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Experimental study on prevention and control of coal spontaneous combustion with heat control inhibitor

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ABSTRACT

Traditional inhibitors have such disadvantages as unstable inhibitory effects and short active lifetimes. Sodium bicarbonate, stable in nature, is expected to absorb heat and lower the temperature upon heated and decomposition, enabling its decomposition product to be effective for preventing coal oxidation and spontaneous combustion. Accordingly, the present study investigates the characteristics of sodium bicarbonate and proposes a novel method for preventing the spontaneous combustion of coal using sodium bicarbonate. By establishing a programmed temperature experimental system of coal spontaneous combustion in the laboratory, the researchers added sodium bicarbonate (0.5–3 g) to the coal samples, and analyzed changes in CO and O_2 concentration. The results out of the present experimental conditions, compared with those of coal samples treated with magnesium and calcium chlorides, show that adding different amounts of sodium bicarbonate can inhibit coal oxidation with an optimal addition amount of 3 g. When the amount of sodium bicarbonate added was larger than 2 g and the temperature above 130 °C, its inhibitory effect is more significant than that of existing inhibiting agents.

1. Introduction

Coal spontaneous combustion is one of the major disasters in coal mining, resulting in approximately 400 annual fires in China. There has been an estimation of more than 4.2 billion tons of coal losses so far in coalfields of northern China. Meanwhile, toxic and harmful gases such as NO_2 and SO_2 are released during the process of coal spontaneous combustion. The combustion of coal produces more nitrogen oxide and sulphur oxide than those from the combustion of coal-water slurries and coal-water slurries containing petrochemicals (Nyashina et al., 2017, 2018; Dmitrienko et al., 2018a,b), they will seriously threaten the safety of miners in the pit. Consequently, fire prevention and control technology is of great significance to the safe operation of coal mines (Liang and Luo, 2008; Wang et al., 2003; Mao et al., 2010). Current coal mine fire prevention technologies include Inert gas (Zhang and Liu, 2008), three-phase foam (Qin, 2008), inhibitors (Shi et al., 2007; Li et al., 2012), gel fire extinguishing technology (Xu et al., 2013), et al., Among which the frequently adopted method is to add inhibitors to prevent spontaneous combustion of coal seam. Those inhibitors can be classified into two categories according to their mechanism of action: physical and chemical. The widely used physical resistance agents are CaC_{l2}, MgC_{l2}, along with other inorganic salts (Slovak and Taraba, 2012; Watanabe and Zhang, 2000; Zheng, 2010; Ma et al., 2015). These inhibitors work by absorbing moisture in the air to form a water film on the surface of the coal, thereby preventing the reaction between coal and oxygen. These inhibitors are both cost-effective and highly efficient. However, the long-term spraying of inorganic salt inhibitors will corrode the underground metal pipelines and equipment, resulting in financial losses (Wang et al., 2013). Besides, such solutions with inhibitors' high flowability, are usually accompanied with the effects of the dip angle of the coal seam, which may reduce the contact between the inhibitor and the coal. Meanwhile, the active lifetimes of the inhibitors are short and need to be loaded incessantly. At present, the main chemical inhibitors applied are Na_3PO_4 (Zhan et al., 2011), ionic liquid (Wang et al., 2012), et al. By disrupting or reducing the high reactivity of the functional groups of the coal, they work to prevent coal

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spontaneous combustion. These inhibitors are highly efficient, but their suppression effect is not stable when applied to certain types of coal, due to the complexity of coal structures. Therefore, it is necessary to develop a new type of inhibitor to make the prevention more convenient, effective and stable.

In view of this, the present study presents a method of applying the heat control inhibitor as a means to prevent coal oxidation and spontaneous combustion based on heat release technology of temperature controlled capsule inhibitor (Wang et al., 2015; Jiang et al., 2017). The inhibitor solution with high water content is first sealed into a temperature controlled capsule and then spread to the goaf. The solution in the capsule is not released to take effect until the coal reaches the critical temperature threshold. As a new type of inhibitor, it has a variety of advantages such as good dispersity, stability as well as a long active lifetime and the dip angle of the coal seam has very slight influence on it. As the coal temperature rises, it will decompose, absorb heat, lower the temperature and produce products with inhibition effects.

2. Mechanism and selection of heat control inhibitor

2.1. Mechanism

The mechanism of heat control inhibitor can be specified from the following three aspects:

(1) The physical and chemical properties of the heat control inhibitor are stable. When coal spontaneous combustion does not occur, its inhibition effect maintains.
(2) When the process of coal spontaneous combustion begins, the coal temperature will start to rise, and the inhibitor decomposes by itself and absorbs a large amount of heat to slow down or even stop the coal oxidation process.
(3) When the inhibitor's preliminary endothermic process fails to reduce the activation energy of coal oxidation, its decomposition product can continue to play an inhibitory effect on the coal spontaneous combustion process by cutting off the oxygen and evaporating the heat.

