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Biomass torrefaction: Modeling of volatile and solid product evolution kinetics

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HIGHLIGHTS

- Model developed to describe evolution of volatiles during willow torrefaction.
- Composition of volatiles defined in terms of nine identifiable chemicals.
- Solid residue composition defined in terms of carbon, hydrogen and oxygen content.
- Coupled to solid mass loss kinetic rate equations.

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ABSTRACT

The aim of this work is the development of a kinetics model for the evolution of the volatile and solid product composition during torrefaction conditions between 200 and 300 °C. Coupled to an existing two step solid mass loss kinetics mechanism, this model describes the volatile release kinetics in terms of a set of identifiable chemical components, permitting the solid product composition to be estimated by mass conservation. Results show that most of the volatiles released during the first stage include highly oxygenated species such as water, acetic acid, and carbon dioxide, while volatiles released during the second step are composed primarily of lactic acid, methanol, and acetic acid. This kinetics model will be used in the development of a model to describe reaction energy balance and heat release dynamics.

1. Introduction

Torrefaction is a thermochemical pretreatment process which improves biomass utilization characteristics such as gravimetric heating value, grindability as measured by the grinding energy per unit heating value, and hydrophobicity (Acharjee et al., 2011; van der Stelt et al., 2011). During torrefaction, biomass is treated at temperatures between 200 and 300 °C, in an inert atmosphere for a period usually between 15 and 60 min.

The relevant process parameters during torrefaction include the temperature, reaction time, heating rate, feedstock, and particle size. The chemical characteristics – including ultimate analysis – of biomass torrefied under numerous combinations of temperature, reaction time, and feedstock have been investigated experimentally by Prins (2005), Arias et al. (2008), Bridgeman et al. (2008), Almeida et al. (2010) and Medic et al. (2011). Typically, the torrefied product retains 80–95% of the energy and 70–90% of the mass of the original raw biomass. The remaining 10–30% of the mass is released in the form of gaseous species. Prins (2005) and van der Stelt (2011) have analyzed the evolution of volatile species released during torrefaction utilizing gas chromatography (GC) and high performance liquid chromatography (HPLC).

While experimental work on torrefaction remains active, few models exist to comprehensively describe the evolution of the volatile products or solid composition and energy balance over a range of conditions. To address this need, we have developed a series of models to assist in the study of torrefaction according to the following steps:

1. A kinetics model to describe the release of volatiles and the resulting change in composition of the solid product.
2. A thermochemical model to estimate product properties (e.g. specific heat and heat of formation) and reaction energy balance based on the changes in chemical composition predicted by the volatile release model.
3. Coupling of this thermochemical model to a single particle heat and mass transfer model of torrefaction to study process conditions and particle size effects.

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