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/CET1756063

Potential Biogas Generation from Food Waste through Anaerobic Digestion in Peninsular Malaysia

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Malaysia's rising energy demand and increasing generation of municipal solid waste (MSW) has made a linkage to the implementation of Waste to Energy (WtE) strategy. On the supply side, waste segregation at source was first implemented in Malaysia during September 2015, where the organic food waste is separated from other waste. Food waste is a potential feedstock for biogas generation. However, there is lacks of study to identify its potential. Even on the demand side, where biogas is utilized as one of the renewable energy sources, the palm oil mill effluent (POME) is given more attention as feedstock when compared to the other organic waste, for instance, food waste. This is obvious when biogas facilities are constructed in palm oil mills to utilize biogas generated instead of other places like landfill sites. This paper aims to identify the potential of biogas generation from food. It is concluded that approximately 60 Mm^3 of CH_4, which is equivalent to 16.3 MW electricity can be produced yearly based on food waste generated on year 2010. The amount is calculated based on Intergovernmental Panel for Climate Cange (IPCC) methane gas emission from biological treatment equation. A revenue of approximately 42 M MYR is estimated by selling the electricity through Feed-in-Tariff (FiT) scheme. The opportunities and challenges of such implementation is discussed following the finding.

1. Introduction

Increasing population and economic growth in Malaysia has caused the increasing generation of solid waste. On year 2011, the amount of solid waste produced has reached around 30,000 t/d (Johari et al., 2014), a staggering amount that is causing potent effect on environmental health through the release of greenhouse gases (GHG) and leachate (Johari et al., 2012). In Malaysia, 95 % of the collected solid waste is disposed to landfill (Johari et al., 2014). It is estimated to have released 310220 tonnes GHG annually (Johari et al., 2012). In order to overcome the situation, on year 2013, Malaysia started to practice WtE strategy. There is one incineration plant that is operating in Langkawi with 100 t/d of MSW capacity, producing 1 MW electricity. Due to high moisture content of waste (52.65 - 66.2 %) that causes high operation costs, the other four plants have been closed down. It also leads to more attention on landfill gas (LFG) recovery (Tan et al., 2014). There were around 291 landfill sites in Malaysia during 2007, with only 3 % sanitary landfill (Johari et al., 2012). Study shows that 47 % of CH_4 released in Malaysia comes from the landfill (Tan et al., 2014), not to mention that the 100-year global warming potential (GWP) of CH_4 is 25 times more potent to the environment than CO_2 (Eco Network, 2015).
During September 2015, Ministry of Housing and Local Government (MHLG) implemented mandatory waste segregation at source at some of the states in Malaysia. The states involved included Federal Territory of Kuala Lumpur, Putrajaya, Pahang, Johor, Melaka, Negeri Sembilan, Perlis and Kedah. Regulation and guideline were drawn up by the National Solid Waste Management Department (JPSPN) (The Sun Daily, 2014). With the progressive implementation of WtE strategy in the country, this paper takes food waste as biogas source and analyse its energy potential.

Please cite this article as: Hoo P.Y., Hashim H., Ho W.S., Tan S.T., 2017, Potential biogas generation from food waste through anaerobic digestion in peninsular malaysia, Chemical Engineering Transactions, 56, 373-378 DOI:10.3303/CET1756063

1.1 Solid waste management in Malaysia

MSW in Malaysia are processed differently according to their characteristics. The MSW management in Malaysia is highly dependent on landfilling (94.5 %), only some MSW go to recycling (5.5 %) and composting (1 %). Waste recycling is mainly carried out by the garbage scavengers at landfill sites. With raising concern over environmental sustainability, the government is in planning and transiting towards a more effective and sustainable waste management methods. Malaysia targets to achieve MSW recycling rate of 22 % by 2020 in order to improve waste processing performance (Tan et al., 2014).

