Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2024, 11(10):72-84

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Experimental Study on the Marker Gases of Coal Seam Spontaneous Combustion in Liujialiang Coal Mine

Zhongliang LU[1, 2], Jiayi LI[1]

[1]School of Safety Science and Engineering, Henan Polytechnic University, China
[2]Supported by the State Key Laboratory Cultivation Base for Gas Geology and Gas Control, China
[2]State Collaborative Innovation Center of Coal Work Safety and Clean-efficiency Utilization, China

Abstract Spontaneous combustion of coal seam seriously threatens the production safety of mine, in order to better predict the spontaneous combustion of coal seam in coal mine and guide the prevention and control of coal mine fires, the author takes the coal samples from different working faces in the No. 2 and No. 5 coal seams of Liujialiang Coal Mine as examples to carry out temperature tests, on the basis of analyzing experimental data, the information of CO, C_2H_4, and other gases changing with temperature is obtained, the characteristics and rules of spontaneous combustion of coal seam in Liujialiang Coal Mine are studied, and the marker gases of different working faces are analyzed and optimized, CO and C_2H_4 are selected as the marker gases of spontaneous combustion in the coal face of No. 2 coal seam, No. 5136 coal face of No. 5 coal seam and No. 5135 driving face of No. 5 coal seam. By processing the experimental data, the corresponding mathematical model is established, and the fitting curve obtained can better reflect the change trend of the marker gases during spontaneous combustion of coal seam, which has certain guiding significance for preventing spontaneous combustion of coal seam in working face.

Keywords coal seam spontaneous combustion; simulation of spontaneous combustion of coal seam; marker gas; mathematical model

1. Introduction

Spontaneous combustion of coal is one of the main natural disasters in coal mine production, spontaneous combustion of coal not only causes the waste of coal resources, but also poses a serious threat to the safety of coal miners. However, coal with a tendency to spontaneous combustion accounts for about 2/3 of China's coal reserves, spontaneous combustion of underground coal seam has serious harm to the production safety of coal mine[1-6]. In the process of coal spontaneous combustion, with the increase of temperature, the coal regularly release CO, CO_2, CH_4, olefins, alkynes and other gases. The process of coal spontaneous combustion is actually a complex reaction of various functional groups in the coal structure, which can exhibit good segmented characteristics and can be used for early prediction of coal spontaneous combustion[7-14].

Previously, many domestic scholars have done a lot of research on the early prediction of spontaneous combustion of coal seam. Qiu Xuanbing established a coal seam spontaneous combustion detection system based on CO and CH_4 laser sensors, which has high sensitivity compared with traditional prediction systems; Liu Hongwei studied the delay effect of CH_4 under oxygen-poor conditions in high-gas mines and its influence on the marker gases under different oxygen concentration, and introduced the method of predicting spontaneous combustion in high-gas mines; Yang Xiao has done a lot of research on the changes of marker gases at critical temperatures[15-17]. At present, most coal mines in China use CO as the marker gas to predict coal spontaneous ignition, but the non-uniqueness of CO is gradually realized in the practical application process. In addition, coal mines are generally composed of multiple coal seams, and the coal types of different coal seams in the same coal mine have different spontaneous combustion and oxidation characteristics, and the conditions of coal seams are also very different, therefore, the prediction index system should be established according to the spontaneous combustion oxidation characteristics of each coal seam, so as to effectively prevent and control the mine fires. The No. 2 and No. 5 main coal seams of Liujialiang Coal Mine belong to the second type of coal seams, and the geological conditions are relatively complex, and the coal dust of various particle sizes are accumulated in a disorderly manner, which have a great impact on the spontaneous combustion of the coal seam in the working faces.

In this paper, the changes of different marker gases in the process of low-temperature oxidation of coal under different working face environments in Liujialiang Coal Mine are systematically studied and quantitatively analyzed, which is of great significance to prevent coal spontaneous combustion in working faces.

2. Materials and Methods

Experimental Principle

Spontaneous combustion of coal seams is due to the chemical adsorption and chemical reaction of coal to release heat in contact with oxygen, when the heat released is greater than the heat absorbed, coal burns due to increased temperature. The low-temperature spontaneous combustion experiment of coal is a simulation of this process, that is, under experimental conditions, relying on the oxidation and exothermy of coal itself, the coal temperature, oxygen consumption, carbon monoxide production and other factors are investigated.

Experimental Instrument

Figure 1 is a simulated experimental device for coal seam spontaneous combustion gas products, which is mainly composed of a program temperature control box, a gas analyzer, a copper coal sample tank, a preheating air circuit, a temperature control system, a gas mass flow controller, etc. The temperature programmed experimental device is mainly composed of three parts: gas supply system, temperature programmed system and gas sample analysis system; The gas supply system mainly includes a compressed air bottle, a pressure reducing valve, a glass rotameter and a display instrument, which are connected with latex pipes in turn; The temperature rise programmed system includes a temperature controller and a temperature rise programmed control equipment, which is equipped with a spiral preheating tube and a sample tank inside, and the temperature control accuracy is 0.1 °C; The gas sample analysis system includes an air bag and an analyzer.

The simulated experimental device for coal seam spontaneous combustion gas products can not only shorten the experimental period, but also reduce the amount of experimental samples, in addition, it can also carry out multiple repeated experiments, which has great advantages.

