Thermal Efficiency Evaluation of Hydrogen Production from Biomass in Thailand

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Abstract

Biomass is now considered to have a key role in building a foundation for energy generation, because it can be produced and implemented effectively. In addition, biomass is used as an alternative energy source in the production of hydrogen, which is an efficient and clean fuel for highly effective combustion with environmental friendliness. In many countries, hydrogen is viewed as a key alternative and sustainable energy in the future. Hydrogen can be produced from a variety of sources by employing different types of manufacturing technology. From these points of view, the goal of this study is to evaluate and improve a biomass gasification process for hydrogen-rich synthesis gas production. The biomass in Thailand, such as rice husk, rice straw, bagasse, palm shell, palm empty bunch, empty corn cobs, and cassava root, is studied as a raw material. The optimal operating condition in terms of high production efficiency with low energy consumption is determined via process simulation. The study shows that important parameters of the gasification process are air/oxygen to biomass ratio, steam to biomass ratio, gasification temperature, and amount of energy input. The results revealed that rice straw can produce maximum hydrogen yield, but low thermal efficiency. In contrast, cassava root has the highest thermal efficiency but lower hydrogen yield. Moreover, thermal efficiency of biomass gasification process can be increased when an energy recovery technique is used.

Keywords: Biomass; Energy recovery; Gasification process; Hydrogen; Simulation

1. Introduction

To date, the demand for petroleum-based fuels has continually increased as petroleum fuel is a key factor in responding to the basic needs of mankind. It is also a key production factor in the industrial sector. However, the main problem in relying on the use of this fuel type is that we can never be certain about the current remaining volume of oil reserves. This factor has caused skyrocketing oil prices until high oil prices have become a global crisis [1]. Presently, the impact of the fuel price crisis coupled with the awareness of global warming problem has brought about changes in the structure of energy usage all over the world. Greater importance is now given to research, development, and promotion of clean energy, e.g., wind energy, solar energy, biochemical fuels, and hydrogen energy, for a greater energy security [2–5].

At the present time, the world human community has started to become seriously concerned about the climate change caused by an enormous amount of carbon dioxide (CO_2) gas in the atmosphere. Hydrogen is considered a clean fuel in the future due to its highly effective combustion with environmental friendliness; only steam is released when hydrogen is combusted with oxygen. This feature makes it different from other types of fuel, which emits carbon dioxide from the combustion process. Moreover, hydrogen is derived from unlimited renewable sources like biomass, which make it an alternative to replace the former energy sources [6–8]. Hence, many countries have exerted their effort toward finding ways to reduce our dependence on and use of petroleum fuels by turning to the support of using hydrogen as a fuel instead [8–9]. A great deal of research and development is currently taking place in the use of hydrogen.

In general, hydrogen can be produced from two main raw materials: (i) fossil fuels in the form of natural gas and coal and (ii) renewable energy sources, i.e., biogas, bio-ethanol, and biomass. Because biomass is available in large volumes, which is mostly derived from plants, it is a key source of renewable energy for the world. Biomass is also classified as an alternative energy to be used instead of the energy source from fossil fuels, which are limited and may become depleted [10]. Among the different technologies proposed for biomass conversion into energy, a gasification process is the most promising way as it provides a gaseous product with high hydrogen content (synthesis gas) [11].

In Thailand, biomass is the best choice with high capacity as alternative energy for hydrogen production. There are rice husk, rice straw, bagasse, palm shell, palm empty bunch, empty corn cobs, and cassava root. Thus, improving the efficiency of biomass conversion is an important issue to be considered. The important parameters affecting biomass gasification process efficiency are air and oxygen/steam to biomass ratio, gasification temperature, amount of energy input, catalyst type, and reactor type. From this point of view, in this study, the optimal operating conditions in terms of maximum hydrogen yield, production efficiency, and minimum energy consumption are evaluated via process simulation to improve the biomass gasification process for hydrogen-rich synthesis gas production.

2. Biomass gasification process

Biomass gasification means incomplete combustion of biomass resulting in the production of combustible gases consisting of carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). This mixture is called producer gas. The main reactions of biomass gasification are as follows [12]:

Water gas: $C + H_2O \rightarrow CO + H_2$ +131.5 kJ/mol
Boudouard: $C + CO_2 \rightarrow 2CO$ +172 kJ/mol
Methanation: $C + 2H_2 \rightarrow CH_4$ - 74.8 kJ/mol
Steaming reforming: $CH_4 + H_2O \rightarrow CO + 3H_2$ +206 kJ/mol
Water-gas shift: $CO + H_2O \leftrightarrow CO_2 + H_2$ -41 kJ/mol

3. Simulation of hydrogen production from biomass

Since Thailand has various types of biomass, seven potential biomass types are chosen as a raw material. There are rice husk, rice straw, bagasse, palm shell, palm empty bunch, empty corn cobs, and cassava root. The proximate analysis and the ultimate analysis of biomass from the Thailand Institute are illustrated in Table 1. In this study, the gasification process is developed using the GTI proprietary gasifier model with the HYSYS process design and simulation program, as shown in Fig.1 [13]. The gasification process consists of four main unit operations : gasifier unit, reformer unit, shift reactor unit, and separator unit. The operating variables for gasification process are air to biomass ratio, stream to biomass ratio, process temperature, and pressure.

