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Impact of KCl impregnation on single particle combustion of wood and torrefied wood

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HIGHLIGHTS

- We study combustion of raw and torrefied wood spheres with varying K content.
- Ignition time and devolatilization time depend mostly on fuel particle mass.
- Both char yield and reactivity influence char conversion time.
- Potassium promotes char yield and char reactivity of raw and torrefied wood.
- Torrefaction increases char yield but does not influence char reactivity.

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ABSTRACT

In this work, single particle combustion of raw and torrefied 4 mm wood particles with different potassium content obtained by KCl impregnation and washing was studied experimentally under a condition of 1225 °C, 3.1% O_2 and 26.1% H_2O. The ignition time and devolatilization time depended almost linearly on the fuel particle mass. The char conversion time was influenced by both the char mass and char reactivity. Both KCl impregnation and torrefaction promoted char yield, while washing slightly inhibited char formation. The char reactivity was increased by KCl impregnation, decreased by washing, and unchanged by torrefaction. Compared to the raw wood particle, the char conversion time was increased by torrefaction, decreased by washing, and almost unchanged by KCl impregnation due to its promoting effect on both char yield and reactivity.

1. Introduction

Over the last decade, there has been an increasing interest in using torrefaction as pretreatment of biomass because of its ability to increase hydrophobicity, grindability and energy density of biomass [1–3]. Torrefied biomass, also known as bio-coal, is a suitable coal substitute with lower SOx and net CO_2 emissions [4]. It can be handled and combusted in a similar way as coal in pulverized-fuel power plants without additional modifications of the plants [5]. Its potential of application in pulverized-fuel power plants and metallurgical processes has been evaluated [5–7]. However, unlike the torrefaction process and its effect on upgrading of biomass fuels which have been extensively investigated, studies on the combustion or gasification characteristics of torrefied biomass are still limited [8–20].

Char conversion is usually the rate limiting step in biomass combustion and gasification. It is generally agreed that torrefaction can increase the char yield of biomass [9,13,14,21]. However, the effect of torrefaction on the char reactivity is still in discussion. Using a thermogravimetric analyzer (TGA), Jones and coworkers reported that torrefaction reduced the reactivity of willow and Eucalyptus chars produced in a drop tube reactor [9,22,23], with the chars produced from the torrefied biomass less reactive than the chars produced from the untreated biomass. Karlström et al. [21] showed that after torrefaction, the char reactivity was increased, decreased and unchanged for straw, olive stones and pine shell, respectively. Our previous work [13] revealed that the chars from raw and torrefied Schima wood had almost the same reactivity.

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The observed discrepancy of the effect of torrefaction on char reactivity may be related to the ash content and composition in biomass. The existing studies indicate that torrefaction does not influence the char reactivity of biomass with low ash content [13,21], while for biomass with high ash content, it may either reduce or promote the char reactivity [9,21–23]. Among the ash forming species in biomass, potassium species, such as KCl, can effectively increase both char reactivity [24,25] and char yield [26,27–39]. In order to better understand the effect of torrefaction on char reactivity, it is therefore of interest to evaluate how torrefaction can influence the char reactivity of biomass with different potassium content. In addition, since potassium promotes both char yield and char reactivity, it is of interest to investigate the effect of potassium on char conversion time under high temperature conditions relevant for pulverized fuel combustion.

In the present work, we prepared wood particles with different potassium content by water washing, impregnation with KCl, impregnation with KCl after washing, and washing after impregnation. The raw and the torrefied wood particles with different potassium content were combusted in a single particle reactor to evaluate the time for ignition, devolatilization and char conversion. In addition, selected char particles were extracted from the single particle reactor to determine the char yield and to analyze the char reactivity by thermogravimetric analysis.

2. Experimental

2.1. Feedstock

Spherical Schima wood particles with a diameter of ~4 mm were used as feedstock. The particle size was chosen to represent the largest particles used in pulverized fired biomass boilers [13,30]. The gross calorific value, proximate analysis and ultimate analysis of the fuel are listed in Table 1. As can be seen, Schima wood is low in ash and alkali and alkaline earth metal content.

The wood particles were machine-produced to ensure uniformity. Each particle was drilled with a 0.4 mm driller, and then weighed on a microbalance (±0.01 mg). The weight of the particles was averaging out at 20.0 mg with a standard deviation of 1.5 mg. The dimensions in three principal axes were measured using a handheld micrometer (±0.05 mm) and the mean diameter was 3.94 mm with a standard deviation of 0.04 mm.

