Study on Gas Distribution and Migration in Stope Based on Gas Monitoring

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Abstract. If the safe concentration of gas in coal mine exceeds the upper limit, it will bring great risks to coal mine production. Therefore, it is of great significance to study the distribution law of gas concentration on coal face. This paper established the layout plan of gas sensor, measured the gas concentration of each observation point under the wind speed of 3m/s, established the trend surface model of first order to fifth order, and solved the trend surface equation of each order, obtained the best trend surface equation through a variety of testing methods, and studied the gas distribution and migration rules in detail.

1. Introduction

As is known, there are many sources of gas in the coal mining face, and the gas concentration is affected by many factors, so the gas concentration distribution of the coal mining face is very complicated. Generally, the gas concentration at the corner is usually the highest. Once the upper limit of the coal mine gas safety concentration is exceeded, it will bring great risks to coal mine production. Therefore, it is of great significance to study the distribution law of gas concentration on coal mining face. In this paper, the monitoring scheme of gas sensor is established by observing the data layout of the air entry and air exit in the coal mining face. In this paper, surfer 9 is used to draw the contour map and trend map of gas concentration distribution on the coal face[1]. Through the contour map and trend map, gas distribution and migration on the coal face are analyzed from an overall perspective.

2. The trend surface of gas distribution is solved

In a gas mine

\[ Q_{CH_4} = Q_1 \times C_{CH_4} \]  (1)

\( Q_{CH_4} \) -- Gas emission from coal face
\( Q_1 \) -- Return air volume of coal mining working face
\( C_{CH_4} \) -- Concentration of gas in coal mining face

The unit of air return on the coal face is cubic meter per minute, the unit of gas concentration on the coal face is percentage, and the unit of absolute gas emission is cubic meter per minute. In this paper, gas concentration is used for numerical analysis[2].
2.1. Distribution and test of gas sensor

We arranged 5 data observation faces between the air intake roadway and the air outlet roadway on the coal mining face, each of which was parallel to the air intake roadway and the air outlet roadway, and the spacing between each face was controlled at 30m. As shown in figure 1 in every face is divided into three layers, each layer spacing of 0.5 m, in each layer, the intervals of 1 m gas measurement of a wireless sensor node, then each observation surface gas measurement has 15 wireless sensor node, the purpose is to get more accurate information, in the same coordinate point layout three sensors, the average of the three sensors, get the point of observation value, so we can get 25 observations. In the coal mining face, a cuboid of wireless sensor gas measurement node is formed. There are 75 wireless sensor gas measurement nodes[3-5]. The overall effect is shown in figure 2.

![Figure 1. Elevation of the observed surface](image1)

![Figure 2. Overall cuboid effect of wireless sensor](image2)

During the observation process, the wind speed in the ventilation alley is guaranteed to be about 3m/s, and each time is about 10 minutes before and after the coal mining. The measurement process is as follows: the staff starts the whole wireless network through the base station node, issues the networking instruction, and wakes up all the wireless sensor measurement nodes for networking until the network is completed; The shearer is located at the upper end of the mining face. About 10 minutes before coal cutting, make the base station node send out the measurement command, start all the measurement nodes to measure the gas concentration before coal cutting, and upload to the base station node to save the data[6-8]. The coal shearer is located at the lower end of the coal mining face. After waiting for about 10 minutes, it controls the base station node again to send out the measurement command to measure the gas concentration of the coal mining face.

