Experimental Study on Spontaneous Combustion Prediction System of No.12 Coal Seam in TongXin Coal Mine

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Abstract. To reduce coal spontaneous combustion hazards, establishing accurate and reliable prediction system, with 12" coal seam with TongXin ore as object, using the large platform of coal spontaneous combustion simulation of coal spontaneous combustion process, the oxygen consumption rate, exothermal intensity and other characteristic parameters were analyzed, and based on the method of index gases, temperature programmed experiments, summarizes the characteristics of the temperature and gas change rule. The experimental results show that the oxygen consumption rate and heat release intensity increase with the increase of coal temperature. At 70.1 ℃, it reaches the critical temperature of coal; at 132.7 ℃, the dry cracking temperature of coal is reached; when the temperature is 244.8 ℃, it reaches the growth temperature of coal; when the coal temperature is between 22.9.1-70.1 ℃, CO and C₂H₆/CH₄ can be selected as the main index gas of No.12 coal seam in TongXin Mine; when the coal temperature is between 132.7-320.5 ℃, CO can be selected as the index gas. Since C₂H₄ can only be detected when the coal temperature reaches about 85 ℃, C₂H₄ and C₂H₆/CH₄ can be used as auxiliary marker gas.

1. Introduction
In the process of coal production, coal spontaneous combustion is an unavoidable natural disaster[1]. The occurrence of coal spontaneous combustion not only releases toxic gases, but also induces secondary accidents such as gas and dust explosion[2]. Therefore, in order to reduce the harm of coal spontaneous combustion, it is of great significance to develop a more accurate and reliable prediction system for coal mine fire disaster prevention and control work[3].

Many Chinese scholars have done a lot of research on the prediction system of coal spontaneous combustion. Kang Jizhong et al[4-7] conducted the spontaneous combustion experiment of coal and detected the generated gas, and the results showed that CO could be used as the main index gas, and CH₄, C₂H₄ and C₂H₆ could be used as auxiliary index gas under specific conditions. Lu Wei[8], Chen Liang[9], Liang Yuntao[10] et al. First proposed the coal-oxygen composite process. Xiao Yang[11] et al. obtained the relationship between the change of coal sample mass and heat release during the experimental process through thermogravimetric experiments. All the above studies provide important ideas for the index prediction system of coal spontaneous combustion process in China. However, programmed heating tests often have defects such as large gas error caused by small amount of coal, difficulty in simulating the natural combustion state of coal seam, etc, and the test results often have large deviation and can not reflect the real natural combustion state of coal seam.

In view of this, this article takes the same TongXin 12" coal seam mine as the research background, collecting a large number of fresh coal sample, based on the platform, large coal spontaneous...
combustion index gases method, the establishment of a large coal spontaneous combustion based on platform with TongXin 12" coal mine spontaneous combustion optimization index system of gas, to guide the coal spontaneous combustion disaster prevention forecast provide certain help.

2. Experiment

2.1 Program heating experiment

The experimental device is shown in Figure 1. The large coal spontaneous combustion platform independently developed by Xi'an University of Science and Technology\(^{12-14}\) is adopted. The experimental device is mainly composed of furnace body, automatic temperature control and control system. Put the coal sample into the crusher to break into a certain size and put it into the furnace, open the air pump, supply a certain amount of air, and start the natural combustion experiment. The particle size and experimental conditions of coal samples are shown in Table 1. and Table 2.

![Figure 1. Experimental device diagram](image)

Table 1. Coal sample size and frequency

| Particle size | Frequency (100%) |
|---------------|------------------|
| +6mm          | 13.51            |
| +4mm, -6mm    | 10.2             |
| +2mm, -4mm    | 24.09            |
| +1mm, -2mm    | 17.92            |
| -1mm          | 33.72            |

