



Combustion of spherically shaped large wood char particles

H. Molintas¹, A.K. Gupta^{*}

Combustion laboratory, Department of Mechanical Engineering, University of Maryland College Park, MD 20742, United States



ARTICLE INFO

Article history:

Received 3 January 2016

Received in revised form 20 February 2016

Accepted 21 February 2016

Available online 25 March 2016

Keywords:

Char

Kinetic parameters

Ash segregated core model

Random pore model

Diffusion

ABSTRACT

This paper examines the effects of temperature and oxygen enrichment on conversion of large wood char particle under non-isothermal conditions. Combustion air and its combination with oxygen are examined at temperatures of 800 and 850 °C for identical initial char weight, diameter and reaction time. One-film ash segregated core and random pore models are used to characterize the combustion condition. The combustion regimes for these particles are found to be near kinetic-diffusion controlled based on the ash segregated core model. Diffusion and reaction rate relationships are also characterized. Oxygen enriched conditions provided greater reactivity as compared to non-enriched oxidation conditions. For the ash segregated core model, the lowest and highest estimated activation energy values are 123 kJ/mol and 180 kJ/mol, respectively. The activation energies obtained with the random pore model showed inconsistencies. Thiele modulus values varied from 500 to 1000, indicating that the surface reaction rates are significantly faster than pore diffusion rates with oxygen being mostly consumed at the particle surface.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

The increased global awareness of dwindling energy resources and consequent damaging effects of climate change have prompted scientists and engineers worldwide to consider a far-reaching approach in developing alternative and renewable energy resources [1]. This approach was envisioned for urgency to accelerate global collaborative research efforts to develop energy sources and seek sustainability for the ever increasing global energy demand during this millennium while also conserving the environment.

Presently, coal is a major fossil fuel energy resource in the United States because it is abundant with several hundred years of reserves. However, the environmental damage caused by massive coal mining via open pit and underground operations are considered destructive to groundwater resources and natural habitat. Burning coal in power plants is also known to produce high levels of CO₂, NO_x and other hazardous gases, especially sulfur oxides. Therefore, renewable energy resources such as biomass fuels and municipal solid wastes have captured the interest of researchers worldwide because these have significantly lower adverse impacts on the environment as compared to coal and other fossil fuels.

Commercialization of large scale biomass and municipal solid waste (non-hazardous biomass-based) combustion and gasification technology with processing scales up to 1000 tons/day is currently being investigated [2]. However, large scale biomass energy systems compete directly with

food crops production and industrial operations for dedicated and enormous land resources [3]. For countries with limited land areas, such as Japan and the Philippines, real estate is a premium. Hence, small scale energy systems (with processing rates of <3000 kg/day) are considered a more reasonable strategy in increasing future biomass energy global energy portfolio than large scale systems. Small scale systems are also ideal in special applications, such as ships [4] and other isolated, remote and space limited areas where decentralized and small scale energy generation could be beneficial. However, the efficiency of small scale biomass and solid waste energy processors needs to be enhanced for their greater acceptability as alternative energy resources to coal and other fossil fuels.

Depending on the type of gasifier or combustor, biomass or solid waste fuels are processed with various particle sizes, ranging from 100 μm to 100 mm [5,6]. However, biomass and solid waste particle sizes are usually larger than pulverized coal char particles. For updraft or downdraft packed bed processors, biomass fuel size particles are used between 2 and 100 mm either as received or with some preprocessing to reduce the size [5]. In fluidized-bed systems, biomass fuels are pelletized between 2 and 10 mm, depending on fluidization conditions [6]. However, because kinetic and design parameters for large particles > 1 mm are scarce, gasifiers or combustors are normally oversized to compensate for operational challenges. Also, these trial and error design methods are expensive. Although it is well known that large char particle combustion processes are affected by diffusional effects, accurate kinetic parameters are not available in the open literature. As a result, a previous study conducted on the overall conversion of a large biomass feedstock particle up to 15 mm showed that actual particle surface temperatures and conversion times were significantly greater than predicted values [7,8]. One of the reasons for these deviations is that the

^{*} Corresponding author.

E-mail addresses: molintas@umd.edu (H. Molintas), akgupta@umd.edu (A.K. Gupta).

¹ Graduate Student.

kinetic data used in modeling was for small particles (<0.25 mm diameter). Additionally, there is a dearth of experimental data regarding large particle combustion processes but the relative diffusion and kinetic rate relationships are lacking.

This paper is focused on providing kinetic data for large oakwood char particle combustion. Four cases are experimentally investigated using air and O₂ enriched air at 800 and 850 °C. Existing mathematical models from the literature are used to evaluate the apparent activation energy, frequency factor, energy released and peak energy rates using Euler Explicit Method via discrete time periods. A linear fit approach was used to evaluate the activation energy and frequency factor from the Arrhenius equation. Char surface temperatures are calculated by considering particle weight and diameter evolution with respect to time using a simplified energy equation for a one-film ash segregated core model (ASCM). The ASCM is also used to compare the relative external reaction and diffusional rates of combustion and determine the combustion regime under the specific test conditions. Thiele analysis and random pore model are also used to examine particle surface reaction, pore diffusion rates and internal kinetic parameters. Experimental data are characterized and optimized using non-linear regression method, which enabled data-fitting into the different combustion models examined for the effects of:

