An Intelligent Early Warning Method Based on Cloud Platform Dynamic Monitoring to Prevent Coal Spontaneous Combustion

Zihang Ma

Corresponding author’s e-mail: 1157084460@qq.com

School of Safety Science and Engineering, Xi'an University of Science and Technology, Xi 'an, 710054, China

Abstract. Spontaneous coal combustion is one of the major disasters in coal mine safety production, transportation and storage. Rapid monitoring of coal spontaneous combustion characteristic parameters and timely early warning of danger levels are important guarantees for achieving the safe production of large quantities of coal. In order to deal with the sudden occurrence of coal spontaneous combustion disasters and the problem of processing large amounts of dynamically changing data, the key to rationally applying cloud platform data collection and processing technology is to dynamically monitor the occurrence of coal spontaneous combustion, establish a data collection database, and construct characteristic temperatures and indicators. The linear relationship between gases forms a coal spontaneous combustion monitoring technology that integrates multi-parameter data, effectively improving monitoring and early warning capabilities. The research results show that the intelligent system composed of cloud platform dynamic monitoring technology and intelligent early warning system has great effect in preventing the occurrence of spontaneous coal combustion. It can accurately and real-time handle and respond to the occurrence of spontaneous coal combustion, and can record various relevant data for later processing. The research is of great significance for realizing intelligent early warning of coal spontaneous combustion and ensuring safe, efficient, intelligent and green production of coal mines.

Keywords: Cloud platform; dynamic monitoring; spontaneous coal combustion; intelligent early warning

1. Introduction

Coal is one of the important energy sources in our country[1]. Coal is also an important fuel. When it comes in contact with air, it will undergo an oxidation reaction and release heat. After the oxidation reaction of coal occurs, the temperature rises, which accelerates the oxidation reaction rate of coal. In this way, the temperature of the coal will become higher and higher. When the temperature exceeds its auto-ignition point, it will spontaneously ignite. Therefore, coal spontaneous combustion is a dynamic process, and cloud platform dynamic monitoring is of great practical significance in preventing the occurrence of coal spontaneous combustion[2].

The process of coal spontaneous combustion has the remarkable characteristics of dynamic change, large amount of information, and suddenness. From its dynamic changes, we can timely and accurately predict the time, possibility, and disaster risk of coal spontaneous combustion,

PMIS 2024, March 15-17, Changsha, People's Republic of China
Copyright © 2024 EAI
DOI 10.4108/eai.15-3-2024.2346559

and achieve intelligent early warning of disasters. More theoretical knowledge and practical technology are needed to overcome this problem. In the past ten years, a total of 166 people died and more than 70 people were injured due to natural fire accidents during coal mining in my country, causing a very bad social impact. According to incomplete statistics, among my country's key state-owned coal mines, more than 54% of the mines mined coal seams have a tendency to spontaneously ignite, and about 50% of them mined coal seams with a shortest natural ignition period of less than 3 months. In addition, there are more than 4,000 hidden dangers of natural fires in mines in my country every year, resulting in more than 360 mine disasters. The goaf area is one of the most serious areas for natural coal fires. The safety of coal mining in my country's mines faces serious threats from natural coal fires. At present, there are still deficiencies in the dynamic monitoring of spontaneous coal combustion disasters, data collection systems, intelligent early warning systems, and key technologies, and they cannot prevent the occurrence of spontaneous coal combustion.

The coal spontaneous combustion early warning system based on the cloud platform can use various sensors and equipment to collect on-site information, and upload the data to the cloud for intelligent processing through Internet of Things technology to achieve real-time monitoring, analysis and early warning of the risk of coal pile spontaneous combustion. The spontaneous coal combustion early warning system based on the cloud platform can improve early warning efficiency and response speed, while also saving costs and reducing safety hazards for enterprises.