Table 1
Gross calorific value, proximate and ultimate analysis of Schima wood.

Parameter	Unit	Value
Gross calorific value	MJ/kg (as received)	18.7
Moisture	wt% (as received)	5.6
Ash	wt% (as received)	1.2
Volatiles	wt% (as received)	75.6
Fixed carbon	wt% (as received)	17.7
Carbon (C)	wt% (dry basis)	49.6
Hydrogen (H)	wt% (dry basis)	6.1
Nitrogen (N)	wt% (dry basis)	<0.2
Sulphur (S)	wt% (dry basis)	<0.1
Chlorine (Cl)	wt% (dry basis)	<0.2
Aluminum (Al)	mg/kg (dry basis)	260
Calcium (Ca)	mg/kg (dry basis)	590
Iron (Fe)	mg/kg (dry basis)	110
Potassium (K)	mg/kg (dry basis)	850
Magnesium (Mg)	mg/kg (dry basis)	210
Sodium (Na)	mg/kg (dry basis)	<10
Phosphorus (P)	mg/kg (dry basis)	2500
Silicon (Si)	mg/kg (dry basis)	1100

2.2. Sample pretreatment and torrefaction

Four ways of pretreatment consisting of washing, impregnation and their different combinations were applied to the Schima wood particles: (a) washing by deionized water at 333 K for 3 h under stirring; (b) impregnation with 1.07% (weight basis) KCl solution at room temperature for 3 h; (c) washing by deionized water at 333 K for 3 h under stirring, followed by impregnation with 1.07% KCl solution at room temperature for 3 h; (d) impregnation with 1.07% KCl solution at room temperature for 3 h, followed by washing by deionized water at 333 K for 3 h under stirring. For all the treatments, less than 0.3 g wood sample was soaked in 150 ml water or KCl solution. After washing/impregnation, all pretreated samples were dried in an oven at 333 K for about 12 h.

Part of the raw and pretreated samples were torrefied in a tube oven in the presence of nitrogen at 290 °C or 350 °C for 1 h, following the procedures described in [13].

All prepared particles were stored in sample bags before being tested in the single particle combustion reactor. The samples, which were washed but not torrefied, were denoted as "washed raw". Similarly, the sample "KCl + washed 290 °C" denotes the Schima wood particles that were first impregnated by KCl solution, and then washed and torrefied at 290 °C for 1 h, and so on.

2.3. Single particle combustion experiments

The combustion experiments were conducted in a single particle combustion (SPC) reactor shown in Fig. 1. The SPC reactor was designed to simulate the combustion conditions in a pulverized fuel-fired boiler. The setup mainly consists of a tube reactor, a burner, a gas supply system and a video recording system. A burner with ninety-four injection nozzles were used to achieve good gas mixing and led to a uniform flow distribution and a flat temperature profile in the center of the reactor, where the biomass particles were placed. Four mass flow controllers (MFCs) controlled the flow to the burner, maintaining flow rates of 8.45 Nl/min, 5.20 Nl/min and 22.80 Nl/min for hydrogen, oxygen and nitrogen,

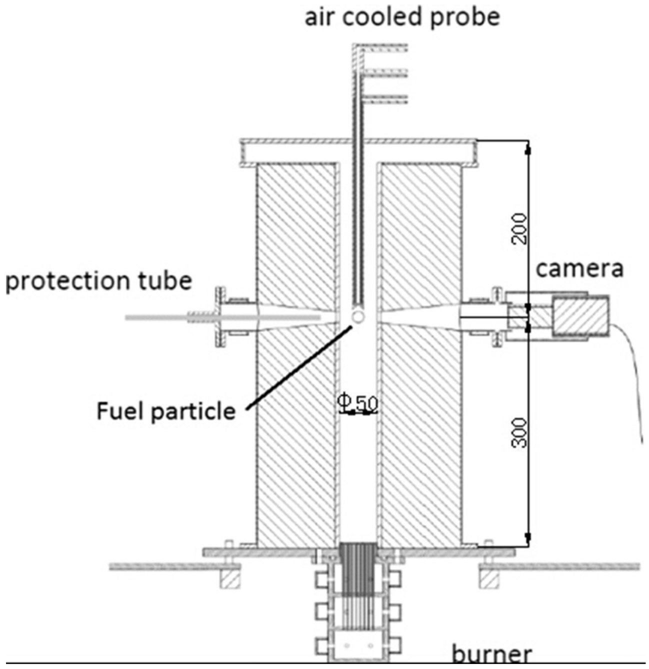

Fig. 1. Schematic diagram of the SPC reactor.