MATEC Web of Conferences **164**, 01027 (2018) https://doi.org/10.1051/matecconf/201816401027
ICESTI 2017

Simulation Study of Bio-Methane Conversion into Hydrogen for Generating 500 kW of Power

Maizirwan Mel[1,*], *Fouad* Riyad Hussein Abdeen[1], *Hamzah* Mohd Salleh[1], *Sany* Izan Ihsan[2], *Fazia* Adyani Ahmad Fuad[1], and *Roy* Hendroko Setyobudi[3,4]

[1]Department of Biotechnology Engineering, International Islamic University Malaysia, Jalan Gombak, Kuala Lumpur 53100, Selangor, Malaysia,
[2]Department of Mechanical Engineering, International Islamic University Malaysia, Jalan Gombak, Kuala Lumpur 53100, Selangor, Malaysia Jalan Gombak, Kuala Lumpur 53100, Selangor, Malaysia
[3)]Waste Laboratory of University Muhamadiyah of Malang, Jl. Raya Tlogomas No. 246 Malang, 65114, Indonesia
[4]Indonesia Association of Bioenergy Scientist and Technologist, BPPT Building II, 22nd Floor Jl. MH. Thamrin No. 8 Jakarta 10340, Indonesia

Abstract. Research and development sectors have made great efforts for finding cleaner and greener supplements for fossil fuels. The uses of POME (Palm oil Mill Effluent) as feedstock of biogas production has attracted many industries to produce energy because this source (waste) is abundance and not fully utilised. Methane from biogas production has shown to have a significant potential to replace the depleting sources as it can be produced from renewable feed stocks. The main objective of this study is to produce hydrogen from methane obtained by digesting of POME and to transform bio-methane into hydrogen for generating 500 kW of electric power using a simulation software of SuperPro Design.

Key words: Anaerobic digestion, bio methane, biogas upgrading, hydrogen production, electric power.

1 Introduction

Fossil fuels have been used extensively all over the world for decades [1]. Consequently, their depletion have caused a continuous increase in the price as well as a high escalation in global warming [2]. Therefore, the research and development sectors have made great efforts for finding alternative energy sources such as biomass, solar, wind, natural gas and biogas, which are cleaner supplements [3, 4]. Among these energy sources, biogas has shown a promising potential to be future energy source as it can be produced from various feed stocks including landfill material, animal manure, wastewater and organic waste from industrial activities [5–7].

The focus of this project is to produce hydrogen from methane obtained by digesting palm oil mill effluent (POME) and to transform bio-methane into hydrogen for power generation. POME is broadly available in Malaysia and the conversion of this waste into a

[*] Corresponding author: maizirwan@iium.edu.my

beneficial product is of great benefits in terms for economy and environment [7−11]. In addition, the conversion of bio-methane to hydrogen prior to its utilization as an energy source is believed to be an environmental friendly process [11−16]. In this study, five major processes are included namely are; biogas production, biogas upgrading, reforming, hydrogen storage and converting hydrogen to energy. The bio-methane obtained from the anaerobic digestion was used for hydrogen gas production to generate 500 kW of power.

2 Materials and Method

2.1 Feedstock selection and site location

The POME is selected as a feedstock for biogas production due to its wide availability in Malaysia. The anaerobic digestion of POME was done using closed tank digester and further upgraded using column adsorption. In order to convert the bio methane into hydrogen gas, steam reforming in catalytic bed reactor with (600 °C to 1 100 °C) was used and compression process was employed to store the hydrogen gas before the combustion process of hydrogen gas into engine.

In order to build a hydrogen production plant, the location of the plant to be built also is an important matter where the consideration of the raw materials availability, space availability, utilities availability, local community considerations, climate, political consideration and transportation. For this project, the hydrogen production plant location is decided to be near the Kempas palm oil mill and near the highway. Thus, POME can be obtained easily and can minimize the cost for transportation of materials.

2.2 Materials preparation

The different processes performed in this project are well explained by the operational diagram shown in Figure 1. The diagram in Figure 1 shows the composition at each stage for the different gas components and shows the details of each unit operation used. SuperPro Design software (v9.5) was used to simulate the overall process. The designed process is shown in Figure 2.