Experimental data:

From the coal wall to the goaf, namely the Y-axis direction, we set its y-coordinates as 0, 1, 2, 3,4. From the observation surface close to the air inlet roadway to the observation surface close to the air return roadway, that is, in the X-axis direction, the X coordinates of sensors in each plane are set as: 0, 30, 60, 90 and 120, respectively. The five sensors with the same x-coordinate are one observation surface. The data results are given below, as shown in table 1:

| Table 1. experimental data |
|----------------------------|
| Gas data results (before coal cutting) | Concentration/% (Y, X) | 0 | 30 | 60 | 90 | 120 |
|-----------------------------------------|-------------------------|---|----|----|----|-----|
| 0                                       | 0.21                    | 0.25| 0.31| 0.39| 0.41|     |
| 1                                       | 0.20                    | 0.23| 0.28| 0.37| 0.41|     |
| 2                                       | 0.18                    | 0.22| 0.26| 0.36| 0.47|     |
| 3                                       | 0.19                    | 0.19| 0.29| 0.38| 0.68|     |
| 4                                       | 0.17                    | 0.21| 0.32| 0.39| 0.83|     |

| Gas data results (after coal cutting) | Concentration/% (Y, X) | 0 | 30 | 60 | 90 | 120 |
|-----------------------------------------|-------------------------|---|----|----|----|-----|
| 0                                       | 0.28                    | 0.37| 0.51| 0.65| 0.62|     |
| 1                                       | 0.27                    | 0.32| 0.46| 0.62| 0.66|     |
| 2                                       | 0.26                    | 0.30| 0.44| 0.60| 0.75|     |
| 3                                       | 0.25                    | 0.29| 0.48| 0.61| 0.89|     |
| 4                                       | 0.24                    | 0.29| 0.52| 0.63| 1.02|     |
2.2. Solution of trend surface equation and modest test of model

We know that if the change is relatively simple gas data analysis, so we can approximate it with a smaller trend plane. If the gas data change is more complicated, then we need to establish a trend surface with a relatively large size of \( n \). But it’s not as if the more frequent the better. When the order is too high, its interpolation and extrapolation characteristics will become significantly worse[9]. The order of the general trend surface should be three to five times.

In this paper, the software SURFACER 9 of the US GOLEDN company is used to solve the trend surface equation and draw the trend surface graph. In this paper, only the trend analysis of the gas concentration before coal cutting is carried out. The method of cutting the coal part is the same as that before the coal cutting, and will not be described again.

When we find the coefficients of the fitting equations of each order, we can also find the trend values and residuals of each observation point in the fitting equations of each order, and then we can calculate the appropriate test parameters of the trend surface model, as shown in Table 2:

| Table 2. Experimental data of fitting equations for various trend surfaces |
|-------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                              | level one       | Second order    | Third order     | Fourth order    | Fifth order     |
| \( SS_m = \sum_{i=1}^{n} (Z_i - \hat{Z}_i)^2 \) | 0.167126        | 0.060549857     | 0.019151        | 0.007499985     | 1.130189395     |
| \( SS_p = \sum_{k=1}^{n} (\hat{Z}_i - \bar{Z})^2 \) | 0.409777        | 0.516346        | 0.557745        | 0.580593        | 1.703718        |
| \( \sum_{i=1}^{n} (Z_i - \bar{Z})^2 \) | 0.576896        | 0.576896        | 0.576896        | 0.576896        | 0.576896        |

\[ R^2 = \frac{SS_m}{SS_e} = 1 - \frac{SS_p}{SS_e} \]

\[ R = \frac{SS_k}{SS_p / (N-k-1)} \]

\[ F = \frac{SS_1}{SS_p} \]

(1) Inspection (test of fitness):
The larger the trend, the better the goodness of the trend surface.
(2) F test (test of the significance of the trend surface model), take \( \alpha = 0.01 \)

| Table 3. Trend surface model significance test |
|-------------------------------|-----------------|-----------------|-----------------|-----------------|
| order | \( F_{0.01}(k, N-k-1) \) | \( F \) | \( F>F_{0.01}(k, n-k-1) \) |
| 1     | \( F_{0.01}(2, 22) = 5.72 \) | 4.0864378 | \( \times \) |
| 2     | \( F_{0.01}(5, 19) = 4.17 \) | 14.21269528 | \( \sqrt{\} \) |
| 3     | \( F_{0.01}(9, 15) = 3.89 \) | 48.5392 | \( \sqrt{\} \) |
| 4     | \( F_{0.01}(14, 10) = 4.60 \) | 129.0209 | \( \sqrt{\} \) |
| 5     | \( F_{0.01}(20, 4) = 14.02 \) | 2.5124373 | \( \times \) |