Table 2. Experimental conditions

| Coal sample | The average particle size (d50/mm) | The experiment of coal with high (h/cm) | Coal heavy (m/kg) | The volume of coal sample(V/m³) | The density of coal (g/cm³) | Should the heavy (g/cm³) | porosity | For air(m³/h) | The initial temperature (T/°C) |
|-------------|-----------------------------------|--------------------------------------|------------------|-------------------------------|--------------------------|------------------------|----------|--------------|-------------------------------|
| Tong Xin    | 2.7                               | 200                                  | 13790            | 12.3                          | 1.45                     | 1.12                   | 0.23     | 3.4          | 22.9                          |

2.2. Coal spontaneous combustion characteristic parameter analysis
2.2.1. Oxygen consumption rate
Under the experimental conditions, according to the theory of heat conduction and mass transfer of coal spontaneous combustion, the oxygen consumption rate of coal is:

$$\frac{dc}{d\tau} = -V(T) \hspace{1cm} (1)$$

where, $c$ is the oxygen consumption velocity,

$$d\tau = \frac{dx}{Q}, \bar{Q} = \frac{Q}{S} \hspace{1cm} (2)$$

where, $Q$ is the experimental air supply volume, $S$ is the cross-sectional area of furnace body[15], then:

$$\bar{Q} \cdot \frac{dc}{dx} = -V(T) \hspace{1cm} (3)$$

$$V(T) = \frac{C}{C_0} V_0(T) \hspace{1cm} (4)$$

where, $C$ is the standard oxygen concentration, and $V_0(T)$ is the oxygen consumption rate of coal under the standard oxygen concentration. Substituting Equation (4) into Equation (3), the following equation can be obtained:

$$dC = -V_0'(T) \cdot \frac{C}{Q \cdot C_0} \cdot dx \hspace{1cm} (5)$$

Integrate both sides to get:

$$V_0(T) = \frac{Q \cdot C_0}{S \cdot (Z_2 - Z_1)} \cdot \ln \frac{C_1}{C_2} \hspace{1cm} (6)$$

It can be seen from Figure. 2 that the oxygen consumption rate increases exponentially with the increase of coal temperature. When the coal temperature is before 70.1 °C, the growth rate is very slow; when the temperature exceeds 132.7 °C, the oxygen consumption increases, and the oxidation reaction stage of the coal sample accelerates.

![Figure 2. Relationship between oxygen consumption rate and coal temperature](image)

2.2.2. Heat release intensity
From the perspective of heat transfer, according to the principle of energy balance[16], the exothermic strength of coal oxidation is:

$$q_{max}(T) = \frac{V_0^0(T)}{V_{CO}(T) + V_{CO_2}(T)} V_0(T) + \Delta H_{CO} + \frac{V_{CO}^0}{V_{CO}(T) + V_{CO_2}(T)} \cdot V_0(T) \cdot \Delta H_{CO_2} \hspace{1cm} (7)$$

Assuming that the oxidation process of coal is carried out under ideal conditions without the
participation of other reactions, then:

$$q_{\text{min}}(T) = \Delta H \cdot V_0^0(T) - V_{CO}^0(T) - V_{CO_2}^0(T) + \Delta H_{CO} \cdot V_{CO}^0(T) + \Delta H_{CO_2} \cdot V_{CO_2}^0(T)$$

(8)

where, is the maximum exothermic strength of coal oxidation, is the minimum exothermic strength of coal oxidation, J/(cm$^3$·s);Is the heat released for every mole of CO; Represents the heat released for every 1 mol of CO$_2$ generation, and represents CO, CO$_2$ generation rate and oxygen consumption rate, mol/(cm$^3$·s)$^{[17-18]}$.

As shown in Figure 3, with the continuous increase of coal temperature, the heat release intensity also gradually increases. Before 70.1 ℃, the maximum and minimum exothermic strength increase slowly and almost have no obvious change. This stage is the physical adsorption process of coal. After 70.1 ℃, the slope of the curve increases sharply, and the coal sample changes from physical adsorption to chemical adsorption. When the temperature exceeds 132.7 ℃, the increase effect of heat release intensity is more obvious.

Figure 3. Relationship between heat release intensity and coal temperature

2.3. Analysis of the change rule of index gas with coal temperature

According to the simulation experiment of coal spontaneous combustion oxidation, in the process of 22.9-320.5 ℃, a certain amount of gas will be generated under different temperature conditions, accompanied by the consumption of O$_2$.

