CHEMICAL ENGINEERING TRANSACTIONS

VOL. 56, 2017

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

Guest Editors: Jiří Jaromír Klemeš, Peng Yen Liew, Wai Shin Ho, Jeng Shiun Lim

ISBN 978-88-95608-47-1; **ISSN** 2283-9216

DOI: 10.3303/CET1756120

Economic and Environmental Assessment for Integrated Biogas Upgrading with CO_2 Utilization in Palm Oil Mill

Lee Ming Kwee[a], Haslenda Hashim[a]*, Ho Chin Siong[b], Ho Wai Shin[a], Lim Jeng Shiun[a]

[a]Process System Engineering Centre (PROSPECT), Faculty of Chemical and Energy Engineering, Research Institute for Sustainable Environment (RISE), Universiti Teknologi Malaysia, Johor, Malaysia
[b]UTM Low Carbon Asia Research Centre, Faculty of Built Environment, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Malaysia
haslenda@utm.my

In Malaysia, one of the source of biogas is from anaerobic digestion of palm oil mill effluent (POME). This biogas trapped is upgraded to biomethane by removal of CO_2 and other unwanted components. Normally biogas upgrading process is designed not to further utilize the CO_2 that can be raw material to produce useful product. Furthermore, CO_2 released is a greenhouse gases that will cause environmental problems. By considering most of the POME treatment in palm oil mills is ponding system in Malaysia, microalgae CO_2 utilization is suggested because the culture can be grown on ponding system of mill. The objective of this study is to assess the applicability of microalgae CO_2 utilization in biogas upgrading technologies. In this study, economic and environmental aspect of microalgae CO_2 utilization in biogas upgrading technologies are investigated. The profit penalty for the biogas upgrading technologies by applying microalgae CO_2 utilization are in the range of 0.036 – 0.111 % and the CO_2 reduction are in the range of 156,439,300 – 175,994,200 kg/y.

1. Introduction

Although, POME is not the only waste generated during processing of fresh fruit bunch (FFB). But it is the most expensive and difficult waste to manage by mill operators. This is because large volumes are generated at a time. The palm oil industry still considers POME treatment a burden rather than as part of the production process, let alone a profit center (Ma, 1999). For these obvious reasons, raw POME or partially treated POME is still being discharged into nearby rivers or land, as this is the easiest and cheapest method for disposal. However, excessive quantities of untreated POME deplete a water body of its oxygen and suffocate aquatic life. Many small and big rivers have been devastated by such discharge as people living downstream are usually affected. Beyond obvious water pollution problems, is the use of both aerobic and anaerobic digestion by palm oil mills in treating POME. Methane, a greenhouse gas, 25 times more potent than carbon dioxide in trapping heat is generated during anaerobic digestion of POME. Palm oil mills are fingered by climate change authorities as being the second largest source of methane generator in Malaysia, (38 %), next to landfills (53 %). Methane or biogas from palm oil mills is therefore chief contributor to world global warming. During the last century, a great deal of research and development as well as application has been devoted to new advance POME treatment technologies (PTT). The major reason for such huge efforts is that POME generated from processing of FFB has been declared as one of the major source of environmental pollution. Ponding system is the traditional method used for POME treatment, and currently it is widely applied in Malaysia, involving over 85 % of the country's palm oil mills (Ma et al., 1993). However, the ponding treatment requires long hydraulic retention times (HRT) (typically 66 d) (Ma et al., 1985) and methane is released by the anaerobic digestion, along with CO_2. Both are greenhouse gases. In the proposed zero-waste processing of palm oil, the methane is separated from CO_2 by biogas upgrading technologies. The CO_2 separated by biogas upgrading technologies is fed to a microalgal culture in a POME pond which uses it as carbon source for growth during photosynthesis under sunlight, in addition to growing on organic carbon in the absence of light.

