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Study of the effect of bacteria on the disappearance and transformation of CO in the sealed fire zone of coal mine

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Abstract. When the underground coal mine gob area has been sealed due to the coal spontaneous combustion, under the low oxygen and potentially high temperature environment, the CO concentration could drop sharply and disappear quickly. But it could rise rapidly after re-opening. These indicate that the disappearance is the only index for coal burnt out. In order to find a way how let CO disappear, experiments have been conducted using the newly developed experiment setup for three samples, raw, watered and bacteria-free coal sample. The CO and CO_2 concentration have been monitored and analyzed. The results show the bacteria in the coal do consume CO and increase the chance of CO transfer to CO_2. These results reveal how let CO disappear in a sealed zone from a new aspect. And the accuracy was improved when used gas index to determine combustion status for coal spontaneous combustion.

1. Introduction

Underground coal fire is one of the most common disasters that affects the safe production of coal mines [1]. According to statistics, there are 72.86% of coal mines that has ever occurred coal spontaneous combustion phenomenon in China [2]. A phenomenon was found from several coal mine fire accidents (such as the fire accident of Duan Poqiao coal mine of Hunan province in 2008 and the coal mine fire accident of Liaoning province in 2005 [3]). After a gob fire being sealed, the CO concentration inside the gob can drop as low as 0 ppm. However, as soon as the gob was re-opened, the CO concentration can rise rapidly in a short period (1-3 days), which may cause the 2nd seal of the gob. Therefore, it can be found that not only the extinction of coal fire but also other factors can lead to the disappearance of CO. Wang [4] has measured the adsorbing capability of coal sample to CO at the different temperature by high-pressure volumetric method to study the variation of CO concentration in sealed gob area. They concluded that the adsorption of coal seam to CO was not accord with the monomolecular layer adsorption model by theoretical analysis. The coke produced by coal combustion can react with CO_2 to form CO under high temperature condition [5], while a large amount of CO can be generated during coal oxidization [6]. However, CO may react with O_2 to produce CO_2 in the process of coal combustion [7]. The generation rate of CO_2 produced by oxygen oxidation of CO is very small in the atmosphere air [8].

There are a diversity of aerogenes in the coal seam. According to the three-stage theory of anaerobic fermentation, the aerogenes can be divided into the hydrolysis and fermentation bacteria, hydrogen-producing aerogenes and methanogenus [9, 10]. Orem et al. [11, 12] confirmed that the microbes obtained from coal seam or coal seam water can transfer coal into methane via experiment. Wang [13] obtained stable gas-producing bacteria group by enrichment from Lignite coal. Conrad & Seiler [14] believed that CO can be oxidized by certain organisms, these organisms can achieve benefits which can only obtain from the oxidation process of CO (such as obtain the energy required for life activities). Some chemoautotrophic bacteria can oxidize a big amount of CO to form CO_2 under the common temperature range (5℃-30℃) and the oxidation rate of CO gradually increased with the increasing of temperature [15]. Carbon source and water are important factors that affect the growth of bacteria [16]. Therefore, it can be deduced that bacteria have a positive effect on the disappearance and transformation of CO in gob. Experimental apparatus and technology for studying the effects of bacteria on the disappearance of CO has been designed and set up to start a new perspective in this paper. Experiments have been conducted for raw coal, raw coal with water and bacteria free raw coal under same and different pressure in an airtight vessel, the variation of concentration of CO and CO_2 has been monitored and analysed. These results can improve the accuracy when using the CO index to determine combustion status in sealed gob.

2. Sample preparation and experiment Process

2.1. Sample preparation

2 kg coal sample were selected in the size range from 0.9mm to 3mm and stored in a nitrogen environment for 24 hours. Then the experimenters made three equal weight (370g) sample labelled as A, B and C. For sample B, 20 mL pure water has been added into the vessel; for sample C, with UV light irradiation for 4 hours. Then the experimenters packed three coal samples into three sterile vessels and sealed them. All these processes were operated under bacteria-free environment. The three vessels were sterilized by high-pressure steam and were dried by vacuum wind drum. The sterilized gas was used during this experiment was sterilized by air sterilization filter (model DR-LT-2S).

