Research on remote monitoring technology of temperature field in goaf of fully mechanized caving face

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Abstract. In this paper, the test site is the working surface hollowing area of Luling Coal Mine 8, coal seam III 811, and the distributed fiber temperature measurement is carried out. Distributed temperature measuring fibers and beam tubes are arranged in the inlet and return wind lanes of the work surface for continuous monitoring. After analyzing the data such as measuring temperature and gas concentration, the remote monitoring technology of the temperature field in the mining area is expanded. Finally, combined with the self-ignition characteristics of the Luling coal seam and the classification criteria of the "three zones" in the mining area, the range of the self-ignition hazard area of the III 811 mining area is accurately determined. This paper provides theoretical and technical support for the development of targeted fire prevention measures and remote monitoring.

1. Geological profile

1.1. Working surface conditions
The average length of the III811 comprehensive release face of Lu Ling mine is 717.0m and the slope width is 175.9m. The soft rock is mined as a protective layer, and the soft rock face is 54.0~64.0 m away from the bottom plate of 9# coal seam and 20.0~27.0m away from the top plate of 10# coal seam.[1]-[2]

The distance between the top of No.8 coal seam and No.7 coal seam is 19.38m on average, and the direct top is siltstone with thickness ranging from 0 to 10.78 m; the gangue in No.8 and No.9 coal seam is mudstone and siltstone with thickness ranging from 0 to 4.44m and average of 1.3m.

1.2. Working surface ventilation
Luling mine uses mixed ventilation, and the ventilation method is extraction. In the next three years, the whole mine will maintain two coal mining working faces, and according to the requirement of reasonable mining ratio, when calculating the ventilation capacity of the whole mine, one coal mining working face will be arranged in the south wind shaft, and one coal mining working face will be arranged in the west wind shaft system, and the capacity of the mine ventilation system will be 2,246,000 t/a.[3]-[4]
1.3. Other mining conditions
The absolute and relative gas gushing amount is 20.4 m$^3$/min and 3.32 m$^3$/t respectively in 811 general release working face, and the protruding danger has been eliminated for coal 8# and 9#. The 8# and 9# coal seams are explosive; they are spontaneous ignition coal seams with natural ignition period of 71~74 days and spontaneous ignition grade II.

2. Experimental study of spontaneous combustion characteristics of 8# coal
The experiment was carried out in a controlled programmed warming box to monitor the oxygen consumption rate, CO, CO$_2$, CH$_4$, C$_2$H$_6$, C$_2$H$_4$ and other products of coal of different particle sizes at different temperatures, and to classify the spontaneous combustion process of #8 coal into four stages: latent, self-heating, spontaneous combustion and quenching, according to the temperature-dependent curves of the products generated and the characteristics of the temperature and coal physicochemical changes such as alkane ratio and alkane hydrocarbon ratio, see Figure 1, where the dashed line is the weathering process line. The sum of the latency and autothermal periods is the natural firing period of the coal.

![Figure 1 Characteristic curve of 8#、9# coal spontaneous combustion process](image)

8# Coal: 1~2 is called latent stage, 2-31 is called natural fire hidden danger stage, 31~4 is called natural fire phenomenon stage, more than 4 is called natural fire stage; 9# Coal: 1~2 is called latent stage, 2-32 is called natural fire hidden danger stage, 32~4 is called natural fire phenomenon stage, more than 4 is called natural fire stage.

Based on the above analysis, the relationship between the spontaneous combustion stage of coal and the indicator gas and temperature can be obtained, as shown in Figure 2.

![Figure 2 The relationship between spontaneous combustion characteristics of coal and temperature](image)

3. Analysis of natural fire patterns in open space
Based on the 811 working face parameters as the basis of simulation, the overburden collapse condition after coal release mining is shown in Figure 3.
Figure 3  Caving condition of overlying strata in fully mechanized top coal caving face

Figure 4 shows the temperature field simulation of the quarry.

| (a) Gas temperature field distribution | (b) Temperature field distribution of caving coal |
|--------------------------------------|-----------------------------------------------|

Figure 4  Distribution of spontaneous combustion fields in Goaf

The beam tube monitoring system was used to analyze the gas in the mining area of the Ⅲ811 working face, and the oxygen concentration distribution in the mining area was obtained, as shown in Figure 5.

