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Coal spontaneous combustion prediction in gob using chaos analysis on gas indicators from upper tunnel

Xincheng Hu [a, b, c], Shengqiang Yang [a, b, c, *], Xiuhong Zhou [a, b, c], Zhaoyang Yu [a, b, c], Chunya Hu [a, b, c]

[a] School of Safety Engineering, China University of Ming and Technology, Xuzhou 221008, China
[b] Key Laboratory of Gas and Fire Control for Coal Mines, Xuzhou 221008, China
[c] State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology, Xuzhou 221008, China

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A B S T R A C T

While gas sampling through upper tunnel is available right now, only little research has been reported for the prediction of coal spontaneous combustion in working face gob by analyzing drained gas in upper tunnel.

This study investigated the characteristic of air leakage of 401 working face gob in Tianchi mine under stereo gas extraction condition. The air that flows to the deep gob and is then drained to upper tunnel makes the prediction of coal spontaneous combustion in gob possible. Sample collector was employed to collect gas samples in the drainage pipeline plugged in upper tunnel and gas chromatograph was applied to analyze the indicator gases. A total of 195 gas samples were gathered including 44 groups that containing CO, O_2 and O_2/N_2 fluctuated in a small range and dropped dramatically when the oxidation of coal in gob was accelerated, while N_2 and the depletion ratio of O_2 obeyed the reverse rule.

R/S analysis (Rescaled Range Analysis) was used to investigate the fractal characteristic of different gas indicator time series. The Hurst indexes of different gas indicator time series follow the same rule that they would gradually become stable with the accumulating data and could deviate their chaos characteristic when CO was detected, which means the oxidation stage of coal in gob was accelerated. Changes of Hurst indexes and fractal dimensions controlled by effective delay time was researched. The fractal dimension (or Hurst index) of O_2, N_2, O_2/N_2 and depletion ratio of O_2 from upper tunnel can be equally applied to indicate the combustion condition of residual coal in gob.

Taken 70 days as the effective delay time, the risk of coal spontaneous combustion in 401 working face gob were divided into two stages: low-temperature oxidation stage (Hurst index >0.8776 or fractal dimension <1.2224) and dangerous stage of coal spontaneous combustion (Hurst index ≤ 0.8776 or fractal dimension ≥ 1.2224). The chaos characteristic analysis of gas index series in upper tunnel provides a novel and effective method to predict the risk of coal spontaneous combustion in working face gob.

1. Introduction

Coal spontaneous combustion has long been one of the most serious disasters in collieries, especially in underground working face gob, stockpiles and so on (Ham, 2005). Although there are many hypotheses on spontaneous combustion, the exact mechanism of self-ignition is still unknown by now. So far a foolproof solution has not yet to be achieved in any country. Consequently, the accurate prediction of coal spontaneous combustion is a key part of safety of underground coal mines, especially the gaseous mines. The spontaneous heating stages and natural oxidation tendency of coal can be deduced through analyzing the phenomenon during self-heating procedure, so necessary hints and warnings can be given ahead of time.

Researchers in Poland divided the gob area in coal mines into three zones (dissipation zone, oxidation zone and suffocation zone) by measuring the intensity of air leakage, distribution of oxygen concentration or temperature variation in working face gob (Jiang et al., 1998; Yang et al., 2000; Deng et al., 2013; Xie et al., 2012;

* Corresponding author. School of Safety Engineering, China University of Ming and Technology, Xuzhou 221008, China.
E-mail address: 839309275@qq.com (S. Yang).

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Pan et al., 2013). This method has been internationally widely applied in hazardous area classification of coal spontaneous combustion in gob. However, the classification criteria depends heavily on experiential results. Researchers still have different views on the critical values between these zones.

As it can manifest the oxidation stage of coal objectively and can be detected from air, rock and coal body directly, temperature is the elementary index indicating coal spontaneous combustion. So far, the main methods of temperature monitoring in coal mine fall into three classes-sensor temperature measuring, infrared temperature measuring and fiber temperature measuring (Liang and Wang, 2011; Wei et al., 2012). Whether combustion is happening or not could be confirmed by checking the temperature and its variation from sensors embedded in the dump or thermal signals monitored by calorimeters. Corresponding measures could be effectively taken in advance according to the prediction results of combustion stage and tendency. However, the temperature distribution is hard to monitor in field owing to the complex condition in gob.

