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Exploration of the gasification of Spirulina algae in supercritical water

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HIGHLIGHTS

- ▶ A factorial experiment was used to explore the effects on gasification reaction.
- ▶ High concentrations of real biomass compounds were gasified continuously.
- ▶ Experiments were conducted to determine Arrhenius parameters.
- ▶ The gasification reaction was modeled using Arrhenius parameters.

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ABSTRACT

This study presents non-catalytic gasification of Spirulina algae in supercritical water using a plug flow reactor and a mechanism for feeding solid carbon streams into high pressure (>25 MPa) environments. A 2_{III}^{3-1} factorial experimental design explored the effect of concentration, temperature, and residence time on gasification reactions. A positive displacement pump fed algae slurries into the reactor at a temperature range of 550–600 °C, and residence times between 4 and 9 s. The results indicate that algae gasify efficiently in supercritical water, highlighting the potential for a high throughput process. Additional experiments determined Arrhenius parameters of Spirulina algae. This study also presents a model of the gasification reaction using the estimated activation energy (108 kJ/mol) and other Arrhenius parameters at plug flow conditions. The maximum rate of gasification under the conditions studied of 53 g/L s is much higher than previously reported.

1. Introduction

Supercritical water (SCW) gasification (SCWG) is an alternative thermochemical conversion technology that causes biomass feed stocks to decompose into hydrogen, methane, carbon dioxide and water vapor in addition to some other residual products (carbon monoxide, ethane, propane). The primary products are desirable as they comprise a valuable fuel gas that is generated from renewable resources. Additionally, the process is neutral in terms of CO_2 emissions as the carbon source is photosynthetic biomass and avoids the additional step of drying in classical gas-phase gasification processes (Kruse et al., 2003).

Most of the work on SCW gasification involving continuous processes has been done on model compounds (glucose, starch gels, alcohols). Selection of model compound favors the use of liquids or water-soluble chemicals, as these are easier to pump into the high pressure SCW reactor. Glucose is a popular model feedstock for continuous processing that has been well studied at both long (~30 min) and short (4 s) residence times (Hao et al., 2003; Hendry et al., 2010; Lee and Ihm, 2009; Yoshida et al., 2004; Youssef et al., 2010). Solid feed stocks are well studied in batch SCW gasification (Kersten et al., 2006; Venkitasamy et al., 2011). These studies are important to evaluate the potential of a feed stock, but have very little promise for scale up. This highlights the necessity of establishing the capability to continuously process non-model biomass compounds in SCW.

Among the biggest challenges in continuous SCW gasification is developing a reliable delivery mechanism for solids into high pressure and temperature environments. Wet biomass, slurries, and suspensions are the most attractive feed options as they have some fluid properties allowing them to be pumped. There has been very limited research on delivery mechanisms for SCW gasification. Antal et al. (2000) made use of a "cement pump" and others have used various pre-treatment techniques including hydrothermal processing (Matsumura and Minowa, 2003) and liquefaction (Matsumura, 2002).

It is well accepted that processing wet biomass is advantageous in that it eliminates the drying step and readily lends itself to the limited solids feeding mechanisms available (Kersten et al., 2006; Kruse, 2008; Matsumura, 2002). Algae is a renewable biomass that

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