Fuel 229 (2018) 34–43

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Study on test method of heat release intensity and thermophysical parameters of loose coal

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ARTICLE INFO

Keywords:
Coal spontaneous combustion
Oxidative heat release intensity
Thermophysical parameter
Metamorphic grade
Particle size

ABSTRACT

Accurate determination of basic parameters of coal spontaneous combustion process can not only directly or indirectly characterize the spontaneous combustion of coal, but also provide a reliable theoretical basis for the accurate prediction of coal spontaneous combustion period and the proposition of prevention measures of spontaneous combustion. In this paper, based on the theory of porous medium heat transfer, the mathematical models of parameters such as oxidative heat release intensity, thermal conductivity, heat capacity and activation energy of loose coal were established by using element balance method. Then, an integrated experiment system for testing characteristic parameters of coal spontaneous combustion was designed and set up, and the characteristic parameters of loose coal spontaneous combustion were accurately tested through the spontaneous combustion heating experiment on large-volume coal. The results show that the thermal conductivities of loose coal samples all decrease with the increase of voidage and rise with the increase of metamorphic grade. The heat capacity grows with the increase of volatile content. The oxidative heat release intensities of samples were increased exponentially with the rising temperature, which first rises slowly in the temperature range of 60–70 °C and then increases rapidly after 70 °C. The sample with a lower metamorphic grade and a stronger spontaneous combustion tendency owns greater oxidative heat release intensity, which grows with the increase of dynamic absorbed oxygen. At the same temperature, the large-size sample has smaller oxidative heat release intensity. The activation energy of coal samples increases with the rise of temperature and metamorphic grade. The experimental results indicate that the test system and method are reliable and can achieve the goal of rapid test.

1. Introduction

Spontaneous combustion of coal seriously threatens the safety of coal production, storage and transportation as well as brings enormous potential safety hazards to the coal industry [1]. The heat released of the combination of coal and oxygen is affected by the oxygen supply, oxidative heat release characteristics and heat dissipation of coal. When the heat release rate of coal is greater than its heat dissipation rate, the heat accumulated within the coal will raise the temperature of coal, ultimately leading to the coal spontaneous combustion. Key parameters influencing this process include thermodynamic parameters of coal oxidation (oxidative heat release intensity), thermophysical parameters of coal (thermal conductivity, heat capacity and permeability coefficient) and kinetic parameters of coal oxidation (activation energy and oxygen consumption rate).

Accurate determination of basic parameters of coal spontaneous combustion process can not only directly or indirectly characterize the spontaneous combustion of coal, but also provide a reliable theoretical basis for the accurate prediction of coal spontaneous combustion period and the proposition of prevention measures of spontaneous combustion. However, some problems still exist in the test of basic parameters at home and abroad. At present, there are two main methods for testing characteristic parameters of coal spontaneous combustion. One is to perform large-scale oxidation experiments actually using tons of coal [2–4]. This method can effectively simulate the process of coal self-heating and yield highly reliable experimental results, but it generally takes several months to complete the test. The long experimental time makes it difficult to realize rapid test. The other method is to measure characteristic parameters of coal spontaneous combustion process by conducting small-sample experiments on pulverized coal through thermal analysis, adiabatic oxidation method and other methods [5]. Although this method can realize rapid test, many parameters cannot be

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https://doi.org/10.1016/j.fuel.2018.05.006
Received 15 December 2017; Received in revised form 28 April 2018; Accepted 1 May 2018
Available online 08 May 2018
0016-2361/

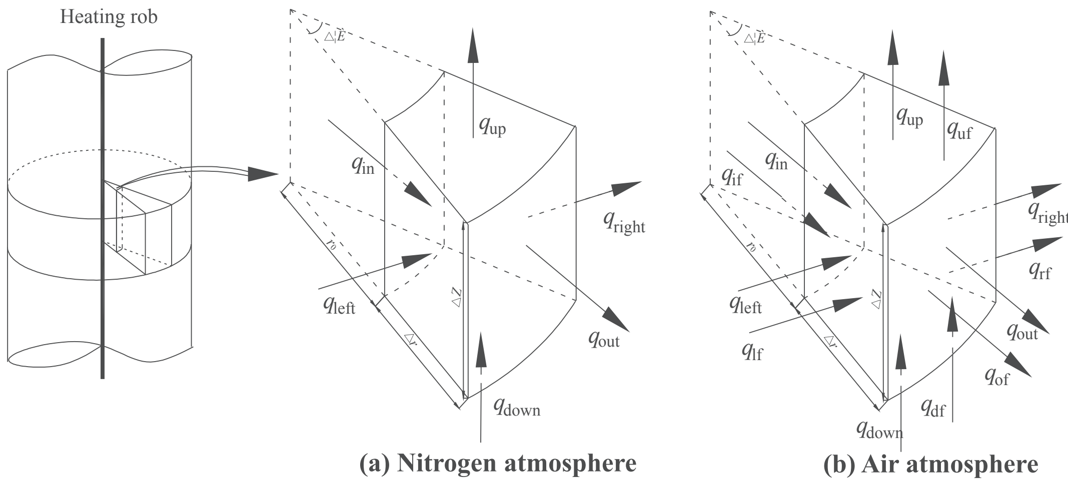

Fig. 1. Schematic diagram of micro unit import and export heat in cylindrical coordinates of coal in nitrogen and air atmosphere; q_{up}, q_{down}, q_{in}, q_{out}, q_{left} and q_{right} are the conductive heat flows between the central unit and the upper, down, inner, outer, left and right units, respectively; q_{lf}, q_{rf}, q_{uf}, q_{df}, q_{if} and q_{of} are the convective heat flows between the central unit and the left, right, upper, down, inner and outer units, respectively.