2.2. Experiment Procedure

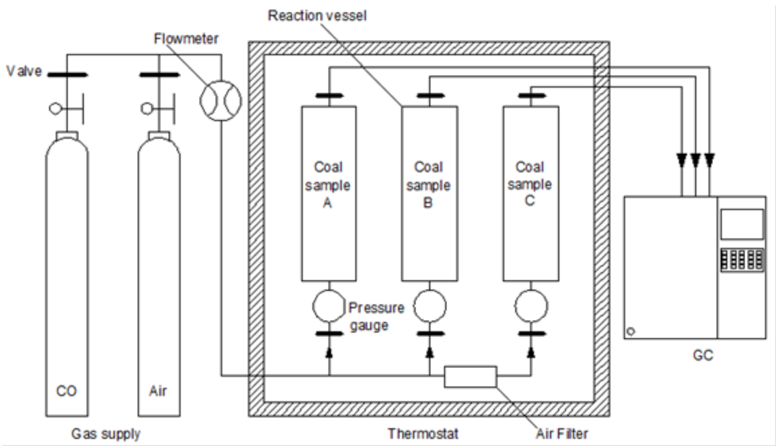

Figure 1. Experiment setup and schematic.

The experiment schematic was shown in Figure 1. Raw coal sample A and watered sample B have been pumped 300 mL atmosphere air and 150 mL CO respectively. Bacteria free sample C has been pumped the same amount of sterilized gases. Then three vessels are sealed and have been put into the thermostat. According to Zhang's [15] study, the appropriate temperature for this experiment is 30℃. The gas sample has been collected every 12 hours and analysed by gas chromatograph after the pressure in the vessels gets re-balanced. Another two sets of experiments with different CO injection amount, 75 mL and 40 mL, have been conducted as well.

3. Results and discussion

3.1. CO concentration comparison under same amount of gas injection

As the generation rate of CO_2 is very small in the atmosphere air [17], this paper isn't considered the effect of oxygen oxidation of CO on experimental results. And the total volume of gas is not changed in the experimental process because of the sealing vessels. After processing the reduction rate of CO concentration and the rise rate of CO_2 concentration by two cumulative method, Figure 2, 3 and 4 have been plotted, respectively. In the figures, A CO, B CO, C CO refer the reduction rate of CO concentration in sample A, B and C, respectively. A CO_2, B CO_2, C CO_2 indicate the rise rate of CO_2 concentration in sample A, B and C, respectively. The effects of bacteria on the disappearance of CO has been analysed as follow.

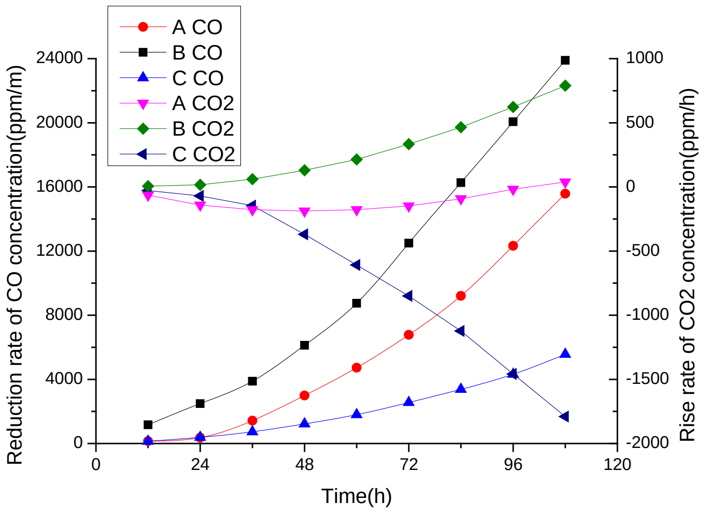

Figure 2. Rate tendency processed by two cumulative methods in 150 mL CO gas.

