Prediction of Coal Spontaneous Combustion Temperature Based on Numerical Analysis

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Abstract: Coal will release CO gas in the process of natural oxidation. The early prediction of coal spontaneous combustion can be realized by detecting CO gas. However, coal temperature is the key and reliable factor to determine the development degree of coal spontaneous combustion. The data of coal temperature and CO gas concentration in the process of low-temperature oxidation are obtained through experiments. Based on the principle of numerical analysis, the relationship model between temperature (independent variable) and CO gas concentration (dependent variable) is established, and the inverse function of the model is solved, so as to establish the functional relationship between CO concentration (independent variable) and coal temperature (dependent variable), and realize the prediction of coal temperature through CO concentration Purpose. The prediction accuracy can meet the engineering requirements by applying this method to an engineering example. This study provides a reliable method for the prediction of coal spontaneous combustion temperature.

1. Introduction

Coal spontaneous combustion is one of the six major disasters that restrict high-efficiency, high-efficiency and safe production in coal mines, and seriously affects the safety and efficiency of coal mine production. The spontaneous combustion process of coal is roughly divided into four stages: preparation stage, self-heating stage, combustion stage and extinguishing stage. There are obvious differences in the phenomenon of coal spontaneous combustion at different stages. Accurately grasping the stage of coal in the spontaneous combustion process is to take fire prevention measures Premise. During the natural oxidation of coal, CO gas is inevitably released, and the spontaneous combustion of coal is usually predicted by detecting the concentration of CO gas. However, coal temperature is the most reliable and critical factor that determines the spontaneous combustion of coal in different spontaneous combustion processes. The method of index gas cannot directly reflect the temperature of coal in application. At present, it is difficult to obtain the temperature of coal at the source of the fire directly. Coal will inevitably release CO gas in the process of natural oxidation. In this paper, the basic principle of numerical analysis is used to establish a relationship model between temperature (independent variable) and CO gas concentration (dependent variable), and the inverse function of the model is solved to establish The functional relationship between CO concentration (independent variable) and coal temperature (dependent variable) realizes the purpose of predicting coal temperature through CO concentration. Taking the test coal mine as an example, a prediction model is established to realize the prediction of coal temperature. The prediction result reaches the prediction accuracy acceptable to the project. This shows that the research method has certain reliability and provides a method for the prediction of coal spontaneous combustion temperature.

1.1 Basic Principles of Numerical Analysis

In the study of statistical methods in scientific experiments, it is often necessary to find the functional relationship between the independent variable x and the dependent variable y = F () from a set of experimental data (xi, yi) (i = 0, 1, ..., m). x). Because the observation data is often inaccurate, it is not required that y = F (x) pass through all points (xi, yi), but only the error δi = F (xi) -yi (i = 0, 1, ... , M) minimum according to some standard. If δ = (δ0, δ1, ..., δn), it is required

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that the norm δ of the vector δ is the smallest. If the maximum norm is used, the calculation is more difficult, and the Euclid norm ‖ δ ‖ 2 is usually used as the standard for error measurement. The general reference to the least square method is: for a given set of data (xi, yi) (i = 0, 1, ..., m), it is required to be in the function space φ = span {φ0, φ1 ..., φn} Find a function y = S * (x) to sum the squared errors

$$\|\delta\|_2^2 = \sum \delta_i^2 = \sum [S^*(x_i - y_i]^2 = \min \sum [S(x_i - y_i]^2$$

$$S(x)=a_0\varphi_0(x)+ a_1\varphi_1(x)+\ldots+ a_n\varphi_n(x) \ (n<m)$$

This is the general least squares approximation, also known as the least square method of curve fitting. When the least square method is used to find the fitting curve, the form of S (x) must be determined first. This is not a purely mathematical problem, but also related to the motion law of the studied problem and the obtained observation data (xi, yi); usually, the form of S (xi) should be determined from the motion law of the problem and the given data tracing, and the actual calculation Choose a better result. The general expression of S (x) is the linear form shown in formula (1.2). If φk (x) is a polynomial of degree k, S (x) is a polynomial of degree n. In order to make the formulation of the problem more general, the least square method is usually considered as a weighted square sum of ‖ ⊢ δ ⊣ ‖ ⊣ _2 ^ 2, as shown in Equation 1.3.

$$\|\delta\|_2^2 = \sum_{i=0}^{m} \omega(x_i)[S(x_i) - f(x_i)]^2$$

In the formula: ω (x) ⩾ 0 is a weight function on [a, b], which means that the data proportions at different points (xi, f (xi)) are different, if ω (x_i) can be expressed at points xi, f The number of repeated observations at (xi), find the function y = S * (x) in S (x) of the form (1.2) to minimize the expression (1.3), which translates into finding the multivariate function 1.4 The minimum point (a_0 ^ *, a_1 ^ *, ..., a_n ^ *) problem.