Please cite this article as: Lee M.K., Hashim H., Ho C.S., Ho W.S., Lim J.S., 2017, Economic and environmental assessment for integrated biogas upgrading with co2 utilization in palm oil mill, Chemical Engineering Transactions, 56, 715-720 DOI:10.3303/CET1756120

1.1 Composition of Biogas and Upgraded Biogas

Biogas consists mainly of combustible clean fuel CH_4, non-combustible CO_2 with trace amounts of water vapor, ammonia (NH_3), H_2S, carbon monoxide (CO), hydrogen (H_2), nitrogen (N_2), oxygen (O_2), dust and occasionally siloxanes (Taleghani, 2005). Although high gas quality is not required for boilers and combined heat and power (CHP) generation and biogas can be applied directly in these technologies, the corrosive characteristics of some biogas components such as water vapor and H_2S justify the necessity of biogas cleaning and upgrading treatments. Biogas should be upgraded for sensitive applications such as vehicle fuel. Consistent biogas quality helps to improve safe driving, eliminates the danger of corrosion, and omits ice-clogging due to high water content. The low calorific value of biogas is attributed to the presence of CO_2 as the main incombustible component (Vélez et al., 2012). Besides CO_2, H_2S and NH_3 are the other undesirable biogas components in the combustion process. H_2S not only damages combustion equipment due to its corrosiveness but the presence of H_2S in biogas components during biogas combustion forms sulfur dioxide (SO_2) and sulfur trioxide (SO_3) which are more toxic than H_2S. Biogas composition differs based on the AD feedstock, biogas production technique and biogas collection system. Table 1 demonstrates biogas composition (Hagen, 2001). Upgraded biogas which contains more than 90 % methane has approximately the same quality as natural gas and can be injected to gas grid, applied as a fuel in CHP generation or utilized as vehicle fuel (Taleghani, 2005).

Table 1: Biogas Composition (Hagen, 2001)

Component	Unit	POME biogas
CH_4	Vol %	60 – 70
CO_2	Vol %	30 – 40
N_2	Vol %	< 1
H_2S	ppm	10 – 2,000

1.2 Records of trapped biogas from palm oil mills in Malaysia

Yacob et al. (2005) estimated that about 0.5 - 0.75 kg of POME would be generated from palm oil mill for every kilogram of FFB. Consequently, for a well-run mill with good housekeeping, it is estimated that 2.5 kg of POME are generated for every kilogram of CPO produced. Arguably, generation of POME will continue to rise in kilograms as production and processing of palm oil continue to rise to meet both domestic and global demand. Table 2 show the biogas generation parameter for palm oil mills with biogas plant in Malaysia. In open tank digestion system, Yacob et al. (2005) reported that every kilogram of treated POME, an average of 0.0055 kg of methane (or approximately 36 % of biogas) is emitted from open digesting tanks.

Table 2: Biogas generation parameter for palm oil mills with biogas plant in Malaysia

	Unit	Value	Reference
FFB received by mills	kg/y	109,814,121,000	MPOB, 2015
Total number of mills	Units	467	MPOB, 2015
Number of mills with biogas plants	Units	68	MPOB, 2015
Estimated FFB received in mills with biogas plant	kg/y	159,900,664,700	
POME generated in mills with biogas plant	kg/y	95,940,398,800	Yacod et al, 2005
Trapped biogas in mills with biogas plant	kg/y	34,538,543,600	Yacod et al, 2005

2. Technology Reviews

The first section reviews the energy potential of palm oil mill waste in Malaysia whereas second section reviews the biogas upgrading technologies and microalgae usage in CO_2 utilization.

2.1 Biogas upgrading

Upgraded biogas (biomethane), unlike wind energy is a well manageable energy source which can be stored, distributed and used in the same way as natural gas. Therefore it is one of the most viable renewable substitutes for natural gas (Adelt et al., 2011). In this study, the biogas upgrading technologies considered are water scrubbing, amine scrubbing, membrane separation, physical scrubbing and pressure swing adsorption.

2.2 Cost analysis of biogas upgrading technologies

The total costs of biomethane production depend on the investment in connection gas pipelines and biogas upgrading facilities as well as operating costs of the upgrading facility. The operating costs include water, electricity, heat and biogas production costs. To calculate the investment costs for all biogas upgrading methods, data on the specific investment depending on biogas input flow rate in m^3/h was used as shown in Table 3 (Bauer et al., 2013).

Table 3: Specific investment of biogas upgrading technologies (Bauer et al, 2013)

	Biogas input flow rate, m^3/h				
Biogas Upgrading method	250	500	700	1000	1400
Water scrubbing, RM/(m^3/h)	23,200	9,280	4,640	4,640	4,640
Amine scrubbing, RM/(m^3/h)	25,056	13,920	10,937	9,280	7,457
Membrane separation, RM/(m^3/h)	20,416	13,456	10,607	9,280	8,287
Physical scrubbing, RM/(m^3/h)	23,200	9,280	4,640	4,640	4,640
Pressure swing adsorption, RM/(m^3/h)	-	13,920	10,208	8,120	6,960

