Prefeasibility analysis of biomass gasification and electrolysis for hydrogen production

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Keywords: Hydrogen, gasification, electrolysis, energetic efficiency, economic assessment
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Introduction

Global energy demand can be considered one of the most relevant issues at the industrial level. Coal and oil are the most common raw materials for energy production. According to the World Coal Association, there are 892 million tons of coal in the world, and based on current energy consumption, these reserves may be exhausted in 110 years (Brisse et al., 2008). Therefore, industries have started looking for alternative energy production methods in response to the accelerated growth in energy demand and the increase of polluting gas emissions from the combustion of fossil resources. Technological advances in the development of renewable energies have already led to numerous studies and research (Barbir, 2009). The role of hydrogen in moving industry and society towards renewable fuels has been recognized by the scientific community and the International Energy Agency (IEA) (Elam et al., 2003). The main challenge of hydrogen lies in its production since hydrogen is not a naturally available fuel. The annual hydrogen production for 2018 was approximately 70 million tons, and its consumption increased by 6% (Bičáková and Straka, 2012). Hydrogen can be produced from a wide range of feedstocks and processes. This diversity in feedstock and production processes makes hydrogen an important ally, capable of ensuring long-term energy security.

Followed by petrochemical processes, electrolytic processes are the most widely applied at the industrial level. Although electrolysis is a well-known method and is considered the simplest technology for hydrogen production, it also has a serious disadvantage: the high electricity demand. For this reason, the main obstacle of electrolytic processes is the financial aspect, so this technology needs further I+D to decrease operating costs. Based on the above, this work aims to develop a techno-economic evaluation of three scenarios for hydrogen production through gasification and electrolysis processes. Two scenarios were taken as base cases involving thermochemical and electrolytic hydrogen production, and the third scenario evaluates the integration of electrolysis with biomass gasification. A techno-economic evaluation was carried out to compare the energy efficiency and economic feasibility of the stand-alone and biorefinery pathways, respectively. Finally, the effect of process operating costs on the cost of hydrogen production was evaluated.

Methodology

During the experimental development of the gasification process, chips of *Pinus patula* provided by Smurfit Kappa Cartón de Colombia S.A. (Yumbo, Colombia) were used as raw material. The experimental procedure was divided into three main sections: (i) Wood chips characterization based on international standards. (ii) Syngas production using a 10 kW downdraft gasifier (GEK Gasifier 10 kW Power Pallet, California, USA) integrated with a combustion engine and a generator. (iii) Experimental assay for hydrogen production by electrolytic processes following the methodology described by Shen et al. (Shen et al., 2011). Briefly, the electrodes were placed in a container immersed in an electrolyte solution. The gas composition produced in both gasification and electrolysis was measured using the portable gas analyzer. Finally, three scenarios were proposed for the simulation procedure to evaluate the performance of hydrogen production processes using stand-alone and biorefinery routes. The first and second scenarios are related to hydrogen production by autonomous routes. The first involves the gasification of wood chips, and the second involves water electrolysis. The third scenario involves hydrogen and electricity production from combined gasification and electrolysis processes. In the third scenario, 50% of the depleted syngas stream (after hydrogen extraction) was used for electric power generation and subsequent hydrogen production by electrolysis.

Results

Table 1 shows the hydrogen production costs for the three scenarios. As can be seen, the scenarios involving gasification processes show the best production rate and the lowest production costs. However, it can be identified that the hydrogen production cost increases when electricity production is involved in the third scenario. This phenomenon has been previously reported by other authors (Consonni et al., 2009). This additional cost is due to the increased equipment required to carry out the combustion of the spent synthesis gas.

Table 1. Economic assessment of the gasification and electrolysis for hydrogen production

Scenario	**Production cost**		
	Hydrogen (USD/tonne)	Oxygen (USD/tonne)	Electricity (USD/kW)
Scenario 1	3333.8		
Scenario 2	5232.1	7,271.0	
Scenario 3	3614.3		0.08

The design of the transformation processes under the biorefinery concept, seeking the maximum utilization of all raw materials, also allows for improving the energy efficiency of the process. This improvement derives from the production of energy carriers such as electricity. The energy efficiencies were 16.2%, 0.08%, and 18.1% for scenarios 1, 2, and 3, respectively. The third scenario presents the highest efficiency, which combines hydrogen production with electricity generation. The results are similar to those previously reported elsewhere (García et al., 2017). The electricity stream produced can be used to supply the energy needs of the process, be sold as a by-product, or be taken to electrolysis processes to increase the hydrogen stream produced. Finally, **Table 2** shows that the major contribution in all scenarios is due to raw material and utility costs. In the first scenario, the main operating cost is raw material and capital depreciation due to complex operating conditions. Then, the second scenario involving the electrolytic process is the costs associated with raw materials and utilities (energy demand). Finally, for the third scenario, the most representative cost is still raw material, utilities, and capital depreciation. In this sense, adding a production line to produce electricity increases the operating costs of the thermochemical processes.

Table 2. Economic assessment for hydrogen production for different scenarios

Item	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	Value*	Share	Value*	Share	Value*	Share
Raw materials cost	0.36	25.5%	0.28	21.4%	0.36	21.8%
Utility cost	0.06	3.7%	0.22	16.8%	0.26	15.7%
Maintenance cost	0.14	9.8%	0.04	3.1%	0.15	8.8%
Labor cost	0.18	13.0%	0.03	2.5%	0.18	11.1%
Fixed & General Costs	0.12	8.2%	0.17	12.9%	0.12	7.3%
Plant Overhead	0.17	12.0%	0.45	34.6%	0.18	10.5%
Capital Depreciation	0.39	27.7%	0.11	8.7%	0.41	24.8%

Value* (mUSD/year)

Conclusions

The analysis of the hydrogen production routes through autonomous processes or biorefinery schemes was carried out to establish the most influential parameters, among them the production rate, the productive yields, and the economic and energetic viability of the process. Thus, parameters such as the number of bioenergy products, the scale of processing, and the cost of raw materials and utilities were the most relevant parameters in the technical and economic analysis of the processes.

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