$$I(a_0, a_1, \ldots, a_n) = \sum \omega(x_i)[\sum a_i\varphi_i(x_i) - f(x_i)]^2$$

According to the necessary conditions for the extremum of multivariate function, there are

$$\frac{\partial I}{\partial} = 2\sum_{i=0}^{m} \omega(x_i)[\sum_{i=0}^{n} a_i\varphi_i(x_i) - f(x_i)]\varphi_k(x_i) = 0 \ (k = 0, 1, \cdots, n)$$

$$(\varphi_i, \varphi_k) = \sum \omega(x_i)\varphi_i(x_i)\varphi_k(x_i)$$

$$(f, \varphi_k) = \sum \omega(x_i)\varphi_i(x_i)\varphi_k(x_i) \equiv d_k \quad (k = 0, 1, \cdots, n)$$

$$\sum (\varphi_k, \varphi_i)a_i = d_k \quad (k = 0, 1, \cdots, n)$$

This equation is a normal equation, rewritten into a matrix form as:

$$Ga=d$$

$$a=(a0,a1,\ldots,an)T,d=(d0,d1,\ldots,dn)T,$$

$$G = \begin{bmatrix} (\varphi_0, \varphi_0) & (\varphi_0, \varphi_1) & \cdots & (\varphi_0, \varphi_n) \\ (\varphi_1, \varphi_0) & (\varphi_1, \varphi_1) & \cdots & (\varphi_1, \varphi_n) \\ \vdots & \vdots & \cdots & \vdots \\ (\varphi_n, \varphi_0) & (\varphi_n, \varphi_1) & \cdots & (\varphi_n, \varphi_n) \end{bmatrix}$$

Since φ_0, φ_1, ⋯, φ_n are linearly independent, so | ⊢ G⊣ | ≠ 0⊣ , then there is a unique solution to the equation a_k = a_k ^ * (k = 0, 1, ⋯, n), and the function f (x) The least squares solution of is:

$$S^*(x) = a_0^*\varphi_0(x) + a_1^*\varphi_1(x) + \cdots + a_n^*\varphi_n(x)$$

That is, S ^ * (x) is the least squares solution.

2. Prediction Model of Coal Spontaneous Combustion Temperature

According to the related information and actual situation, the exponential relationship or parabolic relationship between temperature (t) and CO concentration (C). Establish a mathematical model of the relationship between temperature and CO concentration. The independent variable is temperature and the dependent variable is CO concentration.

$$C=a_0+ a_1t^1+ \cdots+ a_nt^n$$

Or C = aebt + c (2.2)

In the formula: C--CO gas concentration, 10-6;

a0, a1, ..., an--curve equation coefficient;

n--Order of curve equation, generally n is 2 or 3;

a, b, c-coefficients of the exponential equation.

Find the inverse functions of equations 2.1 and 2.2 to get the relationship between CO concentration and temperature. The independent variable is CO concentration (C) and the dependent variable is temperature (t). The inverse function of formula 2.1 is formula 2.3 when n = 3:

$$t = \frac{1}{6a_3}(12\sqrt{3}(4{a_1}^3a_3 - {a_1}^2{a_2}^2 - 18a_0a_1a_2a_3 + 18a_1a_2a_3 * C + 4{a_2}^3a_0 - 4{a_2}^3 * C + 27{a_3}^2{a_0}^2 - 54{a_3}^2a_0 * C + 27{a_3}^2 * C^2)^{1/2}a_3 + 36a_1a_2a_3 - 8{a_2}^3 - 108{a_3}^2a_0 + 108{a_2}^2 * C)^{1/3} - \frac{2}{3a_3}(3a_1a_3 - {a_2}^2)(12\sqrt{3}(4{a_1}^3a_3 - {a_1}^2{a_2}^2 - 18a_0a_1a_2a_3 + 18a_1a_2a_3 * C + 4{a_2}^3a_0 - 4{a_2}^3 * C + 27{a_3}^2{a_0}^2 - 54{a_3}^2a_0 * C + 27{a_3}^2 * C^2)^{1/2}a_3 + 36a_1a_2a_3 - 8{a_2}^3 - 108{a_3}^2a_0 + 108{a_2}^2 * C)^{-1/3} - \frac{a_2}{3a_3} \quad (2.3)$$

