Gas analysis of jian-gou mine goaf

Chengyu Li, Lili Zhang*
Xinjiang Institute of Engineering
Supported by Xinjiang uygur autonomous regional university scientific research program projects: XJEDU2017M043;
Supported by the Education Program of Xinjiang Tianshan Talents: 2018xgytsyc2-6.

Abstract. Jiangou coal mine is a fully mechanized working face, with a height of 23 meters, serious air leakage in the goaf, easy spontaneous combustion of the coal seam, easy spontaneous combustion of the residual coal in the goaf. In order to prevent and control the spontaneous combustion fire in the goaf, we analyzed the thermal weight of B3 + 6 coal seam, obtains five characteristic temperature points. We conducted the heating and oxidation experiment of coal, analyzes the variation rule of the generated gas and its concentration with the temperature, and obtain the CO concentration distribution map of goaf based on the numerical simulation and on-site monitoring data.

1.Working face overview
Jiangou coal mine is a wholly owned mine owned by shenhua xinjiang energy co., LTD., located in the midong district of urumqi city, xinjiang uygur autonomous region.

The geological structure of the working face of coal seam B3+6 is relatively simple, without faults and folds, the roof bedding and joints of the coal seam are relatively developed, and it is easy to break and collapse. The coal seam contains a thin layer containing gangue, mostly less than 0.3m, and its lithology is carbonaceous mudstone and carbonaceous shale, which affect the stability of the coal seam. The working face length is 160m, the working face section is 23m high, and the coal seam is explosive dangerous. The spontaneous combustion period of coal is 1-2 months.

2.thermal analysis of coal
Coal spontaneous combustion is a process of oxidation and exothermic process carried out in stages. Thermogravimetry (tg) is a dynamic technique for measuring the change of the quality of samples with the temperature changing at constant speed or with the change of time under constant temperature conditions.

The coal sample of working face of B3+6 coal seam in alkali ditch coal mine was selected as the research object. Experiment was crushed in inert atmosphere to the particle size is less than 0.2 mm, and in the vacuum drying oven temperature was lower than 60 °C drying (temperature) for several hours, and then put in the dryer. Set aside. Sample indoor ventilation with oxygen concentration 21% of nitrogen and oxygen mixture volume, and 4 °C / min heating rates were used respectively to experiment. Let stand, all coal samples in the sample room after 5 min, the non-isothermal thermogravimetric (dynamic) method is adopted, the temperature rising process used on STC can precisely control the sample temperature control function, by 30 °C temperature to 450 °C, ventilation is 55 ml/min.
Thermal analytical curve and spontaneous combustion process analysis

The thermal weight analysis experiment was conducted on the coal sample, and the weight loss curve (TG curve) of the coal sample was obtained. Then, the weight loss rate curve (DTG curve) could be calculated by differentiating the weight loss curve. The TG curve and DTG curve are as fig 1.

By analyzing the coal sample TG, DTG diagram, we find five characteristic temperature points, and analyze it in detail:

1. Critical temperature $T_1$ of coal sample: that is, maximum point temperature of coal sample's weight loss rate. At this temperature, the chemical reaction speed of coal and oxygen is accelerated, which consumes the oxygen absorbed by the coal body and releases gases such as CO and CO$_2$. At this point, the amount of gas desorption and escape is greater than the amount of adsorption, the weight of coal decreases rapidly, and the weight loss rate reaches a maximum value. As can be seen from the figure 2.2, the critical temperature of coal samples is about 77 °C.

2. Dry cracking temperature $T_2$: that is, the temperature at the end point of coal sample weight loss. At this temperature, the dry cracking rate of small molecules such as side chains and qiao jian in the molecular structure of coal is accelerated, so that the growth rate of active structure is accelerated, the oxygen absorption capacity of coal is enhanced, and the chemical adsorption amount of coal is increased dramatically. The adsorption amount of coal is basically the same as that of gas produced by desorption and chemical reaction, forming a dynamic balance. Coal samples no longer lose weight. As you can see from figure 2.2, coal sample dryness temperature of 220.4 °C.

3. The active temperature of coal $T_3$: that is, the temperature at which the coal sample starts to gain weight. Under this temperature, with a ring structure in coal macromolecular broken key began to accelerate, the coal adsorption and stripping of dynamic balance is broken, as a result of the previous phase chemical reaction consumes a large amount of oxygen, reduce the amount of oxygen the available for reaction, reaction gas production is reduced, the coal surface pore can empty out a lot of oxygen, the chemical adsorption quantity increases, coal sample weight loss rate slows, began to gain weight. As you can see from figure 2.2, the activity of coal sample temperature of 247.4 °C.

