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Energy Generation from Palm Oil Mill Effluent (POME): The Environmental Impact Perspective

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Palm oil is the most commonly used vegetable oil and is found in consumer products ranging from soap and chocolate to cooking oil. Approximately 90 % of global palm oil is supplied by Malaysia and Indonesia. In 2018, Malaysia and Indonesia set a target to increase their palm oil production to approximately 37.8 Mt and 20.5 Mt. It is anticipated that the palm oil residues generated from the production process will also increase. Palm oil mill residues such as oil palm fronds, oil palm trunks, palm oil mill effluent (POME), mesocarp fibres, palm kernel shells and empty fruit bunches have emerging potential to be converted into value-added products. This study focuses on POME because it has the potential to be used for the generation of renewable energy and Malaysia aims to utilise a greater amount of affordable, clean energy in line with the United Nations' Sustainable Development Goals. To this end, this study analyses and compares the CO_2 equivalent (CO_2-eq) of two palm oil mills (POMs 1 and 2) that use different POME treatment technologies, namely the covered lagoon bio-digester (CLB; POM 1) and the continuous stirred tank reactor (CSTR; POM 2) systems. The results of the analysis show that POM 1 produces 1,077.67 kg CO_2-eq, which is lower than that produced by POM 2 which emits 1,429.28 kg CO_2-eq.

1. Introduction

There is high global demand for vegetable oil and, in recent times, Malaysia has become the second largest producer of crude palm oil, a major source of vegetable oil (Tan et al., 2017). Generally, palm oil mills (POMs) generate a large volume of wastewater that contains palm oil mill effluent (POME) which comprises 95 % water and 5 % solids that have high organic content and acidity (Aziz et al., 2017), as illustrated in Table 1, which provides the data reported by some recent studies.

Table 1: Properties of raw POME

Parameter	Unit	MPOB (2014)	Tabassum et al. (2015)	Norfadilah et al. (2016)	Alhaji et al. (2016)
pH		4.2	4.3	3.4 ± 0.1	4.7
Total solids	kg/m^3	40	100	-	40.5
Biological oxygen demand (BOD)	kg/m^3	25	27	37.75 ± 0.1	25
Chemical oxygen demand (COD)	kg/m^3	51	75	69.5 ± 240	50
Total nitrogen	kg/m^3	0.75	-	0.692 ± 45	0.75

POME is primarily generated from three major sources: clarification wastewater which constitutes about 60 %, steriliser condensate at about 36 % and hydrocyclone wastewater at about 4 % (Ahmed et al., 2015).

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Methane, which has 21 times greater global warming potential than CO_2, is the major component of the biogas generated by POME (Loh, 2017). POME poses a serious, indirect threat to the environment (Samsudin et al., 2017). Figure 1 shows the current utilisation of the biogas generated from the treatment of POME in POMs in Malaysia. It is clear from the figure that most of the biogas is flared (58 %), while the second highest utilisation of biogas is for electricity generation (27 %) which is sold to the grid. It is also apparent from the figure that it is critical to encourage sustainable practices in managing POME as 80 % of POMs still practise open system treatment. The main purpose of this study is to assess and compare the CO_2 equivalent (CO_2-eq) of two different treatment technologies (closed pond and closed tank) for POME in generating 1,000 kWh of electricity as there is no any previous studies done on estimating the CO_2-eq for closed system.

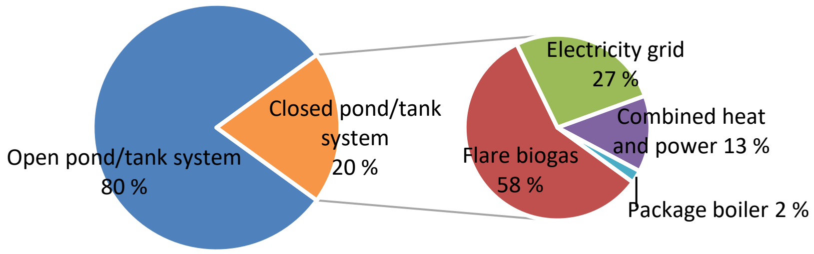

Figure 1: Current utilisation of biogas in palm oil mills (Wan et al., 2016)

2. Method

This study investigates two types of treatment systems that are commonly used in POMs with installed biogas facilities: the closed pond system and the closed tank system. Each of these systems employ different treatment technologies, which may have an effect on the amount of CO_2-eq output. This study compares two POMs in terms of their CO_2-eq throughout the entire process of treating POME to generate electricity. One utilises the closed pond system and a covered lagoon bio-digester (CLB; POM 1) and the other uses the closed tank system and the continuous stirred tank reactor (CSTR; POM 2). The CO_2-eq reduction calculation certified by the United Nations Framework Convention on Climate Change (UNFCC, 2017) is modified in this study in order to compare the CO_2-eq of the two POMs. Based on the results of the analysis, this study identifies the best option in terms of the production of a lesser amount of CO_2-eq in treating POME to generate energy.

