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Changes on the low-temperature oxidation characteristics of coal after CO_2 adsorption: A case study

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ABSTRACT

Coal spontaneous combustion is a natural hazard during mining. In China, the longwall gob area is the main places that are prone to coal spontaneous combustion due to excessive residual coal in the gob and severe air leakage during underground mine ventilation. Injecting CO_2 into gob has many advantages to prevent fire disaster. However the characteristics of coal low-temperature oxidation after CO_2 injection were rarely studied. In this paper, a temperature programmed test system was adopted to simulate coal spontaneous combustion at low-temperature stage before and after CO_2 adsorption. Compositions and concentrations of gases produced by coal samples from Yiyuan mine in China at different temperatures were analyzed. It is found that with the increase of the temperature, the gas concentration of CO_2 generated from coal before CO_2 absorption, expressed the trend of exponential growth. While the CO_2 concentration after CO_2 absorption, showed the distribution of “V” type on the whole, that is, the CO_2 concentration firstly dropped to the minimum value and then rose up gradually. Before reaching to the temperature corresponding to the minimum concentration of CO_2, the CO_2 concentration was significantly higher comparing with that before CO_2 absorption. While over that temperature, with the temperature increasing, the CO_2 concentration was obviously lower than that before CO_2 absorption. During the heating oxidation of coal, the gas concentrations of CO and C_2H_4 showed the increasing tendency with the temperature increasing. However, the initial temperature of CO and C_2H_4 detected firstly during the coal oxidation process after CO_2 absorption was obviously lower than that before CO_2 absorption, what's more, the concentrations of CO and C_2H_4 were also obviously lower than that before CO_2 absorption at the same temperature, showing an obvious “hysteresis” phenomenon of inhibiting coal oxidation. The experimental results provided the basis of a method to control the spontaneous combustion of residual coal by injecting CO_2 into the gob. The field test showed that the index gas concentration of CO was reduced sharply and coal spontaneous combustion in the gob was controlled effectively.

1. Introduction

Coal fires induced by spontaneous combustion have been reported in many countries (Michalski, 2004; Zhou et al., 2006; Pone et al., 2007; Kuenzer and Stracher, 2012). Coal spontaneous combustion is a hazard during mining which not only affects mine production, resulting in significantly economic and resource losses, but also may lead to gas explosion and even heavy casualties (Lu and Qin, 2005). The longwall gob is one of the main places that are prone to coal spontaneous combustion (Taraba and Michalec, 2011). For a coal seam that is being mined, residual coal in the gob area undergoes low-temperature oxidation on exposure to leakage air in the mine ventilation system which may eventually results in the ignition of the residual coal. Therefore, the prevention

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of spontaneous combustion of residual coal in longwall gob has always been important during mining.

Water and grout injection is a conventional technique that has been used to preventing the coal spontaneous combustion (Dalverny and Chaiken, 1991). However, due to the character of water flow, it can not pile up to reach the upper zone of gob and the overlying heated rock. Dense water fog has been used to control the open fires in mine entries on the ventilation system (McPherson, 1993). But its operation process is a little complex when it is used in underground. A series of new flame retardant materials such as Thermocell (Colaizzi, 2004), three-phase foam (Qin et al., 2014; Shao et al., 2015), gel-foam (Zhang, 2014), suspension-sand (Xu et al., 2014) and poly (ethylene glycol) (Dou et al., 2014) were also used to prevent the coal spontaneous combustion in the gob. However, these materials have some problems of their high cost and small diffusion range. Liquid nitrogen perfusion was also used as an immediate method to control the fire zone of coal mine (Zhou et al., 2015). But the storage and gasification equipment of liquid nitrogen are complex and costly. In China, injecting N_2 to longwall gob areas is often used to prevent the spontaneous combustion of residual coal in gob (Mohalik et al., 2005; Ray and Singh, 2007; Chundong et al., 2011). In terms of that the mass of N_2 is lighter than air, it is conductive for the control of coal spontaneous combustion at the middle and upper of the gob area, while is bad for that at the bottom of the gob area. Additionally, supposing that pouring CO_2 whose density is bigger than air into the gob, the residual coal at the bottom of the gob that is easy to spontaneous combustion will be buried completely, which will be better to prevent its oxidation.

