INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 14573–14582

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/he

An innovative system by integrating the gasification unit with the supercritical water unit to produce clean syngas: Effects of operating parameters

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ARTICLE INFO

Article history:
Received 9 April 2016
Accepted 27 April 2016
Available online 19 May 2016

Keywords:
Biomass gasification
Supercritical water
System integration
Operating parameters

ABSTRACT

Advanced technologies such as solid oxide fuel cells generally have a strict requirement on syngas quality especially the concentration of impurities. It is common to sacrifice economy and efficiency to achieve a qualified syngas by applying several cleaning and conditioning steps. The objective of this work is to propose a combined process by integrating the gasification unit with the supercritical water unit (SWU) to provide qualified syngas. The SWU includes supercritical water mixer, separator, supercritical water reactor (SWR) and expander. Detailed operating methods and appropriate equipment are presented. The whole process is modeled by using Aspen Plus to investigate effects of SWR inlet temperature, operating pressure, and mass ratio of tars to supercritical water (T/W) on the final product composition and on the outlet temperature of SWR. Results show that higher SWR inlet temperature facilitates achieving a higher H_2 and CO yield while lower inlet temperature assists in obtaining a higher H_2/CO ratio. Lower SWR operating pressure benefits to achieve a higher H_2 and CO yield and a higher H_2/CO ratio. Lower T/W benefits to have a higher H_2 yield and a lower CO yield, leading to a higher H_2/CO. Tars could be completely decomposed at the given operating conditions in the proposed process. Higher inlet temperature, higher pressure and larger T/W lead to an increased SWR outlet temperature. Combustible components in the syngas mainly contains H_2, CO, and CH_4.

Introduction

Biomass, which is the fourth largest energy resource following coal, petroleum and natural gas, possesses characteristics such as being sustainable, widely distributed and having a small impact on the environment. These characteristics would make it an important part of the future energy system [1]. Whereas, unlike gas and liquid fuel, biomass can not be directly employed cleanly and efficiently. This is one of the motivations to convert the solid biomass to the gaseous and liquid fuel or chemicals. Generally, two kinds of approaches are available to realize biomass conversion, including biochemical and thermochemical approaches. In terms of

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http://dx.doi.org/10.1016/j.ijhydene.2016.04.237

biochemical conversion path, it does not require much external energy, but its productivity is lower than the thermochemical conversion path due to its slower conversion rate.

Gasification is one of the current thermochemical conversion approaches, which could convert carbonaceous materials like coal and biomass into gas mixture mainly containing CO and H_2, providing an excellent base for the production of power, chemicals and liquid fuels [2]. Furthermore, compared with combustion, gasification has a series of advantages such as less SO_2 and NO_x emissions [1]. However, the utilization of biomass gasification is subjected to various problems caused by some tough substances such as tar, particulate and alkali metals. These impurities are generally removed or converted by a series of purification steps to achieve a qualified syngas for downstream applications [3,4]. As a result, system economy and efficiency are discounted. Economical and efficient methods for gas treatment are of increasing interest.

Since supercritical water behaves like organic solvents, organic and nonpolar compounds could be completely miscible while inorganic salts have quite low solubility in it. Hence, supercritical water is capable of providing a homogeneous reaction environment for organic compounds and also capable of separating out inorganic impurities [5–7]. This would benefit to generate a contaminant-free gas mixture. Due to these unique properties, supercritical water has already been taken as a reaction media and has been utilized in the supercritical water oxidation [5,8–10] and supercritical water gasification [10,11] to deal with biomass [12,13], aqueous wastes [8], industrial wastes and sludges [5] such as pharmaceuticals [14], military wastes [15], dioxins [16], PCBs and DDTs [17]. Despite these special properties of supercritical water, the efficiency of merely applying supercritical water gasification technology to convert biomass is reported to be relatively lower [18,19] compared with that of conventional gasification technologies, especially for feedstock with a high concentration [18].

If integrating the supercritical water technology with the conventional gasification technology to combine advantages of the two technologies, the combined process could have the ability of converting complex carbonaceous materials to the clean gas mixture with a high efficiency. However, little knowledge has been known regarding the combination of the two technologies. In the present study, an integrated process between the gasification unit and the supercritical water unit (SWU, including supercritical water mixer (SWM), separator (SWS), reactor (SWR) and expander (SWE)) is put forward. Based on the proposed process, a model is developed by using process simulation software Aspen plus to investigate on the effects of SWR operating parameters on the final product composition and on the SWR outlet temperature. This study would increase knowledge on the proposed process, and would also provide a new method to produce clean syngas and to eliminate environmental problems.

Conceptual process design

Fig. 1 depicts the conceptual process design for the proposed scheme, which integrates the gasification unit with the SWU. The SWU primarily includes four steps such as supercritical water mixer (SWM), supercritical water separator (SWS), supercritical water reactor (SWR), and supercritical water expander (SWE).

The detailed operating procedures for the proposed scheme are described as follows. After being pressurized, dry biomass or biomass slurry is delivered into a gasifier, where biomass is gasified together with the gasification agent (oxygen, steam, carbon dioxide or others) at desired temperature and pressure. In the present study, the form of biomass slurry is adopted. The gasifier could be operated at low pressure and then the product gas from the gasifier is pressurized by a compressor prior to entering the SWU. Alternatively, the operating pressure of gasifier could be set at a level higher than that of the SWU. At this condition, the produced gasification product could flow into the SWU automatically based on pressure difference. Generally, the latter option would be much easier and more economical, due to the higher compression energy consumption for the large volume of product gas. Furthermore, possible problems such as deposition and plugging caused by tars condensation may occur. Among the available gasification technologies such as fixed bed, fluidized bed and entrained bed, fluidized bed gasification technology is preferred and is utilized in the present study due to its advantages particularly such as perfect mixing, uniform temperature distribution and relatively lower operating temperature compared with that of the entrained bed [1].

Product from the gasifier, primarily containing carbon monoxide, hydrogen, carbon dioxide, water steam, light hydrocarbons, tars, alkali metals and other impurities, is fed into the SWM which is operated at least at the critical temperature and pressure of water. In the SWM, supplement water is injected into the SWM to adjust the T/W. To remove contaminants totally, pre-neutralization additives are added into the SWM to promote precipitation for some impurities.

Effluent from the SWM flows into the SWS such as cyclone and zeolite molecular sieve, where inorganic nonsoluble substances could be removed out of the effluent. Then the effluent, not containing any nonsoluble substances, enters the SWR in a homogeneous phase. The SWR is operated under supercritical state with the existence of catalyst, thus the SWR could be any types of reactors that allow catalytic reactions.

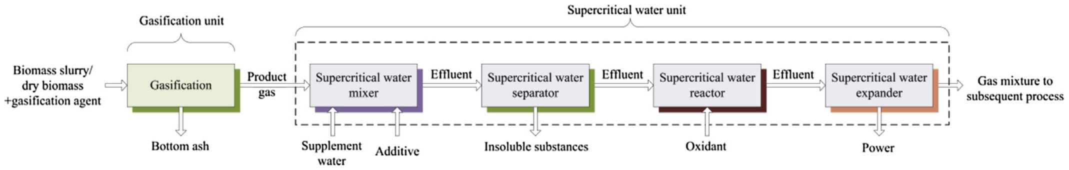

Fig. 1 – Diagram of the conceptual process design.