Industrial Crops & Products 109 (2017) 598–602

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Research Paper

Structural and compositional changes in eucalyptus wood chips subjected to dry torrefaction

Carlos Miguel Simões da Silva[a,*], Benedito Rocha Vital[a], Angélica de Cássia O. Carneiro[a], Emylle V.S. Costa[b], Mateus A. de Magalhães[a], Paulo F. Trugilho[b]

[a] *Departamento de Engenharia Florestal, Universidade Federal de Viçosa, Viçosa, Brazil*
[b] *Departamento de Ciências Florestais, Universidade Federal de Lavras, Lavras, Brazil*

ARTICLE INFO

Keywords:
Lignocellulosic biomass
Mild pyrolysis
Screw reactor
Chemical composition
Thermogravimetry
Mechanical durability

ABSTRACT

The aim of this study was to evaluate the structural and compositional changes in eucalyptus wood chips subjected to dry torrefaction. The experiment was conducted in a semi-continuous screw reactor with indirect heating system. Wood chips samples of three initial moisture contents (0, 15 and 30% dry basis) were torrefied up to three final temperatures (220, 260 and 300 °C) and at three heating times (10, 15 and 20 min). The effect of these variables was evaluated through the analysis of chemical composition, thermogravimetry and mechanical durability of the torrefied wood chips. The increase at temperature and time of torrefaction, as well as the drop in the initial moisture content, promoted significant structural and compositional changes in the wood chips. The torrefied samples present a higher resistance to thermal degradation, more friable structure, higher lignin and lower polysaccharides contents than the untreated samples. These changes made it possible to increase the quality of the eucalyptus wood chips to be use as a solid fuel.

1. Introduction

Lignocellulosic biomass is a renewable energy source with carbon neutral cycle and relatively low cost of production. It comes from energy plantations or residues from the primary or industrial processing of crops and forest products (Acharya et al., 2015; Arteaga-Pérez et al., 2015). Despite meeting important economic and social-environmental precepts, the use of biomass for energy production is still far below the world's productive capacity and energy demand. The application of post-harvest treatments is one of the main alternatives to enhance the energy quality of the biomass and to support its greater use as a fuel source.

Dry torrefaction is a thermal treatment with high potential to be employed in the production chain of solid fuels from lignocellulosic biomass (Van der Stelt et al., 2011; Acharya et al., 2015). This treatment consists in subjecting the biomass to a mild pyrolysis in order to partially eliminate its volatile constituents (Arias et al., 2008; Esteves and Pereira, 2009; Bach et al., 2015). The resulting material is a fuel with intermediate characteristics between raw biomass and charcoal, such as dark color, high carbon and energy contents and low equilibrium moisture content (Medic et al., 2012; Chen et al., 2013; Du et al., 2014; Bach and Skreiberg, 2016). Torrefaction makes biomass more attractive to the primary energy production sectors by promoting an increase in its fuel quality.

The lignocellulosic biomass is a complex organic material composed of structural polysaccharides (cellulose and hemicelluloses), lignins and non-structural components (extractives and ashes) (Yang et al., 2007; Pereira et al., 2013). The volatiles eliminated during torrefaction come from the partial and selective degradation of the lowest calorific fraction of the biomass composition, such as hemicelluloses and some extractives (Esteves and Pereira, 2009; Bach et al., 2015). Hemicelluloses consist of several polysaccharides with a lower degree of polymerization, a higher Oxygen/Carbon atomic ratio and a greater proportion of available hydroxyl groups than the other constituents of the biomass (Yang et al., 2007; Haykiri-Acma et al., 2010).

Structural and compositional changes of torrefied biomass are described in several studies according to reviews published by Van der Stelt et al. (2011), Acharya et al. (2015) and Bach and Skreiberg (2016). Most of cited studies are restricted to native species from countries where torrefaction is already a more known technology. However, there is less scientific information about the effect of torrefaction on biomasses from other regions of the planet. For instance, eucalyptus wood is a raw material that should be better studied for use in the production chain of torrefied biomass. It is a forest genus with high productivity and adaptability at different conditions, it being the main woody biomass cultivated in many tropical countries such as Brazil

* Corresponding author.
E-mail address: karmiguel@yahoo.com.br (C.M.S. da Silva).

http://dx.doi.org/10.1016/j.indcrop.2017.09.010
Received 8 May 2017; Received in revised form 27 July 2017; Accepted 8 September 2017

(IBÁ, 2016).

Eucalyptus is a hardwood from the group of the high density biomasses commonly used for the energy production. The density directly influences the hardness of the biomass, bringing operational difficulties to its mechanical processing. The grinding is a previous stage of the torrefaction that increase the energy cost as a function of the biomass hardness. Therefore, the torrefaction of eucalyptus wood should be done as the minimum pre-processing to reduce the production expenses. In the other hand, post-torrefaction mechanical processing is facilitated by structural changes of the wood resulting in higher grindability (Phanphanich and Mani, 2011; Van Essendelft et al., 2013).

In light of this, the aim of the study was to evaluate the torrefaction effect in structural and compositional properties of larger chips produced from eucalyptus wood. The evaluated variables were temperature and time of torrefaction and the initial moisture of the raw biomass. The treatments were performed in a semi-continuous screw reactor.

2. Material and methods

2.1. Material

Wood chips from seven-year-old *Eucalyptus urophylla* were used for the treatment. The selected chips had specific gravity above 0.45 gcm^{-3} and an average length of 30 mm. One portion of the wood chips was selected and dried indoors with natural ventilation until it achieved moisture of 30 and 15% (dry basis). While another portion was oven dried at 103 ± 2 °C with constant air circulation to reduce the moisture to 0%, thus utilizing wood chips with three initial moisture conditions for torrefaction.