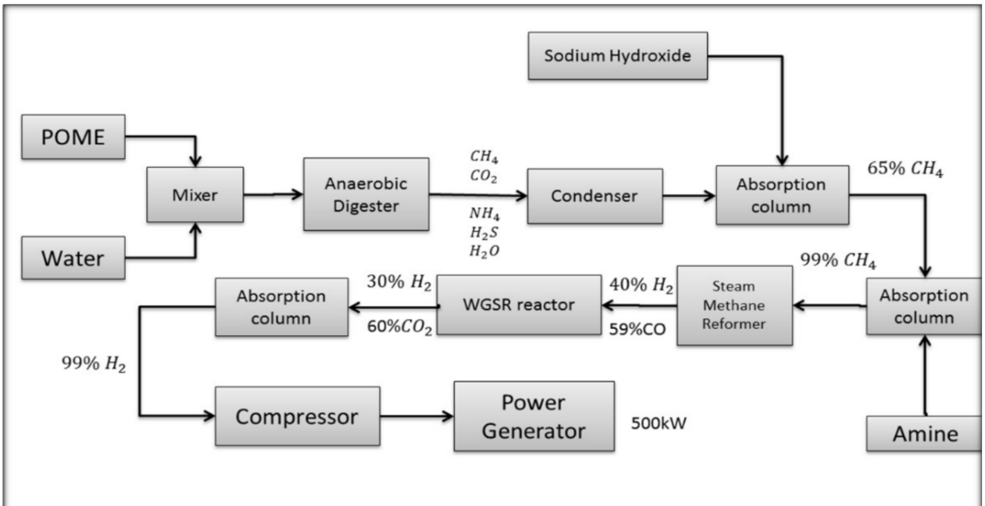

Fig. 1. Operational diagram.

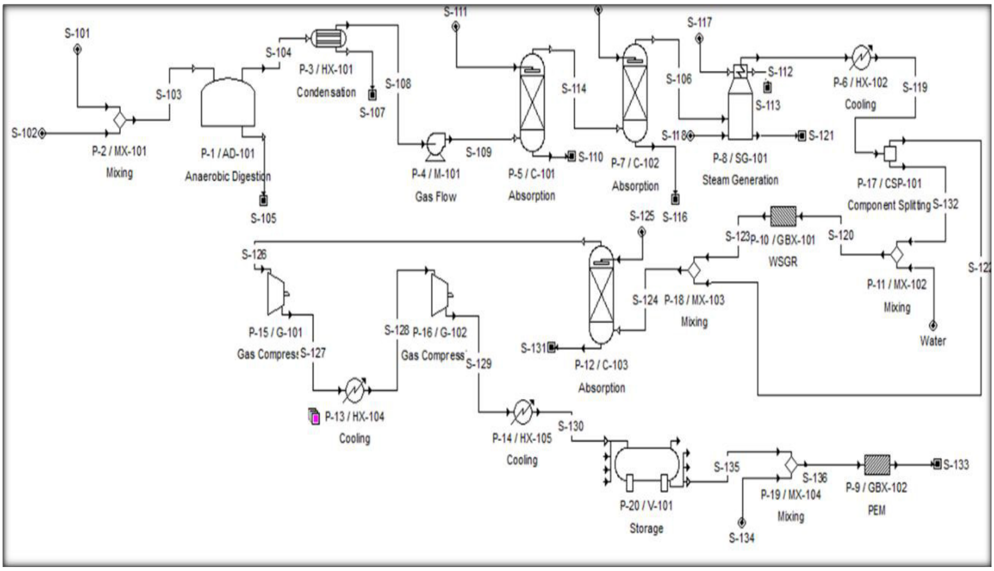

Fig. 2. Process simulation of power generation by hydrogen transformed from bio-methane.

As shown in Figure 1 and Figure 2, raw biogas exits from anaerobic digester enter the condenser to remove water content in the biogas. To make sure the water is totally condensing; flow rate leaving the condenser is monitored and controlled by the flow rate entering the condenser. Condensed water trapped in the condenser is monitored to overcome overflow.

The biogas from digester is blown into absorption column. The biogas then enters the absorption column for H_2S removal. The solvent for removing H_2S, NaOH is pumped into the system where the pump pressure is controlled by the vessel pressure. The operation condition is monitored by pressure gauge and thermocouple for high efficiency. The spent solvent goes out of the column is maintained by level controller.

The purified biogas enters the system from the absorption system where H_2S has been removed to acceptable levels. The flow rate reading in biogas vessel is transmitted to the controller whereby the flow rate of biogas entering is controlled. The solvent for removing CO_2, MEA (Methyl-Ethanolamine) solution is pumped into the system where the pump pressure is controlled by the vessel pressure. The pressure and temperature operated is monitored by pressure gauge and thermocouple to enhance the removal of CO_2. The spent solvent goes out from the column, monitored and maintained by float level sensor. The upgraded biogas leaves the column at expected concentration. Flow rate of upgraded biogas (pure methane) is being monitored and controlled before it enters the steam methane reformer to produce hydrogen. Temperature for both process in the steam methane reforming (SMR) which are steam reformer and fixed bed reactor for water steam generation reaction is being monitored to produce a high percentage of hydrogen. Accordingly, the pressure of both processes also being monitored and controlled by releasing the pressure. Product of water gas shift reactor (WSGR) is CO_2 and H_2, thus scrubber technique is required to separate them. The level of the spent MEA is being controlled and monitored.