3. Results and discussion

3.1 Case study

The technology applied in POM 1 is a CLB, which is an improvement on conventional systems such as the open pond and open tank system. POM 1 consists of a cooling pond, a CLB which uses an anaerobic digester (AD) and an aerobic pond for the further removal of organic pollutants. The biogas generated by the CLB is used to generate electricity on site, which has replaced the usage of diesel generators. The biogas generated is also used to displace a portion of palm kernel shells that are used as fuel for boilers. Any excess biogas that remains unutilised is flared in an enclosed flare. Sludge deposits are directed to a sludge drying bed for moisture removal and then are used for soil applications. Figure 2 illustrates the process applied in POM 1.

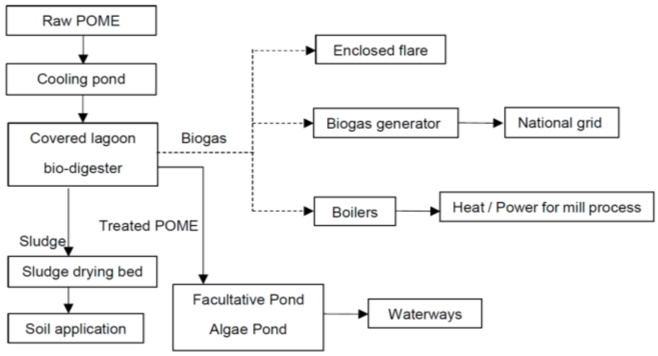

Figure 2: Flowchart of POME treatment using covered lagoon bio-digester in POM 1

The technology employed in POM 2 is a CSTR, which involves the use of an anaerobic digester. POM 2 has similar treatment units to POM 1, but POM 2 has three anaerobic tanks for POME treatment whereas POM 1 only has one. In POM 2, the top of the tanks are covered to trap the biogas. Palm oil mill effluent from the mill is channelled to the storage tank where no reactions take place. Then, POME undergoes anaerobic digestion in three CSTRs. Another gas storage tank functions as the biogas collector and is connected to the gas flare and biogas generator. About 5 % of the gas is sent for flaring while the remaining 95 % is directed towards the gas generator for electricity generation. The treated POME is directed to the waterways after it has undergone aerobic treatment. The sludge is removed and used in soil applications. The process in POM 2 is depicted in Figure 3.

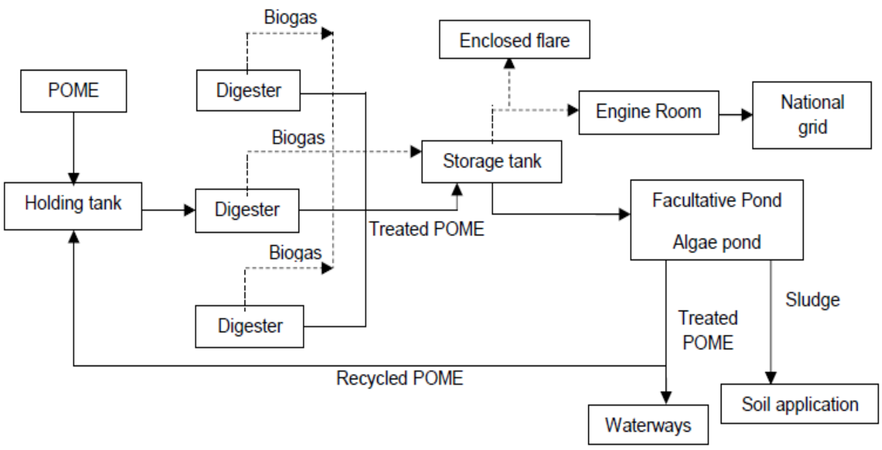

Figure 3: Flowchart of POME treatment using continuous stirred tank reactor in POM 2

3.2 Data inventory

The data used to analyse and compare the processes in POM 1 and POM 2 were derived from the Clean Development Mechanism (CDM) reports on the respective POMs and were estimated on the basis of 1,000 kWh of electricity generation. This was done to ensure ease of comparison between the two different scenarios and a better results output. Table 2 lists the inventory data used for the CO_2-eq calculation for both POMs.

