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Study on the ignition behavior and kinetics of combustion of biomass

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Abstract

Understanding the combustion behavior of biomass is essential to plant design and production control. In this work, we used thermogravimetric analysis (TGA) to study milled straw samples of different particle sizes in atmospheres of nitrogen and air. The ignition temperature was found to be 350℃, and the results were found to be insensitive to the particle size, which ranged from 63 μm to 2000 μm. In addition, a furnace balance system was used to study the impacts of particle size on the combustion of biomass and compare with TGA results. The activation energies of combustion were determined to be 54.37 kJ mol^{-1} for straw pellets and 49.94 kJ mol^{-1} for the milled straw. Further calibration of the furnace-balance system will be carried out in future to obtain more precise and reliable results for biomass fuel characterization.

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Keywords: Biomass; ignition; kinetic; particle size

1. Introduction

Biomass is considered to be a renewable, carbon-neutral fuel; it holds the promise of acting as an alternative energy resource that can address the worldwide energy crisis. One efficient method to convert biomass to energy is by direct combustion [1]; however, several issues face current biomass combustion furnaces, such as low thermal efficiency, heat load instability and slagging [2]. Ignition is the crucial step that initiates combustion, and it influences boiler operation, energy efficiency, and emissions. Thus, the study of ignition behaviour of biomass is important to optimizing biomass combustion. Hence, a deep knowledge of the thermal behaviour of biomass is critical to assess

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the feasibility, design, and scaling of industrial biomass conversion applications [3, 4].

Thermogravimetric analysis (TGA) is commonly used to study the thermal behaviour of solid fuels. Several studies have been carried out with TGA to reveal the ignition behaviour of coal, biomass and coal-biomass blending [5-7]. Grotkjær et al. [8] reported that the ignition temperature of the solid fuel is highly dependent on the particle size, while the sample studied in TGA is normally at fine sizes and the testable quantity is small, which is difficult to study the impact of particle size on ignition behaviour, this has also been reported by Li et al. [9] To distinguish the influence of particle size and shape on thermal behaviour of biomass, a high-temperature furnace-balance system (FBS) is developed and tested.

The aim of this work is to investigate the influence of particle size on the ignition behaviour of straw using TGA and determine the combustion kinetic parameters of different sizes of biomass using a high-temperature furnace-balance system.

2. Materials and methods

2.1 Materials

Straw pellets were milled and screened into three sizes: 1000-2000 μm, 315-500 μm and 63-80 μm. The results from proximate and ultimate analysis of the samples are summarized in Table 1.

Table 1. Proximate and ultimate analysis of sample.

wt, %	Sample tested in TGA		Sample tested in furnace	
M_{ad} (moisture content)	5.6		9.3	
V_d (volatile matter)	57.92		67.8	
A_d (ash content)	7.92		6.7	
FC_d (fixed carbon)	37.16		16.2	
C (*db*)	55.92		45.2	
H (*db*)	5.02		5.25	
O (*db*)	30.48		41.2	
N (*db*)	0.44		0.71	

*db=dry basis

2.2 Estimations of the ignition temperature using TGA

The Netzsch STA 449 F3 Jupiter, which is a high speed furnace, was used to obtain the thermogravimetric (TG) and differential thermogravimetric (DTG) curves for the milled straw samples. The ignition temperature is identified as the lowest temperature at which a solid fuel starts to ignite in air without the aid of an external ignition source. In theory, it is the temperature to which a fuel-air mixture must be increased so that the heat evolved by the exothermic reactions of the system will just overbalance the rate at which heat is discharged to the surroundings [10]. By comparing the behaviour of fuels in an oxidative and an inert atmosphere, the mechanism of ignition can be examined, and through the study of TG and DTG curves, the ignition temperature can be determined. A common approach is to identify the ignition temperature as the temperature at which the weight loss curves in the combustion (in an oxidative atmosphere) and pyrolysis (in an inert atmosphere) experiments diverge [11, 12].

2.3 The high temperature furnace-balance system

The high-temperature furnace balance system (FBS) is a combined device, the furnace is ThermConcept High-Temperature furnace comes with Eurotherm 3208 controller, it can test the combustion of different samples in different sizes and shapes under different conditions and obtain the solid products; the connected balance is Sartorius laboratory balance, which can record the weight change of sample during the tests. The balance is connected to a platform with a thermal insulation tube. Figure 1 shows a picture of the device and a sketch of the connection. During the test, temperature of the furnace is governed by a heating program and data are collected in real-time.

5 g straw pellets (each pellet is about 0.7-1 g in mass, 4 cm in length and 0.5 cm in diameter) and 5 g milled straw pellets were tested in the furnace-balance system to study the heating characteristics of equipment and to calculate the combustion kinetics parameters: activation energy, *E* and pre-exponential factor *A*. The samples were