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Sources of underground CO: Crushing and ambient temperature oxidation of coal

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ABSTRACT

As a harmful gas in underground coal mine, CO seriously threatened the safety of miners. Currently, the spontaneous combustion of residual coal in goaf is generally considered as the main source of underground CO. CO gas is also widely used as an indicator gas in fire prediction in mines. However, high concentrations of CO are also detected in some mines without spontaneous combustion of coal. Therefore, in the paper, with four ranks of coal, we studied other two potential CO sources: crushing and oxidation at ambient temperature. The more completely crushed coal produces more CO. The concentration of generated CO is inversely proportional to moisture content in coal. Therefore, the addition of water can inhibit the generation process of CO during the crushing process of coal. Lignite with low metamorphic grade can be oxidized to produce CO at ambient temperature (25 °C), and anthracite with high coal rank can be only oxidized to produce CO at 60 °C. Infrared spectra indicated that the coal with rich aliphatic hydrocarbons and oxygen-containing functional groups are more susceptible to oxidation at room temperature. Moreover, the smaller particle size of coal is more beneficial to the oxidation at ambient temperature to generate CO. CO generation during coal oxidation is also closely related to the ventilation rate.

1. Introduction

CO is a colorless, odorless, and poisonous gas which greatly threatens human life and health (Jiang et al., 2011, 2013). It is also one of the gases strictly monitored in coal mines (Fierro et al., 1999; Hower et al., 2013; Rosema et al., 2001). In January 2013, 13 people lost their lives by a CO poisoning accident occurred in Yongsheng colliery, Heilongjiang province, China. Because the spontaneous combustion of coal produces a large quantity of CO, CO is also one of the main indicators for the prediction of spontaneous combustion disasters (Wang et al., 2013).

The spontaneous combustion of coal is complex, particularly the oxidation process that occurs at low temperature. It is well known that coal spontaneous combustion is mainly influenced by factors as external conditions and inherent characteristics of coal. Researchers pay attention on related aspects such as coal rank, moisture, particle size, mineral composition, functional groups and heat evolution. Diverse kinetic models were developed for explaining the rate of O_2 consumption and gaseous emission in spontaneous combustion of coal (Wang et al., 2003). According to the pore model resembling tree structures, Wang et al. (1999) discovered that O_2 diffusion in a coal particle is closely related with porosity and particle size. In addition, reaction regime for coal with different particle size includes continuum diffusion, Knudsen diffusion and kinetically controlled. Mao et al. (2013) investigated the temperature variation of 1.5 t coal samples which stored in the furnace with air supply. Through 39 d test, they claimed that 60 °C is a critical temperature for coal self-heating. A survey carried out by Wang et al. (2012) indicates that low rank coal contains numerous hydroxyl radicals and hydroxyl and carbonyl play significant roles in generating CO, by detecting variation in the IR of coals with different coal ranks during low-temperature oxidation. It was reported that with an initial temperature of higher than 70 °C, the generated amount of CO increased remarkably with an increase in temperature and ventilation rate whilst the ratio of CO/CO_2 remained almost constant without considering a thermal runaway (Yuan and Smith, 2011, 2012).

However, in some Chinese mines, such as the mines of Shengdong, Yuanwanli, and Yuanjinfeng, the concentration of CO in 60% of upper corner of return airway on fully mechanized working face reaches 24–120 ppm. The advance rate at the working faces of

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Nomenclature

Mad	moisture content (%)
Ad	ash content (%)
Vdaf	volatile content (%)
FC.d	fixed carbon content (%)

these mines is 10–20 m/d. Under the conditions of rapid recovery, the probability of spontaneous combustion in goaf is small (Yang et al., 2014), but the high concentration of CO is still attributed to the early spontaneous combustion of coal products. Therefore, a lot of spontaneous combustion control measures are adopted (Qin et al., 2013). However, spontaneous combustion does not occur in the goaf, resulting in a lot of waste. Clearly, even plenty of reaction mechanism of coal oxidation were discussed, spontaneous combustion causes are not completely understood (Dou et al., 2014; Oren and Sensogut, 2010). In the United States, some scholars attributed the causes of CO in underground mines to the underground DPM Dispersion (Yi et al., 2011). In 1994, Czechoslovakian scholar B·Taraba (Taraba and Pavelek, 2014; Taraba, 1994) thought that coal crushing would generate CO, but he made no further research. In the paper, we studied the two sources of CO: mechanical crushing and oxidation at ambient temperature and the source of CO and carried out qualitative and quantitative analysis of the concentration of CO in mines to provide the basis for the prevention and control of CO.

