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Maximising Potential of Methane Production from Biogas for Power Generation

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ABSTRACT

Renewable energy projects in many developing countries need financial and legal back up from governments and other supportive bodies. There is a viable alternative to finite energy via usage of biomass waste a renewable energy source. The electrical energy production analysis on biomass waste presented in this paper is based on the experimental analysis carried out using the laboratory and pilot scale bioreactors. Electrical energy generated with oscillatory flow bioreactor (OFBR) was 10.12 kWh or up to 91% higher than the 10 L lab scale bioreactor (0.9 kWh), demonstrating that the novel OFBR has a great potential for renewable electricity. Also, the pilot scale plant achieves a value of 12.3 kWh, which the difference is not quite significant with that of OFBR. These results illustrate that the generation of the renewable electricity is feasible especially with the OFBR thereby achieving high methane potential during the treatment of manure and food waste. Nevertheless, energy recoveries should be enhanced to improve the entire operational performance.

Keywords: Biogas, electrical power generation, methane production, renewable energy

INTRODUCTION

The advancements of large feedlots for livestock have generated an economic opportunity for commercialised agribusiness in Malaysia. Beef and dairy cattle, and poultry are gradually fed in close proximity to maximize proficient production and reduce costs. This practice produces large amounts of animal manure that will exude odour, methane, hydrogen sulphide, nitrous oxide, carbon dioxide, and ammonia (Monteny, Bannink, & Chadwick, 2006). Manure run-off if unrestrained can also produce water pollution due to its phosphorus and nitrates content (Miner, 1999). In recent times, such unprecedented passion in the renewable energy, as a sustainable energy

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source due to the increasing ecological concerns coupled with high energy costs have prompted an increased interest in utilizing biomass waste, such as animal manure, for biogas production (Omer, 2008; Nasir et al., 2013). This can be achieved either by burning manure specifically for fuel or to produce heat, and/or by turning it into "biogas" through anaerobic digestion (Panwar et al., 2011). Anaerobic digestion is a biological process whereby microorganism breakdown the degradable organic content in the absence of oxygen to produce biogas, and a nutrient-rich digestate used as fertiliser (Nasir, Mohd Ghazi, & Omar, 2012). Biogas is made up of basically methane and carbon dioxide, and may have traces of hydrogen sulphide and moisture. Methane has a global warming effect that is 21 times that of carbon dioxide; so using the methane for energy production considerably reduces the greenhouse gas emissions (Jorgenson, 2006). Also, since the manure used in the anaerobic methane digesters is not runoff over the surface of land, this benefit the local drainage basin as well. Manure-based digesters can improve rural economic growth and gives livestock farmers and feedlot operators with diversified revenue source, or at best lower the cost of disposal (Chen, Yang, Sweeney, & Feng, 2010).

In Europe, the number of operational anaerobic digestion plants has increased to over 14,500 as reported by the European Biogas Association's (EBA) Biogas Report 2014 (EBA, 2014), which focus mainly on the electricity generation, supplying heat and/or transport fuel. Similarly, the rapid growth for this technology is recently experienced, especially because of the essential factor of the greenhouse gases emission reduction adopted at the Kyoto Summit (Mata-Alvarez, Mace, & Llabres, 2000). On the other hand, in Asia, the most common application of biogas is for households. For example, in China, it is estimated that up to 15 million households use biogas energy in rural areas, and effective programmes have been set up in Indian and Nepal (Van Nes, 2006). Now, moves are going on to unveil biogas development programmes right across South East Asia, particularly in Malaysia and Vietnam. In Malaysia, there are huge prospect for utilizing biogas resources from palm oil mills, wastewater treatment facilities, landfills and agriculture industry (Sumathi, Chai, & Mohamed, 2008). Highlighting the significance of the country's sustainable biomass feedstock in addition to the government's attention on the green renewable technologies is the country's strategic plan for developing Malaysia as a biogas centre in Asia (Jaafar, Kheng, & Kamaruddin, 2003). In the 10th Malaysia plan, the new energy set to achieve is of 985 MW by 2015, which will contribute to 5.5% of Malaysia's total electricity generation mix. In order to achieve its target, the National Renewable Energy Policy (NREP) was launched, together with various new initiatives attached upon the Renewable Energy Policy 2010 and Action Plan will be embarked on (Hashim & Ho, 2011).

