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Investigation on the co-combustion of oil shale and municipal solid waste by using thermogravimetric analysis

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ABSTRACT

The aim of this study is trying to reveal the thermal characteristics and kinetics of oil shale, municipal solid waste and their blends in the combustion process which are needed for efficient utilization. The combustion experiment is carried out in a thermogravimetric simultaneous thermal analyzer, where the temperature ranged from 110 °C to 900 °C at three different heating rates as 10 °C/min, 20 °C/min and 30 °C/min. Their kinetics were studied by Ozawa–Flynn–Wall and Friedmen methods. According to the data analysis, combustion characteristic index increased progressively with the increase of the proportion of municipal solid waste. And it's suggested that there was certain interaction in the combustion process of oil shale and municipal solid waste. The average activation energy of the blends reached the minimum value, 177.7927 kJ/mol by Ozawa–Flynn–Wall method and 167.4234 kJ/mol by Friedmen method, when the proportion of MSW was 70%.

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1. Introduction

With the fast development of modern industry, there is a growing demand for energy. However, with the crude use of fossil fuels (which are commonly referred as coal, petrol and natural gas) for years, has not only caused the shortage of fuel supply, but also the serious environmental pollution [1]. To deal with the dilemma, the industry has tried exploring new possible fossil energy.

As an important alternative energy resource, the oil shale (denoted as OS) has attracted attention because of its huge reserves all over the world [2]. Mainly spread in the America, Australia, Brazil, China and Estonia [3]. Combined the high calorific value as 4396.05 kJ/kg [4], OS has already become a promising energy source nowadays. Eesti Energia, which is the world's biggest OS to energy company, provides more than 90% electric power in Estonia and the main fuel it used is OS [5]. According to the paper about energy situation in China [6], energy production from fossil fuels (coal, oil and natural gas) is no less than 90%, while the large transportation cost caused by uneven distribution among the provinces in China and the dwindling reserves of fossil fuels make it necessary to find potentially alternative fuels, and OS begins to come into the sight of the electric generation. As is shown in the literature about the current condition of OS in China, the oil shale's reserve in China in about 4.76×10^{10}t in China [7]. Currently, the main utilization methods are retorting and combustion [8], and the utilization is so immature that it might cause a waste of OS. Since OS is non-renewable fossil fuel, it's necessary for us to do some research about OS combustion in order to get maximum efficiency.

With the risen up of people's living standard, there is an increasing amount of municipal solid waste (denoted as MSW), such as the food and fruit residue from everyday meal, the polyvinyl chloride (PVC) from wasted digital items, the wood from abandoned furniture, the waste paper from package [9]. How to deal with the MSW is not easy to find an answer. According to relevant paper, the MSW output in China was about 180 million tons in 2010, and projected to be 210 million tons in 2015 [10]. Because of the rose living standard, there is more food and fruit residue, which means there is more organic matter in MSW [11]. And as it is well known to us all, the more organic matter MSW has, the easier for MSW to burn. It's urgent to deal with growing amount of MSW effectively or it will surround the city and do harm to the environment. The current ways dealing with MSW are as described, landfilling is a major method for MSW disposal, but it's too costly to carry out [12]. Composting is another way widely used to dispose garbage, while the piles of MSW also cover a large area of expensive land and the smelly air with oxysulfide is truly one kind of air pollution [13]. The idea of MSW incineration and

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generating electricity is highly spoken as a method of potential also has some deficiencies. Thus, the method of MSW incineration and generating electricity needs to be improved.

Recently, there are some co-utilization method of wastes and solid fuels like coal [14], paper sludge, and MSW which is a useful and provoking way to deal with the problem. And a number of investigations have already been published about the synergetic influence on the co-processing of solid fuels and bio-resource. For instance, the co-pyrolysis of paper sludge and MSW [15]. And co-combustion of paper sludge and oil-palm solid waste [16]. This leads to the thought of the co-combustion of OS and MSW. As is shown in the related study, decreased burning rate and ignition propagation were the results of increased ash content [17]. Take high ash content of OS into consideration [18], there is the necessity that auxiliary fuel is added into the OS in the combustion system to make sure the stable combustion condition. As is mentioned, the amount of MSW has increased a lot, and there is more organic matter in MSW meaning the higher flammability. From the perspective of MSW reuse and highly efficiency of oil shale use, the co-combustion of oil shale and MSW seems to be a doable way to process oil shale and MSW at the same time. As is shown in some research, the co-combustion of MSW and paper mill sludge is good for the process of decomposition and combustion [19]. In the co-combustion, the reactivity of substances is strengthened, which means the chemical reactivity is higher than combustion of only one substance, thus there is less unburned coke content [19]. Although there are some papers about the co-combustion of solid fuel and biomass resource [20], it's not easy to find reports about the research on the co-combustion of OS and MSW up to now. This paper might contribute to filling the gap in the co-combustion area.