Coal spontaneous combustion (CSC), coal spontaneous combustion and ignition, refers to the natural combustion phenomenon caused by the intrinsic chemical and physical properties of coal in the absence of an external heat source[3]. CSC is one of the most common disasters in coal mine production. This spontaneous combustion usually occurs in coal piles that are stored or stacked, especially in storage sites where coal is stacked on a large scale. Spontaneous combustion of coal may cause serious fires, and cause serious environmental pollution and personal and property hazards.

At present, the methods of monitoring and preventing CSC process mainly include temperature monitoring[4], chemical analysis[5] and gas detection, but they have some shortcomings in the monitoring process. For example, temperature monitoring is to determine whether there is a risk of spontaneous combustion by monitoring the temperature changes in the coal pile. The disadvantage is that it may not be possible to accurately judge the risk of spontaneous combustion of coal by relying only on temperature changes, and it is easy to underreport or false alarms[6]. Chemical analysis is the monitoring of the risk of spontaneous combustion by chemical analysis of the composition of gases in coal piles. The disadvantage is that real-time monitoring is required, and the requirements for monitoring equipment are high, the cost is high, and it is not easy to realize automatic monitoring. Gas detection is the use of gas sensors to monitor changes in the concentration of harmful gases in coal stockpiles[7]. The disadvantage is that the stability of the monitoring equipment is required to be high, and it is not easy to carry out large-scale monitoring.

Although there are some traditional monitoring methods, they all have certain defects and cannot fully meet the real-time, accurate and automatic requirements of CSC monitoring of coal spontaneous combustion. Therefore, more advanced monitoring technologies and research methods, such as automatic monitoring systems based on the Internet of Things and artificial intelligence, are needed to improve the prevention and monitoring efficiency of coal spontaneous combustion of CSC.

Compared with the above detection methods, the acoustic temperature measurement method using the combination of infrasound wave and temperature has the advantages of comprehensive detection, real-time detection[8], high sensitivity, low destructiveness[9] and automatic measurement. Based on this, this paper proposes a new method for determining the CSC process using infrasound and temperature. Firstly, the characteristic temperature of the release of gas CO and C_2H_4 [10]during the heating process of coal and the change of gas release during the heating process were determined by thermogravimetric TG. Then, the good correspondence between infrasound and gas release and temperature in CSC process was studied by using the change of infrasound wave in the whole process. The research in this paper promotes the application of infrasound and temperature in the detection of coal spontaneous combustion, increases the likelihood that multiple parameters of the CSC will assist in detecting alarms, and is of great significance to promote the development of CSC's cloud platform dynamic monitoring.

2. Experimental materials and methods

In this paper, bituminous coal supplied by Shanxi coal yard was taken as the research object, and the oxide film on the surface was removed by sandpaper sanding. In order to obtain coal particles with uniform particle size, a grinding machine was used to obtain particles with a particle size of about 0.3 mm. The thermogravimetric analysis of the above materials was carried out, and a total of 4000Kg of particles with a particle size of about 0.3-9mm were selected for the ultrasonic signal change test in the CSC process.

2.1. Thermogravimetric analysis

The experimental instrument model for thermogravity is Mettler TGA-2. In the experiment, the gas involved in the reaction was ordinary air, the flow rate was 45 ml/min, and the heating rate was 5°C/min, and the temperature range was set to 30°C-600°C. The dosing amount is 5-8mg.

2.2. Coal oxidation heating experiment

The oxidation heating system is usually composed of gas supply equipment, control equipment, auxiliary equipment, temperature control equipment, gas chromatography analyzer and data acquisition and analysis system, as shown in Figure 1. Before the start of the experiment, the experiment was loaded with 20g of sample, and then connected to the temperature sensing device and the gas supply device.

After that, the temperature control sets the temperature of the system to 30°C and the nitrogen flow rate is 95 ml/min, first, the nitrogen is introduced to drive away the other gases in the system, and then the incoming nitrogen is converted into air. The heating rate is set to 0.8°C/min, and the heating range is set to 100-250°C. The gas generated is collected every 15 minutes and the gas composition is analyzed, and the heating is stopped when the temperature of the system rises to 400°C to complete the thermogravimetric experiment.

