



# An experimental and theoretical investigation on torrefaction of a large wet wood particle



Prabir Basu<sup>a</sup>, Anup Kumar Sadhukhan<sup>b,\*</sup>, Parthapratim Gupta<sup>b</sup>, Shailendra Rao<sup>c</sup>, Alok Dhungana<sup>c</sup>, Bishnu Acharya<sup>c</sup>

<sup>a</sup> Mechanical Engineering Department, Dalhousie University Halifax, Canada

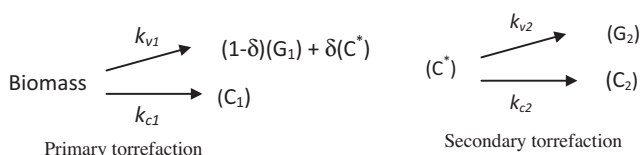
<sup>b</sup> Chemical Engineering Department, National Institute of Technology Durgapur, India

<sup>c</sup> Greenfield Research Incorporated, Halifax, Canada

## HIGHLIGHTS

- A simple kinetic model proposed for primary and secondary torrefaction reactions.
- Drying and 1D heat transfer model incorporated.
- Torrefaction reaction identified as exothermic for Poplar wood.
- Optimum torrefaction temperature, particle size and residence time determined.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

### Article history:

Received 13 December 2013

Received in revised form 14 February 2014

Accepted 17 February 2014

Available online 4 March 2014

### Keywords:

Torrefaction  
Kinetic model  
Heat transfer  
Rate-controlling  
Design

## ABSTRACT

A competitive kinetic scheme representing primary and secondary reactions is proposed for torrefaction of large wet wood particles. Drying and diffusive, convective and radiative mode of heat transfer is considered including particle shrinking during torrefaction. The model prediction compares well with the experimental results of both mass fraction residue and temperature profiles for biomass particles. The effect of temperature, residence time and particle size on torrefaction of cylindrical wood particles is investigated through model simulations. For large biomass particles heat transfer is identified as one of the controlling factor for torrefaction. The optimum torrefaction temperature, residence time and particle size are identified. The model may thus be integrated with CFD analysis to estimate the performance of an existing torrefier for a given feedstock. The performance analysis may also provide useful insight for design and development of an efficient torrefier.

© 2014 Elsevier Ltd. All rights reserved.

## 1. Introduction

The independence and self-sufficiency in energy sector is an indicator of the socio-economic development of any country. Hence the recent research trend focuses towards the exploration of energy by utilization of non-conventional energy sources. A major thrust is on efficient and regulated utilization of the abundantly available natural and renewable resource, the biomass. Biomass

provides a clean, renewable energy source the use of which could significantly improve our environment, economy and energy security by reducing the consumption of fossil fuels, emission of greenhouse gasses and environmental pollution (Chen and Kuo, 2011). Biomass can be used to generate heat and power as per the requirement of industry and domestic uses. This unique advantage over wind power and solar energy via photovoltaic cells makes biomass an important pillar in the energy supply today and in the foreseeable future. Biomass, including a wide range of fuels such as wood, energy crops, forest and agricultural residue, industrial and municipal wastes etc., may be the promising

\* Corresponding author. Tel.: +91 9775390738; fax: +91 343 2754078.

E-mail address: [t\\_sadhu@yahoo.com](mailto:t_sadhu@yahoo.com) (A.K. Sadhukhan).

alternatives for coal. Biomass is predominantly used in unscientific manner in rural areas for cooking and heating purposes. However, the utilization of biomass in an industrial scale is a real challenge. The inherent properties of biomass like high moisture content, low energy density and difficulty in grinding limit its use in coal-fired power plants for co-firing option. Furthermore, the biological decay of biomass during storage possesses additional risk of fire and safety issue during storage. To overcome these limitations, torrefaction has been proposed as a process for upgrading biomass by thermal treatment (Arias et al., 2008).

Torrefaction is a kind of mild pyrolysis in temperatures ranging from 200 to 300 °C and the residence time varies from about an hour to several hours in the absence of oxygen (Li et al., 2012). Ciolkosz and Wallace (2011) presented an overview of the influence of torrefaction temperature and residence time on important fuel parameters like chemical composition, heating value and grindability. The researchers also investigated the heat of reaction by monitoring the energy demand of the torrefaction reactor as the heat of reaction is an important parameter for the control of large-scale torrefaction plants.

During the Torrefaction process, mostly the hemicellulose in biomass depolymerizes releasing volatiles of low energy values and, as a result, the remaining solid has high energy density. This process effectively reduces the H/C and O/C ratio in biomass (Sarvaramini et al., 2013), bringing it closer to coal in terms of combustion properties. Moreover, substantial changes in physical properties like increase in grindability, hydrophobicity (Li et al., 2012) also takes place, making it easier to handle and process as a fuel.

