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Self-heating tendency evaluation of sulfide ores based on nonlinear multi-parameters fusion

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Abstract: In order to reveal the nonlinear dynamics characteristics of unsteady self-heating process of sulfide ores, nine different kinds of sulfide ore samples from a pyrite mine in China were taken as experimental materials and their self-heating characteristics were measured in laboratory. Furthermore, the measured temperature was studied by integrating wavelet transform, nonlinear characteristic parameters extraction and fuzzy comprehensive evaluation. The results indicate that only the ore samples 1, 2, 6 and 9 have obvious self-heating phenomenon, and their self-heating initiative temperatures are 220 °C, 239 °C, 220 °C and 220 °C, respectively, which means that they are difficult to produce self-heating under normal mining conditions. The correlation dimension of self-heating process is fraction and the maximum Lyapunov exponent is positive, which means that it is feasible to study the self-heating process based on chaotic dynamics theory. The nonlinearities of self-heating process of these four samples (ore samples 1, 2, 6 and 9) are 0.8227, 0.7521, 0.9401 and 0.8827 respectively and the order of the samples according to these results is: sample 6, sample 9, sample 1, sample 2, which is consistent with the measured results of self-heating characteristics. Therefore, the nonlinearity method can be used to evaluate the self-heating tendency of sulfide ores, and it is an effective verification of the reliability of measured results.
Key words: sulfide ores; self-heating process; nonlinear characteristic parameter; nonlinearity; self-heating tendency

1 Introduction

Spontaneous combustion of sulfide ores is a conversion of the chemical energy to heat due to oxidation [1−3]. If the reaction heat doesn't dissipate entirely, sulfide ores will be heated and release more and more heat, which is a positive feedback. When the temperature of sulfide ores reaches the ignition temperature, spontaneous combustion will take place. It is well known that spontaneous combustion of sulfide ores is one of the most serious disasters in sulfide deposits mining [4−6]. According to statistics of spontaneous combustion, it has occurred in more than ten mines in China since 1949, such as Wushan Copper Mine, Xiangshan Pyrite Mine and Dongguashan Copper Mine [7]. Spontaneous fires of sulfide ores not only generate massive toxic gas and heat to worsen the work environment, but also bring about large economic losses even loss of human life. For the rapid decrease of surface mineral resources, deep mining has become a trend and its high temperature can cause spontaneous combustion more easily. Therefore, researches on the oxidation mechanism, prevention and control technology of spontaneous combustion are a premise to ensure safe and efficient mining for high-sulfur mines.

In recent years, evaluation for spontaneous combustion tendency of sulfide ores has attracted attention of many researchers and some new evaluation methods have been proposed, such as apparent activation energy method [8], matter-element model [9], evaluation model based on entropy and set pair analysis theory [10], Fisher discriminant analysis method [11] and uncertainty measurement model [12]. To evaluate the spontaneous combustion tendency of sulfide ores synthetically, self-heating initiative temperature, which is measured by

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carrying out self-heating characteristics experiment, is commonly used as an index. As the self-heating of sulfide ores is a nonlinear multi-factor coupling evolution process, research on the unsteady self-heating process by means of nonlinear dynamics theory is worthy of further study. Currently, there are very scarce researches on nonlinear characteristics of self-heating process.

In this work, nine kinds of typical sulfide ore samples from a pyrite mine in China were taken as experimental materials and their self-heating characteristics were measured with precision instruments in laboratory. Combined with wavelet transform, nonlinear characteristic parameters extraction and fuzzy comprehensive evaluation, the nonlinearity of ore samples self-heating process, which is the characterization of complexity for self-heating process, was calculated. Moreover, self-heating tendency evaluation method of sulfide ores based on nonlinear multi-parameters fusion was proposed.

2 Experimental

2.1 Ore samples collection and analysis

Sulfide ore samples were collected from a pyrite mine in China with the sampling method of multi-point sampling, and nine types of representative samples were taken as experimental materials. As an example, the chemical composition of the ore sample 1 is listed in Table 1.

Table 1 Chemical composition of ore sample 1 (mass fraction, %)

Water-soluble iron ion	Total sulfur	Monomer sulfur	Sulfate ion
0.0016	35.27	0.044	1.57

The metallic mineral of the ore sample 1 is pyrite with two-stage mineralization. The largest size of early-stage pyrite particles is about 5 mm, and their average size is about 2 mm. They are fragmented as a result of the stress action. Unlike the early-stage pyrite particles, the late-stage pyrite particles are fine-grained aggregates with the average size of about 5 μm. The micrograph of the ore sample 1 is shown in Fig. 1.

2.2 Experimental method

In the experiment, the particle diameter of ore samples was ground to less than 0.2 mm. Each sample with mass of about 100 g and moisture content of about 5% was installed into the reactor in the automatic heating incubator to measure its self-heating characteristics owing to the weak oxidation of sulfide ores at normal temperature. The initial temperature was set between 40 and 50 °C and one single heating extent was about 10 °C. After the temperature of automatic heating incubator reached the setting temperature, it was kept isothermal for about 30 min. During the experiment process, the maximum temperature of automatic heating incubator was not higher than 250 °C. The experimental devices are shown in Fig. 2.

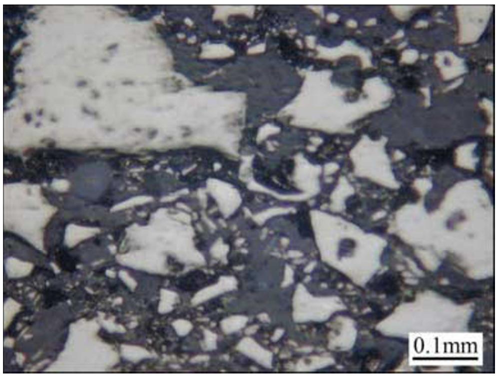

Fig. 1 Micrograph of ore sample 1

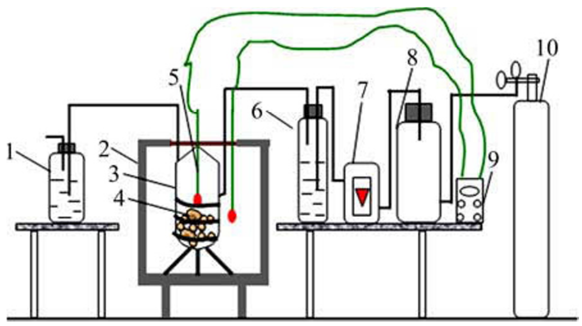

Fig. 2 Schematic diagram of experimental apparatus: 1—Poisonous gas absorption bottle; 2—Automatic heating incubator; 3—Reactor; 4—Ores; 5—Temperature probe; 6—Humidifier; 7—Flow meter; 8—Buffering bottle; 9—Automatic temperature recorder; 10—Oxygen cylinder

3 Experimental results

By analyzing the self-heating characteristic curves of ore samples, it can be found that only the ore samples 1, 2, 6 and 9 have obvious self-heating phenomenon, and their self-heating initiative temperatures are 220 °C, 239 °C, 220 °C and 220 °C, respectively, which means that they are difficult to produce self-heating under normal mining conditions. Figure 3 displays the self-heating characteristic curve of the ore sample 1. It shows that the obvious self-heating period lies between 1200 and 1230 min and the maximum self-heating extent is 5 °C.

4 Preprocessing of measured temperature series

Temperature variations of ore samples are caused by the comprehensive effect of automatic heating incubator