This paper describes how the biogas energy anaerobic digesters create system-wide operational efficiencies in the energy production and the operational costs. Also, the efficiency of utilizing biogas for power generation for an anaerobic digestion system-treating animal and food waste is presented. The findings presented here are based mainly on the laboratory experimental results published. It should be mentioned that this work would not address the economic assessment of the biogas production in general but focus on the possible electrical generation.

TECHNO-ECONOMIC ANALYSIS

Energy production efficiency

Many in the anaerobic digester industries use a cow per kW ratio to denote the power generation efficiency, but this measure has a number of limitations. Firstly, the methane production differs significantly depending on system downtime, so technologies that check or quickly recover from shock have an obvious advantage as per enhanced energy production (Chae, Jang, Yim, & Kim, 2008). An important factor in methane production is the time duration the substrates expend in the digesters, referred to as the hydraulic retention time. It should be noted that shorter retention time depicts an ineffective methane production, so complete revenue is not realized. Whereas, longer retention time depicts more was spent on excess capacity or not sufficient substrate is being added to maximize revenue (Ahring, 2003). Therefore, an optimized digester retention time is needed to maximize revenue with the most suitable capital costs. Secondly, co-digesting manure, by adding other substrates has been found to increase the methane production (Mata-Alvarez, Mace, & Llabres, 2000). Hence, it has been found out that different substrates have various methane productions potential (Table 1).

Table 1
Methane production potential of various organic wastes

Substrates	Methane yield (L/g VS $_{added}$)
Chicken manure	0.295
Dairy manure	0.500
Swine manure	0.322
Corn stover	0.241
Wheat straw	0.245
Rice straw	0.281
Kitchen waste	0.541
Fruit and vegetable waste	0.342
Used animal oil	0.776
Used vegetable oil	0.811
Yard waste	0.183
Switch grass	0.246
Vinegar residue	0.253
Rice husk	0.049

Source: Li, Zhang, Liu, Chen, He, & Liu (2013)

It can be seen form Table 1 that the highest methane production for the various organic substrates studied was achieved by the vegetable oil and used animal oil with a yield of 0.811 and 0.776 L/g VS_{added}, respectively. This is followed by the kitchen waste with a methane yield of 0.541 L/g VS_{added} possibly due to its high content of lipids and protein. Dairy manure also showed a bit higher yield of 0.500 L/g VS_{added}, whereas rice husk demonstrated the lowest methane yield of 0.049 L/g VS_{added}. Similarly, lignocellulosic biomass showed low yields, which were all below 0.300 L/g VS_{added}.

Cost of systems

As it is known that the conventional cows per kW ratio is not perfect for describing the energy production in a digester, similarly, a cost per cow figure is insufficient due to the variables concerned. Hence, a more convenient way to approximate cost is to find out all potential substrates for a given operation, which will set up the capital costs as well as revenue from the energy production and tipping fees (Theodore, 1994). After that, the power generation rates can be estimated in addition to downtime estimates (Ghadfoori & Flynn, 2006). In this way, a financial model can be developed to provide a clearer picture than the conventional cost of capital in dollars per cow.