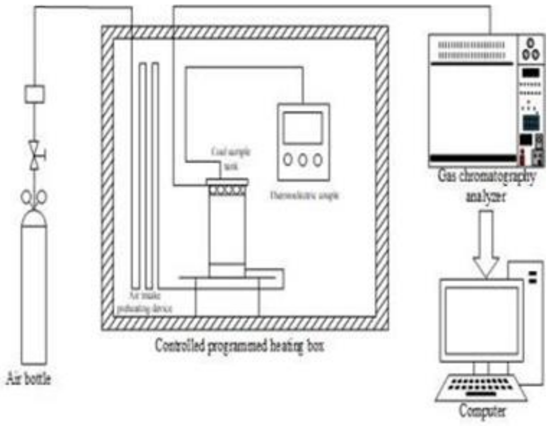

Figure 1: *Schematic diagram of simulation experimental device for coal seam spontaneous combustion gas products*

Primary Method

This instrument mainly uses chromatographic analysis method, with 99.99% pure hydrogen as the carrier gas, through the chromatographic analysis of hydrogen flame to analyze the concentration of CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, CO, CO_2 and other gas components.

Experimental Procedure

The steps of the determination are as follows: the raw coal samples are crushed and screened in the air, and the 20% particle size of 0 mm ~ 0.9 mm, 0.9 mm ~ 3 mm, 3 mm ~ 5 mm, 5 mm ~ 7 mm, and 7 mm ~ 10 mm are mixed. The coal loading height of the test tube is generally 20 cm, and the amount of coal used in the experiment is 1.0 kg. In the programmed temperature test tube, the flow rate of the gas supply is 100 mL/min, the oxygen concentration volume ratio concentration of the gas supply is 20.95% (air), and the heating rate is 0.5 °C/min from room temperature to 110 °C. 110 °C ~ 210 °C: 1 °C/min; 210 °C ~ 330 °C: 2 °C/min. Gas is taken every 20 ℃. In this experiment, samples are taken 5 times at 25 ℃ ~ 110 ℃, 5 times at 110 ℃ ~ 210 ℃, and 6 times at 210 ℃ ~ 330 ℃, a total of 16 samples are taken, and the sampling temperatures are as follows: 30 ℃, 50 ℃, 70 ℃, 90 ℃, 110 ℃, 130 ℃, 150 ℃, 170 ℃, 190 ℃, 210 ℃, 230 ℃, 250 ℃, 270 ℃, 290 ℃, 310 ℃, 330 ℃. According to the obtained data, graphs are drawn to analyze the oxygen consumption rate and gas production rate of the coal samples.

3. Results and Discussion

Combined with the actual mining environment of coal mines, spontaneous combustion of coal seam generally occurs in the coal mining faces and driving faces, therefore, this paper selects the mining face and driving face of No. 2 coal seam and No. 5136 mining face and No. 5135 driving face of No. 5 coal seam in Liujialiang Coal Mine, according to the experimental steps, the gas products in the coal samples of these working faces are detected and analyzed respectively.

Primary Method Measurement of Spontaneous Combustion Gas Products in No. 2 Coal Seam of Liujialiang Coal Mine

Experimental Data of Spontaneous Combustion Gas Products in No. 2 coal Seam of Liujialiang Coal Mine

The experimental data of spontaneous combustion gas products in No. 2 coal seam of Liujialiang Coal Mine are shown in Table 1 and Table 2.

Table 1: Experimental data of spontaneous combustion gas products in coal samples from coal mining face in No. 2 coal seam of Liujialiang

Temperature/℃	CO/ppm	CO_2/ppm	CH_4/ppm	C_2H_6/ppm	C_2H_4/ppm	C_3H_8/ppm
30	22.000	1134.0	14.23	12.34	0	1.599
40	7.156	954.4	10.77	15.59	0	2.465
50	7.406	1112.0	16.78	19.01	0	2.225
60	15.300	1492.0	22.25	30.77	0	2.520
70	38.660	1925.0	36.87	48.85	0	5.075
80	41.210	1003.0	26.98	29.84	0	1.200
90	90.450	1211.0	46.53	44.07	0	1.558
102	178.800	1482.0	50.39	62.63	0	5.804
115	338.200	1915.0	56.45	78.51	0	8.530
126	581.500	2587.0	56.68	94.47	0.778	10.990
140	985.100	3774.0	62.95	99.62	1.601	13.410
150	1568.000	5391.0	65.02	101.80	2.579	17.210
160	2473.000	7753.0	73.34	101.40	4.736	20.480
175	3927.000	1147.0	89.92	101.30	8.768	24.340
190	6104.000	1697.0	118.00	103.00	16.020	33.960
205	9120.000	2423.0	149.30	107.10	28.560	51.690
220	1127.000	2879.0	166.30	90.02	39.660	69.230

Table 2: Experimental data of spontaneous combustion gas products in coal samples from coal driving face in No. 2 coal seam of Liujialiang Coal Min

Temperature/℃	CO/ppm	CO_2/ppm	CH_4/ppm	C_2H_6/ppm	C_2H_4/ppm	C_3H_8/ppm
30	11.160	545.8	20.13	1.515	0	0
40	7.347	779.3	27.78	1.446	0	0
50	9.834	1117.0	39.81	1.866	0	0
60	22.200	1639.0	60.57	2.994	0	0

70	53.860	2277.0	110.80	4.330	0	0
80	32.690	1328.0	57.62	2.498	0	0
90	86.350	1191.0	101.70	2.474	0	0
100	192.200	1534.0	139.00	4.279	0	0
120	355.300	2007.0	156.40	5.903	0	1.4990
130	615.500	2672.0	165.20	7.880	0.7798	0.7412
140	973.100	3694.0	160.00	10.310	1.1630	0.5146
153	1596.000	5496.0	134.80	13.280	2.6300	4.2760
167	2644.000	8403.0	111.30	18.090	4.3580	8.1800
186	5107.000	14940.0	102.60	30.730	10.4500	15.3400
200	8109.000	22320.0	123.30	44.270	19.5700	26.8300
220	12080.000	31450.0	151.00	56.250	35.1000	47.4500

Variation Trend of Spontaneous Combustion Gas Products Concentration with Temperature in No. 2 Coal Seam of Liujialiang Coal Mine

In this paper, the respective amounts of spontaneous combustion gas products produced in coal samples from the coal mining face and driving face of No. 2 coal seam in Liujialiang Coal Mine are analyzed, and the variation trend of their concentration are shown in Figure 2 to Figure 5.