2. Experimental

2.1. Crushing experiments

In crushing experiment, a small ball mill was used. Firstly, 350 g of coal sample with the particle size of 1–3 cm was loaded in the sample tank. Then coal samples were respectively ground for 20–100 min. At different time, gas samples were acquired from the sample tank with a syringe and then analyzed with a gas chromatograph to detect the concentration of CO. The sample tank height is 15 cm and its diameter is 9.5 cm. In the experiment, four kinds of coal samples were adopted. The industrial analysis parameters of coal samples are shown in Table 1. The ball mill used in the experiment is shown in Fig. 1.

2.2. Low-temperature oxidation

Instruments used in the experiments include FULI9790 gas chromatograph and 2000-type coal spontaneous combustion characteristics tester, as shown in Fig. 2.

The experiment system of coal spontaneous combustion characteristics tester is mainly composed of programmed temperature furnace, coal sample tank, temperature measurement devices, temperature measurement and control system, gas flow control system, dehumidification and cooling devices, and computer. Coal

Table 1
Technical parameters of coal samples.

No.	Coal sample	Mad/%	Ad/%	Vdaf/%	FC.d/%	Coal rank
1#	HLE	2.97	4.18	38.91	58.54	Lignite
2#	QD	0.94	18.32	25.56	55.18	Bituminous
3#	YD	0.61	13.62	31.35	59.30	Bituminous
4#	QC	0.58	9.13	22.23	70.67	Anthracite

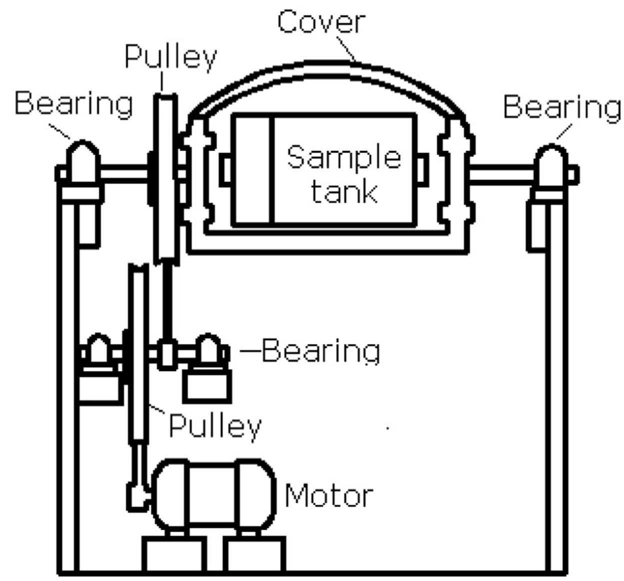

Fig. 1. The schematic diagram of ball mill.

tank diameter is 50 mm and its height is 100 mm. The actual coal loading height is 70 mm or so. Inlet and outlet are arranged at the bottom and top of the tank. A temperature probe is installed on tank top and the probe tip is in the geometric center of the tank. Before the experiment, about 30 g of the coal sample was loaded on the coal tank. After air tightness of connection piping was checked, air was pumped into the coal tank and the air flow was adjusted to 20 ml/min. The thermostat temperature of heating box was set. This experiment start from 20 °C, and the heating rate is 1 °C/min. After the temperature at the center of coal sample tank reached the preset temperature and was maintained for 15 min, the concentrations of oxygen and CO released from coal tank were detected with gas chromatography until the temperature rose to 100 °C.

2.3. Infrared spectrum

We selected four coal samples with different metamorphic grades for infrared spectroscopy analysis. The central part of a large coal lump was selected and crushed. Then coal samples with the particle size of 0.180–0.250 mm was selected for infrared spectroscopy analysis. Test equipment is the Avatar360 Fourier Transform Infrared Spectrometer by Nicolet, U.S. The diffuse reflectance method was adopted for testing. Experimental wavenumber range was 400–4000 cm^{-1} and samples were scanned for 32 times.

3. Results and discussion

3.1. CO generated during crushing

Experimental results indicated that in the air atmosphere, coal sample mechanically crushed in a sealed tank generated CO. The CO generation process is similar to underground coal cutting process with coal shearer. The result can indirectly verify whether coal crushing is an important source of CO generation.

3.1.1. Crushing time

CO concentration in the tank is closely related to the crushing time of coal, as shown in Fig. 3. The 4 kinds of coal samples can produce CO during crushing and CO concentration increases with the increase in milling time. For example, when HLE coal sample