with the airflow, so as to ensure the accuracy of the measurement.

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