As shown in Figure 4, it can be seen from the figure that CO and CO$_2$ concentrations tend to be consistent with the change curve of coal temperature, with an overall exponential function growth, and the growth range of CO$_2$ concentration is significantly higher than that of CO. In the early stage, there is a small amount of CO and CO$_2$ gas. When the temperature reaches about 70.1 ℃, the concentration of CO and CO$_2$ increases slowly; when the temperature exceeds 132.7 ℃, the concentration of CO and CO$_2$ increases rapidly until it reaches the maximum at about 320 ℃.

As can be seen from Figure 5, CH$_4$ gas existed at the beginning of the experiment. The concentration of CH$_4$ gas is generally on the rise, but it turns to an inflection point at 132.7 ℃. This is because before 132.7 ℃, CH$_4$ gas is a desorption product, and after 132.7 ℃, it turns into an oxidation decomposition product. The C$_2$H$_6$ gas increases with the rise of coal temperature, and the increase effect is more obvious when the temperature exceeds 132.7 ℃. After 85 ℃, C$_2$H$_4$ gas was detected, and the overall trend increased with the rise of coal temperature.

As shown in Figure 6, it reflects the relationship between individual alkane ratio and alkene ratio with the change of coal temperature. It can be seen from the figure that C$_2$H$_6$/CH$_4$ shows an overall "rise-down-rise" trend, and the first peak appears at about 175 ℃; when the ratio reaches its maximum. After that, C$_2$H$_6$/CH$_4$ shows a slight increase and decrease after the coal temperature reaches 250 ℃. Both C$_2$H$_4$/C$_2$H$_6$ and C$_2$H$_4$/CH$_4$ increase first and then decrease with the rise of coal temperature. Before about 85 ℃, no C$_2$H$_4$ gas is produced; when the coal temperature rises to about 132.7 ℃, C$_2$H$_4$ gas increases, and C$_2$H$_4$/C$_2$H$_6$ and C$_2$H$_4$/CH$_4$ increase. C$_2$H$_4$/C$_2$H$_6$ increases exponentially in the range of 85-300 ℃.
and reaches the peak value at about 300 °C, then decreases gradually. However, \( \text{C}_2\text{H}_4/\text{CH}_4 \) generally experienced three peaks, the first peak at about 175 °C and the second peak at about 250 °C at a slower rate. After this temperature, \( \text{C}_2\text{H}_4 \) increased sharply and reached the maximum at 275 °C. After this temperature, the ratio of \( \text{C}_2\text{H}_4/\text{CH}_4 \) decreased because the release quantity of \( \text{C}_2\text{H}_4 \) became smaller.

**Figure 4.** Relationship between non-hydrocarbon gases and coal temperature

**Figure 5.** Relationship between hydrocarbon gases and coal temperature

**Figure 6.** Relationship between alkane ratio and alkane ratio and coal temperature

### 3. Conclusion

1. For No.12 coal seam of TongXin Mine, when the coal temperature is 70.1 °C, it reaches the critical temperature of coal sample; when the coal temperature is 132.7 °C, the dry cracking temperature of coal sample is reached; when the coal temperature is 244.8 °C, the coal growth temperature is reached.
At the initial stage of oxidation, CO and alkane ratio $\text{C}_2\text{H}_6/\text{CH}_4$ can be used as the preferred indicator gas of No. 12 coal seam in TongXin Mine; when the temperature reaches the dry cracking temperature, CO can be selected as the mark gas of the same TongXin ore; when the temperature exceeds 85 °C, $\text{C}_2\text{H}_4$ gas can be detected. Therefore, in the oxidation growth stage, $\text{C}_2\text{H}_4$ and the alkane ratio $\text{C}_2\text{H}_4/\text{CH}_4$ can be detected as the auxiliary marker gas of No. 12 coal seam in TongXin Mine, so as to establish the spontaneous combustion prediction system of No. 12 coal seam in TongXin Mine.

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