A Retrofitted Palm Oil Mill Effluent Treatment System for Tapping Biogas

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Abstract
Malaysia being one of largest oil palm producing and exporting country. On average, a palm oil mill produces 0.65m^3 of palm oil mill effluent (POME) for every ton of fresh fruit bunch (FFB) processed. Knowing that treatment of POME would release biogas containing mainly methane and carbon diode, POME becomes one of the best agricultural renewable sources for biogas production as compared with other feedstock produced in Malaysia.

The conventional POME treatment system has no capability to tap the released biogas. A revised treatment process is suggested that is retrofitting the conventional POME treatment system for tapping the biogas emission resulting from POME treatment and subsequently used it as green sustainable energy source for achieving zero green effect.

From the study, tapping 97% purity of methane gas from 50% biogas released from approximately 0.65m^3 of POME produced from every ton of fresh fruit bunch (FFB) with the retrofitted POME treatment system is achievable.

Key words — Palm oil mill effluent (POME), anaerobic digestion, and methane gas.

1. Objectives

The main objective of this study is to propose a revised process technique that can be used to retrofit the existing POME treatment system for tapping the biogas emission resulting from the treatment. With POME is used as the main feedstock for the retrofitted treatment system, it is aimed to tap 97% pure methane gas from 50% the biogas released from approximately 0.65m^3 of POME produced from every ton of fresh fruit bunch (FFB).

With the ability to tap biogas, it is able to achieve closed zero green house effect from the treatment and subsequently used biogas as an alternative energy source.

Table 1: Biomass Resources and Their Estimated Energy Potential in Malaysia [1]

Types of Industry	Production (mton)	Type of Biomass	Residue generated (mton)	Calorific value of biomass (KJ/Kg)	*Potential energy generated (mton)
Oil palm	59.8	Empty fruit bunches	12.30	18,838	5.53
		Fronds and trunk	21.20	-	-
		Fiber	8.75	19,068	3.99
		Shell	3.94	20,108	1.89
Paddy	2.14	Palm kernel	2.11	18,900	95
		Rice husk	0.47	15,324	0.17
		Rice straw	0.86	13,620	0.28
Sugar	1.11	Bagasses	0.36	8021	0.069
Wood	1.67	Sawdust	0.96	19,008 – 19,188	0.44
	0.3	Plywood residue	0.069	10,000 – 19,000	0.024
Municipal solid waste	11,940 ton per day	Municipal solid waste	-	9500	-

2 Introduction

Biogas is a clean and renewable resource that can be used as fuel for generation of electricity, fuel for vehicles, and etc. It discharges less harmfully pollutant to the environment than the burning of fossil fuel. The volume of disposed waste product into soil and water is also much reduced. The main constituents in biogas are methane (CH_4), carbon dioxide (CO_2), and hydrogen sulphide (H_2S), whereby methane accounting for 50 to 70 percent of the biogas volume. Besides reducing pollutant, the digestate, a by-product from the production of biogas, can be used as fertilizer and pesticide. The biogas can be used as fuel to generate electricity and other purpose, hence reducing the need to depend on fossil fuel. Although biogas is a type of green and renewable energy resource, it can cause greenhouse effect that brings harms to the environment if it is released unburned into atmosphere.

In this paper, the authors propose retrofitting the conventional POME treatment system used in palm oil mill, which is viable to tap biogas containing mainly methane gas from the treatment. Thus, with the retrofitted POME treatment system, it is not only can achieve zero harmful emission; it can also generate revenue from the selling of the biogas as alternative fuel source.

3 Palm Oil Mill Effluent (POME) as Feedstock for Biogas Production

Biogas can be produced using a wide range of feedstocks, which are suitable for anaerobic digestion process. Biomass and waste materials can be the feedstock for biogas production regardless of the composition and moisture contents. The waste feedstocks include municipal wastewater, residual sludge, food processing wastewater, diary manure, poultry manure, agricultural waste, municipal solid wastes and etc. Other examples for biomass for biogas production are sugarcane, sorghum, napier grass, woody crops and oil palm waste such as palm oil mill effluent (POME). Table 1 shows the comparison of various biomass resources and their estimated energy potential in Malaysia, while Fig. 1 shows the comparison of methane emission of biogas from various types of feedstock. It shows that POME has approximately $0.4m^3$/kg of volatile solid.

