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Optimizing the torrefaction of mixed softwood by response surface methodology for biomass upgrading to high energy density

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ABSTRACT

The optimal conditions for the torrefaction of mixed softwood were investigated by response surface methodology. This showed that the chemical composition of torrefied biomass was influenced by the severity factor of torrefaction. The lignin content in the torrefied biomass increased with the SF, while holocellulose content decreased. Similarly, the carbon content energy value of torrefied biomass ranged from 19.31 to 22.12 MJ/kg increased from 50.79 to 57.36%, while the hydrogen and oxygen contents decreased. The energy value of torrefied biomass ranged from 19.31 to 22.12 MJ/kg. This implied that the energy contained in the torrefied biomass increased by 4–19%, when compared with the untreated biomass. The energy value and weight loss in biomass slowly increased as the SF increased up until 6.12; and then dramatically increased as the SF increased further from 6.12 to 7.0. However, the energy yield started decreasing at SF value higher than 6.12; and the highest energy yield was obtained at low SF.

1. Introduction

The development of sustainable technologies for the production of environmentally friendly fuels is warranted due to the acceleration of global warming and depletion of the petroleum in the world. Among biomass, lignocellulosic biomass plays a major role in the production of sustainable energy, because it is renewable, abundant, relatively inexpensive, and often locally available. In recent years, growing attention has been focused worldwide on the use of lignocellulosic biomass as a feedstock to produce biofuel pellet as an alternative to fossil fuel (Nilsson et al., 2011; Stahl and Berghel, 2011). The main advantage of wood pellet, in comparison to unprocessed wood, is the higher energy density and therefore a lower transport and storage costs. In addition, wood pellet has low ash content, as compared to agricultural biomass such as rice straw and wheat straw, implying a lower risk of corrosion and fouling (Jenkins et al., 1998; Obernberger and Thek, 2004). However, wood pellet has relatively high moisture content, low energy density, hydrophilic behavior, and storage issues when compared with coal (Chen and Kuo, 2011). Also, wood pellet does not have a constant energy value and ash content because pellet can be produced from various resources. Torrefaction of lignocellulosic biomass was, thus, introduced as a method to dispel these disadvantages (Chen and Kuo, 2011; Repellin et al., 2010; Turner et al., 2010).

Torrefaction is a thermal pretreatment process where raw material is heated in an inert or nitrogen atmosphere at a temperature of 200–300 °C (Prins et al., 2006). This provides a hydrophobic condition for the biomass due to the removal of the hydroxyl group during thermal treatment (Bourgeois et al., 1989). Therefore, torrefied biomass provides suitable chemical and physical characteristics for long-distance transportation and long-term storage. Additionally, the advantages of torrefaction include a higher energy value or energy density, lower O/C ratio and moisture content, and better grinding (Phanphanich and Mani, 2010). During the torrefaction of biomass, most of the volatile compounds are removed from the biomass as vapors, and consequently results in higher energy density. Many researchers have reported that torrefaction temperature for lignocellulosic biomass range from 250 to 300 °C (Chen and Kuo, 2011; Phanphanich and Mani, 2010; Prins et al., 2006; Stahl and Berghel, 2011). In addition, Chen and Kuo suggested that biomass subjected to light torrefaction (less than 1 h) is appropriate for producing solid fuels with a higher energy density, as compared to unprocessed biomass (2010).

However, torrefaction of biomass results in biomass weight loss depending on the torrefaction condition. A high energy value of torrefied biomass is indicative of such weight loss during torrefaction. Therefore, torrefied biomass should be evaluated in terms of energy yield. In this study, the optimal condition for torrefaction to obtain a high energy yield of torrefied biomass was investigated by response surface methodology.

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