Efficiency of electrical energy production from biogas

Generally, biogas anaerobic digesters produce a system-wide operational efficiency in the renewable energy production from agricultural biomass. Energy production from biogas can be a very effective technique for electric energy generation from an alternative energy source (McKendry, 2002). Biogas is usually used as fuel in combined heat and power plants (CHPs) for generating electricity and heat, although it can also be processed and transferred to the natural gas grid (Plochl & Heiermann, 2006). However, this is suitable only if the upcoming heat from the biogas generator can be utilized in a cost-effective and environment-friendly manner (Demirbaş, 2001). The energy content of a biogas mixture is directly proportional to the methane content in it. Hence, in order to convert the biogas to pure methane, the biogas must go through scrubbing and cleaning processes to remove carbon dioxide, hydrogen sulfide, and other traces of gases (Zhao, Leonhardt, MacConnell, Frear, & Chen, 2010). The calorific energy content of each cubic meter of biogas is about 6 kWh (21-23.5 MJ/m^3), which is equal to 0.5-0.6 L of diesel fuel (Ahmad, 2010). However, due to conversion losses, approximately $1m^3$ of biogas (65% methane) can be converted only to approximately 1.7 kWh of the useable electric energy (Oleszkiewicz & Barnard, 2006). Whereas, the rest is converted into heat which can further be used for heating applications. This 1.7 kWh is sufficient energy to power a 100 W light bulb for 15 hours or a 2000W hair dryer for an hour. Therefore, the electrical energy generation from biogas is a suitable technology suitable even for quite minor applications between range of 10 and 100kW (Ahmad, 2010). Similarly, however, the electrical energy generation costs of a biogas plant decrease with an increase in plant size, which automatically reduces the efficiency and the operational cost (Persson, Jönsson, & Wellinger, 2006).

The biogas electrical conversion efficiency is the amount of electrical energy from the total energy available. Conventionally, biogas has been used to fuel engine-driven generators, which attains up to 30-35% energy efficiency, while, much older systems achieve only 20-30% electrical energy efficiency (Galitsky, Worrell, & Ruth, 2003). Lately, the biogas engine generator systems have improved and will achieve 35 to 40% electrical energy efficiency (Jacobs III & Schneider, 2009). In recent years, micro turbines have been tested and used in the biogas applications. These systems are much like a jet engine and are presently being tested in a variety of biogas systems to assess use and durability (Demirbas, 2011).

Energy value of methane from the bioreactor

From the data collected on a batch and semi-continuous 10L lab scale bioreactor treating cattle manure, operating at hydraulic retention time (HRT) of 20 days with an average methane yield of 0.19 m^3/kg VS added and 55% methane content, the electrical energy production was calculated according to this formula as:

Electrical energy production
= [volume of Methane (m^3) × methane energy content (kWh) × efficiency of biogas engine (%)] ÷ 100 (Eqn. 1)

Assuming 30% electric generator efficiency, a 240 kW generator will be required to produce 0.9 kWh of electricity. In peninsular Malaysia, the average per household electricity consumption is 251 kWh per month (Alshafiqab, Nor Azizia, Shamsul & Amyra, 2015), and the average carbon emission factor of electricity use is about 0.684 kg CO_2e/kWh (Zaid, Myeda, Mahyuddin, Sulaiman, 2013). In terms of carbon dioxide emission (CO_2), this is interpreted to release: 0.684 kg CO_2e/kWh × 251 kWh per month = 171.68 kg of CO_2 emission per household per month. As already discussed, CO_2 emission contributes to the greenhouse gas effect responsible for global warming, also according to Advani, Bassi, Bowen, Fankhauser, Johnson, Leicester, Stoye et al. (2013) each kWh of electric energy consumption from the electrical grid produces 0.541 kg of CO_2 (Zaid, Myeda, Mahyuddin & Sulaiman 2013). Therefore, the 0.9 kWh produced from renewable source in this study will save about 0.541 kg of CO_2 emission, thereby reducing the output of carbon dioxide in the air, which makes it possible to minimize the trend of global warming. This will certainly pave the way to a healthy atmosphere and reduction of environmental foot print. Although the electrical energy value obtained was lower, it is expected that further optimization of the design and substrate will enhance the methane yield as such increase the energy production. Cuéllar & Webber (2008) reported that the biogas from livestock manure represents a saving of between 47.2 and 150.4 metric tons of CO_2 in the USA. They concluded that by co-digesting animal waste with other organic wastes will at least double, if not triple, the volume of biogas available, and because the biogas methane can be purified as a renewable fuel for mobile uses for cars as well as farm machinery. Hence, it can displace larger amounts of fossil fuels, thereby contributing even more to mitigating greenhouse gases and energy savings.