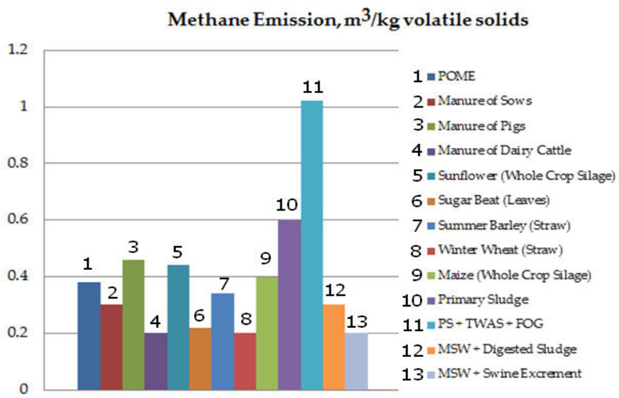

Figure 1: Comparison of methane emission of various feedstocks [2, 3, 4, 5, 6]

Referring to Table 1, it shows that palm oil industry has higher production volume in Malaysia. According to the statistics, Malaysia produces around 42.3% of worldwide palm oil and 48.3% of global palm oil export comes from Malaysia. In addition, the data in Fig. 1 shows that POME has a higher methane emission rate when compared to manure, biomass and municipal solid waste (MSW). On average, 0.1 ton of POME is generated for every ton of fresh palm oil fruit bunch (FFB) processed [8]. Thus, there is a great potential for POME to be utilized to generate high commercial return product and as the fuel to produce renewable energy.

Research data have revealed that methane yielding ranged from 0.47 - 0.92m^3/kg BOD$_{added}$ is achievable in the biomethanation of POME for reaction temperature between 35°C to 55°C [7]. Bioenergy recovery from the treatment of POME not only contributes towards the sustainable growth of the palm oil industry, it also assists Malaysia to achieve its sustainable development objectives, which is in compliance with United Nations Framework Convention on Climate Change (UNFCCC).

Table 2 illustrates the approximate composition of raw POME, while Table 3 shows the characteristics of raw POME and the regulatory discharge limits.

Table 2: The Approximated Composition (%) of POME [9]

Major Constituents	Composition (wt. %)
Moisture	6.9
Crude protein	12.5
Crude lipid	10.2
Ash	14.6
Carbohydrate	29.5
Nitrogen-free extract	26.3
Total carotene	0.019
Total	100.019

Table 3: Characteristics of Raw POME and the Regulatory Discharge Limits [7]

Parameter	Value	Regulatory discharge limit
Temperature (°C)	80-90	45
pH	4.7	5.0-9.0
Biochemical oxygen demand (BOD_3, 3 days at 30°C)	25,000	100(50)
Chemical oxygen demand (COD)	50,000	-
Total solids (TS)	40,000	-
Total suspended solids (TSS)	18,000	400
Total volatile solids (TVS)	34,000	-
Oil and grease (O&G)	4,000	50
Ammonic-nitrogen (NH_3-N)	35	150
Total Kjeldahl nitrogen (TKN)	750	200

4. Conventional POME Treatment System

In the conventional processing of fresh fruit bunch (FFB), steam is used for sterilization and hot water is used for dilution. The steam process produces wastewater with high content of POME. On average, a mill produces $0.65m^3$ of POME per tonne of FFB [13]. The POME has high content of organic matter. Typically a litre of raw POME contains 50,000 - 65,000mg COD [14].

The anaerobic pond system is the conventional stabilization pond for POME used in Malaysia since 1982 due to their low costs. Pond system is an easy operating system but it has disadvantages such as occupying vast land area, relatively long hydraulic retention time (HRT) for effective performance, bad odor, and difficulty in maintaining the liquor distribution and biogas collection. Investigation by Yacob et al. [15] on the methane emission from anaerobic pond shows that 1043.1 kg/day/pond of methane gas are emitted. Thus, the methane gas can be tapped as the resource of renewable energy.

Anaerobic pond has the longest retention time in pond system which is around 20 – 200 days [15]. Table 4 lists the advantages and disadvantages of the conventional anaerobic digestion pond system.

In the conventional POME treatment system as shown in Fig. 2, POME is immediately piped from the mill to a de-oiling tank before it is pumped to cooling and mixing ponds. The wastewater is then treated in open anaerobic tanks [16]. Generally, the retention time of wastewater in the open anaerobic tanks is 20 days. Accumulation of sludge occurs and the water in the tank is drained once every two weeks. The sludge is dried in shallow pits and then sold to smallholding farmers to be used as fertilizer in their plantations. During the treatment in the open anaerobic tanks, an enormous amount of methane gas will be emitted from the anaerobic ponds to the atmosphere, which can cause global warming [16].