- Effect of O₂ enriched air and initial temperatures on conversion
- Characterize relationships between external reaction, external diffusion and pore diffusion rates via the ASCM and random pore model (RPM) and Thiele analysis
- Effects of other combustion parameters on activation energies

2. Background

Drying is a first step of the overall conversion process of biomass feedstocks and this involves the interplay of three phases where the liquid and gas travel in solid surfaces through complex pore networks with various sizes and shapes. After particle drying, (above 100 °C), feedstock devolatilization or pyrolysis commences, wherein tars containing thousands of compounds including, aromatics and other high molecular weight substances are released [9]. Char reduction (gasification, combustion or their combination) takes over immediately after the devolatilization period, which is the longest step or rate-determining in the overall char reduction or conversion [10]. Although these processes could overlap, these occur nearly in series for batch mode feeding because foregoing processes will be more severe than previous ones, depending on reactor temperature conditions and moisture content, porosity, shape, composition, ash content and size of the feedstock. Char reduction is also influenced by multicomponent diffusion of reactants and products as well as energy transport processes across the external and internal boundary layers of particles. However, drying, devolatilization and reduction are generally more intense for large char particles than small particles, <0.25 mm. Also, for large particles, these processes are complicated because there is a significant interplay between mass transfer, chemical reaction and heat transfer processes. For small particles <0.25 mm, extensive studies have been provided on the relative controlling mechanisms under pure kinetic rate controlled conditions [11,12]. However, very few studies have been completed in characterizing the reaction rates and internal or external diffusional rates for large char particles >1 mm. Experimental data are not available for large char particle combustion wherein temporal evolution of particle weights at defined temperatures is established.

Currently, there are three operating regimes that are used to describe char reduction phenomena: (a) kinetic controlled or Zone I, (b) diffusion-kinetic controlled or Zone II and (c) diffusion controlled or Zone III [13]. Successful design and development of combustors require accurate understanding of char oxidation regimes and apparent kinetic parameters under various temperatures and oxidizing conditions. Consequently, for

large char particles, mathematical modeling need to be more detailed and representative than state-of-the-art models as used mostly for small particle combustion such as the one-step global reaction rate model [13]. Therefore, the combustion behavior, operating regimes and kinetic parameters (activation energy and frequency factor) are examined here in this paper for large char particles. Oakwood char particles between 6.7 and 6.9 mm are used as char samples. These particle sizes are favorable for compact gasifiers and combustors with space limitations as they alleviate any preprocessing or pulverizing.

3. Experimental approach

3.1. Char material

The fresh spherical oakwood and its charred particle are shown in Fig. 1a and b, respectively. Char samples were made from spherical oakwood samples (see Fig. 1a). As reported in literature, the ultimate analysis of oakwood is 6.2% H, 50.2% C, 43.5% O and 0.1% N [14]. The spherical oakwood char particles were pyrolyzed using an electric furnace under isothermal operating conditions at 230 °C for 24 h. Char sample preparations and pyrolysis conditions were uniform and identical, having an average volume reduction of 28.4% from its initial size at 9.5 mm (see Fig. 1). Therefore, the char sample particles and their inherent char porous structures are expected to be nearly consistent and identical in this study.

3.2. Experimental procedure

A schematic diagram of the experimental facility shown in Fig. 2 consists of a precision weighing scale, a propane fired reactor, lenses to perform particle imaging, a light source and a high speed camera. The weighing scale was mounted on a rigid aluminum structure, which was resiliently mounted on the floor to mitigate and absorb the effects of any external weight disturbances around the vicinity of the experimental facility. The test matrix for this study is shown in Table 1. The Reynolds numbers were calculated based on the initial reactor temperatures and particle diameters. Experiments were performed by first measuring and recording the initial weight and diameter of char particles to be combusted. These particles were tethered to a stainless steel wire connected to the weighing scale to measure the rate of weight loss. Subsequently, these particles were lowered into the reactor zone immediately when the desired oxidizing agents and reactor temperature are established. A data acquisition system was used to record the temperatures and weight measurements every 5 s. Particle diameters were also monitored and recorded during combustion via imaging photography every 5 s. All measurements were completed after a total reaction time of 40 s, the total time when majority of combusted particles fragment and then disintegrate into smaller particles.

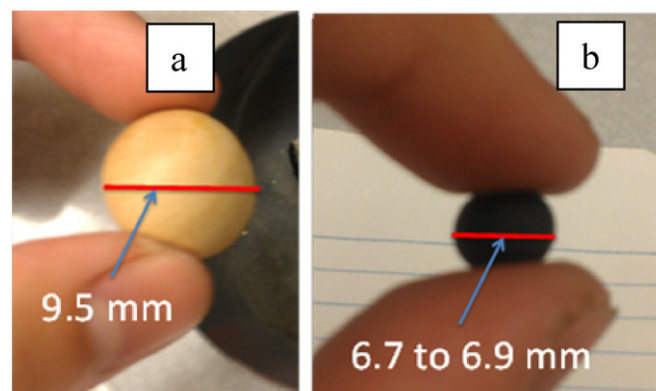


Fig. 1. (a) Raw spherical oakwood with average weight of 0.48 g and (b) spherical oakwood char particle weighing between 0.075 g to 0.081 g.

Download English Version:

<https://daneshyari.com/en/article/6656667>

Download Persian Version:

<https://daneshyari.com/article/6656667>

[Daneshyari.com](https://daneshyari.com)