1.2 Food waste management in Malaysia

Food waste management in Malaysia is under the MHLG responsibility, who is also responsible to prepare regulations for solid waste management for urban wellbeing. During year 2013, according to MHLG, disposal of food waste directly to the landfill sites is the main source of GHG emission. The 10th Malaysian Plan aimed to achieve waste segregation at source to 15 - 25 % by 2015, thus, National Waste Minimizing Master Plan and Action Plan was introduced. It was more focused on recyclable materials, there is lack of strategic plan for food waste management. MHLG therefore collaborated with Ministry of the Environment Japan (MOEJ) to develop a National Strategic Plan for Food Waste Management in Malaysia. The objectives of the project are included to minimize the amount of food waste that is sent to landfill, to suggest proper treatment of food waste produced, to provide solution to recover landfill gasses effectively.

The project collected information of good case practice of food waste management information in Japan, current practice of food waste management in Malaysia, especially on the local constraints and issues. The solution is then customized locally for our nation's food waste management need. There are total of five strategies under the collaboration project where strategy 1 and 2 needs a government to support by establishing food waste recycling regulations and collecting data, strategy 3 is waste generators to reduce food waste as much as possible through waste segregation at source, strategy 4 is to treat and turn food waste into resources at source, strategy 5 is to establish centralized food waste treatment facilities, strategy 6 is to minimize environmental impacts of food waste (National Solid Waste Management Department, 2013).

With the implementation of waste segregation at source nationally since September 2015, it proved that the National Strategic Plan for Food Waste is progressing towards achieving its objectives.

2. Methodology

2.1 Calculation of Potential Biogas from Food Waste

In order to calculate the potential of biogas from food waste in Malaysia, the amount of MSW disposed to the landfill sites is first obtained from literature review (Johari et al., 2014). The MSW is then assumed that it has been segregated at source. According to waste data from IPCC, generally in South East Asia region, 43.5 % of the MSW are consisted of organic food waste (Pipatti et al., 2006b). Table 1 shows the MSW composition from IPCC in South East Asian Region.

Figure 1 illustrates the amount of MSW generated in Peninsular Malaysia. The central of Peninsular Malaysia which included Selangor and Kuala Lumpur amounted the largest MSW generation, 3,240 t/d and 1,950 t/d. It is then followed by the southern Malaysia, Johor which its MSW generation amounted to 2,439 t/d.

Table 1: MSW composition data by percent in Asia region during 2000 (Pipatti et al., 2006b)

Region	Eastern Asia	South-Central Asia	South-Eastern Asia	Western Asia & Middle East
Food waste	26.2	40.3	43.5	41.1
Paper/cardboard	18.8	11.3	12.9	18
Wood	3.5	7.9	9.9	9.8
Textiles	3.5	2.5	2.7	2.9
Rubber/leather	1	0.8	0.9	0.6
Plastic	14.3	6.4	7.2	6.3
Metal	2.7	3.8	3.3	1.3
Glass	3.1	3.5	4	2.2
Other	7.4	21.9	16.3	5.4