Table 1. Ultimate and proximate analysis of biomass in Thailand.

	Biomass						
	Rice husk	**Rice straw**	**Bagasse**	**Palm shell**	**Palm empty bunch**	**Empty corn cobs**	**Cassava root**
Proximate analysis							
Moisture, %	12.00	10.00	50.73	12.00	58.60	40.00	59.40
Ash, %	12.65	10.39	1.43	3.50	2.03	0.90	1.50
Volatile Matter, %	56.46	60.70	41.98	68.20	30.46	45.42	31.00
Fixed Carbon, %	18.88	18.90	5.86	16.30	8.90	13.68	8.10
Ultimate Analysis							
Carbon, %	37.48	38.17	21.33	44.44	21.15	28.19	18.76
Hydrogen, %	4.41	5.02	3.06	5.01	2.56	3.36	2.48
Sulfur, %	0.04	0.09	0.03	0.02	0.04	0.03	0.04
Chlorine, %	0.09	-	-	0.02	0.16	0.05	0.05
Ash, %	12.65	10.39	1.43	3.52	2.03	0.90	1.50
Moisture, %	12.00	10.00	50.73	12.00	58.60	40.00	59.40
Other Characteristics							
Bulk Density, kg/m3	150	125	120	400	380	-	250
HHV, kJ/kg	14755	13650	9243	18267	9196	11298	7451
LHV, kJ/kg	13517	12330	7368	16900	7240	9615	5494

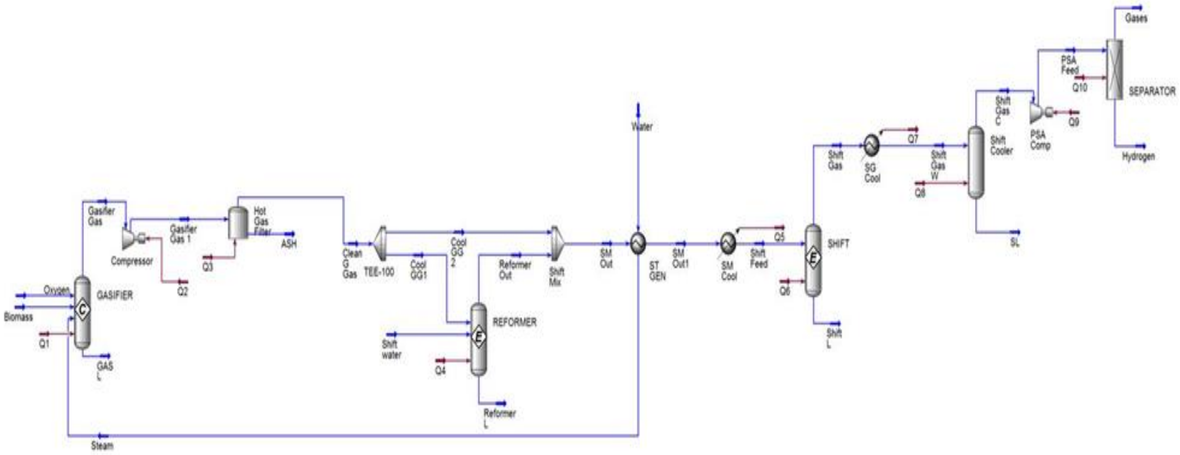

Fig.1. Process flow diagram of hydrogen production from biomass gasification process via ASPEN HYSYS.

4. Results

The objective of this study is to determine optimal operating conditions that maximize hydrogen production efficiency in terms of hydrogen yield and thermal efficiency. The calculation of biomass thermal efficiency is shown in the equation (1).

$$\mathit{Thermal\ Efficiency}\ \ (\%) = \frac{\mathit{Heating\ Value\ of\ hydrogen\ \ product}}{\mathit{Heating\ Value\ of\ biomass} + \mathit{Energy\ input}} \times 100 \qquad (1)$$

From the simulation studies, optimal operating conditions, maximizing hydrogen production and thermal efficiency, are revealed in Table 2. In this study, it is assumed that 100% purity of hydrogen can be produced from the separation unit. The optimal hydrogen products of each biomass are shown in Table 3. The results indicated that rice straw can produce the maximum hydrogen yield, while cassava root has the highest thermal efficiency. Since biomass heating value directly affect the thermal efficiency,a lower heating value has higher thermal efficiency, such as cassava root.