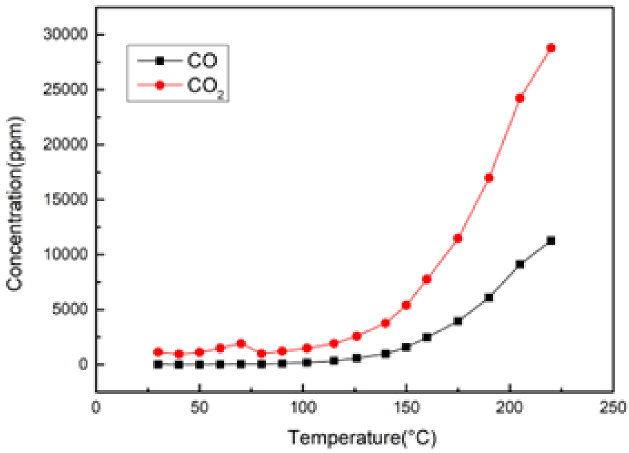

***Figure 2**: Variation trend of CO and CO_2 concentration in coal samples from coal mining face in No. 2 coal seam of Liujialiang Coal Mine*

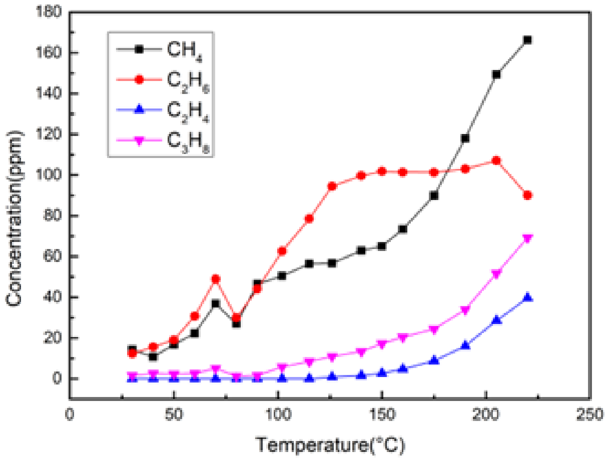

***Figure 3:** Variation trend of CH_4, C_2H_6, C_2H_4 and C_3H_8 concentration in coal samples from coal mining face in No. 2 coal seam of Liujialiang Coal Mine*

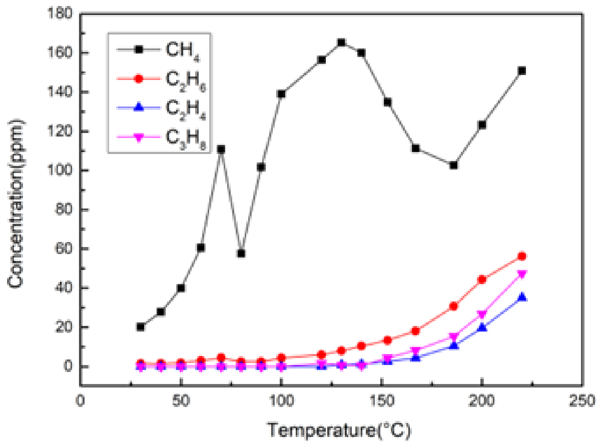

Figure 4: *Variation trend of CO and CO_2 concentration in coal samples from coal driving face in No. 2 coal seam of Liujialiang Coal Mine*

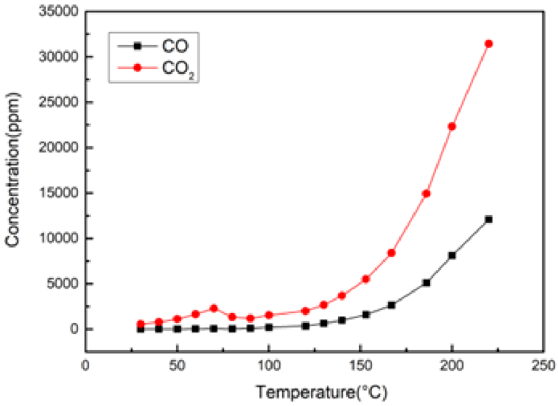

Figure 5: *Variation trend of CH_4, C_2H_6, C_2H_4 and C_3H_8 concentration in coal samples from coal driving face in No. 2 coal seam of Liujialiang Coal Mine*

Data Analysis of Spontaneous Combustion Gas Products in No. 2 Coal Seam of Liujialiang Coal Mine

Through the analysis of the above experimental data, it is found that CO, CO_2, CH_4, C_2H_6, C_2H_4, C_3H_8 and other gases regularly appear in the coal mining face and driving face in the temperature range of 30 ℃ ~ 220 ℃ during the oxidation process of the coal samples of No. 2 coal seam in Liujialiang Coal Mine. Due to the change of gas flow, a sudden change occurs at 70 °C, and the production of CO and CO_2 increase exponentially with the increase of coal temperature; The amount of CO generated is less in the low-temperature oxidation stage, but increases rapidly after 120 °C, indicating that coal has begun to oxidize rapidly at this temperature, the physical adsorption effect is weakened, and the chemical adsorption and chemical reaction occupy a dominant position; C_2H_4 does not appear in the temperature of 30 ℃ ~ 120 ℃, which indicates that the occurrence of C_2H_4 means that the coal will undergo a violent chemical reaction.