The hydrogen enters into two compressors and two heat exchangers. The pressure of the hydrogen leaving the compressor is being monitored and controlled to reduce the storage tank. The temperature of the hydrogen is being monitored and controlled by the flow rate of the coolant.

In order to produce electricity from polymer electrolyte membrane (PEM) fuel cell, air (oxygen) is needed. Thus, flow rate of both hydrogen and air (oxygen) is being monitored and controlled to produce high electricity. Since the PEM fuel cell is operated at 50 °C, temperature is being monitored and controlled by flow rate of coolant into the PEM fuel cell. The reaction will produce water and the water level in the cell stack is monitored and controlled by the flow rate leaving the cell stack.

3 Result and discussion

The sizing of equipment is a major result obtained by this study. As shown in Table 1, the sizing of all the equipment used in this study is presented in details. It is obvious that a big digester of 202 m^3 volume is required for the purpose of generating 500 kW of power. A big digester might be very costly unless it is divided into several smaller digesters with the total volume of 202 m^3. The length of the condenser was calculated to be 16 m which is considered very long as well and needs to be replaced by shorter and more efficient condenser. Column absorption #2 size is also very huge with 263 m^3 volume, but the length to diameter ratio is still in the acceptable range.

The sizing of the other equipment (column absorption #1, fixed bed reactor for SMR, fixed bed reactor for WSGR, cooler 1, cooler 2, compressor 1 and compressor 2) has shown to be reasonable and acceptable. It is believed that the sizing of the equipment is helpful reference to be used for the design of such systems. While, the economic analysis for this study is not discussed.

Table 1. Sizing of each of equipment

Equipment	Size
Digester	Volume = 202.1 625 m^3 Height = 2.42 m Diameter = 7.28 m
Condenser	Heat Transfer Area = 0.4 m^2 Length = 16 m Diameter = 0.03 m
Column Absorption 1	Volume = 8.595 m^3 Height = 7.6 m Diameter = 0.6 m, Stages = 10
Column Absorption 2	Volume = 263.34 m^3 Height = 12.4 m Diameter = 2.6 m, Stages = 18
Fixed bed reactor (SMR)	Volume = 148.45 m^3, Height = 5.74 m, Diameter = 2.9 m, Catalyst diameter = 0.3 cm
Fixed bed reactor (WSGR)	Volume = 31.74 m^3 Height = 3.43 m Diameter = 1.72 m
Cooler 1	Heat Transfer Area = 64 m^2 Length = 3.3 m Diameter =19.4 m
Compressor 1	t = 757 min, volume = 7.6 m^3 compressor power = 373 kW
Compressor 2	t = 0.63 min, volume = 0.4 m^3 compressor power = 18.7 kW
Cooler (2 units)	Heat Transfer Area = 39.2 m^2 Length = 13 m, Diameter = 6 m

3.1 Sizing determination of SMR and WGSR

For conversion of 99 % methane into hydrogen at pressure of 15 atm and temperature of 700 °C with volume feed flow rate 296.904 $L \cdot h^{-1}$. Assuming pellet catalyst size is 0.3 cm and bed density is 0.6 $g \cdot cm^{-3}$

3.2 SMR Reactor

V= (Volume rate) (HRT)
= (296 904.759 L · h−1) (30 min × 1 h · 60 min)
= 148 452.38 L

Assume: H/D = 2, H = 2D, thus D =

$$D = \sqrt[3]{\frac{148.45\,\mathrm{m}^3}{2\pi}}$$

D = 2.9 m, H = 5.74 m, and A= 65.51 m^2

For conversion of 40 % carbon monoxide into hydrogen at pressure of 15 atm and temperature of 250 °C with volume feed flow rate is 2 284 829 L · h−1.

