CHEMICAL ENGINEERING TRANSACTIONS

VOL. 52, 2016

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Peng-Yen Liew, Jun-Yow Yong, Jiří Jaromír Klemeš, Hon Loong Lam

ISBN 978-88-95608-42-6; **ISSN** 2283-9216

DOI: 10.3303/CET1652187

Techno-Economic Sensitivity of Bio-Hydrogen Production from Empty Palm Fruit Bunches under Colombian Conditions

Diana L. Perez Zúñiga[a*], Emelin J. Luna Barrios[a], Yeimmy Y. Peralta-Ruiz[b], Angel D. González-Delgado[c]

[a]Independent consultant in Chemical Engineering, Blas de Lezo Mz 23 Lt 17 Etapa 4, Cartagena, Colombia.
[b]Universidad del Atlantico, Agroindustrial Engineering Department, Km. 7 Vía a Puerto Colombia, Barranquilla, Colombia.
[c]University of Cartagena, Chemical Engineering Department, Av. del Consulado #Calle 30 No. 48–152, Cartagena, Colombia.
ingdlpz@gmail.com

Colombia is the fourth largest palm oil producer worldwide, and local research policies are favoring the study of palm production chain in order to satisfy specific demands detected for the process, which includes the increase of economic feasibility, this aim can be achieved via generation of valuable co-products as hydrogen from residues obtained in different stages taking advantage of the biorefinery concept. This work presents an economic sensitivity evaluation of the hydrogen production from empty fruit bunches (EFB) under Colombian conditions. Economic feasibility was measured taking into account a processing capacity of Colombian to process the EFB obtained from north, central and eastern zones with a hydrogen yield of 8747 t/y. Economic parameters as Net Present Value, Payback Period and economic potentials were calculated. Results shows that process presents a high sensitivity to the feedstock cost, in addition an increase of operating costs up to 1500 USD/t can affect significantly he payback period of the plant.

1. Introduction

Synthesis of hydrogen was carried out through the coal gasification until the replacement of this technology by process as steam reforming, partial oxidation and autothermal reforming of natural gas when the decrease of the oil prices diminished the price of gas (Miltner et al., 2009). In economic terms, reforming is highly efficient, due to the low cost in which the natural gas is bought, and the high percentage of conversion which is obtained in reforming furnaces. However, greenhouse gas emissions generated by this industry are alarming, being one of the most contaminants around the world (Bianchini et al., 2015). Different pathways to produce hydrogen have been studied (Garcia et al., 2016), among them, lignocellulosic biomass gasification presents advantages related to diminishing of the greenhouse gas emissions and the use of agroindustrial wastes that are source of environmental problems derived from its incorrect disposal in rural areas (Yao et al., 2016). Nevertheless, in the synthesis of hydrogen from biomass gasification process, one of the main obstacles is related to costs that have to be assumed to carry out the plant design and operation. On the other hand, the biomass to syngas conversion is strongly associated to the percentage of fixed carbon in its composition, which in many cases is only a little percentage of the elemental carbon, and whose influence on the efficiency and operation cost represents a serious disadvantage due to the large quantity of biomass that has to be bought in order to produce only one kilogram of gas, and utilities required. In this work, an economic and profitability analysis was carried out in order to determine the cost of using the empty fruit bunches (EFB) gasification process to produce hydrogen under economic Colombian conditions.

2. Materials and methods

Modeling and simulation of the process was previously developed by authors and is published in this journal volume. The gasification system was modeled as an empiric model, applying for the mass balance the

Please cite this article as: Perez Zúñiga D. L., Luna Barrios E. J., Peralta-Ruiz Y. Y., González-Delgado A. D., 2016, Techno-economic sensitivity of bio-hydrogen production from empty palm fruit bunches under colombian conditions, Chemical Engineering Transactions, 52, 1117-1122 DOI:10.3303/CET1652187

entrained flow gasifier information given by Ogi et al. (2013). In order to diminish the cost related with the biomass purchasing, the plant was designed as an expansion of a palm-oil extraction plant. Although EFB has been gasified before, the syngas obtained is a low quality gas, with a low hydrogen percentage in its composition due the absence of purification and adequation units. This gas is mainly used as fuel to generate energy in IGCC process (Bell et al., 2013). In Table 1, assumptions and parameters implemented in the economic analysis are summarized.

