Biomass and Bioenergy 118 (2018) 105–114

Contents lists available at ScienceDirect

Biomass and Bioenergy

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

Research paper

The influence of pilot-scale pyro-gasification and activation conditions on porosity development in activated biochars

Flavia Lega Braghiroli[a,*], Hassine Bouafif[b], Nesrine Hamza[a], Besma Bouslimi[a], Carmen Mihaela Neculita[c], Ahmed Koubaa[a]

[a] Institut de Recherche sur Les Forêts (IRF – Research Forest Institute), Université de Québec en Abitibi-Témiscamingue (UQAT), 445 Boul. de L'Université, Rouyn-Noranda, Québec, QC J9X 5E4, Canada

[b] Centre Technologique des Résidus Industriels (CTRI, Technology Center for Industrial Waste), Cégep de L'Abitibi-Témiscamingue (Abitibi-Témiscamingue College), 425 Boul. Du Collège Rouyn-Noranda, QC J9X 5E5, Canada

[c] Research Institute on Mines and Environment (RIME), Université de Québec en Abitibi-Témiscamingue (UQAT), 445 Boul. de L'Université, Rouyn-Noranda, QC J9X 5E4, Canada

ARTICLE INFO

Keywords:
Biochar
Activated biochar
Pyro-gasification and activation conditions
Operating parameters optimization
Statistical analysis

ABSTRACT

Few studies have examined the influence of pyro-gasification and activation conditions on porosity development in activated biochars. In this context, this study investigates the effects of pyro-gasification temperature (315, 399, and 454 °C), activation temperature (700, 800, and 900 °C), and activating agent (CO_2 flow rate: 2, 3, and 5 L min^{-1}) on porosity in materials made from wood residues (black spruce and white birch). Activated biochars were prepared in a two-step process: torrefaction/fast pyrolysis in a pilot-scale plant and activation using an in-house pilot-scale furnace. Results show that the physical properties of activated biochars improved over biochars and wood residues, with fivefold greater surface area for activated birch biochar over biochars, and threefold greater surface area for activated spruce biochars. Statistical analysis results reveal that pyro-gasification and activation temperature, CO_2 gas flow rate, and wood residue type significantly affected the porosity of activated biochars (at $p < 0.05$). The main findings are as follows: i) Torrefaction or pyrolysis pre-treatment step had less impact on the porosity of activated biochars, so lower energy expenditure is required to improve product quality, i.e., porosity; ii) Activation temperature was the major variable to optimize specific surface area; by increasing from 700 to 900 °C, the average surface area for activated biochars made from both wood residues increased to nearly 120 $m^2 g^{-1}$; iii) pilot-scale technologies produced porous activated biochars comparable to laboratory-scale technologies which could boost incentives to use thermochemical biomass conversion, and increase the profitability with these diversified by-products in biorefinery industry.

1. Introduction

Advanced biomass conversion methods (using renewable carbon sources) enable transforming low-cost waste by-products into value-added materials such as chemicals, plastics, food additives, clothing fibers, polymers, paint, heat, fuel, and electricity [1–3]. Biomass conversion is a promising research field that examines and develops sustainable, environmentally friendly products and practices. The main challenge is to produce cost-efficient materials that perform as well or better than fossil fuel-based materials [4]. Thermochemical conversion processes (e.g., torrefaction, pyrolysis, gasification) are used to convert lignocellulosic biomass into solid, liquid, and gas products at various proportions and with physicochemical properties that are significantly enhanced over those of the raw material. The solid material produced is called biochar [5], defined by the International Biochar Initiative (IBI) as a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment [6].

Recently, primary industries (e.g., agriculture, logging, forestry) have been converting biomass residues into biochar to manage the tons of waste generated daily. Biochar can then be commercialized as fertilizers for soil amendment [7–9] and as pellets for bioenergy production [10]. Recent applications reported in the literature, including carbon sequestration (climate change mitigation) and degraded site rehabilitation [11–13], have promoted advances in biochar structure and characteristics, with consequent positive impacts on agriculture and the environment [14]. Moreover, due to the higher carbon content of biochar compared to biomass and the presence of certain oxygenated groups (e.g., carboxylic, phenolic, carbonyl), biochar has been used as

---

[*] Corresponding author.
E-mail address: Flavia.Braghiroli@uqat.ca (F.L. Braghiroli).

https://doi.org/10.1016/j.biombioe.2018.08.016
Received 17 February 2018; Received in revised form 3 August 2018; Accepted 29 August 2018