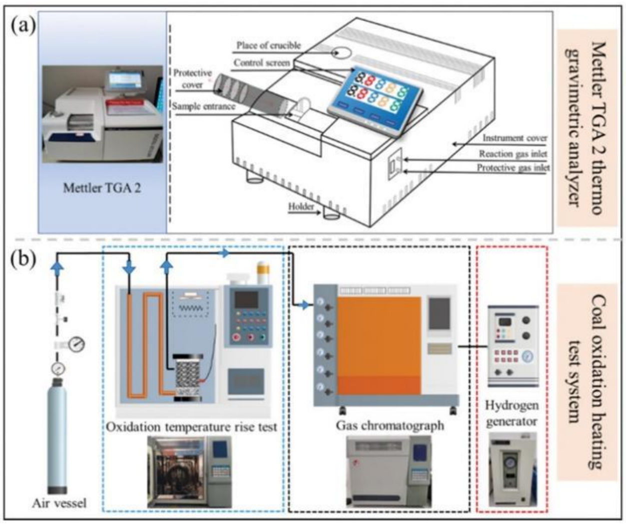

Figure 1. Structure of TGA measurement program during coal heating and oxidation

2.3. Infrasonic signal testing during coal heating

This process is mainly to detect the change of infrasound wave in the process of coal heating and the corresponding relationship between it and the temperature change. The structure of this part of the system mainly includes a gas supply device, a combustion test device, a temperature detection system, and an infrasonic signal collection and detection system, as shown in Figure 2.

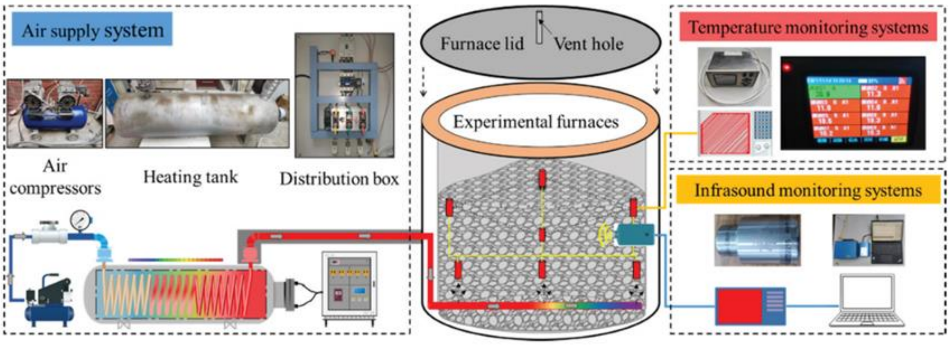

Figure 2. Infrasound test system for CSC

3. Results and analysis

3.1. Changes in temperature at different stages of the CSC process

Through the analysis of the experimental results, the process of coal combustion is roughly divided into four parts. The first part is (T0-T2), which mainly involves the desorption of some gases and the evaporation of water in the system due to heat; In the second part (T2-T4), the adsorption and weight gain of oxygen occurred in the system. In the third stage (T4-Tig), thermal decomposition and system weight loss occurred.

The TG-DTG curve for this procedure is shown in Figure 3. The amount of oxygen absorbed is less than the amount of gas that escapes during this process. Therefore, the whole process is weightless. It can also be seen from the figure that the critical temperature of the coal used in this experiment is 78°C, and the coal-oxygen composite reaction rate is gradually increasing.

