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Process modeling for torrefaction of birch branches

Quang-Vu Bach[a], Øyvind Skreiberg[b], Chul-Jin Lee [a,]*

[a]*School of Chemical Engineering and Materials Science, Chung-Ang University, Seoul 06980, Republic of Korea*

[b]*Department of Thermal Energy, SINTEF Energy Research, NO-7465 Trondheim, Norway*

Abstract

This work presents a complete biomass torrefaction model for Norwegian birch branches. The model can provide detailed distribution of both the main and by-products from the torrefaction process. Reduction in mass and energy yields as well as increase in heating value of the torrefied biomass with increasing torrefaction temperature are observed. Simulation results show good agreement with available experimental data in the literature. Furthermore, the overall energy consumption and the process energy efficiency can be also estimated, which is essential for process up-scaling. It reveals that drying accounts for 76-81% of the total heat demand. More importantly, the process energy efficiency reduces with increasing temperature thus torrefaction at high temperatures is not advisable. The information obtained from the model is important for industrialization and commercialization of the torrefaction process.

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Keywords: Torrefaction; Biomass fuels; Process modeling; Process optimization; Energy efficiency.

1. Introduction

Torrefaction is a thermochemical pretreatment of biomass at temperatures of 200-300 °C in an inert atmosphere and under atmospheric pressure [1-4]. The process can produce a solid fuel with superior fuel properties compared to untreated biomass. Torrefied biomass has increased heating value, better grindability, and more hydrophobicity, which makes the fuel more readily suitable in subsequent conversion processes such as pyrolysis, liquefaction,

* Corresponding author. Tel.: +82-2-820-5941.
E-mail address: cjlee@cau.ac.kr

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gasification and combustion. Besides the main solid product, a number of by-products including water, carbon dioxide (CO_2), carbon monoxide (CO), and various organic compounds can be obtained after torrefaction. They can be classified into two groups: non-condensable and condensable volatiles, although they are all volatiles when formed at the torrefaction temperature. The former are permanent gases, while the latter becomes liquid after cooled to room temperature.

Recently, research and development activities on biomass torrefaction have been very active to look at the torrefaction characteristic of a wide range of biomass species and to investigate the effects of torrefaction parameters (e.g., temperature and residence time) on the fuel properties of the torrefied products [5-10]. However, most of them are experimental studies, from which information for up-scaling the process is limited. In order to fulfill the research gap between academia and industry, process modeling studies are required.

This work aims to build a complete torrefaction model for Norwegian birch branches using a commercial simulator. The model can provide a detailed distribution of main torrefied products and by-products at various torrefaction conditions. The heating value of the main solid product after torrefaction can be predicted and are compared with available experimental data. More importantly, the overall energy consumption and the process energy efficiency are estimated and presented.

Table 1. Description of all units and streams in the torrefaction model.

Unit or stream	Classification	Description	Operating temperature (°C)
DRY-AIR	Cold stream	Air at ambient temperature	25
HX-AIRDR	Heater	Drying air heater	–
HOT-AIR	Hot stream	Hot inlet drying air	180
DRIER	Block	Drying unit	–
EXHAUST	Hot stream	Hot outlet drying air	110
HX-EXH	Cooler	Outlet drying air cooler	–
COLD-AIR	Cold stream	Cooled drying air	50
DRY-BIOM	Hot stream	Hot dried biomass	110
N2-COLD	Cold stream	Nitrogen at ambient temperature	25
TOREFIER	Block	Torrefaction unit	240–300
TOR-BIOM	Hot stream	Torrefied biomass stream	240–300
BYPROD	Hot stream	By-products stream	240–300
HX-COOL	Cooler	Product cooler	–
PROD	Cold stream	Final torrefied biomass product	50
COMB-AIR	Cold stream	Air fed to combustor	25
COMBSTOR	Block	Combustion unit	–
HOT-FG	Hot stream	Hot flue gas	–
HX-FG	Cooler	Flue gas cooler	–
COLD-FG	Cold stream	Cold flue gas	50

2. Methodology

2.1. Torrefaction process flow diagram

The flow diagram of the torrefaction model in Aspen Plus v8.8 is illustrated in Figure 1. Description of all units and streams are presented in Table 1.