$$DGP = \sum_i m_i C_i^v - TAC \tag{1}$$

$$PAT = DGP\left(1 - itr\right) \tag{2}$$

$$EP_1 = \sum_i m_i C_i^v - \sum_j m_j C_j^{RM} \tag{3}$$

$$EP_2 = \sum_i m_i C_i^v - \sum_j m_j C_j^{RM} - U \tag{4}$$

$$CCF = \frac{\sum_i m_i C_i^v - AOC}{TCI} \tag{5}$$

$$PBP = \frac{FCI}{PAT} \tag{6}$$

$$\%ROI = \frac{PAT}{TCI} x 100\% \tag{7}$$

$$NPV = \sum_n ACF_n \left(1 + i\right)^{-n} \tag{8}$$

$$\eta_{On-stream}^{BEP} = \frac{m_{BEP}}{m_{\max}} \tag{9}$$

The economic analysis was carried out using US Dollar as reference, and equations applied were taken from the model of economic analysis proposed by El-Halwagi (El-Halwagi, 2012). FOB costs of equipment were calculated using information of vendors (www.alibaba.com), costs indexes and correlations reported in literature (Turton et al., 2009). Economic indicators were calculated, including the gross profit (depreciation not included) (GP), Gross Profit (depreciation included) (DGP), profit after taxes (PAT), Economic Potentials (EP1, EP2, EP3), cumulative cash flow (CCF), payback period (PBP), return of investment (ROI) and net present value (NPV), also the efficiency On-stream was calculated; Eqs(1) - (9) describes detailed calculation of economic indicators. Where $m_j C_j^{RM}$ is the product of the flow of raw material and the selling price, U are the utilities costs and AOC are annualized operating costs. $m_i C_i^v$ is the product of product flowrate and selling price and TAC is the sum of operating and fixed total annualized costs of the process, and itr is the tax ratem TCI is the total capital investment, FIC is the fixed capital investment, ACF is the net profit for the year n. m_{BEP} is the production capacity on BEP and m_{max} is the maximum production capacity.

3. Results

In Table 2, total capital investment for Biohydrogen production process is presented. Equipment represents the highest costs compared to other factors that affect DFCI. In the process were used a dryer and hammer mill for pretreatment stage; a gasifier to convert raw material into Biohydrogen; in heat recovery and cleaning were mainly used heat exchanges and scrubbing for retrieve and use the heat and remove carbon dioxide mixed with the Biohydrogen obtained in the gasification step, in the shift reactors system were used a high and low pressure towers and for Acid gas removal (AGR) process for Biohydrogen flow purification, a physic absorption process was implemented.

Table 1: Techno-economic assumptions for EFB hydrogen production plant

Processing capacity (t/y)	1,630,000
Main product flow (t/y)	8,747
Raw material cost ($/t)	5
Final product cost ($/t)	3,000
Plant life (years)	20
Salvage value	5.76 % of depreciable FCI
Construction time of the plant (years)	2
Location	Colombia
Tax rate	39 %
Discount rate	12 %
Subsidies	0
Type of process	New and unproven
Process control	Digital
Project type	addition to an existing plant
Soil type	Soft clay
Percentage of contingency	30 %
Tank design code	ASME
Specification diameter vessels	Internal diameter
Number of workers per shift	20
Salary per operator ($/h)	1.38
Utilities	gas, steam, water, electricity
Process fluids	solid-liquid-gas
Depreciation method	MACRS-5 Years

Table 2: Total capital investment for Biohydrogen production process from empty fruit bunches.

Costs of capital investment	Total (US$)
Delivered purchased equipment cost	10,008,811
Purchased equipment (installation)	2,001,762
Instrumentation (installed)	800,705
Piping (installed)	2,001,762
Electrical (installed)	1,301,145
Buildings (including services)	4,003,524
Services facilities (installed)	3,002,643
Total DFCI	23,120,353
Land	600,529
Yard improvements	4,003,524
Engineering and supervision	3,202,819
Construction expenses	3,402,996
Legal expenses	100,088
Contractors' fee	700,617
Contingency	3,002,643
Total IFCI	15,013,216
Fixed capital investment (FCI)	31,120,576
Working capital (WC)	5,601,704
Start up (SU)	3,112,058
Total Capital Investment (TCI)	39,834,337

In Table 3, direct operating costs, fixed charges and general costs are presented. Raw material used were empty fruit bunches and Selexol™ solvent. Utilities costs used for the plant was gas, steam, water and electricity; these costs in Colombia are higher in comparison to other palm producers. Equipment used in production at the time of acquisition must be endorsed by the concessionaire so they can be used, for being many the numbers of equipment, patents and royalties costs are considerably higher.