CH_4, C_2H_6 and C_3H_8 appear at the beginning of oxidation in coal samples from coal mining face in No. 2 coal seam of Liujialiang Coal Mine, and the concentration of each product increases with the increase of temperature; C_2H_4 appears at 126 °C in a small concentration, but with the increase of temperature, its production rate and production amount increase.

In coal samples from coal driving face in No. 2 coal seam of Liujialiang Coal Mine, with the increase of temperature, the concentration of CH_4 first increases and then decreases; The concentration of C_2H_6 increases with the increase of coal temperature; C_3H_8 appears at 120 °C and C_2H_4 appears at 130 °C, their concentration are not high, but with the increase of temperature, the production rate and production amount of C_3H_8 and C_2H_4 are increasing.

Measurement of Spontaneous Combustion Gas Products in No. 5 Coal Seam of Liujialiang Coal Mine

Experimental Data of Spontaneous Combustion Gas Products in No. 5 Coal Seam of Liujialiang Coal Mine

The experimental data of spontaneous combustion gas products in No. 5 coal seam of Liujialiang Coal Mine are shown in Table 3 and Table 4.

Table 3: Experimental data of spontaneous combustion gas products in coal sample of No. 5136 mining face of No. 5 coal seam in Liujialiang Coal Mine

Temperature/℃	CO/ppm	CO_2/ppm	CH_4/ppm	C_2H_6/ppm	C_2H_4/ppm	C_3H_8/ppm
30	5.196	585.6	5.207	8.807	0	1.352
40	1.547	903.0	8.863	46.270	0	6.254
50	11.070	1367.0	14.710	104.900	0	15.920
60	20.760	2105.0	22.430	220.600	0	38.710
70	41.000	2963.0	37.390	420.500	0	82.210
80	28.150	1258.0	18.730	225.300	0	48.730
90	47.500	1181.0	23.740	269.000	0	67.010
110	125.800	1272.0	18.510	223.000	0	113.600
124	202.800	1486.0	17.640	159.000	0	117.200
136	324.300	1868.0	16.990	97.610	0.6422	109.100
150	578.100	2747.0	19.190	52.940	1.1680	87.670
163	981.300	4074.0	23.970	64.280	3.8600	70.430
175	1637.000	6109.0	34.320	28.070	4.0570	55.410
190	2993.000	10260.0	61.040	31.830	8.7880	44.390
205	5177.000	16640.0	94.360	45.600	17.9800	50.240
220	7801.000	23780.0	140.700	59.590	31.5100	58.500

Table 4: Experimental data of spontaneous combustion gas products in coal sample of No. 5135 driving face of No. 5 coal seam in Liujialiang Coal Mine

Temperature/℃	CO/ppm	CO_2/ppm	CH_4/ppm	C_2H_6/ppm	C_2H_4/ppm	C_3H_8/ppm
30	25.170	405.6	4.953	4.771	0	0
40	7.018	561.1	7.824	15.040	0	2.641
50	10.620	865.6	9.564	27.830	0	3.157
60	24.400	1427.0	17.520	61.780	0	7.430
70	51.660	1894.0	27.500	103.500	0	15.590
80	34.730	874.8	14.100	45.980	0	8.673
90	74.330	962.5	23.470	71.590	0	7.347
100	135.000	1152.0	37.110	107.500	0	11.520
110	232.500	1384.0	53.260	149.200	0.9773	18.930
124	391.700	1809.0	74.370	195.200	0.6082	22.800
137	696.800	2647.0	99.110	231.700	1.8610	29.620
150	1231.000	4240.0	120.500	258.700	3.3780	33.240
163	2059.000	6623.0	164.600	263.800	6.3980	41.520
177	3407.000	10070.0	218.400	266.900	12.9200	57.870
193	5394.000	14670.0	276.800	261.400	25.8600	83.850
206	7439.000	18970.0	351.800	240.000	40.5000	109.300
220	9854.000	23760.0	400.600	199.300	60.9400	132.500

Variation Trend of Spontaneous Combustion Gas Products Concentration with Temperature in No. 5 Coal Seam of Liujialiang Coal Mine

In this paper, the respective amounts of spontaneous combustion gas products produced in the coal samples of No. 5136 mining face and No. 5135 driving face of No. 5 coal seam of Liujialiang Coal Mine are analyzed, and the variation trend of their concentration are shown in Figure 6 to Figure 9.

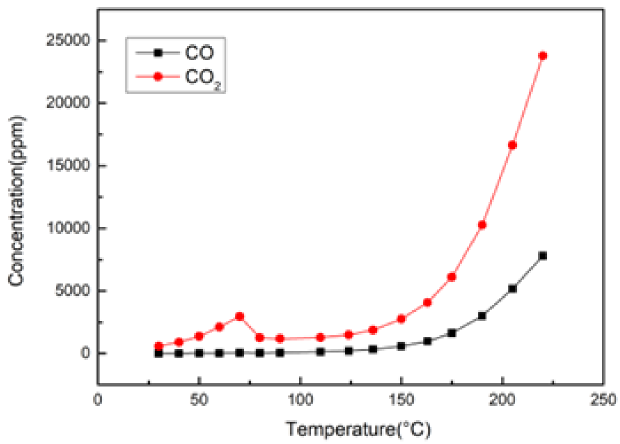

Figure 6: *Variation trend of CO and CO_2 concentration in coal samples of No. 5136 mining face of No. 5 Coal seam in Liujialiang Coal Mine*