Torrefaction is currently being considered as one of the most suitable pre-treatment process for biomass feedstock, particularly for thermal conversion like pyrolysis, combustion, gasification and co-firing system. Torrefaction not only improves the grindability and energy density, it also improves uniformity in properties among different biomass feedstock types and eliminates volatile acids content in bio-oil extracted from a mixture of biomass feed stock. It also improves fluidisation properties of heterogeneous biomass mixture of varying sources (Kersten et al., 2005). There is an enormous potential for utilization of torrefied biomass for co-firing in existing coal fired power plants. With the rise in interest in co-firing, the need for a first-level model for torrefaction process is more pronounced than before. For the design of a new torrefier for a specific type of feed as well as torrefaction of a new feedstock in an existing torrefier, it is vital to know the product quality for a given torrefaction temperature, and residence time. Although pilot plant tests are the best option, it is expensive and may not allow exploration of all variables, while a suitable mathematical model is expected to provide the vital information about the process.

Torrefaction of fine particles of biomass may be considered to be kinetically controlled where transfer resistances can be neglected. Typically, the most simplified kinetic model for torrefaction reaction may be represented by the following equation (Sadhukhan et al., 2008; Murugan et al., 2009).

$$\frac{dX}{dt} = k.(1 - X)^n \quad (1)$$

Where  $X$  is the fractional conversion on dry ash free basis and is defined as:

$$X = \frac{w_i - w}{w_i - w_{ash}} \quad (2)$$

$w$  is the mass of the biomass sample at time  $t$ ,  $w_i$  is the initial mass of the sample and  $w_{ash}$  is the mass of ash in the sample calculated from proximate analysis, all considered on dry basis.  $k$  is the reaction rate constant that usually follows the Arrhenius dependence

on temperature. Di Blasi (2008) proposed that the pyrolysis of biomass at low temperature may be presented by a global one step reaction kinetics for overall decomposition but the kinetic parameters obtained by different researchers are not consistent with this model.

The micro fibrous wood has a complex structure made of three main constituents; cellulose, hemicelluloses and lignin (Chen and Kuo, 2011). They proposed that the torrefaction kinetics of wood might be represented by the individual degradation kinetics of cellulose, hemicelluloses and lignin with three  $n^{\text{th}}$  order chemical reactions. Torrefaction of wood based on thermal degradation kinetics of hemicellulose, cellulose and lignin lead to several thermal events detected by sudden changes in slope of mass loss vs. temperature curves (Sadhukhan et al., 2008).

As torrefaction of wood may be considered to be pyrolysis at low temperature, pyrolysis models are expected to be applicable for torrefaction of biomass without major error. The kinetic model by Bradbury et al. (1979) consisting of an activation step followed by two subsequent reactions may be used. Varhegyei et al. (2011) proposed another model consisting of two first-order consecutive reactions incorporating decomposition of Xylan. They assumed that xylan produces an intermediate product, which reacts further to produce the final product.

Another model was developed by Rousset et al. (2006) incorporating the constituent's lignin, cellulose, and hemicelluloses in proportion with their mass fraction in wood. It was assumed that lignin decomposes into char and volatiles in a simple decomposition path. Cellulose decomposes by two competing reactions, one producing tar and the other producing char and volatiles. Hemicellulose decomposes according to parallel reaction scheme to produce char and volatiles with the creation of an intermediate product. The model involves a large number of kinetic parameters.

Di Blasi and Lanzetta (1997) modelled the torrefaction kinetics by a two-step reaction mechanism with competing reactions for the formation of solid char and volatiles. Prins et al. (2006) used this reaction scheme for torrefaction kinetics of beech and willow wood fines in isothermal TGA apparatus. They estimated the kinetic parameters and found that the activation energies for formation of gaseous volatiles are higher than that of formation of chars, which ensures that the volatile yield increases compared to char with an increase in reaction temperature. Sadhukhan et al. (2009) also observed experimentally a similar trend for pyrolysis of wood.

Biomass being fibrous in nature has poor grindability. The preparation of biomass fines is not only an energy-intensive process but also need the special design for milling system. As torrefaction significantly improves the grindability of biomass (Arias et al., 2008), large biomass particles are better suited. The torrefaction of thick wood particles involves a strong interaction between reaction kinetics and heat transfer phenomena at the level of both single particles and the reaction environment. When exposed in a high-temperature environment, the particle is initially heated up by external convection and radiation depending on the temperature. Transient heat conduction and internal convection take place within the particle, followed by highly endothermic moisture evaporation depending on the initial moisture content. Meanwhile, the already dried region of the particle near the outer surface undergoes thermal degradation. Therefore, the different spatial zones may appear during the process of transient torrefaction; a char layer, a torrefaction region, a drying region and the virgin moist biomass. Water vapour and gaseous volatiles partly leave the particle flowing through the porous structure of solid biomass. The volatiles produced at inner depth of thick biomass particle passes through the pores very slowly. A fraction of volatiles may be deposited on char surface (Koufopoulos et al., 1991) and may undergo secondary reactions over char surface at high

Download English Version:

<https://daneshyari.com/en/article/7078657>

Download Persian Version:

<https://daneshyari.com/article/7078657>

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