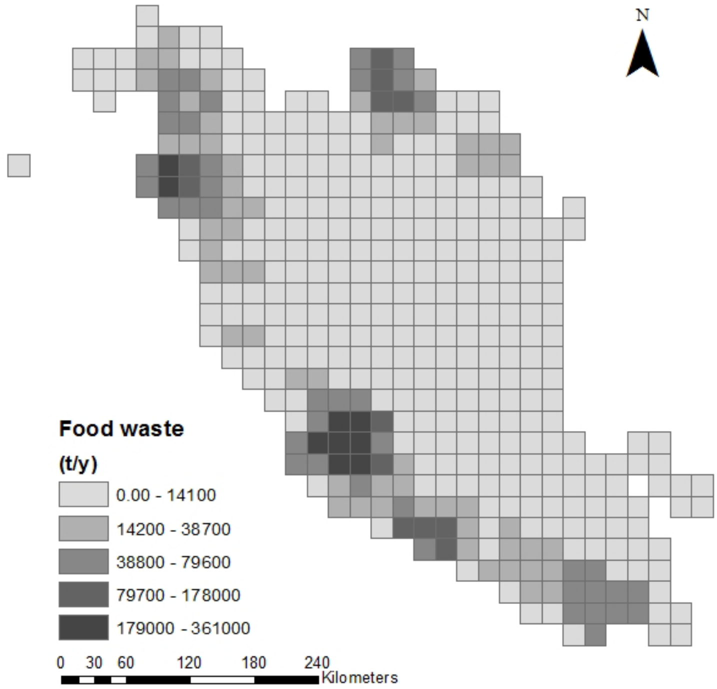

Figure 1: State generation of MSW and its food waste amount in Peninsular Malaysia.

Eq(1) from IPCC is used to calculate methane gas emission from biological treatment, for instance, anaerobic digestion (Pipatti et al., 2006a).

$$CH_4\ Emission = \sum_i (m_i \times EF_i) \times 10^{-3} - R \quad (1)$$

Where CH_4 Emission is a total CH_4 emissions in inventory year, Gg CH_4; M_i is a mass of organic waste treated by biological treatment type *i*, Gg; EF is emission factor for treatment *i*, g CH_4/kg waste treated; *i* is a composting or anaerobic digestion and R is a total amount of CH_4 recovered in inventory year, Gg CH_4.

When calculating the methane gas emission from anaerobic digestion, the amount of recovered gas, R should be subtracted from the total amount of methane emitted. Recovered methane can be used to generate heat or power. The mean of biological treatment that is included here are composting or anaerobic digestion.

EF is determined depending on a few factors, for instance, type of waste, type of supporting material (such as peat and wood chips), amount of supporting material, moisture content, temperature and process aeration. As shown in Table 2, the default Tier 1 method from IPCC is used to determine the emission factor.

By using the default method, the waste is assumed with 25-50 % DOC in N in dry matter and 60 % moisture content. The EF of dry weight are estimated from waste that has originally has 60 % moisture content (Pipatti et al., 2006a).

Table 2: Default emission factors for CH_4 emission from biological treatment of waste (Pipatti et al., 2006a)

Type of biological treatment	CH_4 Emission Factors (g CH_4/kg waste treated)	
	On a dry weight basis	On a wet weight basis
Composting	10 (0.08 – 20)	4 (0.03 – 8)
Anaerobic digestion at biogas facilities	2 (0 -20)	0.8 (0 – 8)

3. Result and Discussion

3.1 Potential electricity generation of biogas from anaerobically digested food waste

The main methane gas emission from waste that is sent to the landfill comes from food waste. By segregating food waste and send them directly to anaerobic digestion, it could reduce the GHGs emission significantly.

The MSW data is taken from the year of 2010 (Johari et al., 2014). Then the value is substituted into the Eq(1). 43.5 % of food is assumed to have been segregated, pre-treated and fed into the anaerobic digestion tank. It is assumed that there is no methane recovered in the process, thus R = 0 in all states. The EF is

assumed on a dry weight basis, thus EF = 2. By substituting all value into Eq(1), the result is as shown in Table 3.
The potential of electricity generation is calculated based on Eq. 2 (Abdeshahian et al., 2016).

$$e_{biogas} = E_{biogas} \times \eta \qquad (2)$$

Where e_{biogas} is a electricity generated (kWh/y); E_{biogas} is an energy content of raw biogas (kWh/y); η is a conversion efficiency (biogas to electricity), %.
Energy content of the biogas is taken as 6 kWh/m^3 (Abdeshahian et al., 2016). 40 % efficiency is assumed for the conversion of biogas to electricity using combined-heat-power engine. E_{biogas} is calculated using Eq(3) (Abdeshahian et al., 2016).