The process of coal spontaneous combustion is comprised of slow oxidation stage, quick oxidation stage and severe oxidation stage according to former studies (Butakova et al., 2013; Chen et al., 2008; Wang et al., 2011; Qi et al., 2012). Different oxidation phases are characterized by corresponding combustion gaseous products and their concentrations, which can be employed to indicate the stage of combustion (Zhu et al., 2010). Being the most widely applied technique, gas analysis method can distinguish the occurrence and the level of combustion by analyzing gas composition and give further prediction of the combustion trend. The formulation and variation law of gas products during self-heating has been investigated and gas analysis index systems have been established in many countries, such as Poland, Japan, China, American, India and Russia (Ham, 2005; Cliff, 2005; Liang and Wang, 2011; Wang, 2008). Single gas indexes e.g. carbon monoxide, carbon dioxide, oxygen consumption, have been widely used to estimate the development stage and predict the development of coal spontaneous combustion. Particularly, alkanes have long been employed to present different oxidation stages e.g. C_2H_4 and C_2H_2 are associated with quick oxidation stage and severe oxidation stage. Despite the simplicity and convenience, single gas method could be easily influenced by added fresh air flow. In order to overcome their drawbacks, other composite indexes were invented subsequently.

Oxygen consumption was initially employed to indicate coal spontaneous combustion by Polish scholars and it was then successfully applied on field in Poland (Wang, 2008).

Graham, a British scholar, proposed composite indexes comprising R_1, R_2 and R_3, by introducing oxygen consumption index (Singh et al., 2002). These three indexes indicate the increase of CO_2 to the consumption of O_2 ratio, the increase of CO to the consumption of O_2 ratio and the increase of CO to the increase of CO_2 ratio, respectively. Although these indexes have been playing positive role in combustion prediction, it could be easily affected by gases such as CO and CO_2 emanating from adjacent gobs or air entering fire zones. Another compound index, representing the ratio between carbon and effective hydrogen of coal oxidation products, called C/H was proposed by Ghosh and Banerjee in India (Wang et al., 2003; Zhu et al., 2012). Owing to the disturbance of methane released from coal, this index is only effectively applied in low gaseous mines (Singh et al., 2007).

Special research of hydrocarbon gases generated during the process of coal spontaneous combustion was closely conducted by Ann G. Kim. He found that the variance and concentration of component are inextricably interwoven with the temperature of coal and proposed hydrocarbon index (Kim, 2004). But this indicator can easily be affected by gases emitting from other regions as well, especially when the total concentration of hydrocarbon gases is relatively light.

As a rule, methane content increases with the deepening of the mining depth, with increasing demand of methane control. More special tunnels emerge with the view to administer coal bed methane (Zhou et al., 2012). Consequently, new characteristic of mining roadway layout arises resulting in more complex air leakage in tunnels underground and thus leading to increased risk of coal spontaneous combustion. Admittedly, traditional gas analysis method do have been widely used and have been playing a positive role in combustion prediction in coal mines. Nonetheless, misinformation and delayed alarms often occur in monitoring the constituent of gas indicators because they can frequently be interfered by complex environment underground. Better contactless technique is therefore increasingly urgent to coal auto-ignition prediction. Fortunately, the new feature brings the hope of new innovative measures to predict coal spontaneous combustion underground.

In recent study, working face 401 in Tianchi coal mine, Heshun County, Shanxi Province, China, was taken as a subject to investigate the new method to predict the coal combustion in gob. As a four-tunneled working face, the air leakage law in 401 working face gob was analyzed. Gas samples in upper tunnel were gathered using gas sample collector and detected by gas chromatography. The chaos characteristic of different indicator index series were analyzed employing R/S analysis (Rescaled Range Analysis) before and after coal spontaneous combustion was observed in 401 working face gob. The primary objectives of this study were to study the chaos characteristics of different gas indexes along with self-oxidation and give further prediction of coal combustion in gob. In the end, The risk of coal spontaneous combustion in 401 working face gob was divided and the corresponding critical values of Hurst index and fractal dimension were confirmed.

2. Gob settings

As shown in Fig. 1, Tianchi coal mine whose main coal seam being mined is Coal Fifteenth, lies in Heshun County, Shanxi Province. The content of coal bed methane of 401 working face approximately amounted to 18.22 m^3/t within a 50 m range near open-off cut. From the point of coal bed methane content, the seam had the danger of coal and gas outburst. Therefore, special technical steps should be taken to handle this.

With the purpose of methane control, some tunnels characterized of one face with four tunnels in 401 working face were specially arranged. As can be seen in Fig. 1, unlike other two-tunnel layout in coal seams, upper tunnel was laid about 25 m above the coal roof in the “fracture zone” to where the methane of coal from gob and adjacent layers would be released. Intake and return tunnel constituted the ventilation system among which the former tunnel was used to provide fresh air while the later was employed to return the polluted air from working face. Besides, tail tunnel and upper tunnel were set specially to discharge methane releasing from the gob and adjacent layers. Specifically, tail tunnel was utilized to discharge the methane exclusively from the gob near the vicinity of working face while the upper tunnel was sealed to drainage methane emitting from the deep gob of working face and adjacent layers.

In the production preparation period, 525 drainage holes were drilled in intake tunnel and return tunnel. After this work, the holes were sealed and connected to high negative pressure drainage system in order to reduce gas content. As air leakage of suction holes, the coal had long oxidation time before exploitation, which may lead to high oxidation degree.