From torrefaction to gasification
Pilot scale studies for upgrading of biomass

Martin Strandberg

Akademisk avhandling

som med vederbörligt tillstånd av Rektor vid Umeå universitet för avläggande av filosofie doktorsexamen framläggs till offentligt försvar i N450, Naturvetarhuset,
Onsdagen den 10 juni, kl. 13:00.
Avhandlingen kommer att försvaras på engelska.

Fakultetsopponent: Prof. Jaap Kiel
Energy Technology, Delft University of Technology, Delft, Netherlands.

Department of Applied Physics and Electronics
Umeå University
Umeå 2015

Organization
Umeå University
Applied Physics and Electronics

Document type
Doctoral thesis

Date of publication
20 May 2015

Author
Martin Strandberg

Title
From torrefaction to gasification: Pilot scale studies for upgrading of biomass

Abstract
Increasing the share of biomass, preferably by replacing fossil fuels, is one way to mitigate the present climate change. Fossil coal can be directly replaced by co-combustion of coal and biomass and fossil engine fuels (gasoline and diesel) could potentially partly be replaced by synthetic renewable fuels produced via entrained flow gasification of biomass. The use of biomass in these processes is so far limited, partly because of the fibrous and hygroscopic nature of biomass.

This thesis demonstrates how the challenging characteristics of raw biomass are mitigated by the pretreatment method torrefaction. Torrefaction is a process where biomass is heated in an oxygen deficient atmosphere to typically between 240 and 350°C for a time period of 2 minutes to 1 hour. Most of the torrefaction R&D in the literature have so far been performed with bench-scale batch reactors. For the purpose of carefully studying continuous torrefaction, a 20 kg/h continuous torrefaction pilot plant was therefore designed, constructed and evaluated.

The overall conclusion from this thesis is that the many benefits of torrefied biomass are valid also when produced with a continuous pilot plant and for typically Swedish forest biomasses. Some of the documented improved biomass properties are increased heating value, increased energy density, higher friability (lower milling energy) and less hydrophilic biomass. Most of the improvements can be attributed to the decomposition of hemicellulose and cellulose during torrefaction.

Mass yield is the most common variable for describing the torrefaction degree but it is challenging to determine for continuous processes. We therefore evaluated three different methods (one existing and two new suggestions) to determine degree of torrefaction that are not based on mass loss. The degree of torrefaction based on analyzed higher heating value of the raw and torrefied biomass (DTF_{HHV}) predicted mass yield most accurate and had lowest measurement uncertainty.

Pelletizing biomass enhance transportation and handling but results from pelletization of torrefied biomass is still very limited in the literature and mainly reported from single pellet presses. A pelletization study of torrefied spruce with a ring die in pilot scale was therefore performed. The bulk energy density was found to be 14.6 GJ/m3 for pelletized torrefied spruce (mass yield 75%), a 40% increase compared to regular white pellets and therefore are torrefied pellets more favorable for long distance transports. More optimization of the processes is though needed for acquiring high quality pellets with lower amount of fines and higher durability than attained in the present study.

Powders from milled raw biomass are generally problematic for feeding and handling. The influence of torrefaction and pelletization on powder and particle properties after milling was therefore studied. The results show that powder from torrefied biomass were enhanced with higher bulk densities, lower angle of repose as well as smaller less elongated particles with less surface roughness. Even higher powder qualities were achieved by pelletizing the torrefied biomass before milling, i.e. another reason for commercial torrefied biomass to be pelletized.

Entrained flow gasification (EFG) is a promising option for conversion of biomass to other more convenient renewable energy carriers such as electricity, liquid biofuels and green petrochemicals. Also for EFGs are torrefied fuels very limited studied. Raw and torrefied logging residues were successfully gasified in a pilot scale pressurized entrained flow biomass gasifier at 2 bar(a) with a fuel feed corresponding to 270 kWth. Significantly lower methane content (50% decrease) in the syngas was also demonstrated for the torrefied fuel with mass yield 49%. The low milling energy consumption for the torrefied fuels

Keywords
Torrefaction, biomass, pilot scale, continuous reactor, grindability, entrained flow gasification, degree of torrefaction, biomass powder

Language
English

ISBN
978-91-7601-287-1

Number of pages
70 + 6 papers