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Energy and exergy analysis of biomass gasification at different temperatures

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ABSTRACT

Biomass is usually gasified above the optimal temperature at the carbon-boundary point, due to the use of different types of gasifiers, gasifying media, clinkering/slagging of bed material, tar cracking, etc. This paper is focused on air gasification of biomass with different moisture at different gasification temperatures. A chemical equilibrium model is developed and analyses are carried out at pressures of 1 and 10 bar with the typical biomass feed represented by $CH_{1.4}O_{0.59}N_{0.0017}$. At the temperature range 900–1373 K, the increase of moisture in biomass leads to the decrease of efficiencies for the examined processes. The moisture content of biomass may be designated as "optimal" only if the gasification temperature is equal to the carbon-boundary temperature for biomass with that specific moisture content. Compared with the efficiencies based on chemical energy and exergy, biomass feedstock drying with the product gas sensible heat is less beneficial for the efficiency based on total exergy. The gasification process at a given gasification temperature can be improved by the use of dry biomass and by the carbon-boundary temperature approaching the required temperature with the change of gasification pressure or with the addition of heat in the process.

1. Introduction

Biomass is regarded as a type of renewable energy since the carbon dioxide emissions, resulting from the use of biomass as a fuel, are fixed by photosynthesis later on. There are global incentives for the use of biomass. The most important is the Kyoto protocol [1].

A promising way to use biomass for production of heat, electricity, and other biofuels is through biomass gasification. It is a thermo-chemical process of gaseous fuel production by partial oxidation of a solid fuel. In this process, the chemical energy of the solid fuel is converted into the chemical and thermal energy of the product gas.

The aim of this paper is to determine what are the benefits of feedstock drying with the product gas sensible heat, whether an optimal moisture content exists at a given gasification temperature, and how the efficiency at a given gasification temperature can be improved. Gasification temperature and its uniformity depend on the gasification technology employed (fixed bed, fluidized bed, entrained bed gasifiers), the gasifying medium used (oxygen and/or hydrogen source), the characteristics of biomass (moisture and ash contents, volatile compounds, particle size), in particular the softening and melting temperatures of the ash, the characteristics of bed material (in order to avoid its slagging/clinkering), and the tar cracking process applied (catalytic or thermal).

The work of Ptasinski et al. [2] is the basis for this paper. In that work gasification of various biofuels was analyzed at the so-called carbon boundary point (CBP). The CBP is obtained when exactly enough gasifying medium is added to avoid carbon formation and achieve complete gasification. Desrosiers [3], Double and Bridgwater [4] proved that the CBP is the optimum point for gasification with respect to energy-based efficiency, and Prins et al. [5] proved that it is the optimum point with respect to exergy-based efficiency, as cited by Ptasinski et al. [2]. It was also concluded in [2] that gasification of sludge and manure is not possible at the optimum point, because these fuels contain large amounts of moisture so that the carbon boundary temperature is lower than 600 °C. To gasify these fuels, the use of the product gas sensible heat for drying of biomass (in the absence of an alternative, external source of heat) was recommended.

This paper also aims to resolve how the external addition of heat influences the optimal gasification conditions of biomass with different moisture. The allothermal gasification processes obtain all or part of the heat necessary for endothermic gasification reactions by the use of sun energy [6], electrical energy in plasma gasification [7], and by the addition of heat into gasifiers. Gasifiers presented in

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