tested by it. Besides, the test results of some parameters are often different from actual parameters of coal spontaneous combustion process due to the difference of their particle sizes and accumulation thicknesses. Therefore, it is of great significance to design a device and method that can quickly and accurately test characteristic parameters of coal spontaneous combustion and to apply the test results to the calculation of various coal spontaneous combustion processes such as mine fire caused by coal self-heating.

There are lots of methods for testing coal oxidation heat at home and abroad, such as thermal balance method, bond energy estimation method, direct test method by adiabatic calorimeter or micro calorimeter, differential scanning calorimetry method and reference oxidation method. Xu et al. [6] proposed a large experimental bench method for testing the heat release intensity of coal. The method can yield relatively accurate results, but it is not suitable for the test of large quantities of coal sample because of the long experimental period (a few months). The bond energy estimation method presented by Xu et al. [7] is based on the deduction of coal spontaneous combustion process. However, since coal spontaneous combustion process is affected by many factors, it is difficult to describe the adsorption and reaction process of coal oxidation, and thus the accuracy can hardly be guaranteed. Jones [8] adopted the improved heating rate (HR) method and the micro calorimetric method to study the self-heating characteristics of coal. Similarly, many scholars in China also adopted the micro calorimeter to directly test the trace reaction heat of materials. For example, Carras and Young [9] continuously determined heat variation in the metabolic process of bacteria by using a micro calorimeter. Nevertheless, no scholar has directly tested the low-temperature oxidation heat of coal with a micro calorimeter so far. Moreover, many scholars also used the differential scanning calorimetry method to determine oxidation heat of coal, but this method which can just test small samples (about 10 mg) is unable to reflect the actual situation of coal oxidation. Therefore, it is necessary to find a more effective method for determining oxidative heat release intensity of loose coal. The current methods for measuring the thermal conductivity of loose coal mainly include hot-wire method [10], one-dimensional radial heat flow method [11], parallel hot-wire method [12], dual plate method [13], plane heat source method [14], etc. These methods which all belong to small-sample test are somewhat different from the actual situation of mine. In order to obtain more accurate measurement results, the thermal conductivity test should be carried out on large-volume loose coal in the appropriate environmental conditions. In addition, a more systematic method for testing heat capacity of coal has not been formed yet currently. Thus, many scholars directly cited the empirical value in the calculation process.

At present, there are a number of test methods for testing characteristic parameters of coal spontaneous combustion. Although these methods have made some achievements, they all test coal samples separately, so errors or inaccuracy are inevitable if they are applied to another coal sample. Hence, this paper established a small-scale coal oxidation experimental device based on the theory of heat and mass transfer in porous media and the theory of coal oxidation. This device can be used to test a plurality of characteristic parameters of coal spontaneous combustion, including thermophysical parameters (thermal conductivity and heat capacity), thermodynamic parameters (oxidative heat release intensity) and oxidation kinetic parameters (activation energy of low-temperature oxidation).

2. Experimental principle

According to the theories of heat transfer, mass transfer and seepage mechanics of porous media [15], the theoretical calculation models of oxidative heat release intensity and thermal conductivity system of loose coal were established in this paper. First, a programmed temperature experiment was performed on coal in nitrogen atmosphere. The coal was sealed after it was filled with nitrogen. At this moment, gas in the coal cylinder stayed in a quiescent state, and the coal only transferred heat without getting oxidized and releasing heat, so the amount of convective heat transfer can be ignored. A micro unit randomly taken from the coal can reach the following thermal equilibrium at any time interval: total import heat of the micro unit + heat generated by heat source within the micro unit = total export heat of the micro unit + increment of the thermodynamic energy (i.e. internal energy) of micro unit.

In the cylindrical coordinate system, no heat is generated in coal in nitrogen atmosphere and the heat generated by the internal heat source is zero. Fig. 1(a) is a schematic diagram of micro unit import and export heat in cylindrical coordinate of coal in nitrogen atmosphere.

In this work, the loose coal is assumed to be a homogeneous and porous medium of constant physical properties. Furthermore, there is no heat transfer between the object micro unit and the left and right units. Therefore, it's safe to consider that $q_{left} = q_{right}$, since the high-temperature region of coal was simulated by using a central heating rod to heat the tested coal cylinder. In this case, the equation of two-dimensional heat conduction equilibrium within the experimental bench in the cylindrical coordinate system can be described as: