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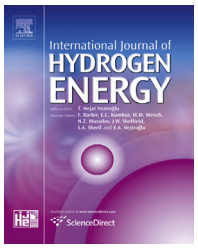

Analysis of the energy efficiency of solar aided biomass gasification for pure hydrogen production

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ABSTRACT

This paper presents a simulative analysis of the energy efficiency of solar aided biomass gasification for pure hydrogen production. Solar heat has been considered as available at 250 °C in three gasification processes: i) gasification reactor followed by two water gas shift reactors and a pressure swing adsorber; ii) gasification reactor followed by an integrated membrane water gas shift reactor; iii) supercritical gasification reactor followed by two flash separators and a pressure swing adsorber.

Simulations are performed with the commercial software Aspen Plus® by considering biomass moisture content and the amount of solar heat as system variables. Results are presented in terms of energy and exergy system efficiency and are discussed and compared with the case of no solar integration.

Introduction

Hydrogen is a promising and environmentally friendly energy carrier for stationary and mobile power generation and can be coupled with PEM fuel cells for efficient electricity generation with zero on-site emissions [1]. The global environmental advantages of hydrogen employment depend on the type of primary energy source used for its production. Indeed, if hydrogen is produced from fossil fuels [2–5], the global environmental advantage is essentially related to the better fuel to electricity conversion achievable with PEM fuel cells with respect to classical thermal power plants, whereas, if hydrogen is produced from a renewable source, such as solar, wind or biomass, a close to zero carbon balance can be achieved. Among the different renewable sources, biomass has the great advantage of being relatively energy dense and of allowing a comparatively stable hydrogen production due to the possibility of feedstock storage. The most promising process to produce hydrogen from biomass is gasification [6–8], in which biomass is thermally decomposed in presence of a gasifying agent to form syngas. The studies available in the literature have shown that, due to the energetic cost of drying dilute biomasses, gasification is energetically sustainable only if the biomass moisture content is sufficiently low [9–12].

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For biomasses with high moisture content, supercritical water gasification represents an energetically attractive alternative to classical gasification [13–15] because it does not require prior biomass drying [16,17]. Unfortunately, the technological complexities related with the supercritical state (i.e. high pressure and temperature) have hindered the deployment of this process and the valorization of dilute biomasses.

In this work, we explore the potential of solar heat integration as a way to improve the energy efficiency of classical gasification processes. In general terms, the approach followed considers integration of solar heat with an endothermic chemical process with the final goal of upgrading low–mid temperature solar energy to chemical energy. Successful low–mid temperature solar heat integration has been reported for several processes, such as methanol decomposition in syngas [18], in which solar heat has been integrated with the reactor, methane chemical looping combustion [19,20], in which solar heat has been integrated with the fuel reactor for NiO reduction, methane steam reforming [21,22], in which solar heat has been integrated with the steam generation unit, methanol steam reforming [23], in which solar heat has been integrated with the reformer.

This manuscript presents a comprehensive simulative energy analysis of the impact of low temperature solar heat integration in processes for power generation based on pure hydrogen production via biomass gasification and subsequent conversion of hydrogen in electricity in a PEM fuel cell. Three processes have been investigated: i) gasification reactor followed by a conventional water gas shift section and a pressure swing adsorber (CG); ii) gasification reactor followed by an integrated membrane water gas shift reactor (MWGS); iii) supercritical gasification reactor followed by two flash separators and a pressure swing adsorber (SCG).

Results are discussed in terms of energy and exergy efficiency by considering biomass moisture content and the amount of solar heat integrated as variables.

Methodology

The simulations were performed in stationary conditions by using the commercial software Aspen Plus® [24].

The property method selected was RKS-BM for the subcritical gasification processes (CG and MWGS) and PR-MHV2 for the Supercritical Gasification (SCG).

Biomass was modeled as a stream of 10 kg/h of glucose with a variable amount of water (moisture) available at 25 °C and 1 atm. The steam needed in the subcritical gasificators was generated starting from a dedicated water stream at 25 °C and 1 atm in order to obtain water to carbon ratio equals to 2 in the gasifier.

The flowsheets of the processes, with the relative assumptions, are presented in the *Flow sheet and model libraries description* section, while the definitions of system efficiencies used throughout the text are reported in the *Energy efficiency definitions* section.

Flow sheet and model libraries description

In this paragraph, the name of the blocks and streams reported in capital font, whereas the Model Library employed is reported in capital, bold, italic font.

System with conventional gasification (CG)

Fig. 1 reports the flowsheet of the system based on conventional gasification, which will be referred to as CG. The

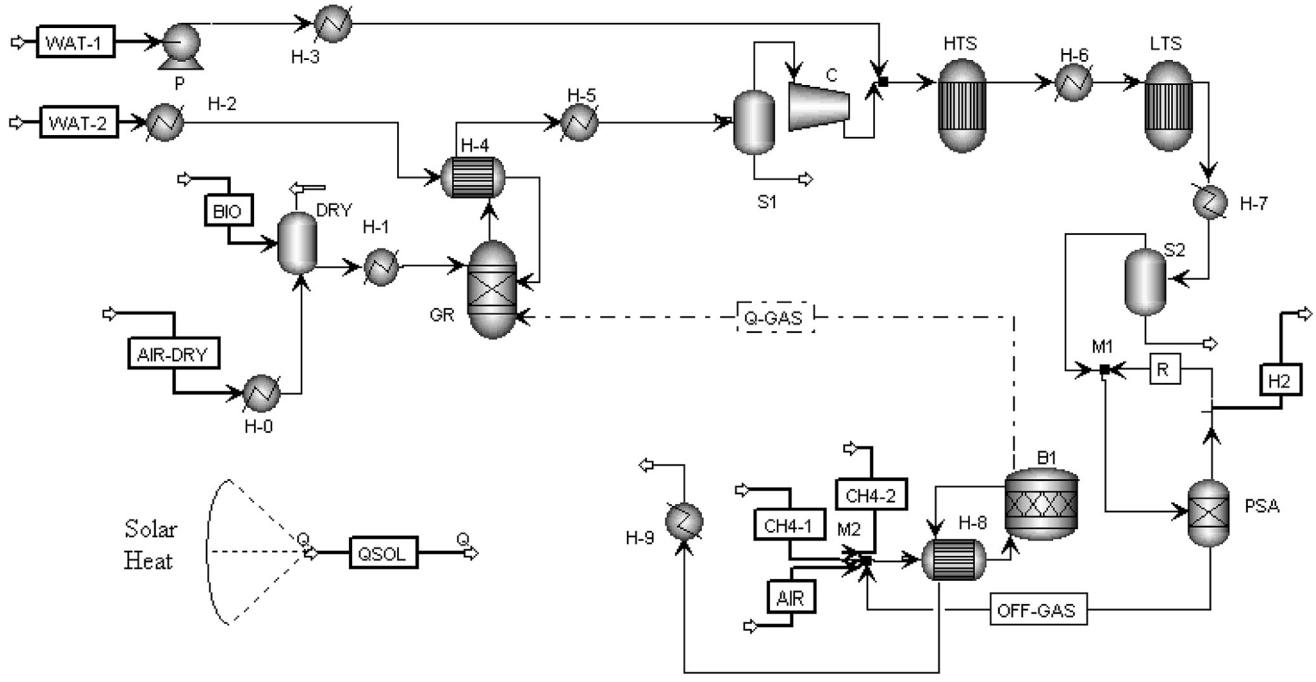

Fig. 1 – Flowsheet of the system with conventional gasification.