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Kinetics of oxidation and spontaneous combustion of major super-thick coal seam in Eastern Junggar Coalfield, Xinjiang, China

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ABSTRACT

In this study, the kinetics of a major coal seam oxidation which was collected from the Eastern Junggar coalfield of China, were investigated by programmed heating experiments and the thermo-gravimetric analysis (TGA) as well as the chemical thermodynamic tool FACTSage. Results show that the change of O_2 consumption rate, CO and CO_2 generation rate in process of coal oxidation are coincident with the content changes of fixed carbon, volatile, and sulfur but differ from those of ash and moisture contents. From results of TGA, the characteristic temperatures, i.e., the dehydration-oxygen-adsorption temperature T_1, the pyrolysis temperature T_2, the ignition temperature T_3, the maximum combustion-rate temperature T_4, and the burnout temperature T_5, were calculated. The T_3, T_4, and T_5 exhibit a similar variation tendency. It was found that the pyrolysis temperature T_2 was easier reached by the coal sample collected from Xiheishan Mining area compared to those from other two mining areas. It also shows that the effect of particle size on characteristic temperatures are lightly different: T_1 remained almost unchanged, T_2 and T_3 decreased, while T_4 and T_5 demonstrated an initial growth followed by a drop and a further rise. At the T_2-T_4 stage, the sample size is positively correlates with its reaction activation energy. Meanwhile, results also show the CO_2 and CO are the major gaseous products in coal oxidation process, and some trace elements compounds are also produced at different stages of temperature. Therefore, these compounds prosed the possibility to indicate consequent stage of coal oxidation stages.

1. Introduction

Coal spontaneous combustion is an issue threating the coal mining over the world. In particular, in Xinjiang region of China, the situation of coal spontaneous combustion is very serious due to the shallow deposition of massive coal reverves, the unscientific mining with low recovery of coal, the intrinsic property of coal spontaneous combustion and the arid climate there, etc. It was reported there still exists 47 coal fire sites in this region, which burns up million tons of coal each year and causes seriour impact on local environment. Investigation to these coal fires indicates almost all coal fires were ignited by coal spontaneous combustion during or after mining. The super thick coal seam (up to 90 meter thichness) depsoits in the Eastern Junggar Coalfield (Xinjiang, China), which covers the area of 15,334 km^2, has 458 billion tons of predictive coal reserves, which is characterized as a low rank and a high tendency of spontaneous combustion. In 2009, it was reported more than ten thousands tons of coal in Wucaiwan Mine of this coalfield were burned out due to the coal spontaneous combustion (Wang et al., 2009). In 2014, the Jiangjunmiao coal fire, the Jiangjungebi coal fire, and the Beishan coal fire in the coalfield were found by Xinjiang Coal Fire Fighting Bureau, which is in charge of the extinction of coal fire in Xinjiang region. These three coal fires were estimated to burn up about 520,000 tons of coal resources each year. Furthermore, due to the mining of this super thick coal seam, some issues, such as the selection of proper mining method and the development of effective method and technology against coal spontaneous coal combustion, arises.

In order to effectively control the coal spontaneous combustion in this coalfield, the thermokinetic characteristics of coal oxidation and spontaneous combustion need to be investigated.

Focusing on this topic, lots of research work were conducted in past decades: Xu et al. (1997) and Deng et al.(1999, 2016) investigated the characteristics of coal oxidation and spontaneous combustion by using a large-scale experimental apparatus. Yu et al.(2001, 2006) studied the same topic by using a programmed heating oxidation experimental devices. Wang et al. (2014) studied the 13 elementary reactions of

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coal's spontaneous combustion process as well as. Lu et al. (2005) also investigated the proneness of coal oxidation and spontaneous combustion by using an adiabatic oxidation experimental device for investigating coal's spontaneous combustion proneness. Sujanti and Zhang (1999) employed programmed heating device for clarifying the effects of the addition of inorganic additive on the critical temperature and reaction activation energy of coal's spontaneous combustion. Küçük et al. (2003) examined the effects of coal particle size and water on the spontaneous combustion characteristics in a heating furnace. Taraba et al. (2011) investigated the effects of the addition of organic and inorganic additives on coal's spontaneous combustion. Ren et al. (1999) performed the adiabatic oxidation study on the propensity of pulverized coals to spontaneous combustion. Using the wet oxidation potential method and cross-point temperature method, Ray et al. (2014) conducted a comparative study on the spontaneous combustion characteristics of coal samples from Indian coalfields. Nimaje and Tripathy (2016) combined the cross-point and flame temperature methods with the Olpinski index technique and the wet oxidation potential method to investigate the tendency of coal spontaneous combustion. Some of results from above research were widely used to control coal spontaneous combustion in mining.

In the present study, authors attempt to investigate the characteristics of oxidation and spontenoue combustion of the super-thick coal seam in Eastern Junggar Coalfield, including quantification of the O_2-comsumption rate, the CO and CO_2 generation rate, the activation energy of coal reaction, and the generation of trace elements compound. A comprehensive methods, including the programmed temperature-raising experimental apparatus, the Thermogravimetric analysis, and the chemical analysis (FACTSage), were employed in this study. Fig. 1 shows the locations of collecting coal samples in Easrtern Junggar Coalfield named with Wucaiwan, Dajing, and Xiheishan Mining areas respectively.