Figure 5  Change of oxygen concentration in goaf of Ⅲ811 working face

Physical simulation conclusion: in the range of about 15-20m behind the face, the direct top collapse, overhang, not filled; 20m later in the range of falling gangue is gradually compressed, tends to compaction.

RFPA simulation: 10m behind the face direct top collapse, overhang; 10m to 25m range, the old top partly collapsed, local still overhang; 25m to 75m range, the gangue falling gangue is gradually compressed, tends to compaction closure.

FLAC simulations: cyclic compaction step is about 15m, the width of the rock beam structure.

4. Fiber optic remote monitoring system for temperature field in the air pockets
KJ588 mining fiber optic distributed temperature measurement device is selected, using fiber optic sensing signal and transmission signal, using OTDR technology and Raman scattered light sensitive to
temperature characteristics, detecting the temperature changes along the fiber optic at different locations, to achieve a wide range, long-range temperature detection.

4.1. Distributed temperature measurement system

Working diagram of distributed temperature measurement system is shown in Figure 6.

![Figure 6 Working diagram of distributed temperature measurement system](image)

4.2. Distributed Temperature Sensing Monitoring System (DTSMS)

Based on the Raman scattering principle of optical fiber, the integrated system of distributed temperature sensing software and hardware can provide all-round and multi-dimensional continuous temperature monitoring of the target area. It is divided into two parts: the substation system (Client) and the master control station system (Server), which are connected by the enterprise communication ring network or special communication optical fiber to realize the remote real-time collection, display, storage and distribution of temperature data.

4.3. Remote monitoring system

Based on the Team Viewer program, a connection can be established between two computers by automatically generating partner IDs and entering each other's IDs into Team Viewer. The connection between the remote computer and the mainframe computer in the dispatching room of the Lu Ling mine is realized in order to remotely view and monitor the temperature field changes in the mining area.

5. Engineering practice

5.1. Distributed temperature measurement fiber arrangement in the airfield

According to the specific situation of 811 working face of LuLing mine, one optical fiber is laid in the machine lane and three optical fibers are laid in the wind tunnel in the field test. Each optical fiber along the chain machine to the depth of the mining area 170m, wind tunnel in the three optical fiber buried in the interval of 30m. Buried in the internal fiber of the mining area using the screen pipe protection, in the upper and lower corners of the high-pressure oil pipe protection. After the completion of the optical fiber laying, should strengthen the maintenance, improve the level of protection, to ensure normal temperature measurement, sampling.

The distributed fiber optic temperature monitoring system can continuously measure the temperature, and reflect the temperature condition of each point in the airgathering area in real time in the monitoring software, and take the fiber optic temperature measurement results at 100m, 200m and 300m fixed points on the inlet side and return side, respectively, and record the fixed point temperature change law with time.
5.2. Real-time monitoring data from a fibre-optic temperature measurement system in the open area

5.2.1 Fiber Optic Temperature Data
Table 1 shows some of the temperature measurement data exported by Channel 1.

| Max Value | Max Position | Min Value | Min Position | Average Value | Record Time | Device ID       | Device Name |
|-----------|--------------|-----------|--------------|---------------|-------------|----------------|-------------|
| 37.8      | 846          | 26.6      | 54           | 29.30187      | 7:52:03     | D1234_192.168.0.14 | TT2         |
| 38.4      | 846          | 26.7      | 93           | 29.42471      | 7:52:14     | D1234_192.168.0.14 | TT2         |
| 37.8      | 846          | 26.5      | 96           | 29.34344      | 7:52:26     | D1234_192.168.0.14 | TT2         |
| 37.0      | 846          | 26.5      | 93           | 29.24848      | 7:52:37     | D1234_192.168.0.14 | TT2         |
| 36.6      | 844          | 26.6      | 53           | 29.32236      | 7:52:48     | D1234_192.168.0.14 | TT2         |
| 37.4      | 846          | 26.7      | 97           | 29.4048       | 7:53:00     | D1234_192.168.0.14 | TT2         |
| 37.9      | 846          | 26.5      | 57           | 29.40386      | 7:53:11     | D1234_192.168.0.14 | TT2         |
| 37.7      | 846          | 26.4      | 95           | 29.21206      | 7:53:22     | D1234_192.168.0.14 | TT2         |
| 36.2      | 844          | 26.6      | 100          | 29.23185      | 7:53:34     | D1234_192.168.0.14 | TT2         |
| 37.4      | 846          | 26.4      | 95           | 29.29052      | 7:53:45     | D1234_192.168.0.14 | TT2         |
| 37.1      | 846          | 26.6      | 53           | 29.29813      | 7:53:56     | D1234_192.168.0.14 | TT2         |
| 37.4      | 846          | 26.5      | 100          | 29.276        | 7:54:08     | D1234_192.168.0.14 | TT2         |