2.2. Reactor

The thermal treatments were carried out in a semi-continuous screw reactor developed at the Federal University of Viçosa (Brazil). Patents have been subjected to the equipment and its use in the BR 10 2016 010484 0 − INPA (National Institute of Intellectual Property − Brazil). As shown in Fig. 1, the reactor consists of a main structure of carbon steel and it is equipped with transport, indirect heating, cooling, and burning systems.

The transport system includes a screw of 1.3 m in length powered by an electric motor controlled two analog time relays. It is characterized as semi-continuous flow due to a sequence of pre-established stops after each complete rotation of the screw in order to achieve the residence time of each treatment. The heating system includes an external casing surrounding the transportation system, through which the heating gas passes to indirectly heat the wood chips through the heat exchange with the metal pipe. The cooling system includes a second external casing through which water is forced to circulate and cool the pipe and wood chips. In the burning system, the connection chamber is provided between the reactor and the burner which supplies the required heat energy for the process. A detailed description of the equipment was made by Da Silva (2016).

2.3. Experimental design

Three experiments were analyzed independently, using an entirely randomized design with three replications each effect:

- "Final Temperature" of torrefaction: Eucalyptus wood chips of 0%-moisture were torrefied for 15 min up to the final temperature of 220 ± 3 °C, 260 ± 3 °C, and 300 ± 3 °C.
- "Residence Time" of torrefaction: Eucalyptus wood chips of 0%-moisture were torrefied up to the final temperature of 300 ± 3 °C at the heating time of 3, 9 and 15 min.
- "Initial Moisture Content" of raw material: Eucalyptus wood chips with an initial moisture content of 0, 15 and 30% were torrefied up to 300 ± 3 °C final temperature and 15-min heating time.

2.4. Analysis

The extractives content was ascertained by the method of extraction with alcohol-toluene and following the standard of TAPPI-Technical Association of the Pulp and Paper Industry (2001). The total lignin content was obtained according to the methodology employed by Pereira et al. (2013). The insoluble lignin was determined by filtration and the soluble lignin by UV spectroscopy after a complete acid hydrolysis of the polysaccharides present in the samples. The ash content was determined according to DIN-Deutsches Institut für Normung (2009) by heating of samples at a controlled temperature of 550 ± 10 °C. The content of structural polysaccharides, also called holocelullose, was calculated by subtracting the total lignin, extractives and ash content from 100%.

Thermogravimetric analysis was done to evaluate the stability to thermal degradation of torrefied samples through the residual mass and the rate of degradation as a function of the gradual increase of temperature. This analysis was accomplished by a DTG-60H apparatus under an atmosphere of nitrogen gas at a constant flow rate of 50 ml/min and a heating rate of 10 °C min^{-1}.

The mechanical properties of the wood chips were verified by

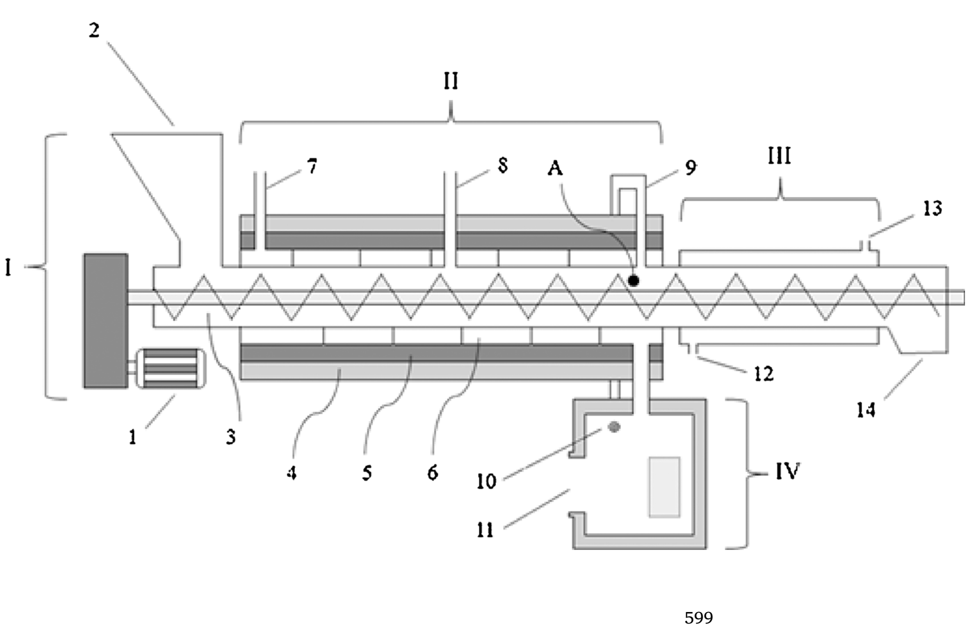

Fig. 1. Layout in side view of the reactor for biomass torrefaction in semi-continuous flow. Adapted from the master's thesis of first author (Da Silva, 2016). Where: I − Transport System; II − Heating system; III − Cooling system; IV − Burning System; 1 − Motor; 2 − Silo/input wood chips; 3 − Worm screw; 4 − Insulating layer; 5 − Refractory layer; 6 − Flow of heating gas with metal fins; 7 − Electric Exhaust/heating gas output; 8 − First "chimney"; 9 − Second "chimney"; 10 − Connection "chimney" with the burning system; 11 − Connecting between burner and camera breaks flames; 12 − Water supply; 13 − Water outlet; 14 − Exit of torrefied wood chips. A − Local of the final temperature treatment.