Table 2: Input and output mass and energy of POM 1 and POM 2 treatment technologies using 1,000 kWh electricity as the functional unit

	Unit	POM 1 (CLB)	POM 2 (CSTR)	Reference
Input				
POME generated	m^3	28	38	Calculated
Recycled POME (before AD)	m^3	-	38	
COD of POME (before AD)	kg	1,115.52	2,032.99	
Outlet				
COD of POME (after AD)	kg	111.55	203.20	
COD of POME (waterways)	kg	47.40	18.70	
Electricity	kWh	1,000	1,000	
Sludge	kg	70.56	201.38	
Emission factor				
Global warming potential	kg CO_2-eq/kg CH_4	21	21	(CDM, 2008)
Grid displacement	kg CO_2-eq/kWh	0.614	0.614	(CDM, 2008)
Methane correction factor				
Digester efficiency		0.9	0.9	(CDM, 2009)
Treated POME directed to waterways		0.1	0.1	(CDM, 2008)
Recovery/combustion utilisation		1.0	1.0	(CDM, 2008)
Methane production per kg COD digested	kg CH_4/kg COD	0.21	0.21	(CDM, 2009)

3.3 Calculation on CO_2-eq

The equation that was modified from the CDM methodology booklet (UNFCC, 2017) is used to estimate the CO_2-eq of the two POMs that employ different POME treatment technologies. The total CO_2-eq calculated for each POM is exclusive of the calculation for $E_{h,leakage,pipeline}$, $E_{h,,bottling}$, and $E_{h,dissolved}$ as the POMs do not utilise any other processes such as upgrading and bottling for the distribution of biogas in a compressed form. The total CO_2-eq for each POM is calculated by using Eq(1):

$$E_{h,total} = E_{h,power} + E_{h,ww,final} + E_{h,sludge} + E_{h,fugitive} \quad (1)$$

Where:
$E_{h,total}$: Total emissions in per h (kg CO_2-eq)
$E_{h,power}$: Emissions from electricity consumption per h
$E_{h,ww,final}$: Emissions from remaining untreated carbon in final output of wastewater per h
$E_{h,sludge}$: Emissions from sludge per h
$E_{h,fugitive}$: Emissions from inefficient capture of methane per h.
Both POMs generate biogas which is then converted into electricity. The emissions from the energy produced by the biogas generators in the POMs are multiplied with the electricity grid emission factor based on Eq(2):

$$E_{h,power} = E_{h,elec} \times EF_{CO_2} \quad (2)$$

Where:
$E_{h,elec}$: Electricity consumption per h (kWh)
EF_{CO2}: Electricity grid emission factor.
Eq(3) is used to calculate the emissions by focusing on the COD from the treated wastewater which is commonly directed into waterways. This type of emission is also considered in the calculation of CO_2-eq produced during the process of treating POME for energy generation.

$$E_{h,ww,final} = Q_{h,ww} \times COD_{h,ww,final} \times B_{o,ww} \times MCF_{ww,final} \times GWP_{CH_4} \quad (3)$$

Where:
$Q_{h,ww}$: Volume of wastewater treated per h (m^3/h)
$COD_{h,ww,final}$: COD of final output of wastewater per h (kg/m^3)
$B_{o,ww}$: Capacity of methane production of the wastewater
$MCF_{ww,final}$: Methane correction factor for wastewater directed to waterways
GWP_{CH4}: Global warming potential for methane.
Fugitive emissions are a very common contributor to CO_2-eq as not every process implemented in a POM is 100 % efficient in converting wastewater into a value-added product. Emissions from an inefficient methane capture and flare system can be estimated by the calculation shown in Eq(4):

$$E_{h,fugitive} = E_{h,fugitive,ww} + E_{h,fugitive,ww,s} \quad (4)$$

Where:
$E_{h,fugitive,ww}$: Fugitive emission inefficiencies in anaerobic treatment of wastewater per h (kg CO_2-eq)
$E_{h,fugitive,ww,s}$: per h (kg CO_2-eq).
The value of $E_{h,fugitive,ww,s}$ for both POMs investigated in this study do not apply anaerobic treatment to sludge. Eq(5) is calculated:

$$E_{h,fugitive,ww,s} = 0 \quad (5)$$

The POMs do apply anaerobic treatment system for wastewater, which is calculated as in Eq(6):

$$E_{h,fugitive,ww} = (1 - CFE_{ww}) \times MEP_{h,ww,treatment} \times GWP_{CH_4} \quad (6)$$