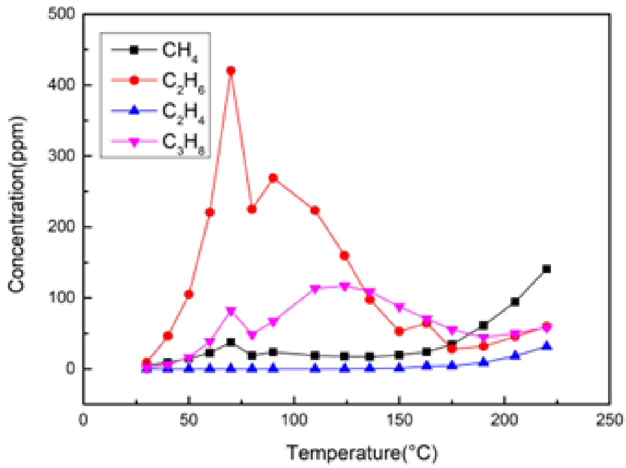

Figure 7: *Variation trend of CH_4, C_2H_6, C_2H_4, C_3H_8 concentration in coal samples of No. 5136 mining face of No. 5 Coal seam in Liujialiang Coal Mine*

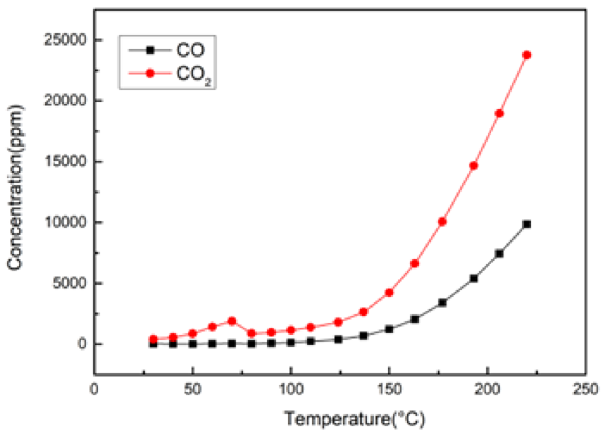

Figure 8: *Variation trend of CO and CO_2 concentration in coal samples of No. 5135 driving face of No. 5 Coal seam in Liujialiang Coal Mine*

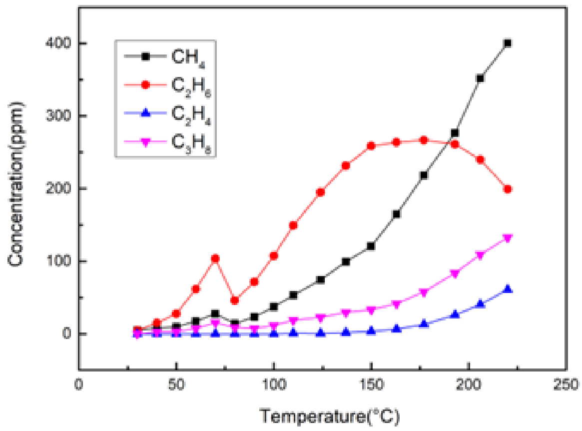

Figure 9: *Variation trend of CH_4, C_2H_6, C_2H_4, C_3H_8 concentration in coal samples of No. 5135 driving face of No. 5 Coal seam in Liujialiang Coal Mine*

Data Analysis of Spontaneous Combustion Gas Products in No. 5 Coal Seam of Liujialiang Coal Mine

Through the analysis of the above experimental data, it is found that CO, CO_2, CH_4, C_2H_6, C_2H_4, C_3H_8 and other gases regularly appear in No. 5136 mining face and No. 5135 driving face in the temperature range of 30 ℃ ~ 220 ℃ during the oxidation process of the coal samples of No. 5 coal seam in Liujialiang Coal Mine. Due to the change of gas flow, a sudden change occurs at 70 ℃, and the production of CO and CO_2 increase exponentially with the increase of coal temperature; The amount of CO generated is less in the low-temperature oxidation stage, but increases rapidly after 120 °C, indicating that coal has begun to oxidize rapidly at this temperature, the physical adsorption effect is weakened, and the chemical adsorption and chemical reaction occupy a dominant position; C_2H_4 does not appear in the temperature of 30 ℃ ~ 100 ℃, which indicates that the occurrence of C_2H_4 means that the coal will undergo a violent chemical reaction.

C_2H_6 and C_3H_8 appear in the coal samples of No. 5136 mining face of No. 5 coal seam in Liujialiang Coal Mine at the beginning of oxidation, and the concentration of each product first increases and then decreases with the increase of temperature; C_2H_4 appears at 136 °C in a small concentration, but with the increase of temperature, its production rate and production amount increase.

In the coal samples of No. 5135 driving face of No. 5 coal seam in Liujialiang Coal Mine, with the increase of temperature, the concentration of C_2H_6 first increases and then decreases; The concentration of C_3H_8 increases with the increase of coal temperature; C_2H_4 appears at 110 °C, its concentration is not high, but with the increase of temperature, the production rate and production amount of C_2H_4 is increasing.

Optimization and Mathematical Model of Spontaneous Combustion Marker Gas in Coal Seam

Optimization of Marker Gas for Spontaneous Combustion of Coal Seam

Generally speaking, the best gas index of spontaneous combustion of coal seam must have the following conditions [18-24]:

1. Sensitivity: Once the coal in the coal mine is in a state of spontaneous combustion, the coal temperature exceeds a certain value, there will be marker gas, and its generation will increase steadily with the increase of coal temperature.

2. Regularity: There is a good correspondence between the concentration change of marker gas and coal temperature, with good repeatability.