4. Coal sample growth temperature $T_4$: that is, the temperature at the minimum point of coal sample weight loss rate. At this temperature, the breaking speed of large circular molecules in coal molecules is accelerated, the number of active structures exposed increases, the amount of oxygen
adsorption of coal samples increases dramatically, which is greater than the amount of gas produced by coal desorption reaction, the weight of coal increases, and the rate of weight loss decreases sharply or even becomes positive. As can be seen from the figure 2.2, the growth temperature of the coal sample is about 276.0 ℃.

(5) Ignition temperature of coal sample T5: that is, the temperature of coal sample weight to maximum value. At this temperature, the number of active structures and the amount of oxygen adsorption in coal reach the maximum value, and the weight gain of coal reaches the maximum, i.e. the accumulated adsorption amount reaches the maximum. As the temperature rises, it starts to burn, uses up oxygen and releases a lot of gas, and the coal sample begins to lose weight. As you can see from figure 2.2, coal samples of ignition temperature of 362.0 ℃.

3. Gas component analysis in goaf
Coal spontaneous combustion is a very complex physical and chemical change process, and it is a variable and self-accelerating exothermic process, which is mainly coal-oxygen compound oxidation. Among them, physical changes include gas adsorption, desorption, evaporation and condensation of water, heat conduction, coal body temperature rise, loose structure, etc. Chemical changes include chemical adsorption and chemical reaction of various active structures in coal surface molecules with oxygen, generating various oxygen-containing groups and producing a variety of gases, accompanied by thermal effects (exo- and endothermic). Due to the chemical reaction, internal crosslinking bonds of coal molecules are redistributed, which changes the physical and chemical properties of coal and further affects the process of coal-oxygen composition. This experiment is to heat up the coal sample in the program heating box. Under different temperatures, the amount and spontaneous combustion characteristics of CO, CO₂ and other gases produced by the coal sample are tested.

The experimental system of coal’s temperature rise and oxidation was established. By analyzing the variation rule of the gas released by the coal sample in the process of temperature rise and oxidation, the index gas suitable for the prediction and prediction of coal’s natural fire was determined.

The coal sample of working face of coal seam B3+6 in alkaline ditch coal mine was adopted. Before sampling, the surface oxidation layer of coal sample was removed first, then it was broken up and screened out 100g of 5mm target particle as the experimental coal sample. According to thermal analysis results of coal samples, heating experiment by 30 ℃ temperature to 220 ℃, and oxidizing experiment other conditions such as table 1.

The data obtained from the experiment are given in table 2. According to the experimental data, the gas change trend diagram is drawn, as showed in fig. 2 and fig. 3.

| Table 1 Experimental conditions |
|---------------------------------|
| Coal sample | granularity (mm) | Weight (g) | air mass flow (ml/min) | rate of temperature increase (℃/min) |
| B3+6 煤层 | 5 | 100 | 120 | 0.2 |