In Malaysia, trapped biogas in mills with biogas plant is 34,538,543,600 kg/y. According to MPOB 2015, mean COD of palm oil mill effluent is 51,000 mg/L and by considering 8000 operating hours per year in palm oil mill. The trapped biogas in mills with biogas plant is 84,653.3 m^3/h. Average biogas input flow rate for 68 mills with biogas plant is 1,244.9 m^3/h. The specific investment of biogas upgrading technologies after correlation is shown on Table 4. The operating costs of the biogas upgrading facilities were calculated using the data shown in Table 5. Water rate used is RM 1.50 /m^3 and electricity tariff used is RM 0.39 /kWh. The calculated capital and operating cost of biogas upgrading technologies are shown in Table 6. 20 years of lifetime is used to calculate the capital cost.

Table 4: Specific investment of biogas upgrading technologies after correlation (Bauer et al., 2013)

	Biogas input flow rate, m^3/h
Biogas Upgrading method	1,244.9
Water scrubbing, RM/(m^3/h)	4,640
Amine scrubbing, RM/(m^3/h)	8,162
Membrane separation, RM/(m^3/h)	8,672
Physical scrubbing, RM/(m^3/h)	4,640
Pressure swing adsorption, RM/(m^3/h)	7,410

Table 5: Operating cost parameter of biogas upgrading technologies (Kovacs, 2013)

	Water scrubbing	Amine scrubbing	Membrane separation	Physical scrubbing	Pressure swing adsorption
Water consumption, m^3/m^3 of biogas	22×10^{-5}	3×10^{-5}	-	-	-
Electricity consumption, kWh/m^3 of biogas	0.265	0.1	0.22	0.25	0.23
Thermal energy consumption, kWh/m^3 of biogas	-	0.55	-	-	-

Table 6: Calculated capital and operating cost of biogas upgrading technologies

	Water scrubbing	Amine scrubbing	Membrane separation	Physical scrubbing	Pressure swing adsorption
Capital cost, RM/h	36.13	63.75	67.50	36.13	57.63
Operating cost, RM/h	0.104	0.254	0.086	0.098	0.090
Total cost, RM/h	36.23	64.00	67.59	36.23	57.72

2.3 Cost analysis of microalgae CO_2 Utilization

Microalgae are microscopic organisms that typically grow suspended in water and are driven by the same photosynthetic process as that of higher plants (Hanelt et al., 2007). Microalgae can comprise bacteria (cyanobacteria), diatoms (e.g., Chromalveolata), other protists (e.g., Chromista), and unicellular plants (e.g., Chlorophyta) (Bahadar and Khan, 2013). However, unlike higher plants, microalgae do not require a vascular system for nutrient transport, as every cell is photoautotrophic with directly absorbing nutrients. Microalgal cells are sunlight-driven cell factories that can convert carbon dioxide (CO_2) into raw materials for producing biofuels (e.g., biohydrogen, biodiesel, and bioethanol), animal food chemical feedstocks and high-value bioactive compounds (e.g., Docosahexaenoic acid (DHA)) (Razzak et al., 2013). In particular, the ability of these cells to absorb CO_2 suggests microalgae cultivation as an attractive alternative for CO_2 sequestration that can be applied to fossil fuel power plant gas effluents to facilitate the reduction of greenhouse gas emissions (Yun et al., 1997). CO_2 fixation via microalgae is a potential and promising method for CO_2 capture and storage (Zhao and Su, 2014). CO_2 fixation and storage via microalgae are essentially photosynthesis, which can transform water and CO_2 to organic compounds without extra energy addition or consumption and without secondary pollution. Compared to other carbon capture and storage (CCS) methods, CO_2 fixation via microalgae has many benefits, such as a high photosynthesis rate (e.g., 6.9×10^4 cells/mL/h (Suali and Sarbatly, 2012)), a rapid growth rate ($0.7 – 3.2\ d^{-1}$ (Ryu et al., 2009)), good environmental adaptability and low cost of operation. As a special advantage, biomass from microalgae for energy consumption is provided after CO_2 capture. The performance of CO_2 fixation via microalgae and biomass production depends on the cultivation conditions (e.g., temperature, light, pH, and nutrient availability), species of microalgae, CO_2 concentration and toxic pollutants in the flue gas (Zhao and Su, 2014). Table 7 shows the microalgae processing information. The depth of the algae pond is assumed to be 4.5 m and annual fixation target is 10 %. Table 8 shows the microalgae CO_2 utilization cost parameter. Table 9 show the calculated capital and operating cost of microalgae CO_2 utilization.

