International Journal of Mining Science and Technology 23 (2013) 489–493

Contents lists available at SciVerse ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

New technological partition for "three zones" spontaneous coal combustion in goaf

Pan Rongkun [a,b], Cheng Yuanping [b,*], Yu Minggao [a], Lu Chang [a], Yang Ke [c]

[a] Department of Safety & Science Engineering, Henan Polytechnic University, Jiaozuo 454000, China
[b] National Engineering Research Center of Coal Gas Control, Faculty of Safety Engineering, China University of Mining & Technology, Xuzhou, Jiangsu 221116, China
[c] College of Resource and Environmental Science, Chongqing University, Chongqing 400015, China

ARTICLE INFO

Article history:
Received 22 October 2012
Received in revised form 2 December 2012
Accepted 1 January 2013
Available online 24 July 2013

Keywords:
Goaf
Spontaneous combustion
Three zones
Target

ABSTRACT

On detailed analysis basis of spontaneous coal combustion for the three zones in mine goaf, we use O_2 and CO concentrations to divide the three zones of the coal combustion. Through our experiment, we selected a typical working face and focused on the changes in gas concentrations. In order to overcome establishment limitations of actual layout location and underground conditions in a mine goaf, we based our observations on the three zones, combined them with numerical simulation, described the distribution and the changes in O_2 and CO concentrations during the coal spontaneous combustion in the goaf, which provided us with an understanding of the distribution of coal spontaneous combustion in the three zones in the form of maps. Essentially, our study summarizes the changes of O_2 and CO concentrations in the entire goaf and shows them to be in agreement with our observations at the scene. The study shows that it is feasible to divide the three zones, given our comprehensive targets of O_2, CO and our numerical simulation. This method avoids the limitation of dividing the three zones with a single target and the likely errors of observations at the scene. In addition, the method offers a basis for optimizing measures of fire-fighting with important and practical effects.

1. Introduction

When coal is broken after it has been mined, it is oxidized and heated up to levels of spontaneous combustion if brought into contact with air under certain conditions. China is a country seriously affected by spontaneous combustion of coal. In 2002, Wang and Li reported that mines with spontaneous combustion accounted for 51% of all major coal mine accidents, and more than 90% of all fires in coal mines are caused by spontaneous combustion, of which 60% occurred in mined-out areas [1,2]. Due to their origin, the frequently occurring spontaneous fires in mined-out areas develop at a low speed in their initial spontaneous combustion, but by the time they are discovered, the combustion has already reached dangerous levels. Such conditions require greater perception, prediction and prevention.

In advancing working faces, the goaf can be divided into "three zones" including cooling, oxidation and a suffocation zone, which appear as dynamic distribution areas with different degree of coal oxidation and scope [3]. These three zones change dynamically with the advancing working face. The way to determine the distribution of oxygen in the "three zones" plays a key role in controlling spontaneous combustion in mined-out areas. In particular, these three zones play an essential role in injecting nitrogen for fire extinguishing, and directly determine the release position, flow, strength and other parameters during nitrogen injection. Therefore, studying the distribution of "three zones" during spontaneous combustion in the mined-out area working face should aid in determining the location of the "three zones", predict the scope of spontaneous combustion and provide a premise for mines to control and extinguish fires [4].

2. "Three zones" dividing method

At present, there are three ways to divide the "three zones" [5–8].

2.1. According to the speed of the leaking wind

The goaf can be classified as the cooling zone area where the wind speed is greater than 0.24 m/min, the oxidation zone area where the wind speed is between 0.24 and 0.1 m/min, or the suffocation zone area where the wind speed is less than 0.1 m/min.

* Corresponding author. Tel.: +86 516 83885948; fax: 86 516 83995097.
E-mail addresses: prk2008@126.com (R. Pan), yiliprk@126.com (Y. Cheng).

2095-2686/$ - see front matter © 2013 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2013.07.005

2.2. By O_2 concentration

We can classify the goaf area where the O_2 concentration is greater than 18% as cooling zone, the goaf area with O_2 concentration between 7% and 18% as the oxidation zone and the goaf area with O_2 concentration less than 7% as the suffocation zone.

2.3. Heating rate

Several domestic and foreign researchers have suggested that we can use the heating rate index as the standard to divide the "three zones" in the goaf. They suggest that when the heating rate (K) of the goaf, is bigger than 1 °C/day, the area is an oxidation zone. Actually, the indicators for wind speed leakage and O_2 concentration are the same. Both of them are based on the situation of the leaking wind flow to divide the "three zones", nevertheless it is very difficult to measure the leakage of wind speed in a goaf. According to the speed of the leaking wind, the standard to divide the "three zones" is usually used theoretically and in numerical simulation. It is relatively easy to measure O_2 concentration in the mined-out areas, but impossible to arrange measuring points everywhere in the goaf. Therefore, we cannot determine whether the coal is oxidized on the absolute value of O_2 concentrations only, and considerable errors occur in classifying the oxidation and cooling zones. Hence, temperature is used as the indicator to divide the "three zones". For $K \geqslant 1$ °C/day is too large and is not in all mined-out areas, and the range of daily heating rates will rise the temperature to a value in order to burn spontaneously. The suffocation zone can be determined basing on oxygen consumption during coal oxidation, and also on the inert gas emission. In each case, the temperature may not show a clear increase. On the other hand, if the temperature in the goaf does not increase, then we can conclude that the "three zones" do exist.

