

Modeling of Biomass Char Gasification, Combustion, and Attrition Kinetics in Fluidized Beds

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ABSTRACT: Char conversion is one of the most pivotal factors governing the effectiveness of fluidized bed gasification systems. Gasification-assisted attrition is a phenomenon whereby heterogeneous reactions progressively weaken a char's structure throughout its lifetime leading to enhanced attrition and the production of a significant fraction of fines that exit the reactor unconverted. While this effect has been observed and measured experimentally, few models have been developed to quantitatively account for it, particularly for biomass chars. In this study, a transient gasification and combustion particle model is presented to describe primary fragmentation, attrition, and heterogeneous reactions of a single batch of particles. A conversion-dependent structural function is proposed to describe gasification-assisted attrition, and the model parameters are fitted to published experimental data from Ammendola, P.; Chirossi, R.; Ruoppolo, G.; Scala, F. *Proc. Combust. Inst.* **2013**, *34* (2), 2735–2740. The fragile structure of char derived from wood chips contributes to a higher initial attrition rate than char from wood pellets, but the hardness of both feedstocks is shown to deteriorate rapidly as they convert. A shrinking particle combustion model which accounts for variable feedstock properties is comprehensively presented and validated against the aforementioned data set. The combustion behaviors of both feedstocks are found to strongly depend on particle size/geometry because of significant mass transfer limitations. Using a residence time distribution approach, the model is extended to describe a continuously fed system in order to examine the sensitivity of steady-state outputs (conversion and residence time) to the operating temperature, pressure, and kinetics. As the temperature increases, the char reactivity also increases but the coupled and competing effect of gasification-assisted attrition acts to shorten the residence time of the char particles making complete char conversion very difficult even at 900 °C—the upper operating temperature limit for most single-stage fluidized bed gasification systems. Low operating temperatures result in longer average residence times and higher steady-state char inventories, and slower kinetics lowers the overall conversion. Because of inhibition effects, elevated operating pressures have a smaller impact on improving conversion compared to higher temperature. The steady model further provides a rigorous method for estimating the maximum stable biomass feeding rates as a function of relevant independent parameters including reactor temperature, pressure, volume, and feedstock characteristics.

1. INTRODUCTION

Because of rising concerns over greenhouse gas emissions and regulatory production mandates, alternatives to traditional fossil-derived transportation fuels are receiving much attention. Fluidized bed biomass gasification (FBBG) is a promising technology for the thermochemical conversion of lignocellulosic biomass to second generation renewable fuels. Owing to the high rates of heat/mass transfer and the thermal inertia of the bed material, fluidized bed reactors can be used to process a wide variety of feedstocks with minimal preparation. After appropriate gas cleanup, the syngas produced by gasification can be utilized in an already-commercialized catalytic Fischer–Tropsch process to produce drop-in diesel or combusted to generate electricity.

The reactive environment of a fluidized bed gasifier is characterized by a number of complex physical and chemical processes occurring over a range of time scales.¹ During FBBG, raw biomass fed into a fluidized bed of inert granular material initially undergoes rapid mixing, heating, drying, and devolatilization which results in a mixture of light and condensable gases (pyrolysis products) as well as highly porous carbonaceous char—the latter further reacts with steam and carbon dioxide to produce syngas. A portion of the char may also combust with

oxygen, generating heat to drive the endothermic gasification reactions. Because of the abrasive and chaotic environment of the fluidized bed, the fragile char particles experience mechanical effects such as attrition and secondary fragmentation which produce fines that can be blown out of the reactor, unconverted.

FBBG faces several technical hurdles to achieve commercialization. Because of the melting and agglomeration tendencies of the alkali/alkaline metals contained in biomass ash, the maximum operating temperatures are usually limited to less than 900 °C.² The relatively low operating temperature results in the formation and growth of condensable tars³ in the product syngas (2–50 g Nm⁻³) as well as incomplete conversion of the char. Depending on the end application, the significant methane fraction must also be subsequently re-formed. These three issues remain as major hurdles to further commercialization of the technology.⁴

In particular, char conversion has been shown to be a pivotal, rate-limiting step, which governs many performance metrics of

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