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Membrane gas permeation in the upgrading of renewable hydrogen from biomass steam gasification gases

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ABSTRACT

Combination of the biomass steam gasification and the membrane gas permeation is a potential process for the production of renewable hydrogen. This work first briefly reviews possible membrane materials for the hydrogen enrichment from biomass gasification producer gas mixtures. Subsequently, two permeator arrangements, a single stage and a two-stage with sweep, are evaluated through numerical modeling. The evaluation discusses the most essential upgrading parameters: achievable hydrogen purity, hydrogen recovery and energy requirement in the upgrading. It is shown that the two-stage arrangement using membranes with H_2/CO_2-selectivity of 9 allows production of hydrogen fuel with the hydrogen content of 98% in volume (v/v) and the hydrogen recovery of around 75%. Further improvement of the membrane H_2/CO_2-selectivity is necessary to enhance the process sustainability and economics.

1. Introduction

Hydrogen has one of the highest known fuel mass specific energy densities and it can be converted to electrical power with relatively high efficiencies. Majority of current hydrogen production processes are based upon the fossil hydrocarbon reforming [1]. Since they typically involve emissions of carbon dioxide to the atmosphere, no climate neutrality is met in the hydrogen production. On the other hand, if produced from renewable resources like biomass, solar radiation or renewable electrical power from wind and water, hydrogen can be a truly climate-neutral fuel. A widespread application of the hydrogen fuel is aimed at the exclusion of carbon from combustion processes and the omission of the carbon dioxide-induced climate change. Various energy conversion paths that lead to the production of renewable hydrogen are possible [2] and a great number of research work is presently done in order to identify, develop and optimize the renewable hydrogen production chains [3–10]. In spite of the criticism on the utilization of renewable resources for the energy production, certain works demonstrate that renewable hydrogen production can be feasible [11].

Biomass steam gasification appears currently to be an established technology with several industrial-scale realizations. FICFB (Fast Internally Circulating Fluidized Bed) process is perhaps the most popular biomass gasification type. Several FICFB biomass gasifiers are in operation and a few are commissioned or planned to be built in the next future [12]. Biomass steam gasification producer gas has a relatively high content of hydrogen in terms of volume or molar fractions. Pfeifer et al. [13] report the hydrogen volume fraction from a conventional FICFB gasification to equal around 40% in volume (v/v). This value can be considerably increased above 60% in volume (v/v) if the AER (Absorption Enhanced Reforming) gasification concept is employed [14]. In addition to hydrogen, substantial amounts of carbon dioxide, carbon monoxide, methane and air components are present in the gas mixture. Biomass steam gasification producer gas contains also significant amounts of longer aliphatics, polyaromatic hydrocarbons, benzene, hydrogen sulphide, organic sulfur and ammonia. As for the energy utilization, the gases of interest are hydrogen, methane with longer aliphatic hydrocarbons and carbon monoxide.

Biomass steam gasification combined with an affordable and reliable method for the recovery of hydrogen from the produced gas mixture can be a potential method for the production of renewable hydrogen. The problem of hydrogen recovery from gas mixtures can be approached by a variety of separation processes. Membrane gas permeation appears to be an interesting alternative to established adsorption processes that is capable of hydrogen recovery from biomass gasification producer gas. Membrane gas separation plants are very compact and reliable processes. Moreover, much research is currently performed to further improve the

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