3. Testability: The presence of the marker gas can be detected with an ordinary chromatographic analyzer.

According to the above test results, the gas products decomposed during the oxidation process of coal samples tested between 30 ℃ ~ 220 ℃ are CO, CO_2, CH_4, C_2H_6, C_3H_8 and C_2H_4. Existing studies have shown that olefins, acetylene and carbon monoxide are the products of carbon oxidation during coal spontaneous combustion, and these gas masses do not exist in coal adsorbed gases[25-28], therefore, these gas groups are the characteristic gas parts that mark the process of spontaneous combustion oxidation of coal. In general, CH_4 and CO_2 are the main components of coal spontaneous combustion adsorption gas, and the rest are a small amount of alkane gas, namely C_2H_6 and C_3H_8. These alkane gases are sucked away as the temperature of the coal rises. CH_4 and CO_2 are susceptible, so they are not marker gases during the spontaneous combustion oxidation of coal. Whether C_2H_6 and C_3H_8 can be used as marker gases of coal spontaneous combustion depends on the initial temperature and the change law after precipitation. Therefore, CO and C_2H_4 are selected as the marker gases for spontaneous combustion in the coal seam of Liujialiang Coal Mine, and both of them have good characteristics.

CO Index Analysis

In many mines, CO is widely used as the main fire marker gas when predicting the spontaneous combustion of coal. In the process of low-temperature oxidation, the amount of CO generated is closely related to the temperature of the coal seam, and the CO concentration shows a monotonic upward trend with the increase of the coal seam temperature, showing a slow change trend between 45 °C ~ 160 °C, among which, the oxidation rate between 45 °C ~ 80 °C is relatively slow, and the oxidation rate increases between 80 °C ~ 160 °C, and when the temperature exceeds 160 °C, the amount of CO generated increases sharply, and the coal begins to enter the accelerated oxidation stage, and CO can be used as an early marker gas for the prediction of natural ignition in coal mines. In order to more check the release rule of marker gas during the oxidation process of coal samples between 30 °C ~ 220 °C, in this paper, the curve fitting is carried out according to the experimental data, and the regression mathematical model is obtained through the data regression analysis.

The method of curve fitting is adopted to fit the CO concentration in the coal samples in the coal face of No. 2 coal seam of Liujialiang Coal Mine according to the temperature, as shown in Figure 10, and the corresponding fitting formula is obtained, as shown in formula (1).

$$y = A1e^{-x/t1} + A2e^{-x/t2} + A3e^{-x/t2} + y0$$

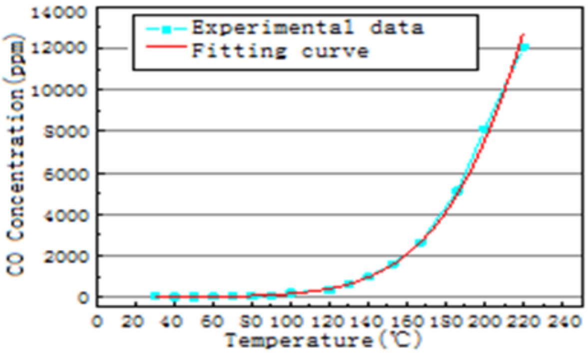

Figure 10: *Relationship between CO concentration and temperature in coal samples from coal mining face in No. 2 coal seam of Liujialiang Coal Mine*

$$Y = e^{(1.28654+0.77x-1.2955E-4x^2)} \quad R^2 = 0.99976$$

The method of curve fitting is adopted to fit the C_2H_4 concentration in the coal samples in the coal face of No. 2 coal seam of Liujialiang Coal Mine according to the temperature, as shown in Figure 11, and the corresponding fitting formula is obtained, as shown in formula (2).

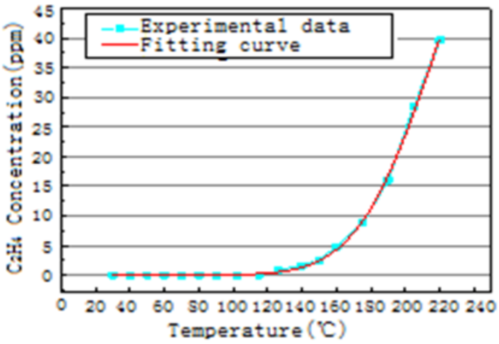

Figure 11: *Relationship between C_2H_4 concentration and temperature in coal samples from coal mining face in No. 2 coal seam of Liujialiang Coal Mine*

$$Y = e^{(-14.06473+0.14072x-2.72846E-4x^2)} \quad R^2 = 0.99999$$

The method of curve fitting is adopted to fit the CO concentration in the coal samples in the driving face of No. 2 coal seam of Liujialiang Coal Mine according to the temperature, as shown in Figure 12, and the corresponding fitting formula is obtained, as shown in formula (3).

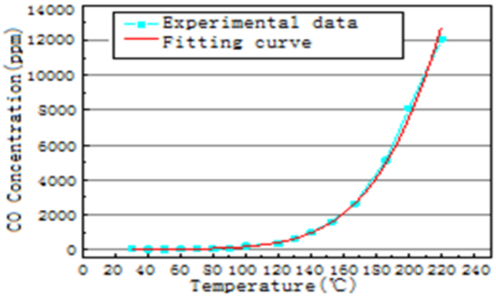

Figure 12: *Relationship between CO concentration and temperature in coal samples from coal driving face in No. 2 coal seam of Liujialiang Coal Mine*

$$Y = e^{(-0.75395+0.06842x-1.00059E-4x^2)} \quad R^2 = 0.99983$$

The method of curve fitting is adopted to fit the C_2H_4 concentration in the coal samples in the driving face of No. 2 coal seam of Liujialiang Coal Mine according to the temperature, as shown in Figure 13, and the corresponding fitting formula is obtained, as shown in formula (4).