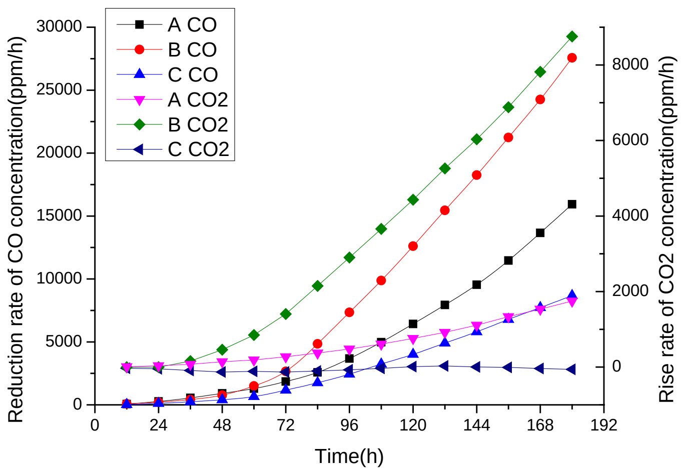

Figure 3. Rate tendency processed by two cumulative methods in 75 mL CO gas.

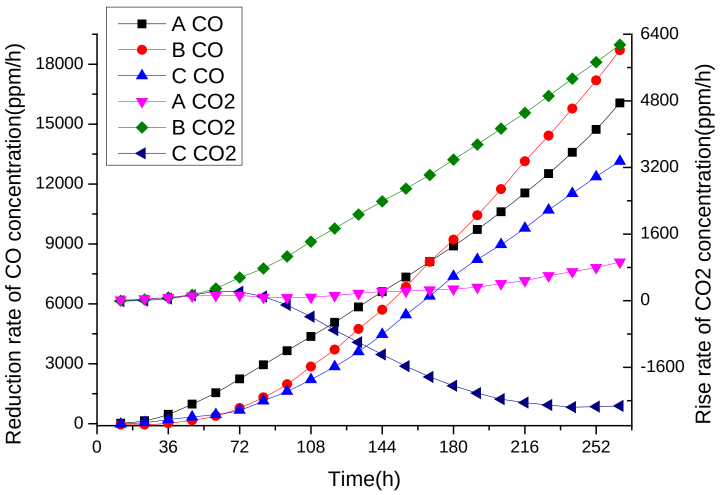

Figure 4. Rate tendency processed by two cumulative methods in 40 mL CO gas.

From Figure 2, 3 and 4, the reduction rate of CO concentration for sample C is positive number, which indicates that CO concentration reduces in sample C. The reason of this phenomenon is that coal samples can adsorb CO in the sealing vessels, which can be proved by Wang's [4] study. The production of CO and CO_2 are much less and limited as a result of coal oxidation in the low-temperature oxidation stage of coal [17], so that aerial oxidation of coal doesn't affect experimental results in the paper. It's clear that the reduction rate of CO concentration has an increasing trend and the reduction rate of CO concentration for sample A and B is greater than sample C. This indicates that some kinds of CO consuming bacteria group exist in the raw coal which accelerate the reduction rate of CO concentration. The reduction rate of CO concentration in sample B is the greatest and sample A is the second. The reason is that water in the sample promotes the rapid propagation of bacteria in the coal and resulted a larger amount of bacteria in sample B. So the reduction rate of CO concentration in sample B is bigger than sample A.

In Figure 2, 3 and 4, the rise rate of CO_2 concentration for sample A and B is positive number, which indicates that CO_2 concentration rises in sample A and B. But the rise rate of CO_2 concentration for sample C is negative number, which indicates that CO_2 concentration reduces in sample C. The reason is that coal samples can adsorb CO_2 in the sealing vessels, which can be proved by [18]. The rise rate of CO_2 concentration has a rising trend in both samples A and B, especially in sample B. But the rise rate of CO_2 concentration drops in sample C. The phenomenon turns out that the bacteria in the coal promote the generation of CO_2 and this effect becomes more obvious when there more bacteria exist in the coal.

In both samples A and B, the reduction rate of CO concentration and the rise rate of CO_2 concentration have increased. But in sample C, CO concentration and CO_2 concentration decrease at the same time. Thus, it can be concluded that the bacteria can cause CO concentration to reduce and CO_2 concentration to rise. The bacteria consume CO and release CO_2 to form organic matter to keep vital activity and reproduction. So the process promotes the transformation from CO to CO_2.

3.2. CO concentration comparison under different amount of gas injection

For each of the three samples with different CO injection amount, the rate tendency of CO concentration has been plotted in Figure 5, 6 and 7 by two cumulative methods, respectively. In the figures, 150mL CO, 75mL CO, 40mL CO refer the reduction rate of CO concentration in sample with different CO injection amount, 150mL, 75 mL and 40 mL, respectively.