2.2. Selection of heat control inhibitor

The primary criterion for selecting appropriate inhibitors is that the inhibitor must be stable but can be easily decomposed. In addition, the inhibitor can produce inhibitory substance in the critical temperature range of coal spontaneous combustion.

Sodium bicarbonate is relatively stable at room temperature, and when heated, can be easily decomposed to absorb the heat, lower the temperature and reduce coal heat. The resulting CO_2 and H_2O will cover the surface of the coal, cutting off the oxygen and thereby inhibiting the spontaneous combustion of coal (Li, 2008; Zhou, 2006). In addition, a NETZSCH type differential scanning calorimeter is used to obtain a DSC curve (Fig. 1). The curve in Fig. 1, as illustrating various heat absorbed by sodium bicarbonate per unit mass in unit time with the rise of temperature will be used to explore the thermal performance of sodium bicarbonate. Then, the researchers conducted a programmed temperature experiment, and obtained the curve of CO concentration change of the raw coal with temperature variation (Fig. 2) out of Fig. 1. Additionally, the endothermic temperature of sodium bicarbonate decomposition ranges from 60 °C to 160 °C, during which the endothermic reaction is especially severe between 80 and 150 °C. Fig. 2 (a) shows that the raw coal enters into the first stage of accelerated oxidation at approximately 80 °C. The second stage then begins, as shown in Fig. 2 (b), when the temperature reaches around 150 °C. This indicates that the critical temperature threshold of the raw coal is approximately 80 °C and its dry cracking temperature is about 150 °C. The temperature interval of sodium bicarbonate decomposition coincides with the critical temperature range of coal oxidation and spontaneous combustion.

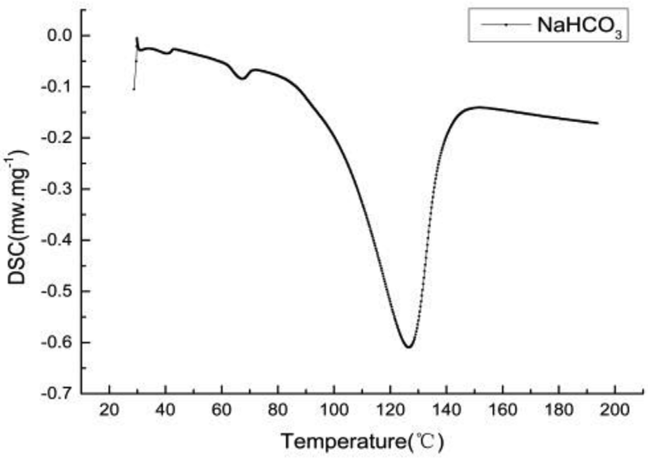

Fig. 1. DSC curve of the Sodium bicarbonate.

Therefore, this work takes sodium bicarbonate as the heat control inhibitor, and investigates its efficiency in suppressing coal spontaneous combustion with programmed temperature experiments (Lu et al., 2005).

3. Programmed temperature experiments

3.1. Experimental equipment

The programmed temperature experiment can greatly reduce the amount of coal used in each experiment (In the experiment of this paper, the amount of coal used in each experiment is 5 g, which is negligible compared with the amount of coal used in large-scale spontaneous combustion simulation experiments). This suggests that the experiments can be better controlled. At the same time, the programmed temperature experiment also greatly shortens the experimental cycle (Generally, the experimental cycle of a sample is about 12 h, significantly shorter than that of a large scale simulation experiment) and allows the experiment to be more operable. Consequently, the present study adopts the programmed temperature experiment.

Fig. 3 shows the physical map of the programmed temperature experimental system, which consists of five parts: the gas path system, the tubular furnace, the reaction device, the condensing tube and the drying bottle, as well as the gas collection and the analysis system.

The gas path system consists of a nitrogen cylinder, an air bottle, a pressure reducing valve, a stabilizing valve, a flow stabilizing valve and a flow meter, which provides the required gas for each stage of the experiment. The experimental heating device is the MTF 12/38/400 type tubular furnace imported from Britain, whose maximum operating temperature is 1200°, and whose heating rate can meet the minimum standard of 1 °C/min, (with the measurement error of ± 1 °C). The reaction device is composed of brass, with its fine heat conduction, while the air inlet end and the outlet end of the reaction device are deployed at different horizontal planes to facilitate gas circulation and avoid gas accumulation. Drying bottles and condenser tubes are applied to dry and cool the high-temperature water vapor produced in the experiments. The gas collection and analysis system consists of the following seven parts as: the CO sensor (measurement range as 0–2000 ppm, and measurement error as 0.5 ppm), the CO_2 sensor (the measurement range as 0–5000 ppm and measurement error as ± 50 ppm), the O_2 sensor (the measurement range as 0–25%, and the measurement error as 0.1%), the temperature sensor (the measurement range as 0–900 °C, and the measurement error as ± 3 °C), the gas collection bottle, the PLC and the EM231 data module and the host computer. Such a system can collect and display data in real time.