Effects of Sulfur Components on Crossing Point Temperature of Coal

Xuyao Qi[*], Deming Wang, Haihui Xin and Guansheng Qi

Faculty of Safety Engineering, China University of Mining and Technology, Xuzhou, China

*Corresponding author: Fax: +86 516 83590598; Tel: +86 13585490927; E-mail: qixuyao@gmail.com

The crossing point temperature of initial and blended dried coal samples were tested. The weight percentages of FeS_2 in blended coal samples were 3, 5 and 7 %. 50 g of coal particles ranging from 0.18 mm to 0.38 mm in size were put into a coal vessel attached at the center of oven. The temperature program increased the temperature at a rate of 0.8 ºC/min. Dry-air was permitted to flow into the coal vessel at different rates. The results indicate that the effects of sulfur components depend on reaction conditions and coal ranks. The reactivity of sulfur components in the coal is low under dry and low temperature conditions. These components form a film that covers the coal surface and slightly inhibits the self-heating of the coal. The inhibition degrees are different for different ranks of coal, which is due to the types and amount of active groups. It is usually more obvious for lower ranks of coal.

Key Words: Coal, Crossing point temperature, Sulfur component, Spontaneous combustion.

INTRODUCTION

Crossing point temperature (CPT) is an important parameter in spontaneous combustion of coal. In coal self-heating, the rate of the rise in coal temperature during coal oxidation would become greater under appropriate conditions. The temperature at the point where the coal temperature begins to exceed the surrounding temperature is the crossing point temperature of coal. It has been used to evaluate the propensity of coal to spontaneous combustion by some investigators[1-3].

During coal self-heating, many factors may influence the rising of coal temperature[4,5]. Sulfur components in coal is one of the factors. As known, there are some sulfur components in coal, which include organic and inorganic sulfur[6]. Though the affecting mechanism of sulfur components on coal oxidation is still disputed until now, the important role of sulfur components in coal self-heating has been confirmed by many investigators[7-10]. At this time, the effects of some factors have been analyzed by different investigators, such as air humidity and flow rate, surrounding heating rate, volatile matter, oxygen content, moisture content, ash content, coal particle size and inhibitor additive[11-13]. However, the effect of sulfur components on crossing point temperature is not very clear at this time. This paper analyzes the effects of sulfur on temperature rising of coal and the value of crossing point temperature.

Different methods have been used to test crossing point temperature of coal in previous literatures. An oil-bath method ran at a constant heating rate was initially used in 1915[14]. Other investigators modified the testing method through altering reaction atmosphere, heating bath, coal reaction vessel, *etc.*[3,16]. For accurate and quick testing of crossing point temperature, a new experimental system is explored in this paper based on the existing method.

EXPERIMENTAL

Coal samples: Two different ranks of coal were tested. The lignite was collected from Beizao coal mine located in North China and the anthracite was collected from Kabuliang coal mine located in Northwest China. The sealed coals were delivered to the laboratory as rapidly as possible. The surface was removed and the interior core was crushed in a vacuum glove box. Then the coal particles ranging from 0.18 to 0.38 mm were sieved for tests. The proximate analysis of the samples is listed in Table-1.

For avoiding effects of moisture in coal, we dried coal particles at 40 ºC under a vacuum condition. The drying process continued until the mass change of the coal sample was less than 0.1 % per hour. We added different amount of FeS_2 to initial dried coal particles to make blended coal samples. The weight percentages of FeS_2 in blended coal sample were 3, 5 and 7 %.

Testing system: The testing system consisted of a facility for simulation of coal oxidation and a temperature logger, as shown in Fig. 1. The simulation facility is an enclosure capable of programmed temperature control, a gas tube and a coal

TABLE-1

PROXIMATE ANALYSIS OF COAL SAMPLES

Coal samples	M_{ad} (%)	A_{ad} (%)	V_{ad} (%)	FC_{ad} (%)	$Q_{net, ad}$ (kJ/g)	H_{ad} (%)	S_{td} (%)
Beizao lignite	9.86	20.65	30.01	34.08	21.81	4.49	0.37
Kabuliang anthracite	1.12	6.86	11.76	80.26	32.93	3.78	0.23

reaction vessel. The temperature logger was a set of thermocouples and an analyzing system.