5.2.2 Historical statistics on fiber-optic monitoring
See Figure 7 for an example of work surface channel 1 (2019.08.12 - 2019.09.12).

5.2.3 Fibre-optic monitoring single point historical statistics
See Table 2 shows that the table distance is the location of 2019.10.12 face for the starting point of the "0 m", a total of 90 m behind the statistics face range.

Table 2  Two channel single point data statistics of optical fiber monitoring in partial goaf

| Record Time | Distance to the face | Average Value of Channel Name 1 | Average Value of Channel Name 1 |
|-------------|----------------------|---------------------------------|---------------------------------|
| 2019.08.01  | 86.4                 | 24.30012                         | 23.71892                         |
| 2019.08.15  | 69.6                 | 29.28525                         | 29.99011                         |
| 2019.09.01  | 49.2                 | 25.12248                         | 24.41424                         |
| 2019.09.15  | 32.4                 | 25.07201                         | 23.97449                         |
| 2019.09.30  | 14.4                 | 24.76306                         | 24.80969                         |
| 2019.10.01  | 13.2                 | 24.53337                         | 24.18437                         |
| 2019.10.02  | 12.0                 | 25.04988                         | 22.47268                         |
| 2019.10.03  | 10.8                 | 24.84085                         | 22.41093                         |
5.2.4 data analysis
A scatter plot was generated from the statistical data (Figure 8). Vertical coordinates are the monitored temperature values in °C; vertical coordinates are the distance, the distance from the working surface (2019.10.12) position.

The measured results show that the temperature is slightly lower in the range of 10 m behind the working surface, around 21°C; the temperature gradually increases in the range of 10 ~ 80 m, in the range of 23 ~ 32°C. Basically with the previous theoretical analysis, simulation of the "three band" is consistent, that is: the width of the dispersion zone 10 ~ 15 m, the width of the oxidation zone (self-heating) 60 ~ 70 m or so. It is consistent with the conclusion of the theoretical analysis.

6. Conclusions
(1)The fiber optic temperature measurement system for the temperature field in the air gathering area at the general release working face integrates computer, fiber optic sensing, photoelectric control and other technologies, and is connected to the management network in the LAN to realize information sharing, real-time dynamic monitoring and remote monitoring of the temperature field in the air gathering area.

(2)Through the index gas experiment, the analysis of 8 coal spontaneous combustion and O2 concentration, the temperature of the intrinsic relationship between; the use of numerical simulation software, the temperature field distribution in the mining area; at the same time through the physical simulation results, the analysis of the overburden cap drop rule, experimental and simulation results to guide the beam tube and optical fiber detection work carried out.

(3)By burying the bundle pipe in the working face into the return air lane, according to the change of O2 concentration, measured the scope of spontaneous combustion in the mining area "three zones", the suffocation zone is more than 70 ~ 80 m.

(4)We innovated the optical fiber arrangement of the working surface, the depth of the optical fiber buried in the mining area reaches 170m, to achieve full coverage of the mining area temperature field monitoring, and get the temperature distribution of the mining area: within 10m behind the working surface, the temperature is slightly lower, around 21°C: the temperature gradually increases in the range of 10～80m, in the range of 23～32°C.

(5)Combined with numerical simulation of temperature field, physical simulation, beam tube monitoring and fiber optic monitoring results, we clarified the relationship between spontaneous combustion in the mining area "three bands" and the overlying rock beam, mine pressure: theory and practice show that: the width of the dispersion zone 10 ~ 15 m, the width of the oxidation zone (self-heating zone) about 60 ~ 70 m: to provide theoretical guidance for on-site prevention.

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