Where:
CFE_{ww}: Capture and flare efficiency of the methane in the wastewater
GWP_{CH4}: Global warming potential for methane
$MEP_{h,ww,treatment}$: Potential amount of methane emitted Methane emission potential of the wastewater treatment plant per h.
Note that Eq(6) uses the value for methane emissions in the wastewater treatment plant calculated using Eq(7):

$$MEP_{h,ww,treatment} = Q_{h,ww} \times COD_{h,ww,treated} \times B_{o,ww} \times MCF_{ww} \quad (7)$$

Where:
$Q_{h,ww}$: Volume of treated wastewater per h

$COD_{h,ww,treated}$: COD removed from wastewater
$B_{o,ww}$: Capacity of methane production of the wastewater
MCF_{ww}: Methane recovery correction factor.
Note that the emissions from sludge are neglected in this study as the final sludge is used for soil applications. They would also be neglected if the sludge were disposed of in landfill with methane recovery or combusted in a controlled manner.
Eq(8) is calculated as:

$$E_{h,sludge} = 0 \quad (8)$$

3.4 Data analysis

The inventory data estimated for 1,000 kWh of electricity generation in Table 2 above are used to calculate the estimated CO_2-eq for the overall process using Eqs(1) – (8). The estimated amounts of CO_2-eq emitted by each POM using the different treatment methods are analysed and compared in Table 3.

Table 3: Estimated analysis of CO_2-eq produced by POMs 1 and 2

	Unit	POM 1	POM 2
$E_{h,elec}$	kWh	1,000	1,000
EF_{CO2}	kg/kWh	0.614	0.614
$E_{h,power}$	kg CO_2-eq	614	614
$Q_{h,ww}$	m^3	28.00	38.00
$COD_{h,ww,final}$	kg/m^3	1.69	0.49
$B_{o,ww}$		0.21	0.21
$MCF_{ww,final}$		0.1	0.1
GWP_{CH4}		21	21
$E_{h,ww,treated}$	kg CO_2-eq	20.87	8.21
$E_{h,fugitive,ww,s}$	kg CO_2-eq	0	0
$Q_{h,ww,treated}$	m^3	28.00	76.00
CFE_{ww}		0.9	0.9
MCF_{ww}		1.0	1.0
$COD_{h,ww,treated}$	kg/m^3	35.86	24.08
$E_{h,fugitive,ww}$	kg CO_2-eq	442.80	807.07
$E_{h,total}$	kg CO_2-eq	1,077.67	1,429.28

Both POMs employ closed system practise in utilising POME to generate electricity where POM 1 uses covered lagoon bio-digester and POM 2 with continuous stirred tank reactor. However, the total amount of CO_2-eq emitted differs for both scenarios. In this study, the emitted CO_2-eq is compared for three phases which are the CO_2-eq from the electricity utilisation, CO_2-eq during the final discharge of POME into waterways and CO_2-eq at anaerobic digester. The two POM wastewater treatment plants are compared on the basis of 1,000 kWh of electricity generation. The $E_{h,power}$ for both POMs seem to be the same because both the energy production and the emission factor for the grid used are similar. The emissions calculated for $E_{h,ww,final}$ differ for both scenarios because this factor is highly dependent on the amount of wastewater entering the system as well as on the amount of COD treated in each POM. It can be seen that the COD content in the POME is affected by the amount of POME entering the AD system. The value of $E_{h,fugitive,ww,s}$ is assumed to be zero for both POMs as no anaerobic treatment process is involved in producing the final sludge. The value for $E_{h,fugitive,ww}$ would not result in zero emissions because there is anaerobic treatment of POME and the process is not 100 % efficient. Both POMs assume that the efficiency of the anaerobic digestion of POME is about 90 %. The total CO_2-eq is higher in POM 2 (1,429.28 kg CO_2-eq) which implements a CSTR system compared to POM 1 (1,077.67 kg CO_2-eq) which utilises a CLB treatment system.

4. Conclusion

The results of this study indicate that POME can potentially emerge as a major contributor to the energy mix in the future. Palm oil mill effluent is able to generate renewable biogas upon biological treatment (AD) which is then converted into electricity. However, about 80 % of POMs in Malaysia still use an open pond or an open tank system while only the remaining 20 % employ a closed pond or closed tank system. Different treatment technologies and design configurations will have different impacts on greenhouse gas emissions. Calculating the CO_2-eq for POMs which implement the closed system is crucial in order to optimise the reduction in emissions. While the closed system is not 100 % efficient, at least its greater utilisation could help to prevent global warming issues from becoming worse. It is critical to encourage decision-makers and planners to take into consideration the importance of installing biogas facilities in all POMs in the future so that Malaysia can move closer to attaining its SDGs.

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