Moreover, an energy recovery technique is also applied for improving the biomass gasification efficiency. In this process, gas streams produced from the reformer and shift reactor units have high temperature, and the temperature of these streams have to be reduced before flowing into another unit. Therefore, waste energy occurs in the reformer and shift reactor gas streams. The waste energy can be recovered as partial energy input for the reformer unit as shown in Fig. 2. In addition, thermal efficiency of energy recovery-biomass gasification process is presented in Table 4. The results revealed that when energy recovery is used, thermal efficiency of hydrogen production from all biomass types can be increased, especially for cassava root that increased by 14.74%.

Table 2. Optimal operating conditions for hydrogen production**.**

Operating variables	**Operating conditions**
Air to biomass ratio	0.30
Steam to biomass ratio	0.63
Gasifier temperature and pressure	1073 K, 792.9 kPa
Reformer temperature and pressure	1473 K, 689.5 kPa
Shift reactor temperature and pressure	473 K, 551.6 kPa
Separator temperature and pressure	366 K, 1482 kPa

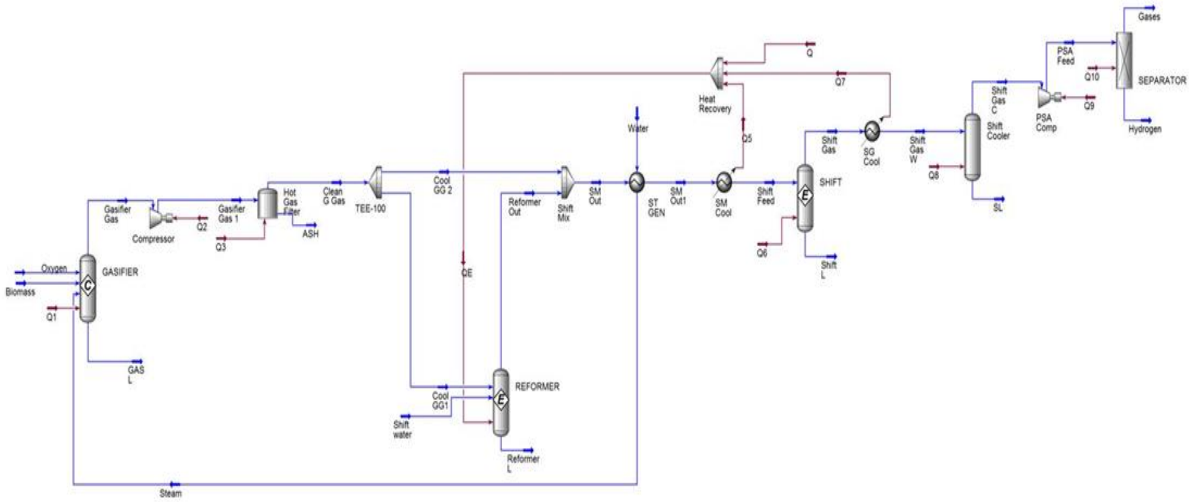

Fig. 2. Process flow diagram of biomass gasification with energy recovery technique.

Table 3. Maximum hydrogen production and thermal efficiency of hydrogen production from biomass gasification process.

Biomass types	Hydrogen production (kg/h)	Thermal efficiency (%)
Rice husk	1500.60	47.85
Rice straw	1513.40	52.62
Bagasse	1229.40	57.49
Palm shell	1502.60	40.36
Palm empty bunch	1121.80	51.92
Empty corn cobs	1337.20	53.87
Cassava root	1112.20	59.77

Table 4. Thermal efficiency analysis of hydrogen production from biomass gasification process with energy recovery technique.

Biomass types	**Thermal efficiency (%)**		
	Gasification	**Gasification with energy recovery**	**% Thermal efficiency increase**
Rice husk	47.85	51.44	3.59
Rice straw	52.62	56.93	4.31
Bagasse	57.49	67.23	9.74
Palm shell	40.36	42.87	2.51
Palm empty bunch	51.92	62.44	10.52
Empty corn cobs	53.87	59.61	5.74
Cassava root	59.77	74.51	14.74

5. Conclusion

The demand for energy has continually increased and hydrogen is considered as a clean fuel, in the future. In this research, hydrogen production from biomass gasification is studied via process simulation. The goal is to determined optimal operating conditions maximizing hydrogen production yield. In addition, thermal efficiency of gasification process is also evaluated. The results revealed that at the optimal operating conditions of air to biomass ratio, stream to biomass ratio, process temperature and pressure, rice straw can produce the maximum hydrogen yield (1513.40 kg/h), while cassava root has the highest thermal efficiency (59.77%). Furthermore, an energy recovery technique is also applied for improving the biomass gasification efficiency. The study shows that the thermal efficiency of hydrogen production from all biomass types can be increased.

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