This paper mainly focuses on combustion chemical reaction kinetics of OS, MSW and their mixture with different mass ratio at different heating rate, trying to study and analyze the co-combustion of OS and MSW. The frequently-used Ozawa–Flynn–Wall (OFW) method was applied to obtain apparent activation energy in the combustion [21]. And another widely-used iso-conversional thermogravimetric method [22], the Friedmen method was used to ensure accuracy of results. What's more, the mechanism of interaction between OS and MSW is investigated at different mass ratio. The results obtained from the two calculating methods will help to understand the co-combustion process of OS and MSW better. With the results from the detailed calculation about the co-combustion process, referential information for designing and optimizing the co-combustion technology for the mixture could be obtained. Thus this paper will offers the reference in practical application of OS and MSW co-combustion.

2. Experiment methods and materials

2.1. Experimental facility and method

In this study for co-combustion experiments, the thermogravimetric simultaneous thermal analyzer modeled METTLER TOLEDO TGA/DSC1 was used. This analyzer has a temperature precision of ±0.5 °C and the microbalance sensitivity is less than ±0.1 μg. The samples used in the non-isothermal co-combustion experiment were heated from 110 °C to 900 °C at different heating rates of 10, 20 and 30 °C/min, with an air flow at the rate of 80 ml/min which could make sure the samples were in an atmosphere suitable for combustion. As is mentioned in the related literature, compared with isothermal methods, results obtained from non-isothermal methods are more reliable [23].

As is shown in the related papers [24], different uncertainties like heat/ mass transfer model constant, deformation model constant, pressure in the combustion chamber all have influences on the temperature measurement. However, the influences are not huge that the temperature detected is quite reliable. While radiation should be taken seriously in combustion especially in the high temperature zone. Because of the radiant energy loss, the high temperature zone becomes smaller [25]. The temperature detected by the thermal analyzer were adjusted accordingly then.

All the initial mass of the samples were 10 ± 0.5 mg to reduce the possibly random errors. Several experiments without samples were carried out to gain the baselines, which could be used as corrections to systematic errors of the instrument. In order to make sure the accuracy of experiments' results, all the experiments were conducted twice and the reproducibility was quite satisfactory.

Experimental conditions used for TG analysis are showed in Table 1 and specifications of thermogravimetric analyzer are showed in Table 2.

2.2. Materials

The oil shale (denoted as OS) studied was collected from the oil-shale mine field in Maoming, Guangdong Province in China which lies in southeast Asia within a larger scope. OS was crushed and ground to get the desired particle size (<178 μm).

The municipal solid waste (denoted as MSW) was a complicated mixture [26]. The main components of MSW have already been listed above. As a determination of the MSW in Guangzhou showed, the mass ratio of food residue, fruit residue, wood, paper and textiles and polyvinyl chloride (PVC) was 36.50%, 11.32%, 12.85%, 8.16%, 6.49% and 24.68%, respectively. All the components were collected from South China University of Technology (SCUT) and the neighborhood nearby, listed in Table 3. After air-dried at 105 °C for 24 h, all the MSW ingredients were crushed and ground separately, in order to ensure the ideal particle size (<178 μm). And the raw particles were mixed according to the mass ratio to get preliminary MSW. After one hour in a micro rotary mixer, we could get MSW in powder form (particle size <178 μm), as recommended in user's manual of thermal analyzer.

OS could burn well and study on its combustion had been published [27], while the combustion of MSW is quite hard since a tremendous amount of energy is required. According to the related study [19], we assumed MSW combustion was doable. And the experiment verified conjecture.

Add processed MSW into oil shale powder to get the samples for experiment. The mass proportion of oil shale is 100%, 90%, 70%, 50%, 30%, 10%, 0 (and the according mass proportion of MSW is 0, 10%, 30%, 50%, 70%, 90%, 100%, respectively). All the mixture samples were placed in micro rotary mixer one by one for about two hours, to make sure the contents in samples were uniformly distributed. Driers were used for the ultimate samples' storage. The results from ultimate analysis and the proximate analysis of OS and MSW were shown in Table 4.

Table 1
Experimental conditions used for TG analysis.

RT[a]	RH[b]	AF[c]	MS[d]	TR[e]	MS[f]
22 ± 0.5 (°C)	35 ± 3 (%)	80 (ml/min)	10 ± 0.5 (mg)	110–900 °C	0.1 μg

[a] RT, the room temperature.
[b] RH, relative humidity of the room atmosphere.
[c] AF, air flow in thermal analyzer.
[d] MS, mass of the sample.
[e] TR, temperature range in the thermal analyzer during the experiment.
[f] MS, microbalance sensitivity.

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