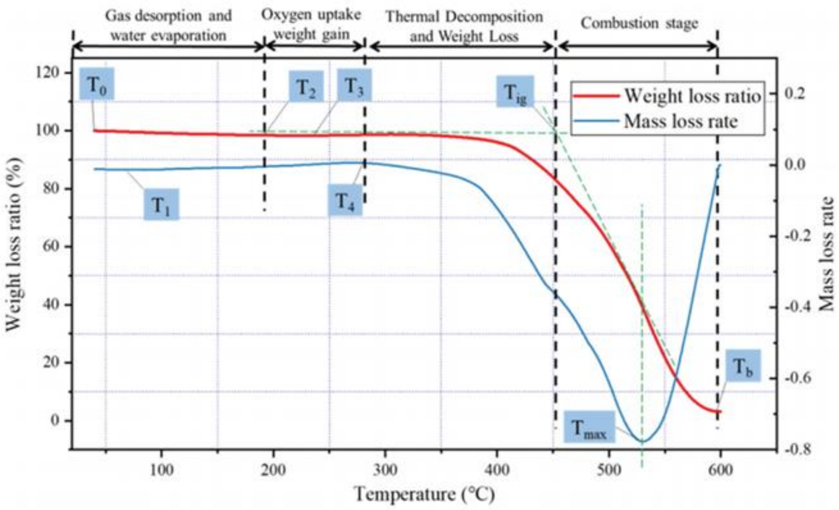

Figure 3. TG-DTG curve of CSC

3.2. Monitor the types of CSC process gases and their releases

Based on the experimental results, we divided the coal into three different stages in the process of spontaneous combustion: slow, rapid and vigorous oxidation, and the reaction mechanism is different in different reaction stages, and the types of gases released are also different. Therefore, the degree of spontaneous combustion of coal can be judged by the amount and type of gas released. The change in gas during this warming process is shown in Figure 4.

As for Figure 4, we can see, no gas was produced in the system at the beginning. As the heating process progresses, trace amounts of CO are produced at 78°C. At 175 °C, C2H4 is generated. With the increase of temperature, the amount of gas released also increases gradually, and the concentration of gas released is positively correlated with the temperature of the system.

Careful analysis shows that at the beginning, it is in the slow oxidation stage, the temperature of the coal sample is relatively low, and the coal mainly reacts slowly through chemical absorption and adsorption of oxygen, and the combination process will destroy some coal structures and release a little heat. The temperature of the system gradually increases with the oxidation process, the adsorption rate accelerates, and some substances in the coal body begin to decompose. Due to the oxidation reaction of some functional groups such as carboxylic acids with oxygen, some CO is produced. As the temperature increases, the degree of oxidation increases, and some aromatic gases are produced. Its internal structure is also seriously damaged, and its decomposition is accelerated, producing a large number of active group substances.

3.3. Change of infrasound signal over time in CSC process

From the collection, detection and analysis of the infrasonic signal in the process of coal spontaneous combustion, the variation of the infrasound signal in the above process with time is obtained, as shown in Figure 4. The sound pressure mentioned in the diagram refers to the pressure change due to infrasonic interference.

As can be seen from Figure 4, The infrasonic signal intensity and density fluctuate greatly during the spontaneous combustion process of coal, fluctuate, and are continuously pulsed. Besides, although they are all improving as the experiment is carried out, the trend of change does not correspond to each other.