Therefore, the accuracy of these three methods to divide the "three zones" in a goaf is rather limited. All the three methods are derived from direct field measurements, and the test results are easily affected by geological conditions, placement of the measurement tubes, sample acquisition and other factors. Hence, there are always large errors in dividing of "three zones".

In order to find a more suitable method to divide the "three zones", we consider the oxidation process of coal by oxygen. The nature of spontaneous combustion is a very complex interaction between coal and oxygen [9]. Under favorable conditions, oxygen oxidizes coal producing CO. If coal and the oxygen are in contact, oxygen will always be consumed and generate CO and other gas simultaneously, i.e. [10]:

Coal + oxygen → CO + other gas + ash

When coal and oxygen are in contact, concentration of O_2 will decrease while that of CO will increase, providing a certain interrelation between them. Therefore, based on our observations of the "three zones" in a number of mine, we have selected a typical working face and have proposed an integrated indicator for O_2 and CO concentrations to analyze their flow field in mined-out areas by using numerical simulation. If these two indicators, which can be used to study the state of the three zones in mined-out areas, are applied comprehensively, they will be able to provide a good guide to in situ divisions of the three zones.

3. Field observations and numerical simulate

On the basis of O_2 and CO concentrations, we opted for the #12,051 working face of the number 13 mine of the Pingdingshan Coal Mine as our study target in order to analyze the advantages of dividing the three zones. The face from east to west is 1386 m and the length of the slope is 128 m. The average inclination of the seam is 28°. The coal seam is 5.8 m thick, the mining height is 2.8 m, the recovery rate is 95% and the bulk density is 1.43 t/m^3. The mining face uses a U-type ventilation system, with an air volume of 1490 m^3/min. The direct top of the coal seam is a sandy mudstone, of which a portion is inter-bedded by an unstable 0.4–2.25 m thick mudstone layer. The roof consists of fine inter bedded sandstone with an average thickness of 11.8 m. The direct floor consists of sandstone and a 0.25 m thick sandy mudstone. There are 15 m wind curtains hanging in the corner below and above the mining face. During the process of exploitation, the goaf showed abnormal phenomena with the risks of spontaneous combustion.

3.1. Field observations

In order to investigate the dynamic changes of spontaneous coal combustion in the "three zones" of the goaf, we embedded a beam pipe in the airway which was externally protected by an iron pipe. We covered the external front-end sampling head with iron pipes and opened several holes in the iron pipe. The iron pipe of the sampling head was wrapped up by the copper mesh preventing coal pieces from entering the pipe, and arranged it along the goaf with a 90° elbow and a flange. After opening the gas pump, we entered the mine every day to collect gas samples. In order to improve the precision of our sampling, we pre-pumped for 20 min before sampling to exclude the air in the beam pipe. The gas samples were sent above ground for analysis by gas chromatography and the O_2 and CO concentrations were determined along the strike in the mined-out area. The results of our observations are shown in Figs. 1 and 2.

The figure shows that with the advancing working face, the oxygen concentration is decreasing at the measuring points, with the speed in the return lane decreasing faster than that in the inlet lane. If we divide the three zones purely on the basis of the oxygen indicator, then we can conclude that the oxidation zone in the inlet lane is greater than that in the return lane.

With the advancement of the working face, the goaf of the roof gradually begin to collapse, so that the goaf begin forming a loose which is relatively-tight and tight within some scope. At the same time, ventilation leakage from an easy to a difficult process along with the concentration of oxygen decrease. To a certain extent, the wind leakage carries enough oxygen to ensure continued oxidation of the floating coal. It can also reduce some of the heat generated by oxidation. When the crushed coal and oxygen are in contact, oxygen is consumed; its concentration decreases along the direction of the wind flow, while the CO concentration increases. Xu and Wei and Wang showed that the rate of CO production from oxidation of coal is related to the oxygen consumption rate as follows [11,12]:

$$V_{\rm CO}(T) = \frac{C_{O_2}}{C^0_{O_2}} \times V^0_{\rm CO}(T) \quad (1)$$

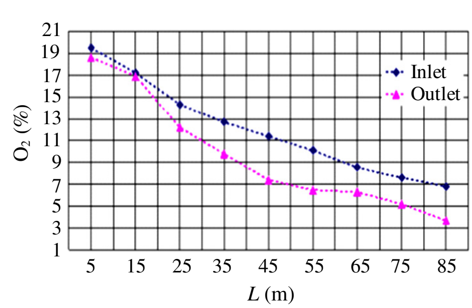

Fig. 1. O_2 concentrations as a function of length of the goaf.