Similarly, from the experimental results obtained for a novel oscillatory flow bioreactor (OFBR) operated semi-continuously for cattle manure treatment. The bioreactor was initially operated at a loading rate of 2.5 g VS/L/day, after which it was increased step-wise from 2.5 to 3.5 g VS/L/day on day 33, and to 4.5 and 5.5 on day 85 and 124, respectively. The average HRT corresponding to these OLR were 20, 12, 11.3 and 9.3 days, respectively. By assuming 30% electric generator efficiency, a 240 kW generator will be required to generate 10.12 kWh of electricity from the result of the experiment. At a price of 21.8 sen/kWh (Abdullah, Abdullah, Hassan, & Hussin, 2012), the biogas generated from treating the cattle manure waste through the anaerobic digestion using the OFBR would save 220.6 sen on the electricity. In addition, CO_2 emission of 12.14 kg will be saved monthly using this novel reactor. On the other hand, the result of batch and semi-continuous anaerobic digestion of food waste at carbon: nitrogen (C/N) ratio of 17, assuming 30% electric generator efficiency, a 240 kW generator will be required to produce 10.7 kWh at lab scale. The pilot scale experiment operated under the same condition, achieved an electrical energy of 12.3 kWh. This will also save CO_2 emission of 12.8 and 14.7 kg for the lab scale and pilot scale, respectively.

Presently, there are quite a few biogas plants in Malaysia, most of which operated at palm oil mills for treating the palm oil mill effluent (POME). As of now, four oil palm biogas projects were permitted to be Feed-in Approval Holders (FIAHs) for grid connection under the feed-in-tariff (FiT) system [36]. Two of these biogas plants are Bell Eco Power Sdn. Bhd., and Achi Jaya Plantations Sdn. Bhd., both are located at Johor and were already connected to the grid with a total capacity of 3.25 MW (Chin, Poh, Tey, Chan, Chin, 2013). In addition, there are a number of firms that provide technical know-how for the application of biogas technology in palm oil mills such as International Asia Sdn. Bhd., Novaviro Technology Sdn. Bhd., Biogas Environmental Engineering Sdn. Bhd. by setting up mostly the sealed cover ponds over the present anaerobic digester systems to save cost (Chin, Poh, Tey, Chan, Chin, 2013). However, strong government commitment is significant by formulating the regulatory context of capturing methane gas from the anaerobic digestion of POME. This will generally encourage the shift from the conventional open pond system to closed digester biogas system for capturing methane gas. Also, government should provide incentives and possibly tax deduction to biogas producers particularly to the palm oil mills to support them with an increased capital expenditure of the biogas power plant. Therefore, with the improvement in the anaerobic digester system for anaerobic treatment of POME, it is certain that POME will turn into a viable biogas resource to enhance Malaysia's renewable energy sector in the nearest future.