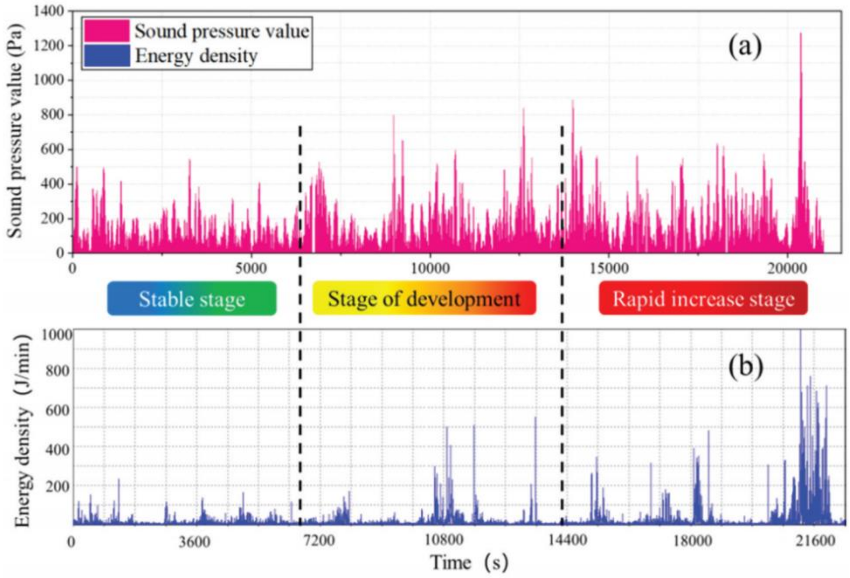

Figure 4. Infrasound signals collected over time during the CSC process

4. Conclusion

In this study, the characteristic temperature change points of the coal oxidation heating process, the release law of gases such as CO and C2H4, the generation of infrasound signals and their variation laws and corresponding relationships with temperature were obtained through experiments, and the correlation between the characteristic temperature and the infrasound signals of index gases was analyzed. Finally, data is collected through the cloud platform to monitor and warn the coal spontaneous combustion process in real time. The following conclusions were reached:

(1) The temperature at which the strong oxidation stage of the coal begins is 173 °C. Thermogravimetric and oxidation experiments show the relationship between temperature point and gas release species, and the correspondence between temperature, gas and infrasound wave is obtained.

(2) The infrasonic signal generated during the CSC experiment will gradually increase with the experiment and is positively correlated with temperature. It is mainly divided into three stages: stability, development and rapid growth. In the first stage, The signal information is relatively weak, most of the collected signals are lower than 230 Pa, and the density of the collected energy is not higher than 74 J/min. As the temperature of the system continues to increase as we move to the next stage, the energy density of these types also increases, at 350-400 J/min. In the final stage, the energy density increases rapidly, and the actual infrasonic waves exceed 1100 Pa. Through this experiment, we preliminarily obtain the change trend of infrasound signal in the CSC process, which provides a theoretical basis and basis for the practical application of infrasound in CSC monitoring and early warning.

(3) In this experiment, the temperature, gas change and infrasonic signal during the spontaneous combustion of coal were comprehensively investigated, and it was found that there was a certain relationship between them. Therefore, in the process of practical application, we can also consider the above three aspects, so as to enhance its application in the actual coal industry.

References

[1] Hao L(2024) CO-based early warning threshold for coal spontaneous combustion. Materials Chemistry and Physics,313:128730.

[2] Arif Emre Dursun (2023) Fatal Accident Analysis and Hazard Identification in Turkish Coal-Extracting Industry Using Analytic Hierarchy Process. Mining, Metallurgy & Exploration,41:149-172.

[3] Hu Z (2017) An integrated methodology for monitoring spontaneous combustion of coal waste dumps based on surface temperature detection. Appl. Therm. Eng.,122:27–38.

[4] Xiao Y (2016) Experimental study on the corresponding relationship between the index gases and critical temperature for coal spontaneous combustion. Journal of Thermal Analysis and Calorimetry,127:1009–1017.

[5] Liu Y (2012). Application of distributed optical fiber temperature sensing system based on Raman scattering in coal mine safety monitoring. Maldives. pp. 1–4

[6] Li J (2019)Comprehensive utilization and environmental risks of coal gangue: A review. J. Clean. Prod,239:117946.

[7] Onifade M (2020)A review of research on spontaneous combustion of coal. Int J Min Sci Technol ,30 (3):303–11.

[8] Liang Y T (2023) Study on the Coupling Characteristics of Infrasound–Temperature–Gas in the Process of Coal Spontaneous Combustion and a New Early Warning Method. Combustion Science and Technology ,1-21.

[9] Kong B (2021) Study on the electromagnetic spectrum characteristics of underground coal fire hazardous and the detection criteria of high temperature anomaly area. Environ. Earth Sci,80 (3).

[10] S. A. Albert (2022) Atmospheric Structure Prediction for Infrasound Propagation Modeling Using Deep Learning. Earth and Space Science, 9 (8):1-12.