The programmed temperature enclosure provides a surrounding environment at an accurate and uniform temperature by means of a gas bath. The dry air temperature was the same as the surrounding temperature because the dry air was preheated before flowing into the coal reaction vessel. Preheating was achieved by passing the air through a 50 m copper tube located inside the programmed enclosure. The coal reaction vessel was made of pure copper, which has a good thermal conductivity. At its bottom, there is a 20 mm high gas buffer space segmented with a 0.15 mm stainless steel mesh aperture, as shown in Fig. 1b. This buffer space ensures a steady, dry air flow into the coal sample. Thermocouple 1, fixed at the center of the thermally programmed enclosure, was used to monitor the surrounding temperature while thermocouple 2, fixed at the center of the coal reaction vessel was used to monitor the coal temperature.
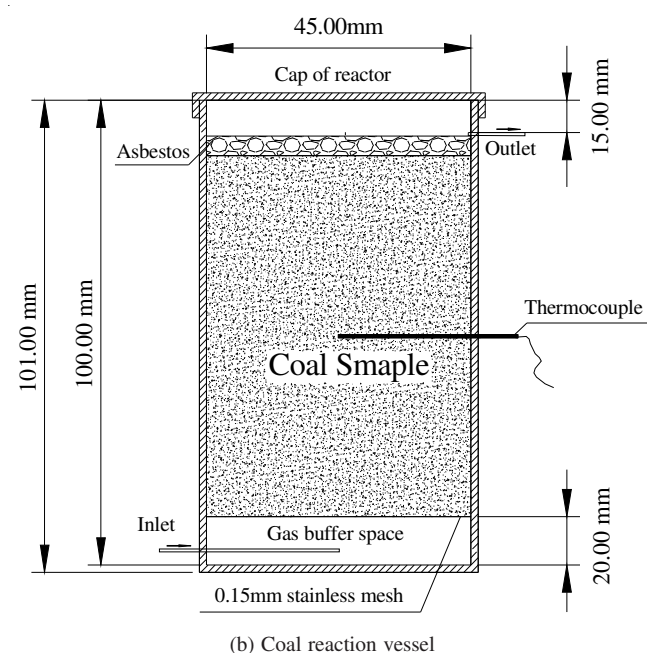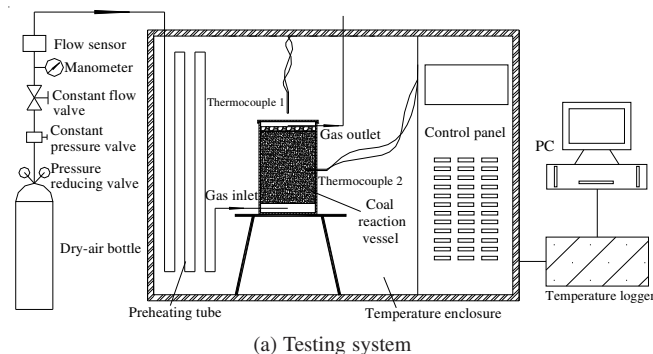

(a) Testing system

(b) Coal reaction vessel

Fig. 1. Schematic diagram of the testing system

Testing procedures: The tests were carried on according to the procedures as follows.

(1) We put 50 g (± 0.01 g) of coal sample into the coal reaction vessel. A thin bed of asbestos was laid on top of the coal sample to prevent the gas tube from becoming plugged.

(2) The programmed temperature enclosure was set to run at a constant temperature of 40 ºC while dry air with an oxygen concentration of 20.96 % was permitted to flow through the coal reaction vessel at a rate of 8 mL/min. The temperature logger was used to continuously monitor the coal and surrounding temperatures.

(3) When coal temperature reached 40 ºC, the programmed temperature enclosure was set to run at a programmed heating rate of 0.8 ºC/min while the flow rate of dry air was maintained at 8 mL/min. The reaction intensity at low temperatures is weak and corresponding oxygen requirement is small. The flow rate at 8 mL/min not only satisfies the oxygen requirements in this stage, but also avoids heat loss, which is key for the development of coal self-heating.

(4) When coal temperature reached 70 ºC, the programmed temperature enclosure continued heating at a rate of 0.8 ºC/min but the flow rate of dry air was changed to 96 mL/min. The reaction intensity and corresponding oxygen requirement increases with the rise of coal temperature. So we changed the rate of dry air to a different rate at 96 mL/min after 70 ºC.

(5) We ended the experiment when coal temperature was 5 ºC higher than the surrounding temperature.

RESULTS AND DISCUSSION

Based on the results, the temperature rising trends of initial and blended coal samples are shown in Figs. 2 and 3. It indicates FeS_2 inhibits the coal oxidation process in some degree under dry and low-temperature conditions. A similar phenomenon was also found in Pietrzak and Wachowska's investigation[17]. They proposed that coal reactivity usually decreased with an increase in coal rank but they found that a lignite sample having a sulfur content of 11.4 % had very low reactivity.

In general, FeS_2 can react with O_2 and H_2O. However, the reactivity of FeS_2 is low and it is almost inert under dry and low-temperature conditions. During coal oxidation, these nonreactive sulfur components form a film that covers the coal surface. It plugs pores and crannies in the coal and inhibits heat transfer and the contact between the coal and O_2. As a result, coal oxidation is inhibited by these sulfur components under dry and low-temperature conditions.

