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Fuel conversion and ash formation interactions

A thermochemical study on lignocellulosic biomass

Anna Strandberg

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Fakultetsopponent: Doktor, Maria Zevenhoven,
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Anna Strandberg

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Abstract

Biomass is considered to be CO_2 neutral, and to be able to reduce the dependency on fossil fuels the need for expanded and sustainable biomass feedstock is increasing. Ash-related problems are some of the most important aspects of this increasing use of new biomass assortments in thermal energy conversion systems. An improved basic understanding of fuel conversion, ash formation, ash transformation and ash interactions with the converting fuel is therefore important.

In the present thesis, the main objective was to provide new knowledge on thermochemical fuel conversion, specifically on how ash formation interacts with fuel conversion for lignocellulosic biomasses. The main methods used were experimental characterization of decomposition behavior and analysis of morphology and elemental composition of samples, using different appliances, analytical methods and fuels. Multivariate data analysis was successfully used on thermogravimetric data for prediction of compositional data and fuel properties.

New, detailed explanations of structural changes in char morphology and ash properties during conversion were provided including descriptions of the influences of ash formation on fuel conversion rates under different conditions. The influences were found different depending on both particle size and ash composition. One implication of these findings is that for fuels with low temperature melting ash, the diffusion barrier formed causes difficulties for typical thermogravimetric experiments aiming at determination of reactivity in the kinetically controlled regime. This is recommended to carefully consider for future studies. On a single pellet level, char encapsulation was not found to dominate and limit gas transport and conversion for any of the fuels tested. In practical applications, however, the situation may be different with thick ash layers accumulating on a fuel bed surface. Another important finding was the extensive formation of cracks and internal cavities during combustion of pellets, providing new insights in the fundamentals of fuel conversion.

Clean woody fuels, rich in calcium, formed a porous ash layer with no sign of limiting char conversion rates. The phase chemical transformations involving carbonate and oxide formation from poplar pellets was studied in detail. For grassy fuels, on the other hand, low melting point silicates are expected to form. The physical properties of K-Ca-silicates from silicon rich straw fuels were also characterized, providing new insights on ash formation on micrometer scale resolution; at high temperature, the silicate melt formed bubbles on the surface that partially covered the char, while for lower temperature a more rigid net structure was formed.

Keywords
Char conversion, pyrolysis, devolatilization, ash transformation, biomass, fuel characterization, fuel composition, ash composition, silicate formation, carbonate formation, thermogravimetric analysis, micro-tomography

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