CONCLUSION

In most developing countries power production from renewable sources has emerged to be particularly profitable in areas that are not in the national grid. There are signs of financial and legal back up for feeding in electricity from biogas power plants, and a considerable increase in feed-in tariff for biogas power in some countries such as Malaysia. As a major contributor to Malaysia's economy, palm oil industry can be expected to continue its prominence in the future making palm oil mill effluent (POME) a sustainable biogas energy source for Malaysia. Hence, anaerobic digestion is an excellent treatment practice for POME as it converts it to sustainable energy that will benefit the palm oil mill and the government with regard to the environment, climate change and profitable future. However, there are many problems that impede the advancement of renewable energy using POME as the main source. But the most important factor is the reluctance of the palm oil mills in Malaysia to undertake into advanced efficiency technologies such as closed anaerobic bioreactors due to cheaper operating costs and ease of operation. Thus, it is essential to mobilize market forces by setting up policies, regulatory framework, and appropriate incentives to encourage the palm oil industries. In addition, more financial support will be needed and researches should be performed to enhance the methane and biogas yield from the anaerobic digestion of POME. With the improvement in the anaerobic bioreactor technology of POME, like the application of the novel OFBR, it is certain that POME will act as a good biogas resource to boost Malaysia's renewable and sustainable energy sector.

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REFERENCES

Abdullah, A. S., Abdullah, M. P., Hassan, M. Y., & Hussin, F. (2012). Renewable energy cost-benefit analysis under Malaysian feed-in-tariff. In *Research and Development (SCOReD), 2012 IEEE Student Conference*, (pp. 160-165).

Ahmad, S. (2010). Energy and Bio-fertilizers for Rural Pakistan: Opportunities, Integrated Technology Applications, Vision and Future Strategy. *Managing Natural Resources for Sustaining Future Agriculture, 2*(17), 1-31.

Ahring, B. K. (2003). Perspectives for anaerobic digestion. In *Biomethanation* (pp. 1-30). Springer Berlin Heidelberg.

Alshafiqab, N. A., Shamsul, S., & Amyra, M. Y. (2015). Optimization Performance of Power Generation and Freshwater Production Utilizing Ocean Thermal Energy Application. In *3rd International OTEC Symposium,* Universiti Teknologi Malaysia Kuala Lumpur, Malaysia.

Chae, K. J., Jang, A. M., Yim, S. K., & Kim, I. S. (2008). The effects of digestion temperature and temperature shock on the biogas yields from the mesophilic anaerobic digestion of swine manure. *Bioresource Technology, 99*(1), 1-6.

Chen, Y., Yang, G., Sweeney, S., & Feng, Y. (2010). Household biogas use in rural China: a study of opportunities and constraints. *Renewable and Sustainable Energy Reviews, 14*(1), 545-549.

Cuellar, A. D., & Webber, M. E. (2008). Cow power: the energy and emissions benefits of converting manure to biogas. *Environmental Research Letters, 3*(3), 1-8.

Demirbaş, A. (2001). Biomass resource facilities and biomass conversion processing for fuels and chemicals. *Energy Conversion and Management, 42*(11), 1357-1378.

Demirbas, A. (2011). Competitive liquid biofuels from biomass. *Applied Energy, 88*(1), 17-28.

EBA. (2014). *European Biogas Association*. Retrieved November 12, 2015, from http://european-biogas.eu/

Elfeituri, F. E., & Taboun, S. M. (2002). An Evaluation of the NIOSH Lifting Equation: A Psychophysical and Biomechanical Investigation. *International Journal of Occupational Safety and Ergonomics, 8*(2), 243–258.

Galitsky, C., Worrel, E., & Ruth, M. (2003). Energy Efficiency Improvement and Cost Saving Opportunities for Corn Wet Milling Industry: An Energy star Guide for Energy and Plant Managers. *Ernest Orlando Lawrence Berkeley National Laboratory and US Environmental Protection Agency.* University of California Berkeley, CA.

Ghadfoori, E., & Flynn, P. C. (2006, March). Optimum sizing for anaerobic digestion. *BIOCAP Canada Foundation.* Department of Mechanical Engineering, University of Alberta.

Hashim, H., & Ho, W. S. (2011). Renewable energy policies and initiatives for a sustainable energy future in Malaysia. *Renewable and Sustainable Energy Reviews, 15*(9), 4780-4787.

Jaafar, M. Z., Kheng, W. H., & Kamaruddin, N. (2003). Greener energy solutions for a sustainable future: issues and challenges for Malaysia. *Energy policy*, *31*(11), 1061-1072.