2. Materials and methods

2.1. Programmed heating oxidation tests

Fresh coal samples were collected from the coal seams in (i) Beishan Mine, (ii) Tebian North (open-pit) Mine, (iii) State Grid Energy Mine, (iv) Hongshaquan (open-pit) Mine, and (v) Wucaiwan (open-pit) Mine. (Hereinafter, the respective seams are referred to as 1#, 2#, 3#, 4# and 5#). Geographically, seams 1# and 4# belong to Xiheishan Mining area, 3# to Dajing Mining area, and 2# and 5# to Wucaiwan Mining area. Under ambient temperature, the coal samples were crushed, sieved into the particles with different sizes (specifically, 40–60 meshes, 80–100 meshes, 120–140 meshes, 160–180 meshes, and over 200 meshes), and finally sealed for preservation. Table 1 lists the proximate and ultimate analysis results of different coal seams.

As shown in Fig. 2, the applied programmed heating experimental system consists of the gas circuit, programmed heating control system, temperature recording system, adiabatic heating oxidation furnace, gas chromatography, and some accessory devices.

In the experiments, 100 g coal was first put into the coal sample tank in adiabatic heating oxidation furnace. Then, the gas circuit was switched on, and dry air was pumped at a rate of 80 ml/min. Meanwhile, the programmed control switch in the adiabatic heating furnace was turned on, to increase the ambient temperature to 500 °C by the following steps: from ambient temperature to 50 °C for 15 min, then from 50 °C to 75 °C for 15 min, and from 75 °C to 100 °C for 15 min, with the heating rate being set as 1.67 °C/min. After the temperature exceeded 100 °C, it was further increased at a rate of 1 °C/min. When the adiabatic heating oxidation furnace was heated to the preset temperature, the heating process was paused for 5 min; at that moment, gas sample was taken, and temperatures of the furnace and the coal sample were recorded by the temperature monitoring system. Using the gas chromatography, the compositions of gas samples were measured. In this study, the main focus was made on some representative gases including O_2, CO, and C_nH_m. The test was terminated when the coal temperature reached or exceeded the temperature in the furnace (i.e., the critical temperature). The above experimental procedures were repeatedly applied to coal samples of different sizes.

2.2. Thermogravimetric analysis (TGA)

The TGA technique is used to measure the mass loss of the coal sample with the increase of temperature under programmed temperature variation regimes. When coal sample undergoes dehydration, oxidation, and decomposition in the programmed heating process, its mass changes accordingly. Using thermocouple and thermobalance, the relationship between the coal sample mass (m) and temperature (T) in the programmed heating process is recorded and the respective coal sample thermogravimetric curve is constructed, as well as its derivative (DTG) curve. In this study, an STA 7300 thermogravimetric analyzer (Hitachi Co., Ltd., Japan) was used via the following procedure: the coal sample was placed into the thermogravimetric analyzer, and then, air was pumped at a rate of 300 ml/min, and coal sample was heated from 30 °C to 1000 °C at a rate of 10 °C/min, during which the coal sample's masses at different temperatures were recorded, and TG and DTG curves were plotted.

2.3. Chemical analysis (FACTSage)

Chemical thermokinetics refers to the energy conversion processes. The FACTSage chemical thermokinetic analysis software (Thermofact/CRCT, Canada) was used in this study for thermokinetic analysis. Following the principle of the minimization of Gibbs free energy under isothermal-isobaric condition, the components and their mass concentrations were acquired based on the Lagrange undetermined coefficient method, and moreover, the distributions of the products under different coal/oxygen reaction conditions were simulated.

3. Results and analysis

3.1. Coal spontaneous combustion and oxidation characteristics

Using the experimental procedures described in subsection 2.1, the critical temperatures of the coal samples with different sizes as well as the concentrations of O_2, CO, CO_2 and C_nH_m at the low-temperature oxidation phase at different reaction temperatures were measured. According to the experimental data of different coal samples, O_2 consumption rates, CO and CO_2 generation rates of different coal samples at the T_a-T_c and T_c-T_b stages were calculated and summarized in Table 2. The relations between the above indices and the quality of each coal seam are depicted in Figs. 3 and 4.

As seen from Table 2, samples from 1# and 4# coal seams show the lowest and the highest CO initial temperatures of 49.90 °C and 68.70 °C, respectively. Samples from 2# and 4# coal seams show the lowest and the highest combustion temperatures of 156.70 °C and 165.20 °C, respectively. At the T_a-T_c stage, samples from 4# and 5# coal seams exhibit the lowest and the greatest O_2 consumption rates of 0.003 %/°C and 0.017 %/°C, respectively. Samples from 2# and 4# coal seams have the lowest and the greatest CO generation rates of 0.301 ppm/°C and 0.616 ppm/°C, respectively. Samples from 4# and 2# coal seams have the lowest and the greatest CO_2 generation rates of 3.511 ppm/°C and 7.558 ppm/°C, respectively. At the T_c-T_b stage, samples from 1# and 3# coal seams have the lowest and the greatest O_2 consumption rates of 0.029 %/°C and 0.009 %/°C, respectively. Samples from 5# and 3# coal seams have the lowest and the greatest CO generation rates of 30.31 ppm/°C and 45.29 %/°C, respectively. Samples from 1# and 3# coal seams have the lowest and the greatest CO_2 generation rates of 75.74 %/°C and 147.85 %/°C, respectively.

It can be observed from Fig. 3 that the consumption rate of O_2 and