Table 7: Microalgae processing information

Information	Value	Unit	References
Fixation rate	4.02	g CO_2/L.d	Rezwani et al., 2016
Algae yield	2.19	g algae/L.d	Rezwani et al., 2016
Annual fixation target (10 %)	177,771,900	kg CO_2/y	
Culture volume	1,260,000	L	
Area	0.28	km^2	
Algae produced	327,100,300	kg microalgae/y	

Table 8: Microalgae CO_2 utilization cost parameter (Lundquist et al., 2010)

Information		Value	Unit
Microalgae cultivation	Capital cost	2,636,800	RM/km^2
	Operating cost	0.4763	RM/kg
Microalgae harvesting	Capital cost	0.1026	RM/kg
	Operating cost	0.1285	RM/kg
Microalgae drying	Capital cost	0.4627	RM/kg
	Operating cost	0.5529	RM/kg

Table 9: Calculated capital and operating cost of microalgae CO_2 utilization

	Microalgae cultivation	Microalgae harvesting	Microalgae drying	Total
Capital cost, RM/h	4.61	0.41	1.87	6.89
Operating cost, RM/h	1.92	0.52	2.23	4.67

2.4 Economic and environmental analysis of microalgae CO_2 utilization in biogas upgrading

The economic viability of microalgae usage in palm oil mill is compared in term of profit and CO_2 reduction. Table 10 shows the selling price of biomethane and microalgae. Table 11 shows the economic assessment and CO_2 emission reduction.

Table 10: Economic Parameter

Product	Selling Price	Unit	References
Biomethane	0.815	RM/kg	Masebinu et al., 2015
Microalgae	0.724	RM/kg	Phillip, 2008

Table 11: Economic assessment and CO_2 emission reduction

	Water scrubbing	Amine scrubbing	Membrane separation	Physical scrubbing	Pressure swing adsorption
Without CO_2 Utilisation					
Capital cost, RM/h	36.13	63.75	67.50	36.13	57.63
Operating cost, RM/h	0.10	0.25	0.09	0.10	0.09
Total Cost, RM/h	36.23	64.00	67.59	36.23	57.72
Revenue of Biomethane, RM/h	2,174.43	2,262.30	1,851.91	2,130.06	2,064.18
Revenue of Microalgae, RM/h	-	-	-	-	-
Total Revenue, RM/h	2,174.43	2,262.30	1,851.91	2,130.06	2,064.18
Net Profit, RM/h	2,138.20	2,198.30	1,784.32	2,093.83	2,006.46
With CO_2 Utilisation					
Total Upgrading Cost, RM/h	36.23	64.00	67.59	36.23	57.72
Capital Cost of Microalgae Processing, RM/h	6.89	6.89	6.89	6.89	6.89
Operating Cost of Microalgae Processing, RM/h	4.67	4.67	4.67	4.67	4.67
Total Cost, RM/h	47.79	75.56	79.15	47.79	69.28
Revenue of Biomethane, RM/h	2,174.43	2,262.30	1,851.91	2,130.06	2,064.18
Revenue of Microalgae, RM/h	10.56	10.77	9.58	10.45	10.45
Total Revenue, RM/h	2,184.99	2,273.07	1,861.49	2,140.51	2,074.63
Net Profit, RM/h	2,137.20	2,197.51	1,782.34	2,092.72	2,005.35
Profit Penalty between Upgrading with and without CO_2 Utilisation, %	0.047	0.036	0.111	0.053	0.055
CO_2 Reduction, kg/y	172,439,700	175,994,200	156,439,300	170,661,000	170,661,000

3. Conclusion

In this study, the economic potential of applying microalgae CO_2 utilization in biogas upgrading plants is promising in term of GHG emission reduction. Based on the economic assessment, the profit penalty for all five upgrading technologies are in the range of 0.036 – 0.111 %. Although this imply profit reduction (0.79 – 1.98 RM/h) on applying microalgae CO_2 utilization but the reduction is not significant. The CO_2 reduction for applying microalgae CO_2 utilization in biogas upgrading technologies are in the range of 156,439,300 – 175,994,200 kg/y. The efficiency of different species of microalgae in absorbing CO_2 is suggested to further investigate for improving the CO_2 reduction and cost-effectiveness of selected microalgae.