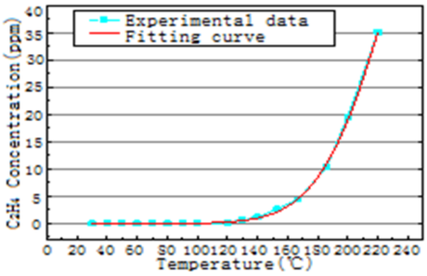

Figure 13: *Relationship between C_2H_4 concentration and temperature in coal samples from coal driving face in No. 2 coal seam of Liujialiang Coal Mine*

$$Y = e^{(-13.39297+0.12788x-2.30979E-4x^2)} \quad R^2 = 0.99999$$

The method of curve fitting is adopted to fit the C_3H_8 concentration in the coal samples in the driving face of No. 2 coal seam of Liujialiang Coal Mine according to the temperature, as shown in Figure 14, and the corresponding fitting formula is obtained, as shown in formula (5).

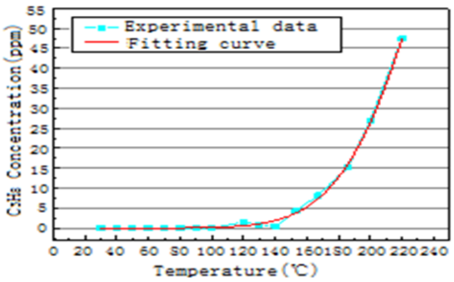

Figure 14: *Relationship between C_3H_8 concentration and temperature in coal samples from coal driving face in No. 2 coal seam of Liujialiang Coal Mine*

$$Y = e^{(-10.69041+0.10687x-1.85129E-4x^2)} \quad R^2 = 0.99997$$

The method of curve fitting is adopted to fit the CO concentration in the coal samples of No. 5136 coal face of No. 5 coal seam in Liujialiang Coal Mine according to the temperature, as shown in Figure 15, and the corresponding fitting formula is obtained, as shown in formula (6).

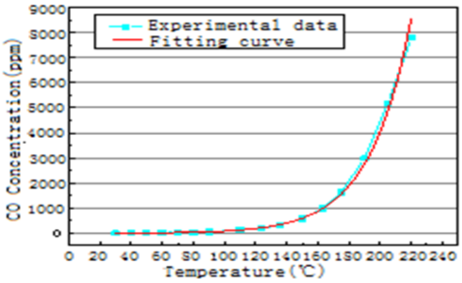

Figure 15: *Relationship between CO concentration and temperature in coal samples of No. 5136 mining face of No. 5 Coal seam in Liujialiang Coal Mine*

$$Y = e^{(-0.34176+0.04181x-9.98265E-6x^2)} \quad R^2 = 0.99987$$

The method of curve fitting is adopted to fit the C_2H_4 concentration in the coal samples of No. 5136 coal face of No. 5 coal seam in Liujialiang Coal Mine according to the temperature, as shown in Figure 16, and the corresponding fitting formula is obtained, as shown in formula (7).

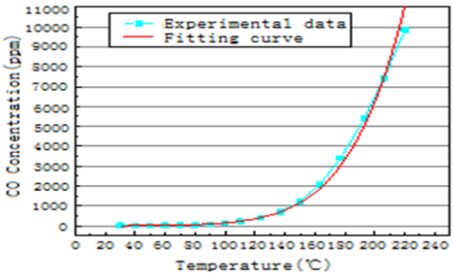

Figure 17: *Relationship between CO concentration and temperature in coal samples of No. 5135 driving face of No. 5 Coal seam in Liujialiang Coal Mine*

$$Y = e^{(-0.19862+0.05945x-7.375E-5x^2)} \quad R^2 = 0.99988$$

The method of curve fitting is adopted to fit the C_2H_4 concentration in the coal samples of No. 5135 driving face of No. 5 coal seam in Liujialiang Coal Mine according to the temperature, as shown in Figure 18, and the corresponding fitting formula is obtained, as shown in formula (9).

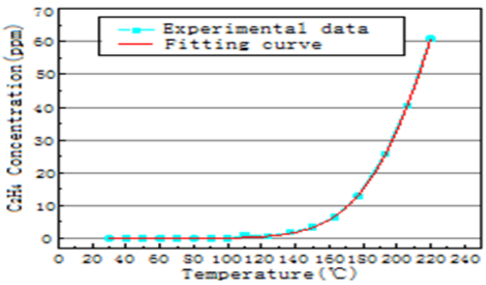

Figure 18: Relationship between C_2H_4 concentration and temperature in coal samples of No. 5135 driving face of No. 5 Coal seam in Liujialiang Coal Mine

$$Y = e^{(-12.31302+0.12304x-2.19919E-4x^2)} \quad R^2 = 0.99999$$

Figure 10 to Figure 14 are the measurement curves of the mining face and driving face of No. 2 coal seam in Liujialiang Coal Mine and the fitting curves of the change of the concentration of the marker gases with the temperature of the coal seam and the roof, formulas (1) to (5) are the corresponding fitting formulas. Figure 15 to Figure 18 are the measurement curves of No. 5136 coal face and No. 5135 driving face of No. 5 coal seam in Liujialiang Coal Mine and the fitting curves of the change of the concentration of the marker gases with the temperature of the coal seam and the roof, formulas (6) to (9) are the corresponding fitting formulas. The measurement and fitting curves show that the fitting curves reflect the change trend of the measured values well, and the obtained mathematical model is of great significance for predicting the spontaneous combustion of coal.

4. Conclusion

According to the observation and analysis of the content of the marker gases in the coal samples of different working faces of the No. 2 and No. 5 coal seams of Liujialiang Coal Mine, as well as the data processing of the measured values of the marker gases, the corresponding mathematical model is established, and it is found that the change trend of each marker gas has a good correlation with the spontaneous combustion of coal, which is of great significance for predicting the spontaneous combustion of coal and preventing fires.