Table 3: Annual total production cost at 100% capacity.

Operating costs	Total (US$/y)
Raw materials	8,150,000
Utilities	595,298
Operating labor	216,000
Direct supervisory and clerical labor	38,880
Maintenance and repairs	720,634
Operating supplies	108,095
Laboratory changes	32,400
Patents and royalties	405,249
Total DPC	10,266,556
Depreciation	1,201,057
Local taxes and insurance	384,338
Plant overhead costs	585,309
Total FCH	2,170,704
Administration costs	146,327
Distribution and selling costs	2,971,826
GE	2,307,655
Total Operating Cost (OC)	13,508,299

Break-even analysis of production rate is shown in Figure 1(a). Production rate at the Break-even point is approximately 1,800 t/y, compared to maximum production capacity of 8,747 t/y, the process is feasible operating under the 100 % of installed capacity. Operational problems, preventive and responsive maintenance activities result in turnaround periods during which the process is shut down partially or completely, furthermore, market conditions may necessitate temporary reduction in the production rates to maintain a certain selling price or to stay within the demand level (El-Halwagi, 2012).

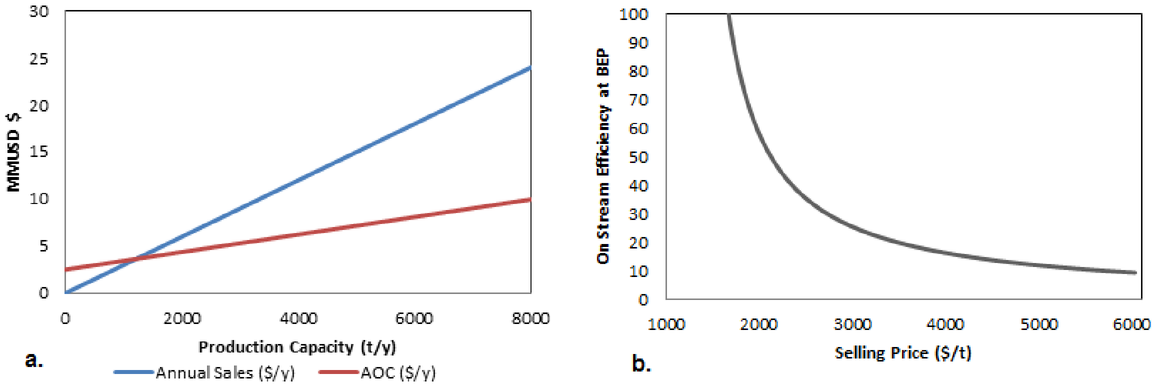

Figure 1: Break-even analysis of Biohydrogen production from palm EFB. a) Break even production capacity. b) Effect of Biohydrogen selling price on Stream efficiency at the Break Even Point.

Table 4: Results of economic indicators for Hydrogen production from empty palm fruit bunches.

Gross Profit (depreciation not included) (GP)	9,950,324
Gross Profit (depreciation included) (DGP)	8,749,267
Profit After taxes (PAT)	5,337,053
Products (Revenues)	26,241,000
Economic Potential 1 ($/y)	18,091,000
Economic Potential 2 ($/y)	17,495,702
Cumulative Cash Flow (CCF) (1/yr)	0.32
Payback Period (PBP) (years)	5.8
Return of Investment (%ROI)	13.4
Net Present Value NPV ($)	19,553,400