There is a critical weight percentage of FeS_2 added. The results show the effects are similar for blended coal samples at weight percentages of 5 and 7 %. Under dry and low-temperature conditions, FeS_2 influence the spontaneous combustion of coal through inhibiting heat transfer and the contact between coal and oxygen. If the amount of FeS_2 is enough to form a layer on coal particle, the inhibition degree will not increase
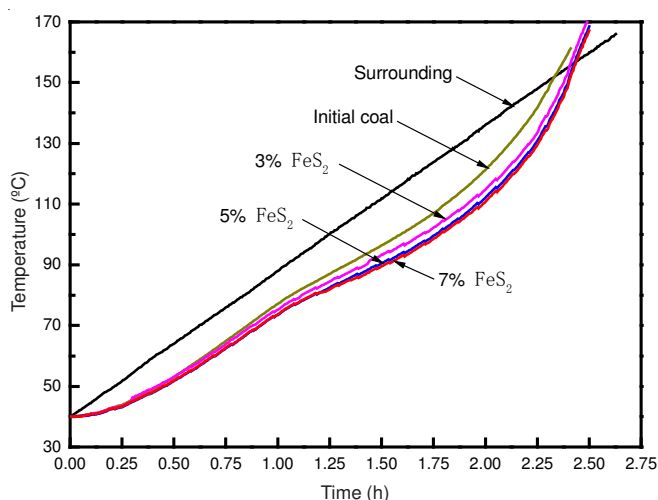
Fig. 2. Temperature rising trends of initial and blended Beizao lignite
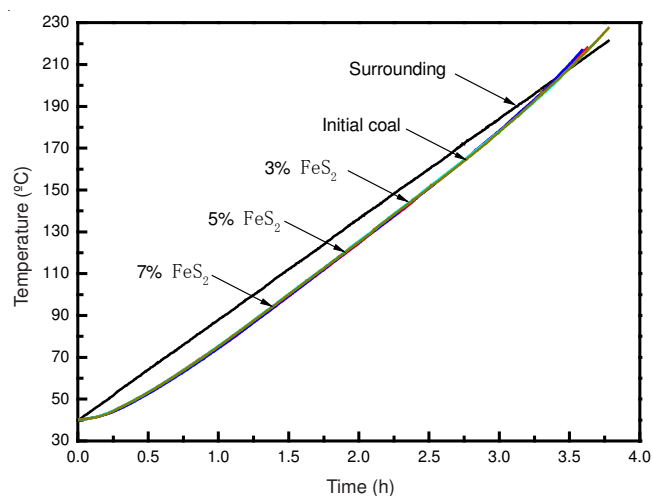

Fig. 3. Temperature rising trends of initial and blended Kabuliang anthracite

with more FeS_2 added. It indicates the change of temperature rising trend is due to the inhibition on the transfer and contact of active groups.

TABLE-2
CROSSING POINT TEMPERATURES OF
INITIAL AND BLENDED COAL SAMPLES

Proportion of FeS_2 (%)	Beizao lignite (°C)	Kabuliang anthracite (°C)
0	152.0	204.0
3	155.3	203.0
5	156.5	207.5
7	157.0	207.0

The sulfur components play different inhibition effects on spontaneous combustion of coal. It is more obvious for lower ranks of coal. For higher ranks of coal, the effects is not very obvious. The results show the temperature rising trends of initial and blended Kabuliang anthracite samples are similar. The curves nearly coincide for coal samples with different weight percentage of FeS_2. There are more types and amount of active groups in low ranks of coal than high rank

ones. The FeS_2 covering coal particles can inhibit contact and reaction between coal and O_2 at a bigger degree. As a result, the inhibition effects on temperature rising are more obvious as well. For equal rank coal samples, the coal with the higher sulfur content usually has a smaller rate of temperature rise and a higher crossing point temperature than the coal with a lower sulfur content. For example, we found Changguang gas rich coal, with a high sulfur content of 5.01 %, had a crossing point temperature of 180.1 °C, which was higher than the other coal samples with a very similar rank and moisture content.

Conclusion

The crossing point temperature of initial and blended dried coal samples were tested using a self-designed equipment. The results indicate that the effects of sulfur components depend on reaction conditions and coal ranks. The reactions of sulfur components in coal occur at an appropriate moist and temperature condition and enhance coal self-heating. However, under dry and low temperature conditions, the non-reactive sulfur components cover coal particles and inhibit heat transfer and the contact between coal and oxygen. Consequently, they inhibit temperature rising and result in the increase of crossing point temperature. The inhibition degree is associated to coal ranks and weight percentage of FeS_2 added. It is usually more obvious for low ranks of coal.

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