Table 4: Advantages and Disadvantages of the Conventional Anaerobic Digestion (Pond System)

	Advantages	Disadvantages
Conventional anaerobic digestion (pond)	Low cost Recovered sludge from pond can be sold as fertilizer	Large volume for digestion Long retention times No capability to capture emit-tedbiogas

After treatment in the tank, the wastewater is piped to facultative ponds and algae ponds. Facultative or aerobic ponds are necessary to further reduce BOD concentration in order to effluent that complies with Federal Subsidiary Legislation, 1974 effluent discharge standards [17]. The COD in the outlet from the open anaerobic tank is around 13,000 - 15,000mg COD/litre. After a succession of algae ponds, at discharge level the wastewater has an organic load of around 500mg COD/litre. The treated wastewater is discharged on waterway and complies with the requirement of around 500mg COD/litre [18].

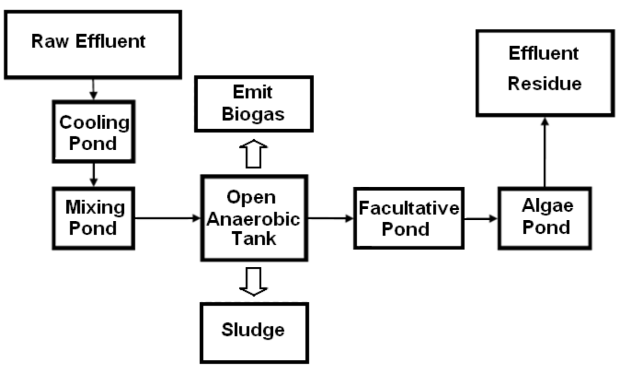

Figure.2: Conventional POME treatment system (as adopted by Serting Hilir Palm Oil Mill) [18]

5 Retrofitted POME Treatment System

In order to tap the methane gas – the main constituent of biogas emitted from POME treatment, a retrofitted POME treatment system as shown in Fig. 3 is proposed. This system can reduce green house effect emission through avoidance of methane emission from the open anaerobic tank of conventional POME treatment and at the same time the digestive temperature can be

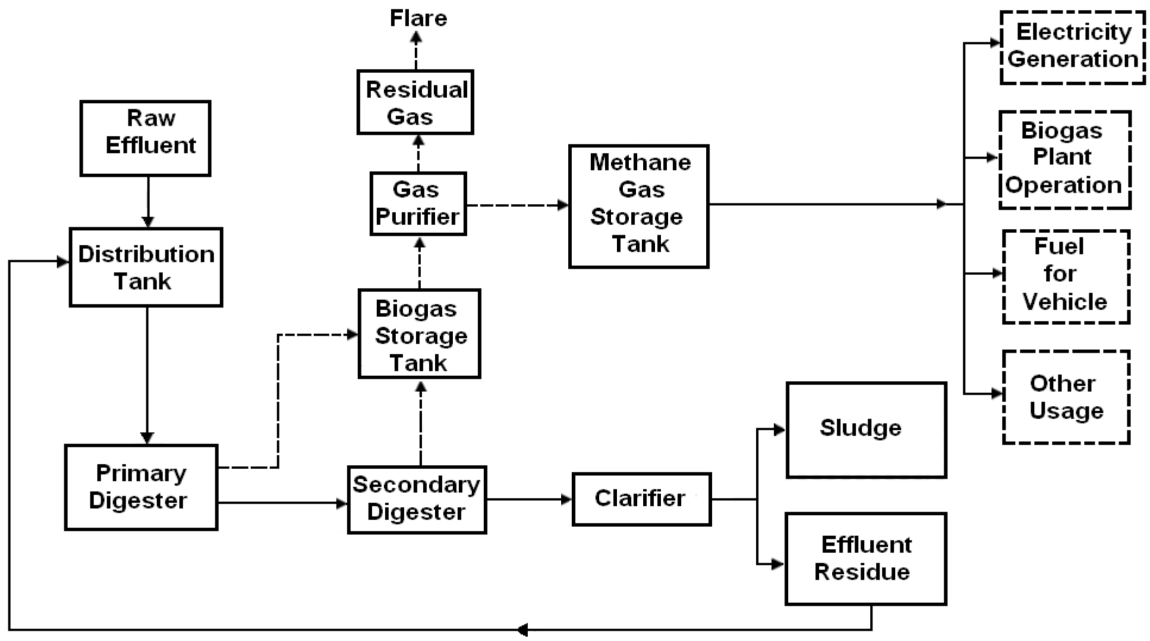

Figure 3: Retrofitted POME treatment system

controlled to around 55^{0}C [7] for optimized yielding of biogas. The retrofitting existing conventional POME treatment system involves retrofitting of the existing open tanks used in a typical the oil palm mill. These open anaerobic tanks are converted into one distribution tank, one primary digester tanks, and one secondary tank. The top portion of the tanks is refurbished with enclosure cover to capture the biogas [18].