| Table 2 Experimental data |
|---------------------------|
| T (℃) | CO (ppm) | CO₂ (ppm) | CH₄ (ppm) | C₂H₄ (ppm) | C₂H₆ (ppm) | C₂H₂ (ppm) | C₃H₈ (ppm) |
| 30 | 1.01 | 56.57 | 1.23 | 0 | 0 | 0 | 0 |
| 40 | 1.33 | 93.92 | 3.16 | 0 | 0 | 0 | 0 |
| 50 | 1.05 | 178.67 | 6.69 | 0 | 0 | 0 | 0 |
| 60 | 4.80 | 239.05 | 12.91 | 0 | 0 | 0 | 0 |
| 70 | 10.80 | 340.55 | 19.76 | 0 | 0.34 | 0 | 0 |
| 80 | 29.24 | 427.87 | 33.84 | 0 | 1.27 | 0 | 0 |
| 90 | 67.08 | 560.67 | 40.81 | 0 | 3.22 | 0 | 0 |
| 100 | 145.29 | 746.17 | 52.69 | 0 | 4.45 | 0 | 0 |
By analyzing the experimental data and trend diagram, we can find that the coal sample at 30 °C to 220 °C temperature around regularly appear in the process of oxidation of CO, CO₂, CH₄, C₂H₄, C₂H₆, C₂H₂ and C₃H₈ gas, CO, CO₂ and CH₄ are three kinds of gas began to appear in 30 °C, CO gas generation product basic exponentially with the rise of coal temperature rise. When the detected CO, the mined-out area within the coal fire temperature at least 30 ~ 80 °C; CO generation of smaller at low temperature oxidation stage, coal temperature reaches a critical temperature T₁ (77 °C), after its generation increase rapidly, it shows that the temperature of coal oxidation has started quickly, physical adsorption is getting more and more weak and chemical adsorption and chemical reaction has a major position. CH₄ with the increase of coal temperature increase first and then, reach maximum at 170 °C, which is due to the adsorption of coal sample gas is released under the condition of heating, to release a quantity to around 170 °C maximum. C₂H₄ appears at 130 °C, the concentration of small but varies with temperature change regularly. Appear relatively late, C₃H₈ gas coal appears only when the temperature reached 160 °C, the emergence of the gas that coal heating and has developed to the point of very dangerous. C₂H₆ in 70 °C, the coal sample at the temperature began to analysis of chemical reaction; Coal and when the temperature reaches 200-220 °C (i.e., dry temperature T2) C₂H₂ increased significantly, compared with the other gas, appear relatively late, the emergence of C₂H₂ indicates that coal has entered a severe chemical reaction.

![Graph of CO and CO₂](image-url)

Fig. 2 The variety graph of CO and CO₂
Through comprehensive analysis of the change rule of gas concentration with temperature and combined with the characteristic temperature of coal, it is concluded that CO, C2H4 and C2H2 are the symbolic gases of coal spontaneous combustion, and the gas production rate of coal spontaneous combustion index increases exponentially with the increase of coal temperature. Coal spontaneous combustion is divided into three stages:

1. The index of CO gas is a good indicator of early prediction of spontaneous combustion of coal, coal mine in PPM level wind CO, coal at the slow oxidation stage, the temperature at 50 °C ~ 150 °C;
2. When PPM level CO and C2H4 occur, the coal body is in the accelerated oxidation stage;
3. When PPM level C2H2 occurs, the temperature is generally greater than the dry cracking temperature, and the coal is in the stage of intense oxidation, which will lead to an open fire. Using these three indexes, we cannot only predict the fire, but also distinguish its stage, and take different measures to prevent fire.

### 4. field test

For 5 consecutive days from June 4-8, the area behind the coal mining face at the back of 10m-100m was monitored. A measuring point was arranged every 10m interval. The monitoring data are as table 3. The average concentration of CO at the corner of the coal face was monitored for 5 consecutive days from June 4-8. The datum is as table 4.

| Distance of station | June 4 | June 5 | June 6 | June 7 | June 8 |
|--------------------|--------|--------|--------|--------|--------|
| 10m                | 25     | 25     | 25     | 25     | 25     |
| 20m                | 26     | 26     | 26     | 26     | 26     |
| 30m                | 32     | 31     | 30     | 33     | 32     |
| 40m                | 42     | 39     | 39     | 43     | 42     |
| 50m                | 53     | 51     | 50     | 53     | 53     |
| 60m                | 62     | 60     | 61     | 63     | 62     |
| 70m                | 53     | 52     | 51     | 53     | 53     |
| 80m                | 43     | 43     | 42     | 42     | 43     |
| 90m                | 40     | 40     | 40     | 40     | 40     |
| Date    | June 4 | June 5 | June 6 | June 7 | June 8 |
|---------|--------|--------|--------|--------|--------|
| CO/ ppm | 10.2   | 9.8    | 9.7    | 10.2   | 10.3   |

Table 4 CO concentration monitoring data

COMSOL software was used to build the model, simulation and compare it with the field measured data, and finally determine the CO concentration contour line of goaf during normal production as showed in the fig.4.

5. conclusion

(1) By thermogravimetric analysis experiments, we get the TG and DTG curves of coal samples, find five characteristic temperature points, respectively, 77 °C, 220.4 °C and 247.4 °C, 276.0 °C and 276.0 °C.

(2) By raising the temperature of coal oxidation experiments, we get the gas generated and its change rule of coal sample between 30 °C to 220 °C.

(3) Through field measurement and COMSOL software simulation, we obtained the CO concentration contour in the goaf during normal production.

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