3.3 WSGR Reactor

V= (π/4) D^2 H
V= (Volume rate) (HRT)
= (2 284 829.595 L/h) (50s × 1min/60s × 1h/60min)
= 31 733.74 L

$$D = \sqrt[3]{\frac{31.74\,\mathrm{m}^3}{2\pi}}$$

D = 1.72 m, H = 3.43 m, and A= 23.18 m^2

Mass of catalysts

$$w_c = \left(950\,\mathrm{kg}\cdot\mathrm{m}^{-3}\right)\left(0.18\,\mathrm{m}^3\right)$$

$$w_c = 171\,\mathrm{kg}$$

4 Conclusion

POME is a waste produced in palm oil mill industries and if released to the environment untreated can cause major environmental pollution. It consists of large amount of volatile and suspended compounds that can be used for biomethane production. Then this biomethane can be converted into hydrogen to generate 500 kW of power. This is an ideal approach and can greatly provide green and clean sustainable energy and also lead to a considerable income for the company.

References

1. G.L. Juste. *Int. J. Hydrog. Energy* **31**, 14:2112–2121 (2006). https://www.sciencedirect.com/science/article/pii/S036031990600067X

2. S. Shahid, A. Minhans, O.C. Puan. *Jurnal Teknologi* **70**, 4 (2014). https://jurnalteknologi.utm.my/index.php/jurnalteknologi/issue/view/148
3. D. Deublein, A. Steinhauser. *Biogas from waste and renewable resources: An introduction*. Wiley-VCH: Germany (2008). http://onlinelibrary.wiley.com/book/10.1002/9783527621705
4. N.A. Azli,, A.H.M. Yatim. A modular structured multilevel inverter for fuel cell applications. Journal of Teknology 32. [Online]. Available from: http://www.researchgate.net/profile/Nik_Rumzi_Nik_ Idris/publication/224375883_The_Role_Power_Electronics_in_Future_Energy_Systems_and_Green_Industrialization/links/53e2efe00cf2b9d0d832c419.pdf#page=122 (2000). [Accessed on 20 May 2016].
5. H.K. Ahn, M.C. Smith, S.L. Kondrad, J.W. White. *Appl. Biochem. Biotechnol.* **160**, 4: 965–975 (2010). https://www.ncbi.nlm.nih.gov/pubmed/19462259
6. K. Braber. *Biomass and Bioenergy* **9**, 1–5:365–376 (1995). https://www.sciencedirect.com/science/article/pii/0961953495001034
7. M.J. Chin, P.E. Poh, B.T. Tey, E.S. Chan, K.L. Chin. *Renewable and Sustainable Energy Reviews* **26**:717–726 (2013). https://www.sciencedirect.com/science/article/pii/S1364032113003857
8. S. Tabassum, Y. Zhang, Z. Zhang. *Journal of Cleaner Production* **95**:148–155 (2015). https://www.sciencedirect.com/science/article/pii/S0959652615001699
9. P.E. Poh, M.F. Chong. *Bioresource Technology* **100**, 1: 1–9 (2009). https://www.sciencedirect.com/science/article/pii/S0960852408005427
10. A.R. Khalid, W.W. Mustafa. *Environmentalist* **12**, 4:277–285 (1992). https://link.springer.com/article/10.1007/BF01267698
11. N.H. Abdurahman, N.H. Azhari, Y.M. Rosli. *The Performance Evaluation of Anaerobic Methods for Palm Oil Mill Effluent (Pome) Treatment: A Review* [*Online*] from http://cdn.intechopen.com/pdfs/42628/InTech-The_performance_evaluation_of_anaerobic_methods_for_palm_oil_mill_effluent_pome_treatment_a_review.pdf (2013).
12. Reith, J.H., R.H. Wijffels, H. Barten. Bio-Methane and Bio-Hydrogen: Status and Perspectives of Biological Methane and Hydrogen Production. Dutch Biological Hydrogen Foundation. [Online]. Available from: http://www.cabdirect.org/ abstracts /20033182266.html (2003). [Accessed on 20 May 2016].
13. M.D. Redwood, M. Paterson-Beedle, L.E. Macaskie. *Reviews in Environmental Science and Biotechnology* **8**, 2: 149–185 (2009). http://eprints.bham.ac.uk/1007/
14. D. Liu, D. Liu, R.J. Zeng, I. Angelidaki. *Water Research* **40**, 11: 2230–2236 (2006). https://www.sciencedirect.com/science/article/pii/S0043135406002004
15. G. Kvesitadze, T. Sadunishvili, T. Dudauri, N. Zakariashvili, G. Partskhaladze, G. Ugrekhelidze, et al. *Energy* **37**, 1: 94–102 (2012). https://www.sciencedirect.com/science/article/pii/S0360544211005792
16. P.A.M. Claassen, T. De Vrije. *International Journal of Hydrogen Energy* **31**, 11: 1416–1423 (2006). https://www.sciencedirect.com/science/article/pii/S0360319906002102