And:

$$M= 12\sqrt{3}(4{a_1}^3a_3 - {a_1}^2{a_2}^2 - 18a_0a_1a_2a_3 + 18a_1a_2a_3 * C + 4{a_2}^3a_0 - 4{a_2}^3 * C + 27{a_3}^2{a_0}^2 - 54{a_3}^2a_0 * C + 27{a_3}^2 * C^2)^{1/2}a_3 + 36a_1a_2a_3 - 8{a_2}^3 - 108{a_3}^2a_0 + 108{a_2}^2 * C$$

Then the above formula can be changed to:

$$t = \frac{M^{1/3}}{6a_3} - \frac{M^{-1/3}}{3a_3} - \frac{a_2}{3a_3} \quad (2.4)$$

When n = 2, it is 2.5 type:

$$t = \frac{\sqrt{{a_1}^2 - 4a_2a_0 + 4a_2C} - a_1}{2a_2} \quad (2.5)$$

$$t = \frac{ln(\frac{C-c}{a})}{b} \quad (2.6)$$

3. Solution of Coal Spontaneous Combustion Temperature Prediction Model

The solution process of the coal spontaneous combustion temperature prediction model is to first use a certain basic data to fit the functional relationship between temperature (t) and CO concentration (C). Then, the fitting equation with smaller residual modulus is selected as the relationship model between temperature and CO concentration. Finally, the coefficients of the corresponding relationship model are brought into the corresponding inverse function equation to obtain the relationship between the CO concentration and the temperature, thereby obtaining the

mathematical model for predicting the coal bed temperature by checking the CO concentration. As a fitting in MATLAB, the least squares polynomial fitting is performed using the polyfit function, and its calling format is as follows:

$$p=polyfit(x_0,y_0,n) \quad (3.1)$$

Where: x0, y0-known data;
n--the degree of polynomial;
p is the coefficient of the returned polynomial.

4. Examples of Coal Spontaneous Combustion Temperature Prediction

In order to test the reliability of the prediction model, the coal sample collected at the lower part of the 7128 working face of the test coal mine was subjected to an oxidation heating experiment to obtain the concentration of gas CO released by the coal sample at different temperatures, as shown in Table 1.

Table 1 Concentration of Co Gas Released At Different Temperatures

No.	T/℃ CO/10-6	No.	T/℃	CO/10-6	
1	21	0.12	6	70	8.69
2	30	0.91	7	80	15.19
3	40	1.87	8	90	24.28
4	50	2.61	9	100	37.48
5	60	4.26	10	110	65.00

According to the coal mine safety regulations, the allowable concentration of CO is 2410-6, and the data in rows 1-7 in Table 1 is used as sample data, and the data in rows 8-10 is used as prediction data. Carry on data fitting through MATLAB software, and finally find that when n = 3, the residual modulus is the smallest. The fitting curve is shown in Figure 1, and the fitting residual chart is shown in Figure 2. The function equation of temperature (t) and CO concentration (C) is:

$$C=0.0001t^3-0.016t^2+0.63t-7.58 \quad (4.1)$$

Substituting the corresponding coefficient in (4.1) into (2.3) gives:

$$t = 0.24 * (84 * \sqrt{9922500 * C^2 - 18654900 * C + 8856229} + 264600 * C - 248732)^{1/3} - 204.76 * \left(84 * \sqrt{9922500 * C^2 - 18654900 * C + 8856229} + 264600 * C - 248732\right)^{-1/3} + 38.10 \quad (4.2)$$

Bring the concentration of CO in rows 8-10 of Table 1 into equation (4.2) to obtain the temperature prediction results, as shown in Table 2. It can be seen from this method that the prediction accuracy meets engineering requirements.

Table 2 Prediction Results of Coal Spontaneous Combustion Temperature

No.	$CO/10^{-6}$	T/℃	T/℃ Gap/℃	Gap/%	
8	24.28	92.69	90	2.69	2.99
9	37.48	101.76	100	1.76	1.76
10	64.23	114.83	110	4.83	4.39

5. Conclusion

The temperature of coal is the most reliable and critical factor that determines the spontaneous combustion of coal in different spontaneous combustion processes. Coal will inevitably release CO gas during natural oxidation. In this paper, the basic principles of numerical analysis, combined with literature and engineering practice, first established the relationship model between temperature (independent variable) and CO gas concentration (dependent variable), and then solved The inverse function of the model is obtained, so as to establish the functional relationship between CO concentration (independent variable) and coal temperature (dependent variable) to achieve the

purpose of predicting coal temperature through CO gas concentration. Taking the test coal mine as an example, the model that first established the relationship between temperature and CO gas concentration was established, and then established the functional relationship between CO concentration and coal temperature. The CO gas concentration was used to predict the coal temperature. Accepted prediction accuracy, the research content of this paper provides a method for the prediction of coal spontaneous combustion temperature.

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