$$E_{biogas} = Energy\ content_{biogas} \times \dot{m}_{biogas} \qquad (3)$$

Where $Energy\ content_{biogas}$ is a calorific value of biogas (kWh/m^3) $\dot{m}_{biogas}$ is an amount of biogas produced (m^3/y). Energy content of the biogas produced is 6 kWh/m^3, considering 21.5 MJ/m^3 biogas (1 kWh = 3.6 MJ) (Abdeshahian et al., 2016).
A total of 60 Mm^3 CH_4 is estimated can be produced from MSW in 2010. If the biogas produced were to be sent to combined-heat-and-power (CHP) engine of 35 – 40 % efficiency, it is estimated that 16.3 MW of electricity could be produced yearly.
The food waste were assumed to be sent to near-atmospheric pressure AD, which is a relatively more mature and commercially available technology that could produce biogas with 57 % methane content. The efficiency of the AD can even go up to 94 % methane-content biogas generation base on different AD technology selection (Budzianowski and Budzianowska, 2015).
With the feed-in-tariff (FiT) for RE in Malaysia (Table 4), it is estimated that the biogas produced could lead to a revenue of 42 MMYR yearly by selling electricity to Tenaga National Berhad (TNB).

Table 3: Estimated CH_4 emission and electricity generation from food waste in 2010.

State	MSW (Mt/d)	Food Waste (t/d)	CH_4 Emission (m^3/y)	Energy content of raw biogas (kWh/y)	Electricity (kWh/y)
Perlis	120	52.20	409,741.94	2,458,451.61	983,380.65
Kedah	1,504	654.24	5,135,432.26	30,812,593.55	12,325,037.42
Penang	1,800	783.00	6,146,129.03	36,876,774.19	14,750,709.68
Perak	1,864	810.84	6,364,658.07	38,187,948.39	15,275,179.35
Pahang	1,094	475.89	3,735,480.65	22,412,883.87	8,965,153.55
Selangor	3,240	1,409.40	11,063,032.26	66,378,193.55	26,551,277.42
Kuala Lumpur	1,950	848.25	6,658,306.45	39,949,838.71	15,979,935.48
Negeri Sembilan	1,162	505.47	3,967,667.74	23,806,006.45	9,522,402.58
Melaka	906	394.11	3,093,551.61	18,561,309.68	7,424,523.87
Johor	2,439	1,060.97	8,328,004.84	49,968,029.03	19,987,211.61
Kelantan	729	317.12	2,489,182.26	14,935,093.55	5,974,037.42
Terengganu	651	283.19	2,222,850.00	13,337,100.00	5,334,840.00
TOTAL	17,459	7,594.67	59,614,037.10	357,684,222.60	143,073,689.00

Table 4. FiT for biogas in Malaysia (Ministry of Energy, 2009)

RE Utilisation - Biogas	Year	RM/kWh	Degression(%)
< 4MW	16	0.32	0.5
4 MW – 10 MW	16	0.30	0.5
10 MW – 30 MW	16	0.28	0.5

3.2 Opportunities and challenges of biogas from food waste

Till November 2016, there is no electricity feed in from the biogas into the National Electricity Grid although the FiT scheme has been introduced since 2011. Till June 2015, there is a total 17.24 MW of electricity capacity generated from biogas, with all biogas plants located at the palm oil mills (Sustainable Energy Development Authority Malaysia, 2015). Electricity is generated from biogas released from the anaerobic digestion of palm oil mill effluent (POME). The cost of grid connection has always been the top challenges to the FiT option due to high return of investment (ROI) (Kumaran, 20016). Not to mention the high energy loss during the energy conversion and transmission process. At the meantime, the potential of upgrading the biogas and injecting it into the National Gas Distribution System (NGDS) remained unexplored.