Acknowledgments

The financial support in the form of research grant by the Ministry of Higher Education (MOHE) Malaysia with grant no. R.J130000.7301.4B145, Q.J130000.2546.14H46 and the JICA SATREPS programme are gratefully acknowledged.

Reference

Adelt M., Wolf D., Vogel A., 2011, LCA of biomethane, J. Nat. Gas Sci. Eng. 3 (5), 646–650.

Bahadar A., Khan M.B., 2013, Progress in Energy from Microalgae: A Review. Renewable Sustainable Energy Rev., 27, 128–148.

Bauer F., Hulteberg C., Persson T., Tamm D., 2013, Biogas upgrading – Review of commercial technologies, SGC Rapport 270, 83.

Hagen M., 2001, Adding gas from biomass to the gas grid, Report SGC 118, Swedish Gas Centre, SGC.

Hanelt D., Bischof K., Dunton K., 2007, Life Strategy, Ecophysiology and Ecology of Seaweeds in Polar Waters, Rev. Environ. Sci. Biotechnol 6, 95–126.

Kovacs (2013), Proposal for a European Biomethane Roadmap, European Biogas Association, Renewable Energy House, Belgium.

Lundquist T.J., Woertz I.C., Quinn N., Benemann J.R., 2010, A realistic technology and engineering assessment of algae biofuel production, Energy Biosciences Institute, University of California, Berkeley, California, USA.

Ma A., Cheah S., Chow M., Yeoh B., 1993, Current status of palm oil processing wastes management, Ed. Yeoh B.G., Chee K.S., Phang S.M., Isa Z., Idris A., Mohamed M., Waste Management Malaysia: Current Status Prospects Bioremediation, 111–136

Ma A., Ong A.S., 1985, Pollution control in palm oil mills in Malaysia, J Am Oil Chem Soc 62, 261–266

Ma A.N., 1999, Treatment of palm oil mill effluent, Eds. Singh G., Lim K.H., Leng T., David L.K., Oil palm and the environment: a Malaysian perspective, Malaysian Oil Palm Growers' Council, Kuala Lumpur, 113-126.

Masebinu S.O., Aboyade A.O., Muzenda E., 2015, Economic Analysis of Biogas Upgrading and Utilization as Vehicular Fuel in South Africa, World Congress on Engineering and Computer Science 2015 Vol II WCECS 2015, San Francisco, USA

Pienkos P.T., 2008, Historical Overview of Algal Biofuel Technoeconomic Analyses, National Algal Biofuels Technology Roadmap Workshop, National Renewable Energy Laboratory, NREL, U.S.

Razzak, S.A., Hossain, M.M., Lucky, R.A. and Bassi, A.S. (2013). Integrated CO2 Capture, Wastewater Treatment and Biofuel Production by Microalgae Culturing-A Review, Renewable Sustainable Energy Rev. 27: 622– 653.

Rezvani S., Moheimani N.R., Bahri P.A., 2016, Techno-economic assessment of CO_2 bio-fixation using microalgae in connection with three different state-of-the-art power plants, Computers and Chemical Engineering 84, 290-301.

Ryu H.J., Oh K.K., Kim Y.S., 2009, Optimization of the Influential Factors for the Improvement of CO2 Utilization Efficiency and CO2 Mass Transfer rate, J. Ind. Eng. Chem 15, 471–475.

Suali E., Sarbatly R., 2012, Conversion of Microalgae to Biofuel, Renewable Sustainable Energy Rev. 16, 4316–4342

Taleghani G., Kia A.S., 2005, Technical–economical analysis of the Saveh biogas power plant, Renewable Energy 30 (3), 441–446

Vélez F., Segovia J.J., Martín M.C., Antolín G., Chejne F.Q.A., 2012, A technical, economical and market review of organic Rankine cycles for the conversion of low-grade heat for power generation, Renew Sustain Energy Rev 16, 4175–4189

Yacob S, Hassan MA, Shirai Y, Wakisaka M, Subash S, 2005, Baseline study of Methane Emission from open digesting tanks of palm oil mill effluent treatment, Chemosphere 59, 1575–1581

Yun Y.S., Lee S.B., Park J.M., Lee C.I., Yang J.W., 1997, Carbon Dioxide Fixation by Algae Cultivation Using Wastewater Nutrient, J. Chem. Technol. Biotechnol. 69, 451–455.

Zhao B., Su Y., 2014, Process Effect of Microalgal- carbon Dioxide Fixation and Biomass Production: A Review, Renewable Sustainable Energy Rev. 31, 121– 132.