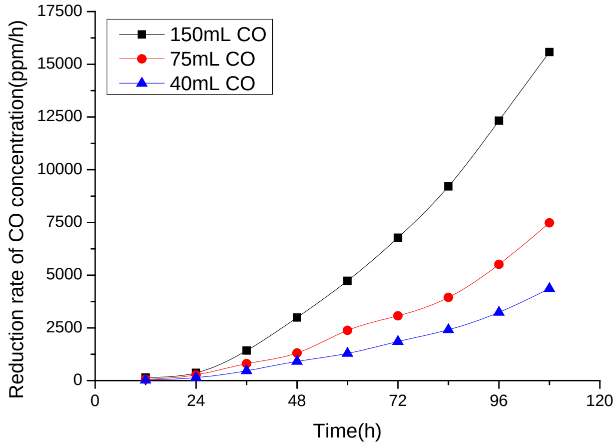

Figure 5. Rate tendency processed by two cumulative methods in sample A.

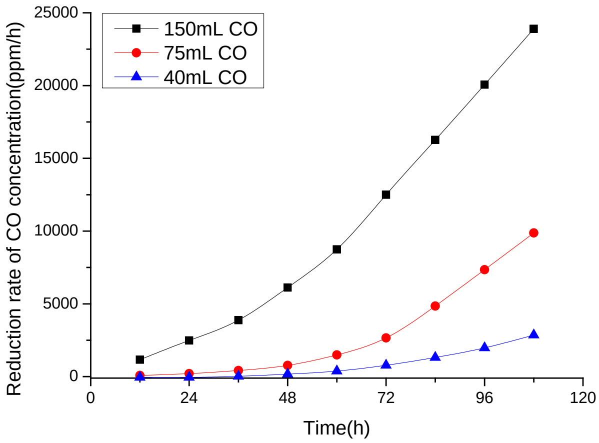

Figure 6. Rate tendency processed by two cumulative methods in sample B.

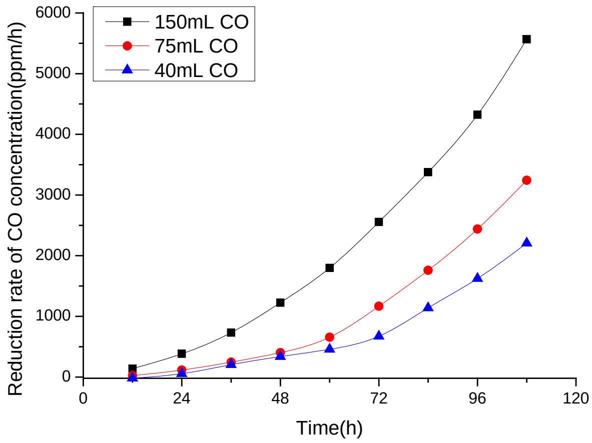

Figure 7. Rate tendency processed by two cumulative methods in sample C.

Different amount of CO injected to the same coal sample can cause different pressure and CO concentration in the sealing vessels. Figure 5, 6 and 7 show for the same sample the reduction rate of CO concentration is the greatest for 150 mL CO injection and the smallest for 40 mL injection. These indicates the reduction rate of CO concentration is also affected by pressure. The higher the pressure is, the greater the reduction rate of CO concentration is in the sealing vessels. There are two reasons for this phenomenon. One reason is that coal has a greater CO adsorption capacity under high pressure. And another one is that CO concentration affects the reproduction rate of bacteria. The higher the reproduction rate of bacteria is under high CO concentration environment, the faster the rate of bacteria consuming CO is.

4. Conclusions

From the comparison of same amount of CO injection for different coal samples, it can be concluded that bacteria have accelerated the disappearance of CO. And by comparing with different injection amount for the same coal sample, the results indicate the higher the pressure is, the greater the reduction rate of CO concentration is.

Under normal temperature, bacteria take a positive effect on the disappearance of CO and generation of CO_2. The reason is that chemoautotrophic bacteria consume CO to form organic matter and release CO_2 during vital activity. In general, the existence of bacteria accelerates the transformation of CO to CO_2.

Acknowledgments

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