As observed in Figure 2, there are higher population density at central and southern region of Peninsular Malaysia, which indicate higher food waste production. Both regions have natural gas pipeline passing through, locating between 5 – 20 km from the nearby landfill sites. Through this way, it is possible to inject upgraded biogas into the NGDS, which could possibly lead to more profitable income. Socially it would potentially create more job opportunities. Environmentally it would reduce that carbon footprints of fossil fuels burning.

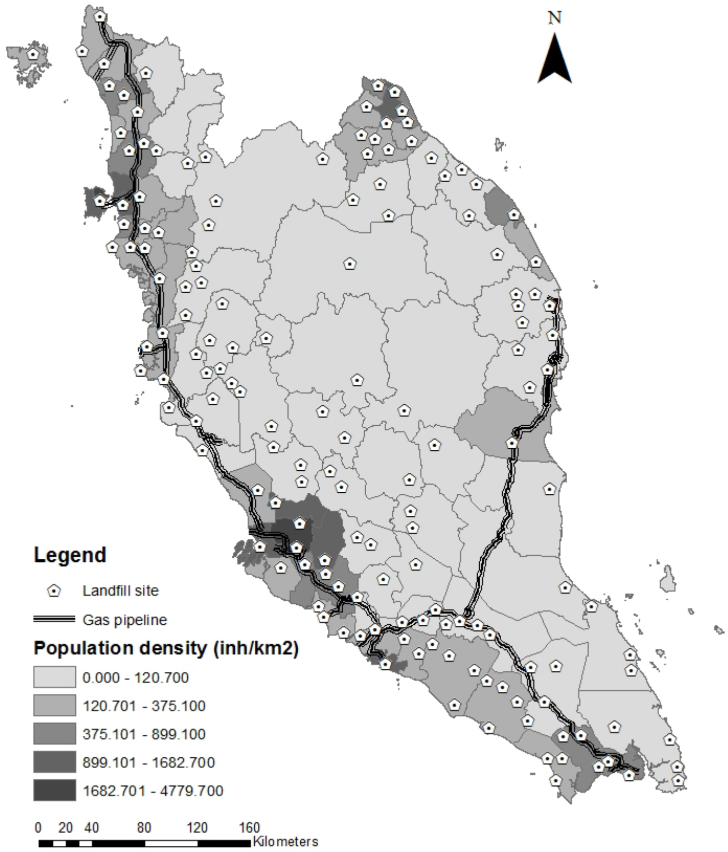

Figure 2. Potential of natural gas grid connection to landfill sites.

The foreseen challenges of upgrading biogas and injecting it into the natural gas grid included the financial barrier. So far there is no feed-in rate for upgraded biogas, biomethane. The investment cost of biogas plant is high as compared to current practice of MSW landfilling, although waste segregation at source has been implemented. Through waste segregation at source, food waste is separated from inorganic waste, making it more readily to be digested anaerobically. Secondly, with the heavily subsidized fossil fuel consumption in Malaysia (Mustapa et al., 2010), the cost competitiveness of biomethane to natural gas is always a challenge in promoting biomethane. Thirdly, unavailability of local anaerobic digestion technology is also a challenge to the deployment biogas upgrading and injection. As a feedstock-sensitive technology, it is important to customize the anaerobic digester technology in order to fit into the characteristic of local waste, thus optimizing the performance of anaerobic digester.

4. Conclusion

In conclusion, segregation of food waste at source do not only reduce MSW sent to the landfill, through anaerobic digestion, it could potentially produce 60 Mm^3 of biogas, which is equivalent to a potential of 16.3 MW electricity. A revenue of 42 MMYR could be generated yearly by selling the electricity through government FiT scheme. Further study should be carried out to identify the cost biogas plant construction and its optimal supply chain system. With the abundance of biomass sources in Peninsular Malaysia, for example, agricultural waste and animal farm waste, these biogas plant feedstocks should also be considered to maximize the biogas production.

Acknowledgement

UTM Ainuddin Wahid scholarship is gratefully acknowledged for its financial support during Ms Hoo Poh Ying's PhD pursuits.

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