References

[1]. Y. T. Liang, X. J. Hou, H. Z. Luo (2016). Current situation and development countermeasures of coal mine fire prevention and control in China. Coal Science and Technology, 44(06): 1-6+13.

[2]. B. T. Qin, X. X. Zhong, D. M. Wang (2021). Research progress on the characteristics of coal spontaneous combustion process and prevention technology. Coal Science and Technology, 44(01): 66-99.

[3]. Y. Gao (2014). Research on the symbiotic disaster of goaf gas and coal spontaneous combustion caused by coal mining. China University of Mining and Technology (Beijing).

[4]. W. Z. Huang (2005). Research on natural ignition mechanism and prevention technology of coal gangue mountain. Chongqing University.

[5]. J. Deng, J. C. Xu, G. Q. Ruan (1994). Summary of coal spontaneous ignition forecasting technology at home and abroad. Journal of Xi'an Institute of Mining and Technology, (04): 293-297+337.

[6]. J. M. Zhang, S. N. Ning, Y. Cao (1998). Study on the environmental impact of spontaneous combustion of coal seams in northern China and its treatment countermeasures. Journal of Disaster Reduction in China, (01): 34-38.

[7]. J. Deng, J. C. Xu, X. K. Chen (2003). Research progress of coal spontaneous combustion mechanism and prediction theory. Journal of Liaoning Technical University, (04): 455-459.

[8]. M. G. Yu, Q. A. Wang, W. C. Fan (2001). Research on the prediction of natural ignition period of coal seam. Journal of China University of Mining and Technology, (04): 64-67.

[9]. J. C. Xu, M. G. Xu, J (2000). Deng. Research on natural ignition prediction technology based on coal-oxygen composite process analysis. Journal of Fire Science, (03): 21-27.

[10]. Y. G. Wu, J. M. Wu, J. F (2007). Wang. Experimental study on spontaneous combustion index gas in coal seam. Chinese Journal of Coal, (04): 40-42.

[11]. Q. Liu, D. M. Wang, X. X. Zhong (2013). Gas test of natural ignition index of coal seam based on programmed heating. Journal of Liaoning Technical University (Natural Science Edition), 32(03): 362-366.

[12]. J. G. Niu, T. Y. Wang (2023). Research on Internet of Things monitoring and early warning technology of coal seam spontaneous combustion disaster in gob area. Coal Mine Modernization, 32(02): 64-69.

[13]. Y. A. Zhou, C. H. Ye, Y. L (2022). Chen. Research on early multi-level early warning method for spontaneous combustion and ignition process of mine coal seam. Inner Mongolia Coal Economy, (02): 5-8.

[14]. R. Wang, B. M. Shi (2022). Research on the determination of index gas and the division of "Three Zone" of spontaneous combustion in Zhujixi Coal Mine. Coal Technology, 41(09): 99-102.

[15]. X. Qiu, Y. Wei, J. Li (2020). Early detection system for coal spontaneous combustion by laser dual-species sensor of CO and CH4. Optics & Laser Technology, 121: 105832.

[16]. H. Liu, F. Wang, T. Ren (2021). Influence of methane on the prediction index gases of coal spontaneous combustion: A case study in Xishan coalfield,China. Fuel, 289: 119852.

[17]. Y. Xiao, Q. Li, J (2017). Deng. Experimental study on the corresponding relationship between the index gases and critical temperature for coal spontaneous combustion. Journal of thermal analysis and calorimetry, 127(1): 1009-1017.
[18]. Y. Xiao, Z. P. Wang, L. Ma (2008). Study on the correspondence between coal spontaneous combustion index gas and characteristic temperature. Coal Science and Technology, (06): 47-51.
[19]. Y. X. Wang (2001). Prediction of coal mine spontaneous combustion fires by index gas. Coal Mine Safety, (06): 15-16+58.
[20]. L. Q. Zhu, X. Q. Zhou, J. G. Xie (2008). Experimental analysis and optimal selection of natural ignition marker gas. Journal of Mining and Safety Engineering, 25(04): 440-443+448.
[21]. Y. H. Xu, M. G. Xu, J. C. Xu (2005). Discussion on several key problems of prediction and prediction of coal spontaneous combustion fire index gas. Mining Safety and Environmental Protection, (01): 16-18+24-0.
[22]. Z. H. Xie, L. Z. Jin, B. H. Ren (2004). Coal spontaneous combustion characteristics and optimal selection of indicator gases. Coal Mine Safety, (02): 10-12.
[23]. C. L. Wang, A. Y. Wu, K. X. Cai (2006). Experimental study on spontaneous combustion tendency of coal and optimization of index gas. Chinese Journal of Safety Science, (10): 131-134+4.
[24]. W. Wang (2020). Determination of coal seam spontaneous ignition indicator gas and critical value. Coal Mine Safety, 51(12): 219-223.
[25]. Z. Q. Li, H. M. Yang, H. Z. Luo (1997). Application and analysis of coal seam spontaneous ignition indicator gas. Coal Mine Safety, (02): 38-41.
[26]. J. Fu, K. Zhao, H. Y (2019). Zhang. Application of grey correlation method in the selection of coal spontaneous combustion flag gas. Coal Mine Safety, 50(05): 181-185.
[27]. P. J. Wu, J. G. Zhang, H. Y. Kang (2010). Experimental analysis and study on the selection of coal seam natural ignition index gas. Journal of North China University of Science and Technology, 7(04): 25-29.
[28]. J. C. Yan, J. Yao (2009). Experimental study on the selection of landmark gases and spontaneous combustion tendency of coal samples. Journal of North China University of Science and Technology, 6(02): 26-29.