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Combined supercritical water gasification of algae and hydrogenation for hydrogen production and storage

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Abstract

Combined system for converting algae to hydrogen is developed based on principles of enhanced process integration technology to achieve high total energy efficiency. The system mainly consists of supercritical water gasification, hydrogen separation, hydrogenation, and combined cycle. Enhanced process integration combines both exergy recovery and process integration technologies, therefore, exergy destruction throughout the combined system can be minimized leading to high energy efficiency. Algae are converted initially to hydrogen-rich syngas through supercritical water gasification. Hydrogen separation is performed to produce hydrogen which is hydrogenated to achieve more convenient storage and transport. The remaining gas is combusted for power generation using combined cycle. Process modeling and evaluation regarding the effect of some operating parameters to total energy efficiency are performed. The combined system can achieve high total energy efficiency, higher than 60%.

Keywords: algae, supercritical water gasification, hydrogen, co-production, energy efficiency

1. Introduction

Algae cover very diverse photosynthetic and polyphyletic organisms. They include unicellular and multicellular forms which almost live in aquatic environment. Algae are widely utilized as food and nutrition, energy source [1], fertilizer, pollution control including CO_2 bio-fixation [2], and bioremediation. As energy source, currently algae are

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mainly converted to biofuel including biohydrogen, biodiesel, bioethanol, and butanol [3]. As potential renewable energy resources, algae are preferred among the available biomasses due to their characteristics of high photosynthetic efficiency and growth rate, excellent CO_2 absorption and fixation rates, and capability to live under severe conditions [4]. In addition, algae have no direct competition for being used as food, which is different with some terrestrial biomasses [5]. Appropriately treated algae have relatively high calorific value, which ranges from 19 to 25 GJ/t [6]. Unfortunately, algae generally have high moisture content, up to 95 wt% wb, which becomes the barrier in their utilization [7].

In energy utilization, conversion of algae to any secondary energy sources, especially hydrogen and power, has received an intensive attention. Recently, as energy carrier and fuel, hydrogen receives higher attention due to its beneficial characteristics of cleanliness, high efficiency, and high gravimetric energy density [8]. The gravimetric energy density of hydrogen is very high, about 33 kWh/kg, however, its volumetric energy density is very low, which is only 3 Wh/L under ambient condition, leading to difficulties in storage and transportation. Therefore, efficient methods for transportation and storage of hydrogen are urgently demanded.

Conversion of algae to fuel can be performed through thermochemical and biochemical methods. However, thermochemical conversion seems to be more applicable for large scale energy conversion due to faster conversion rate and higher conversion efficiency [9]. Several previous studies have proposed hydrogen production from algae [10,11]. Unfortunately, as there is no notable effort has been made for effective heat circulation, their energy conversion efficiency was very low.

This study focuses on the effort to integrate effectively the conversion of algae to hydrogen and storage of produce hydrogen. Therefore, an integrated system consisting of supercritical water gasification (SCWG) of algae, hydrogen separation, hydrogenation, and combined cycle is modeled and evaluated. In addition, some operating parameters are also evaluated in terms of energy efficiency. The concept of proposed combined-processes and modeling evaluation are described in section 2, while its performance results are figured out in section 3. In addition, section 4 concludes the main core of the current study.

Nomenclature

CV	calorific value
d	diameter
H	fluidization height
m	mass flow rate
p	pressure drop
W	work
U	superficial velocity

Subscripts

p	particle
g	gas

Greek letters

ε	void fraction
ρ	density
μ	dynamic viscosity
φ	sphericity

2. Proposed combined processes and evaluation

Fig. 1 shows the conceptual diagram of the proposed combined processes including SCWG, hydrogen separation, hydrogenation, and combined cycle. To achieve high heat circulation throughout the whole combined processes, an enhanced process integration (EPI) is adopted. EPI is potential to minimize the exergy loss in a certain process and the whole combined processes. It unites two main technologies: exergy recovery and process integration. Process intensification is performed initially in each single process with consideration of process simplification and better material and energy pairing. The unrecoverable energy/heat from certain process in then utilized in other processes, therefore, the total exergy loss throughout the combined processes can be reduced further. EPI has been evaluated and applied in several processes including coal drying [12,13], biomass drying [14], biomass gasification [15], and magnetocaloric heat circulator [16].