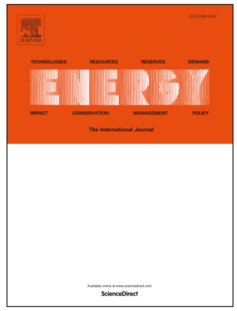

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Energy conversion of agricultural biomass char: steam gasification kinetics

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Abstract

The present study investigates steam gasification kinetics of chars from six agro-industrial biomass residues (citrus pomace, grape pomace, reed, olive pomace, reed lignin and straw lignin). Experiments were performed in a TGA in steam/N_2 mixtures at different temperatures and steam partial pressures. Kinetic parameters are determined by fitting computed char conversions to experimental char conversions. The conversions curves are computed using recently suggested models which are selected based on the K/(Si+P) ratio. The objective of the study is threefold: (1) to determine kinetic parameters for agricultural biomass chars, (2) to validate the models and (3) to test whether a unified activation energy can be used to predict the char gasification times. The activation energies varied between 135-165 kJ/mol, and the reaction orders with respect to steam varied between 0.4 and 1.0 for the investigated chars. By using a unified activation energy of 150 kJ/mol for all of the chars, computed char gasification times were in good agreement to experimental measurements. The results support recommendations that the choice of kinetic models should be based on the K/(Si+P) ratio of the chars. The introduction of an Avrami-Erofeev model allowed predicting the conversion behavior of the chars that showed sigmoidal conversion.

Keywords: biomass gasification, agricultural biomass, kinetics, steam gasification

1. Introduction

Thermal gasification of biomass and waste can be used to recover fuel bound energy [1]. Thermal gasification can be also used to produce valuable chemicals such as ammonia or to produce ash residues from which valuable elements, such as phosphorous [2], can be recovered. Thermal conversion of solid wastes can be divided into drying and pyrolysis followed by gasification of the char residue. In general, char gasification is the slowest thermal conversion stage. The kinetics of the char gasification influence how industrial gasification systems should be designed and operated [3]. As the char residue is gasified, the char residue reacts simultaneously with H_2O, CO_2 and O_2 [4]. The reactions with H_2O and CO_2 are of particular importance for biomasses because of the high reactivity towards H_2O and CO_2 [5].

Char gasification reactions can be divided into non-catalytic and catalytic reactions. Under kinetically limited conditions, the non-catalytic char gasification rate is proportional to the number of active sites, which can be expected to be proportional to the internal surface area. The internal surface area may either increase or decrease during char conversion [6]. Models taking into consideration effects or pore growth are for example the Avrami-Erofeev model [7] or the random pore model [6]. For pure carbons and coal chars with low contents of catalytic elements the internal surface area, or more specifically, the number of carbon active sites limits the reaction rate. Biomass chars, on the other hand, typically have significant contents of catalytically active elements [4,8-11]. Char gasification kinetics, both with respect to CO_2 and H_2O, has been investigated in numerous studies for lignocellulosic biomass chars (see the review by Di Blasi [5]), but to a lesser extent for agricultural biomass chars. Char gasification reactions of lignocellulosic biomass chars, e.g. wood chars, are catalyzed by at least fuel bound