Jacobs III, J. A., & Schneider, M. (2009). Cogeneration Application Considerations. *GE Energy*. Corporate Publication, Technical Evaluation and Marketing Analysis.

Jorgenson, A. K. (2006). Global warming and the neglected greenhouse gas: A cross-national study of the social causes of methane emissions intensity, 1995. *Social Forces*, *84*(3), 1779-1798.

Kuorinka, I., Lortie, M., & Gautreau, M. (1994). Manual Handling in Warehouses: The Illusion of Correct Working Posture. *Ergonomics*, *37*(4), 655 – 661.

Li, Y., Zhang, R., Liu, G., Chen, C., He, Y., & Liu, X. (2013). Comparison of methane production potential, biodegradability, and kinetics of different organic substrates. *Bioresource Technology, 149*, 565-569.

Marras, W. S., Lavender, S. A., Leurgans, S. E., Fathallah, F. A., Ferguson, S. A., Allread, W. G., & Rajulu, S. L. (1995). Biomechanical Risk Factors for Occupationally Related Low Back Disorders. *Ergonomics, 38*(2), 377-410.

Mata-Alvarez, J., Mace, S., & Llabres, P. (2000). Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource Technology, 74*(1), 3-16.

McKendry, P. (2002). Energy production from biomass (part 2): conversion technologies. *Bioresource Technology, 83*(1), 47-54.

Miner, J. R. (1999). Alternatives to minimize the environmental impact of large swine production units. *Journal of Animal Science, 77*(2), 440-444.

Monteny, G. J., Bannink, A., & Chadwick, D. (2006). Greenhouse gas abatement strategies for animal husbandry. *Agriculture, Ecosystems and Environment, 112*(2), 163-170.

Nasir, I. M., Ghazi, T. I. M., & Omar, R. (2012). Production of biogas from solid organic wastes through anaerobic digestion: a review. *Applied Microbiology and Biotechnology, 95*(2), 321-329.

Nasir, I. M., Ghazi, T. I. M., Omar, R., & Idris, A. (2013). Batch and semi-continuous biogas production from cattle manure. *International Journal of Engineering and Technology*, *10*(1), 16-21.

Oleszkiewicz, J. A., & Barnard, J. L. (2006). Nutrient removal technology in North America and the European Union: a review. *Water Quality Research Journal of Canada, 41*(4), 449-462.

Omer, A. M. (2008). Green energies and the environment. *Renewable and Sustainable Energy Reviews, 12*(7), 1789-1821.

Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: a review. *Renewable and Sustainable Energy Reviews, 15*(3), 1513-1524.

Persson, M., Jönsson, O., & Wellinger, A. (2006). Biogas upgrading to vehicle fuel standards and grid injection*. IEA Bioenergy task*, *37*, 1-34.

Plochl, M., & Heiermann, M. (2006). Biogas farming in central and northern Europe: a strategy for developing countries? Invited overview. *Agricultural Engineering International*, *8*(8), 1–15.

Sumathi, S., Chai, S. P., & Mohamed, A. R. (2008). Utilization of oil palm as a source of renewable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, 12(9), 2404-2421.

Theodore, L. (1994). *Pollution prevention*. Switzerland: Gordon and Breach Science Publishers.

Van Nes, W. J. (2006). Asia hits the gas: Biogas from anaerobic digestion rolls out across Asia. *Renewable Energy World, 9*(1), 102-111.

Zaid, S. M., Myeda, N. E., Mahyuddin, N., & Sulaiman, R. (2013). The Need for Energy Efficiency Legislation in the Malaysian Building Sector. In T*he 3rd International Building Control Conference,* Kuala Lumpur, Malaysia.

Zhao, Q., Leonhardt, E., MacConnell, C., Frear, C., & Chen, S. (2010). Purification technologies for biogas generated by anaerobic digestion (pp. 1-24). *CSANR Research Report.*