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ScienceDirect

Energy Procedia 105 (2017) 642 – 647

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Gasification of high heating-rate biomass-derived chars at elevated temperatures

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Abstract

In this study, gasification behavior of high heating-rate chars were investigated using an entrained flow reactor with an optical particle-sizing pyrometer. Two biomass chars produced from forest residue and torrefied forest residue as well as one coal char produced from low sulfur Black Thunder subbituminous coal have been gasified at temperature over 1700 K. Both the char surface temperatures and surrounding gas temperatures were precisely measured. Despite large discrepancies in constituents, the two biomass chars showed rather similar surface temperatures at the tested conditions. However, a slight lower surface temperature was obtained by the coal char gasification. A comprehensive model was also applied to aid understanding of the conversion process of char gasification. One set of intrinsic kinetic parameters for both the heterogonous water-gas reaction and the Boudouard reaction were found to effectively capture the experimental data at the two investigated conditions.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: Char; Biomass; Gasification; Surface temperature; Torrefaction; Kinetics

1. Introduction

Biomass is one of the most attractive alternative carbon sources because of its renewability and availability. It is particularly interesting to convert biomass into syngas that contains mainly hydrogen and carbon monoxide. The biomass-derived syngas has a big potential to produce liquid transportation fuels and important industrial intermediates such as lower olefins [1]. However, because of the inherent fuel properties of biomass, certain pretreatments are often required for an efficient conversion process, such as

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Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.369

torrefaction. Compared to raw biomass, torrefied biomass has better grindability, higher energy density, and significantly improved hydrophobic behavior. Gasification of biomass is a complex process in particular the rate-limiting step of char conversion. Increased efforts have been given to investigate the behavior of high heating rate char conversion at high temperature conditions that are relevant to industrial reactors [2–6]. However, time-resolved char temperature profiles are rarely reported at such conditions, especially for chars produced from biomass and torrefied biomass. The temperature history of the char particle is a direct reflection of the char conversion process. In addition, an accurate profile of the char temperature is very valuable for validating numerical models.

In the current work, an entrained flow reactor with an optical particle-sizing pyrometer was used to investigate gasification of high heating-rate chars produced from biomass and torrefied biomass. High precision surface temperatures of chars were obtained. Moreover, a sophisticated char conversion model was applied to examine kinetic parameters of the heterogonous water-gas reaction and the Boudouard reaction. One char produced from a low sulfur coal was also studied for comparison reason.

2. Experimental methods

The biomass investigated is a type of forest residue consisting of tops and branches of trees. The corresponding torrefied biomass was produced in a torrefaction reactor consisting of four electrically heated screw conveyors [7]. In the torrefaction process, the biomass were preheated at 498 K for 5 min and then torrefied at 548 K for 30 min. The coal examined in this study is for comparisons a low sulfur subbituminous coal from the Powder River Basin coal region named Black Thunder. The biomass char (BC), torrefied biomass char (TBC), and coal char (CC) were produced in an electrically heated drop tube reactor (DTR) located at the Combustion Research Facility of Sandia National Laboratories [8]. The wall temperatures of both the reactive section and the preheater section were 1200 °C. A bulk gas stream of 182 slpm (liters per minute at 0 °C and 1 atm) of preheated N_2 was introduced into the reactor to generate the desired pyrolysis atmosphere. It is worth noticing that the coal char was produced at slightly different atmosphere, which is a mixture of a stream of 180 slpm of N_2 and a stream of 5.5 slpm of O_2. The details of the char production have been presented elsewhere [8,9]. To aid data acquisition, both the biomass chars were sieved to 71-90 μm, and the coal char was sieved to 75-90 μm. Proximate and ultimate analyses of the feedstocks and chars have been summarized in Table 1. Due to the low char yields of biomass and torrefied biomass, proximate analysis of the corresponding chars were not performed.

Table 1. Proximate and ultimate analysis

	Biomass	Torrefied biomass	Coal	Biomass char	Torrefied biomass char	Coal char
Proximate analysis (wt. %, as received)						
moisture	6.3	4.2	9.3			3.7
ash	2.2	2.7	4.8			9.5
volatile	70.0	61.6	42.3			12.1
fixed carbon	21.5	31.5	43.6			74.1
Ultimate analysis (wt. %, dry ash free)						
C	52.1	59.5	69.0	69.8	78.1	89.6
H	6.1	5.6	5.0	2.7	2.2	0.8
O (by diff.)	41.3	34.3	25.4	27.0	19.0	1.3
N	0.5	0.6	1.0	0.5	0.7	8.0
S	<0.02	<0.02	0.5	<0.02	<0.02	0.4