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Preliminary study of pyrolysis and gasification of biomass and thermosetting resins for energy production

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Abstract

The gasification of the biomass is an efficient way to employ the renewable source for the production of electric power. Nevertheless, the water content in the biomass can be very high and the performances of a power plant that exploits the syngas produced can be negatively affected. The mixing of thermosetting resin with the biomass in order to increase the performances even with high moisture of the biomass is evaluated in a two stage gasifier. An Aspen Plus model that simulates the sub-processes of the gasification is implemented. The equations that describe the pyrolysis and the gasification are regressed with the data available in literature. The power production obtained with a mixture of 30% of thermosetting resins and biomass with 65% of water is higher than the ones obtained with biomass with 45% of water.

Keywords: Pyrolysis; Gasification; Biomass; Thermosetting; Gasifier; Aspen Plus; Cold Gas Efficiency; Power Production; Electricity.

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1. Introduction

The efficient utilization of biomass is important to replace a significant amount of fossil fuels used for the energy production. Biomass gasification produces a fuel gas that coupled with advanced power generation systems, such as gas turbines or fuel cells, offers high efficiencies as proposed by Doherty et al. in 2015 [1]. The gasification of the

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biomass may be described by a sequence of processes in function of the temperature as proposed in [2]: drying (at 100-200°C), pyrolysis (at 200-700°C), gasification (700-900°C) and combustion (above 800°C). These processes are not strictly defined and they often overlap in function of the considered technology. Drying and pyrolysis occur heating up the biomass without addition of any form of oxygen. The gasification and combustion take place introducing an amount of oxygen in some form. Among these processes the description of the pyrolysis process is considered particularly challenging because it evolves a great deal of physical and chemical transformations and produces a large number of product species as stated by Neves et al [2]. These authors propose empirical relationships for pyrolytic products distribution and properties in function of the temperature. The products of the pyrolysis can be classified in this type: solid (mostly char or carbon), liquid (tars, heavier hydrocarbons and water), gas (CO_2, H_2O, CO, C_xH_y, etc.). The choice of the technology affects the gasification sub-processes. In two-stage gasifier pyrolysis and gasification take place in separate reactors. An examples of this scheme of plant is investigated by Teixeira et al. [3], they considered a screw conveyer in which the pyrolysis occurs. Similar layout is proposed in the work of Henriksen et al. [4], they present the results of a demonstrative two-stage gasifier of 75 kW. The interest on this scheme of plant is due to the low tar content in the fuel gas produced.

Beside the exploitation of the biomass as renewable energy resources, the waste gasification is an eco-friendly way to reduce fossil-fuel consumption. In particular, waste pyrolysis/gasification of materials like the thermosetting resins can represent a technique to convert wastes into syngas useful as fuel gas. Thermoset polymers do not permanently harden over a critical temperature and do not soften when they are re-heated. The materials degrade and decompose before they can reach temperatures high enough to melt. These types of resins are not completely recyclable as feedstock in the same industrial field. Feedstock recycling, which converts plastic materials into useful basic chemicals, has been recognized as an advanced technology process. Gasification is one example of these feedstock recycling technologies, which converts carbonaceous materials into a combustible gas, that can be applied for heating and power generation. Ongen [5] investigates this option in his work obtaining a methane-rich syngas with high heating value. Yun et al. [6] applied the pyrolysis for glass fiber-reinforced plastic (GFRP) and Pickering [7] proposes the recovery of the fibers from thermoset composite material obtaining syngas. With the gasification of plastic particular attentions are for the high production of tar, as reported in [8] and [9].

A complete description of the main reactions involved in the gasification process and their role are well proposed by Cau et al. [10]. Gasification is generally carried out by injecting sub-stoichiometric air or oxygen (just to promote the combustion of a portion of fuel to provide heat for the endothermic reactions) and eventually steam. In general, an increasing of air (or oxygen) injection promotes fuel combustion, thus involving an increasing temperature of the process, higher CO_2 concentrations and lower CO concentrations in raw syngas. On the other hand, an increasing in steam injection involves a temperature reduction and promotes shift conversion equation, with a subsequent increasing in H_2 and CO_2 concentrations in raw syngas despite a reduction of CO content. The role of the water is important in the products obtained and also in the whole energy balance. In fact, the biomass moisture evaporation is a high energy demand process. However, for high content of moisture, steam is not required and this can simplify the plant layout, especially for small-scale plants. On the other hand, higher moisture lower heating value of the syngas.

The modeling of the gasification sub-process is investigated in several works. Less references are available for the pyrolysis sub-process. This paper presents a complete simulation from the pyrolysis and the gasification for energy production with the evaluation of the energy performances of the whole plant. The chemicals produced in the sub-process are defined with equations regressed with experimental data retrieved from the literature. Due to the high heating value of the syngas obtained with the gasification of the thermosetting resins is investigated the strategy of mixing this type of resins to high-moisture biomass. It is expected the increasing of the heating value of the syngas with respect to the one obtained with only biomass. The results are work out implementing a plant in the simulation software Aspen Plus, already applied by the author [11], [12].

2. Technology

This paragraph describes the technology considered to exploit the biomass and the mixture of the biomass and the thermosetting resins. The obtained syngas is exploited as fuel gas in a gas engine to produce electricity. The process considered is based on a two-stage gasifier similar to the Danish small-scale (75 kW thermal) called *Viking* presented by Henriksen et al. [4].