The first tank is a distribution tank used to intake POME from the mill. After the distribution tank, the temperature of POME is reduced to around 50°C through a heat exchanger. POME will then be treated in two closed tanks, which are the primary digester namely for mixing purpose and secondary digester for fermentation, which take approaximately 14 days. Biogas containing 50% methane will be collected in a gas storage tank. The biogas is then purified using water scrubbing method whereby the biogas is compressed to 10 bars and fed to the bottom of the absorption column with water fed from top of the column. This process would allow carbon dioxide (CO_2) and hydrogen sulphide (H_2S) to be dissolved into water due higher solubility than methane gas. Subsequently approximately 97% pure methane can be obtained after drying process. Any other residual gas after purifier will be flared. The residue in secondary digestive tank is separated into sludge and effluent residue by clarifier. The effluent residue contains approximately 500mg COD/litre, a level below the statutory requirement, can be discharged into the open anaerobic pond [18] or re-cycled back to distribution tank, while the sludge can be used as fertiliser.

From the study, the retrofitted POME treatment of an average palm oil mill will be able to provide continuous feeding of raw POME containing 50,000 to 60,00mg/litre COD into treatment system. This amount of POME can emit biogas 1,029kg/h of biogas after 85 to 90% COD/litre is digested. After gas purification process, 97% purity of methane gas amounted to 410.8kg/h can be tapped.

In summary, conventional open pond systems would pollute the underground water and emit biogas particularly methane gas and carbon dioxide into the atmosphere, while the retrofitted closed tank anaerobic digestion tank has overcome both of these environmental issues. Besides, solving environment issues, the tapped biogas can be used as alternative energy source reducing the need of fossil fuel.

5 Discussion

The retrofitted POME treatment system has several beneficiary aspects namely economical, and environmental aspects.

In economic aspect, methane gas can be used as alternative energy source. It can be used as the fuel for generation of electricity, vehicle, and etc. This would certainly reduce the needs of fossil fuel.

The limited emissions of biogas from the retrofitted treatment system instead of open anaerobic pond would reduce green house gase (GHG) emission tremendously. It also contributes in improving the efficiency and effectiveness of POME treatment in regards of controlling the odour as well as meeting discharge below 500mg COD/litre in compliance with statutory standard. Thus, it minimizes pollution to the environment.

However, there are factors affecting the efficiency of anaerobic digesters in the proposed retrofitted treatment system because the process of anaerobic digestion is highly sensitive to a number of physical factors. Improper control of factors like mixing, pH, temperature, nutrients for bacteria, and organic loading rates would affect the efficiency and effectiveness of the digester.

A proper mixing condition is required in order to achieve good substrate-microbe interaction, improve mass transfer efficiency, prevent the formation of inhibitory intermediates and minimize unstable environmental conditions [18]. There are few ways to promote mixing in which it can be done through biogas recirculation, mechanical mixing, or slurry recirculation [19].

According to Leslie Grady et al. (1999), pH deviation would greatly influence the microbial activity in anaerobic digesters. Of all the microbes used, methanogens are found to be the most sensitive microorganism with pH change. This claim is in a good agreement with Beccari et al. (1996) that discovered pH changes to the optimum value; the methanogenic activity is strongly affected. Hence, an optimum pH value is required in achieving a better performance of anaerobic digesters.

Temperature is an essential factor governing the performance of anaerobic digesters. A lower temperature leads to a decrease in microbial growth, substrate utilization rates as well as biogas production [20]. Besides, Khalid et al. (2011) mentioned that too high temperature would also affect the biogas production. This is because some volatile gases such as ammonia are produced will suppress methanogenic activity. Many investigations are done to study the effect of temperature on the performance of anaerobic digestion [21, 22, 23, 24]. Temperature around 55^0C is found to be optimum.

Studies have shown that COD removal efficiency in wastewater treatment systems is reduced with the increase of organic loading rate (OLR) [25, 26, 27]. Nevertheless, an increase in OLR would lead to an increase in biogas release until a period whereby methanogens could not convert acetic acid to methane in a short time range. However, hydraulic retention time (HRT) and the concentration of substrate have a closely related with OLR. Hence, a balance between these two factors has to be determined in order to improve the performance of anaerobic digester.

6. Conclusion

Among various types of biomass feedstock, palm oil mill effluent (POME) is said to have a great potential in Malaysia because she produces around 42.3% of worldwide palm oil. In addition, POME shows a higher rate of methane emission as compared to other feedstocks. The proposed retrofitted design incorporated zero emission concepts by converting an open anaerobic tank to a closed digestive tank is viable and is able to tap the released biogas. After purification, 97% of biogas - methane gas, can be used as renewable sustainable green energy fuel. It can be used as fuel to generate electricity and other thus reducing the usage of fossil fuel. With reduction of the GHG release, closed to zero green house effect from digestion of POME is achievable.

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