In this case, the empty fruit bunches is a residue which depends on the palm plantation, this is influenced mainly by climatic changes, so their growth is favored in the rainy season, therefore, it is possible that in arid times the amount of EFB available decrease and increase their acquisition cost; as a result the cost of the final product may vary and can also be affected production. Economic indicators are presented in Table 4. In general, the proposed plant has acceptable economic indicators despite being a new process and high tax rate in Colombia; CCF is less than 1.0 which is attractive in a project. The use of EFB for Biohydrogen production compared to other biomasses used to produce biofuels generates better economic benefits. In comparison to biofuels from microalgae via transesterification (6.295 MM$/y) and hydrothermal liquefaction (16.124 MM$/y) pathways (González-Delgado et al, 2015), biohydrogen production via gasification is more profitable, generating an annual income of MM$ 19.553/y. Also, the EFB for obtaining bioethanol and jet fuel was evaluated by Do et al., (2015), with annual sales revenues (ASR) of 10.65 MM$/y and 19.14 MM$/y, this means that Biohydrogen production from this raw material is more economically efficient under assumptions made in this study, with a revenues of 26.24 MM$/y. An important factor that favors the profitability of the project is that it is not necessary to buy new land. A sensitivity analysis of on-stream efficiency versus selling price of Biohydrogen is shown in Figure 1(b). there are a more pronounced effect to fluctuations in selling price around of $ 2,000/t of hydrogen, being less pronounced after $ 4,000/t.

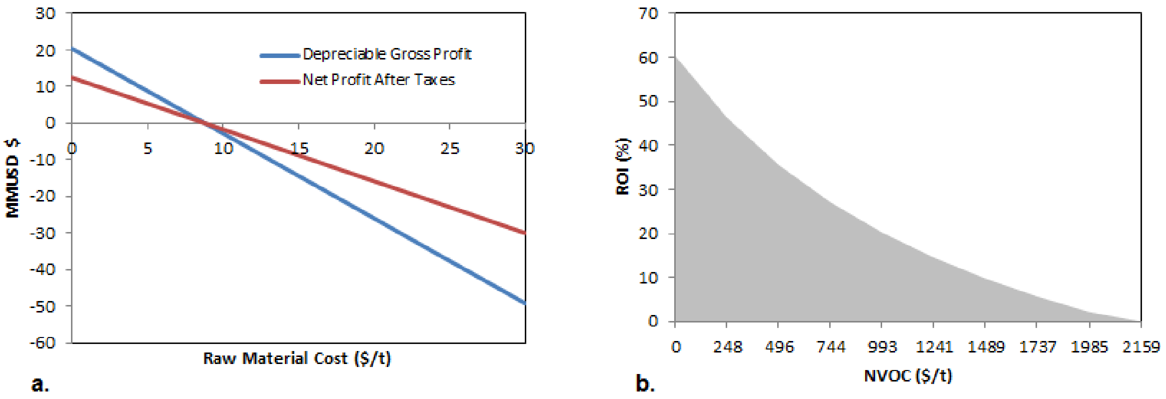

Figure 2: Sensitivity analysis of the cost of raw material and variation of ROI. a) Effect of costs of raw material on process profitability. b) Effect of operating costs on the process ROI.

The effect of raw material costs on process profitability is shown in Figure 2(a). If the cost of EFB increases to $ 7/t, the plant does not generate profits. Variable operating costs tend to change by raw material cost, utilities, waste treatment, among others. The variation of ROI respect to changes in NVOC is shown in Figure 2(b). If variable operating costs come up over $ 2,100/t, there will be no return on investment; the plant can only have a ROI of 60 % in the hypothetic scenario where NVOC are $ 0/t. The increase in operating costs can make that the PBP increase by years, for that reason, it is important to observe the effect of NVOC on PBP.