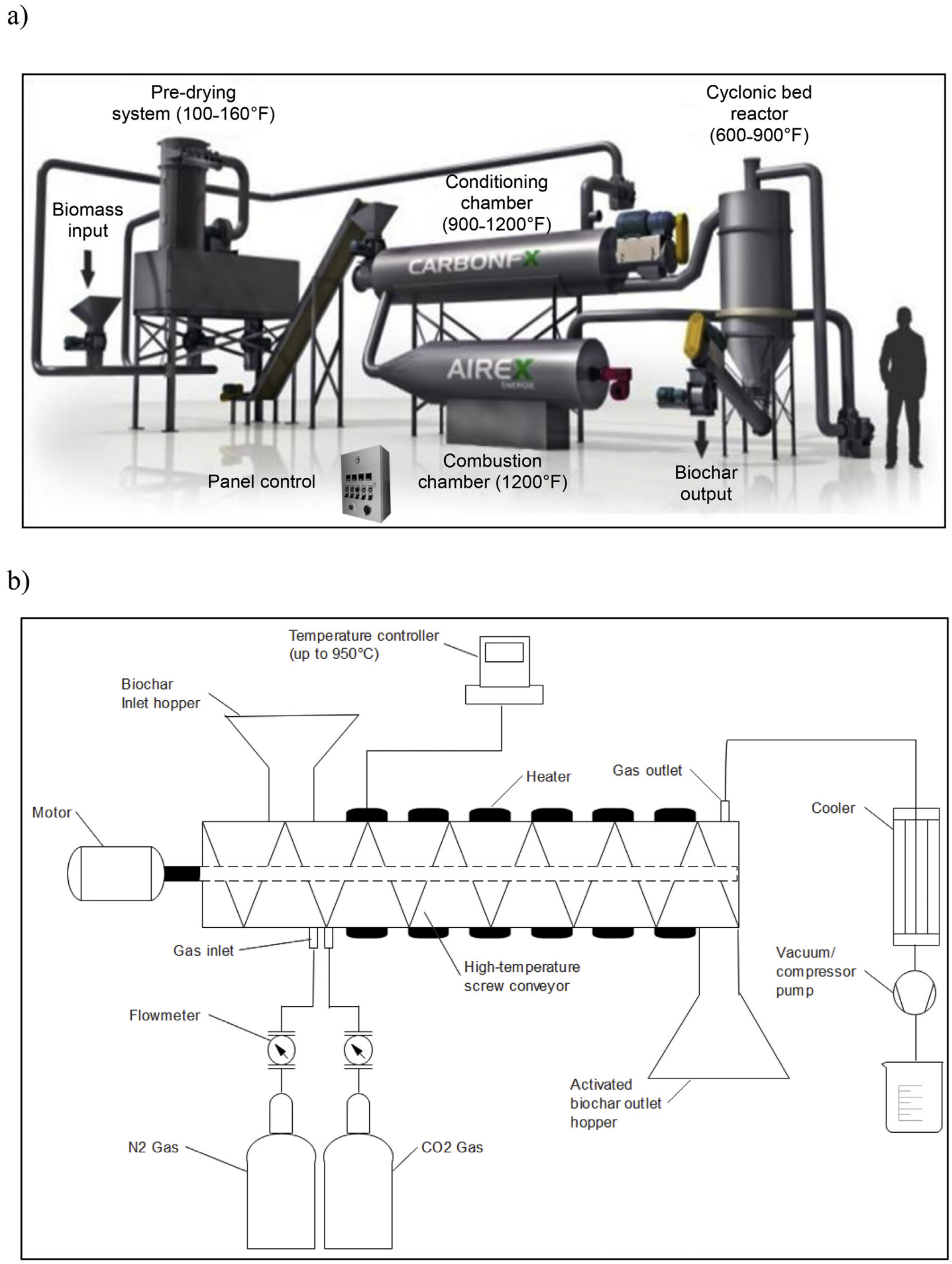

Fig. 1. a) Pilot-scale fast pyrolysis unit (CarbonFX, Airex Energy); b) Biochar activation furnace developed at CTRI (Center Technologique des Résidus Industriels – Technology Center for Industrial Waste), QC, Canada.

carbon electrode materials for application in electrochemical capacitors and supercapacitors [15–17], catalyst supports [18,19], and adsorbents [20]. However, these applications are limited by the relatively low surface area ($< 200\,m^2\,g^{-1}$) and porosity of biochars due to certain limited conditions during large-scale reactor preparation: low-temperature pyro-gasification (e.g., torrefaction at 320 °C max), short residence time (1–2 s), and high heating rate ($1000\,°C\,min^{-1}$).

Activation is a commonly used method to improve the physical properties and adsorptive capacity of biochars [21]. Activation refers to chemical and/or physical treatment of biochar that maximizes the pore density as well as the surface area available for adsorption or chemical reactions. Typically, biochars are impregnated with chemicals such as H_3PO_4 or KOH and/or steam or CO_2 gas at high temperature (e.g., 900 °C), causing a selective gasification of carbon atoms [22]. During this process, low molecular weight carbon molecules are removed, generating voids in the material structure. Thus, when processed at higher temperature, activated biochar presents a better developed porous carbon structure [21]. Several biomass precursors derived from wood residues, chips and pellets, or agricultural wastes such as fruit shells, stones, husks, and hulls have been used to produce activated biochars [23]. Abundant literature have examined the influence of activation parameters (e.g., activation temperature, activation time, gas