\( N \) - the number of gas observation points
\( k \) - the number of terms of the polynomial in the trend surface equation (except for the constant term)

Combining the above two test methods and the angle of relative error, it is best to choose the fourth-order trend surface equation, so we calculate the relative error of each point of the fourth-order trend surface[10].
2.3. Establishment of the trend surface equation
Combining the above test methods and the relative error angle, it is best to choose the fourth-order
trend surface equation.
The trend surface equation is obtained as:
\[ z = f(xy) = 0.2139 + 0.0507x - 0.0032y - 0.0839x^2 + 0.0008xy + 0.0002y^2 + 0.0322x^3 + \\
0.0004x^2y - 4.5385 \times 10^{-5} xy^2 - 1.7716 \times 10^{-6} y^3 - 0.0037x^4 - 7.2222 \times 10^{-5} y^4 + \\
2.4376 \times 10^{-6} x^2y^2 + 2.9012 \times 10^{-7} xy^3 + 5.6584 \times 10^{-9} y^4 \]

3. Distribution law of gas in coal mining face
The coal mining face is a long, narrow and very low coal mining site. This paper only introduces the
gas distribution of the coal mining face before coal cutting, as shown in Figure 3:
(1) the direction of the Y axis, that is, the direction of the goaf to the coal wall;
(2) The direction of the X-axis, that is, the direction from the inlet duct to the outlet duct.

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3.1. Gas distribution trend change
The contour map of the gas concentration distribution of the coal mining face and the trend change
graph of the trend surface analysis fitting model:
From the trend contour map and the anomaly component equivalence graph, it can be found that the denser the line, the faster the trend value changes; the more sparse, the slower the trend value changes. The trend portion corresponds to the portion that causes the macro change, and the abnormal component portion corresponds to the portion that causes the local change. By dividing the observations of each point into trend value, abnormal component and random component, we can clearly know the influence of local geological factors and regional geological factors on the amount of gas emission when studying the gas emission. At the same time, the combination of trend contour map and abnormal component equivalent map is beneficial to analyze the relationship between regional geological factors and local geological factors.

In Figure 5, the contours are denser and denser in the X-axis direction, which means that the gas concentration changes faster near the return air passage, which means that the gas concentration is getting larger and larger from the ventilation tunnel to the return air passage. The increasing rate of gas concentration is relatively low between 0 and 90 m, and the increasing rate of gas concentration is relatively high between 90 and 120 m. It can be found in Figure 4 that the closer to the goaf, the steeper the gas concentration curve, C For the upper corner, the maximum value is reached; in the Y-axis direction, the two gas observation surfaces near the air inlet lane have a small decrease in concentration. In the middle of the coal mining face, the gas concentration is “middle, both sides”. The shape of the big one, at the end of the coal mining face, the acceleration of the gas concentration will increase greatly, that is, its gas concentration curve will be steep. There will be eddy currents at C, and a lot of gas will accumulate here.

4. Conclusion
There are many kinds of coal mine disaster accidents in China. Among them, gas prevention and control is particularly important. This paper uses mathematical software to simulate the gas distribution and migration characteristics of the stope, and analyzes its distribution law from the overall angle, which provides a powerful reference for effectively preventing gas accidents.

Through the combination of the trend contour map and the anomaly component equivalent map, we can clearly analyze the relationship between regional geological factors and local geological factors. The analysis results show that the coal mining face return air lane and goaf the deep part is the place where gas accumulation is easy to occur; the gas in the middle of the working surface presents the distribution law of “middle small, big two sides”, and vortex phenomenon appears near the upper corner, and many gas accumulate here[11].

Gas prevention and control measures should be specifically analyzed according to the actual conditions of different coal mines, and targeted prevention measures should be taken.

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