The coal spontaneous combustion caused by low temperature oxidation is a key safety issue in the mining of coal (Slovák and Taraba, 2010; Li et al., 2014; Song and Kuenzer, 2014). Many scholars have carried researches on low-temperature oxidation of coal. Arisoy and Akgün (1994) studied the effect of various factors such as the oxygen, water vapor, and inherent moisture in coal on the process of spontaneous heating. Küçük et al., (2003) studied the spontaneous combustion of coal of different particle size, moisture content, and propensity. Beamish and Arisoy (2008) investigated the effects of mineral substance content on the spontaneous combustion of coal. Cole et al. (1987) discussed the detailed reaction mechanism of the influences of pyrite on the coal spontaneous combustion. Liu and Zhou (2010) analyzed and classified the influence factors of spontaneous combustion. Furthermore, a number of studies have focused on the study of the production of CO_2 and CO during the low-temperature oxidation of coal (Baris et al., 2012; Wang et al., 2002; Yuan and Smith, 2011; Yuan and Smith, 2012; Zhang et al., 2013). Mao et al. (2013) carried out the spontaneous combustion experiment of large scale coal sample of 1500 kg. Wang et al. (2014) used in-situ FT-IR to analyze the distribution and concentrations of function group on coal surface during the oxidation process when using the chemical inhibitors. However, all of above study mainly concentrated on studying the influence on the low-temperature oxidation of coal with various parameters in the condition of the oxygen supply. After CO_2 injection in the gob area, CO_2 dropped rapidly into the bottom of the gob area, where the residual coal will fully absorb CO_2. However, there is a lack of reports for the study relevant to the characteristics of the low-temperature oxidation after CO_2 adsorption.

In this paper, laboratory studies have been carried out to investigate the changes of low-temperature oxidation characteristics of coal before and after CO_2 adsorption. In addition, an in-situ control of residual coal spontaneous combustion was conducted by injecting CO_2 into gob.

2. Description of Yiyuan coal mine

Yiyuan mine is a typical coal mine classified as “high-methane” in China, and located in Shanxi Province (Fig. 1). It covers an area of 5.69 km^2, and produces by itself 0.90 million tons of coal annually. Working face 150109 is the current mining working face, which belong to No. 15 coal seam of Yiyuan mine. It is adjacent to 150107 and 150111 working face, where the mechanized longwall mining method is used. The working face spans 1100 m and 180 m in strike length and dip length respectively, and the coal seam is approximately 5 m thick on average. The residual coal in the gob is about 1 m in height after mining. Fig. 2 shows the layout of the roadways of working face 150109. The ventilation method of “U” type is applied to the working face, whose air content is 1800 m^3/min. In addition, coal seam is easy to spontaneous combustion whose spontaneous combustion periodicity is about 57 d, and it ever occurred that spontaneous combustion continued for 30 d.

CO concentration can be detected for a prolonged period around the return airflow roadway of working face 150109 during the mining process, indicating that the serious air leakage into the gob area resulting in the low-temperature oxidation of the residual coal in gob. Once the residual coal happen to the rapid oxidation, it is very likely to lead to gas explosion, inducing heavy safety hazard. Given above, the oxidation process of residual coal in the gob area need to be inhibited to guarantee the safety.

3. Experimental

3.1. Experimental apparatus

An experimental apparatus was built to investigate the coal spontaneous combustion before and after CO_2 injection, as is shown in Fig. 3. The experimental apparatus consists of temperature-programmed oven, adiabatic tank, gas preheating pipeline, temperature measurement system, air supply system, and chromatographic analyzer.

Temperature-programmed oven can set up relevant parameters related to the range and the rise rate of the temperature, and keep the temperature constant. It is applied to control the temperature of the coal samples in the adiabatic tank, whose temperature ranges from room temperature to 380 °C with the precision of 0.1 °C in the control. The box of temperature-programmed oven consists of stainless steel liner and asbestos insulation layer, equipped with a heater to heat the box. Moreover, the fan is used to strengthen gas convection in the box, so as to ensure the uniform temperature of gas in the box. Additionally, adiabatic tank, a coal sample jar that is homemade of the copper, is respectively connected with the air supply path, temperature measurement system and the air outlet path.

At the bottom and the top of adiabatic tank is provided with asbestos, at the aim of preventing the pipeline from being plugged and ensuring airflow through the coal sample steadily. Besides, the temperature sensor is equipped with in the adiabatic tank to measure the temperature of coal sample. In order to avoid the case occurring when gas entering the adiabatic tank, where the heat released during the low-temperature oxidation of coal is absorbed by the supply gas without being preheated, there is a 60 m-long copper trachea connected between the air inlet and the air supply pipeline with the function of a gas preheating pipe. Moreover, temperature measurement system ranges from −50 °C to 300 °C, with an accuracy of 0.1 °C.

The air supply system mainly consists of O_2 cylinder (the percentage of O_2 mixed with N_2 is 12% or 19%), CO_2 cylinder (the

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