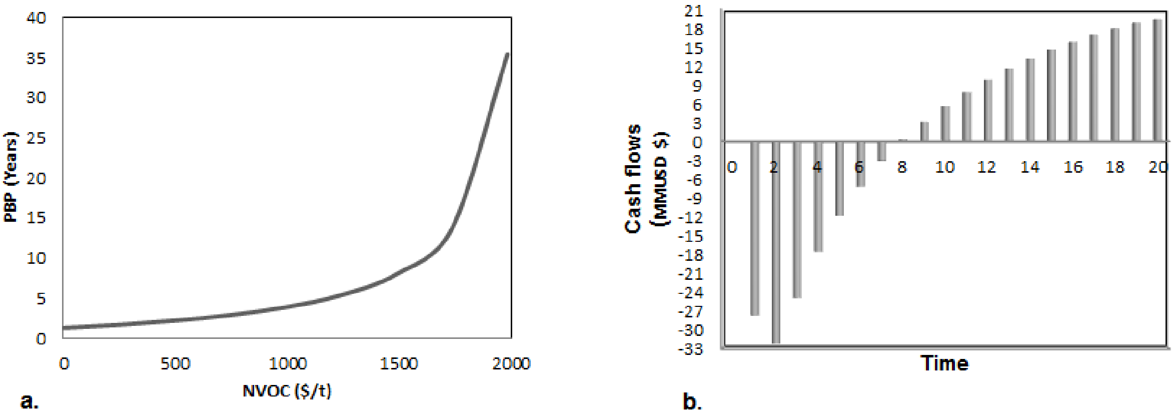

Figure 3: Sensitivity analysis for the payback period and Net present value. a) Effect of process operating costs on the Payback Period b) Net Present Value of the project.

According with Figure 3(a), the plant is sensitive to changes in variable operating costs, which are heavily influenced by the variation in the cost of raw material, it is possible to observe that the payback period tends to infinite when NVOC are approximately $ 2,000/t. Figure 3(b), shows the behavior of net present value. Considering the NPV, the investment will produce profits above the required return, indicating that the project is attractive. Finally, the internal rate of return (IRR) calculated was 21 %.

4. Conclusion

Evaluation of bio-hydrogen production from empty palm fruit bunches under Colombian conditions was performed using technoeconomic sensitivity in order to achieve a future palm-based biorefinery. For a product flowrate of 8,747 t/y under assumptions established the plant is attractive, and can be operated under maximum production capacity, however, the cost of raw material is a critical variable and must be taken into account, because an increase up to 50 % in empty bunches costs can affect the process profitability, so, implementation is recommended only if is an extension of an existing plant (e.g. palm oil production plant). Variable operating costs present a critical value around of 1,500 $/t of raw material, where a short increase can affect significantly the payback period of the plant in years.

Acknowledgments

Authors thank to University of Cartagena and Universidad del Atlantico for the supply of equipment and software necessary to conclude successfully this work.

References

Andersson J., Lundgren J., 2014, Techno-economic analysis of ammonia production via integrated biomass gasification, Appl. Energy, 130, 484–490.

Bell D. a, Towler B. F., Fan M., 2011, Coal Gasification and Its Applications. Elsevier, Amsterdam, the Netherlands

Bianchini, A., Pellegrini, M., Saccani, C., 2015, Solar steam reforming of natural gas integrated with a gas turbine power plant: Economic assessment, Sol. Energy, 122, 1342-1353.

Do T.X., Lim Y., Jang S., Chung H.J., 2015, Hierarchical economic potencial approach for techno-economic evaluation of bioethanol production from palm empty fruit bunches, Bioresource Technol. 189, 224-235.

El-Halwagi, M., 2012, Sustainable Design through Process Integration: Fundamentals and applications to industrial pollution prevention, resource conservation, and profitability enhancement. Butterworth-Heinemann/Elsevier, Oxford, UK

European Fertilizer Manufacturers' Association (EFMA), 2000, Booklet No. 1 of 8: Production of Ammonia. Belgium.

Garcia C., Betancourt R., Cardona C., 2016, Stand alone and biorefinery pathways to produce hydrogen through gasification and dark fermentation using *Pinus Patula*, Environ. Manage. In press.

González-Delgado A.D., Kafarov V., El-Halwagi M., 2015, Development of a topology of microalgae-based biorefinery: process synthesis and optimization using a combined forward-backward screening and superstructure approach, Clean Techn. Environ. Policy, 17, 2213-2228.

Miltner A., Friedl A., and Wuovits W., 2009, Evaluation of susteinable hydrogen production pathways, Chemical Engineering Transactions, 18, 339-344, DOI: 10.3303/CET0918054

Ogi T., Nakanishi M., Fukuda Y., Matsumoto K., 2013, Gasification of oil palm residues (empty fruit bunch) in an entrained-flow gasifier, Fuel, 104, 28–35.

Turton R., Baille R., Whiting W., Shaeiwitz J., Bhattacharyya D., 2012, Analysis, Synthesis, and Design of Chemical Processes. Pearson Education, Ann Arbor, United States

Yao D., Hu Q., Wang D., Yang H., Wu C., Wang X., Chen H., 2016, Hydrogen production from biomass gasification using biochar as a catalyst/support, Bioresource Technol. 216, 159-164.