

# Chapter 6

## Production of Biogas from Palm Oil Mill Effluent

Ravindra Pogaku, Kai Yieng Yong, and V. Prasarnth Raaj Veera Rao

### Introduction

Energy is the key ingredient to any economic activity. Increasing demand of energy due to rapid population and industrial growth has led to the development of POME as the source of sustainable bio-energy. Bio-energy is energy resource that originates from biogenic material and is a type of biogas which can be used for fuel replacement, cooking purpose, energy generation etc. (Kristofferson and Bokalders 1991). It is produced by the biological breakdown of organic matter in the absence of oxygen (NNFCC 2011).

Malaysia is the world's largest producer and exporter of palm oil; contributing 49.5 % of world production and 64.5 % of world exports (Malaysia Palm Oil Board (MPOB) 2004). Although the expansion of palm oil industry has boosted the national economy, it also concurrently generated abundant of by-products such as palm oil mill effluent (POME), empty fruit bunch (EFB), palm kernel shell (PKS) and mesocarp fiber in palm oil mills during the processing of palm oil from fresh fruit bunch (FFB) (Yusoff 2006; Chin et al. 2013). Out of these by-products, POME still remained relatively untapped and will be a threat to the environment if directly discharged to the water course (Poh and Chong 2009). The palm oil extraction process involves use of water. Large quantity of water is required to steam and sterilize the palm fresh fruit bunches (FFB) and as well clarify the extracted oil. It is estimated that for most of the average capacity plant, 1 ton crude palm oil (CPO) produced, 5–7.5 tons of water are required, and more than 50 % of the water will end up as palm oil mill effluent (POME) (Ahmad et al. 2003). It is estimated that in Malaysia about 53 million m<sup>3</sup> POME is being produced (Lorestani 2006) every year based on palm oil production in 2005 (14.8 million tonnes) (Yacob et al. 2005).

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R. Pogaku (✉) • K.Y. Yong • V.P.R. Veera Rao  
Energy Research Unit, Faculty of Engineering, University Malaysia Sabah, Sabah, Malaysia  
e-mail: [ravindra@ums.edu.my](mailto:ravindra@ums.edu.my); [dr\\_ravindra@hotmail.com](mailto:dr_ravindra@hotmail.com)

It is estimated that about 0.5–0.75 tonnes of POME will be discharged from mill for every tonne of fresh fruit bunch. The study in this paper will show the ability of biogas production from POME with together with other waste supplements such as activated sludge and cow dung.

POME, when fresh is a thick brownish in colour colloidal slurry of water, oil and fine cellulosic fruit residues. It is discharged at a temperature of 80–90 °C and has a pH typically between 4 and 5 (Ma and Halim 1988; Polprasert 1989; Singh et al. 1999). POME is the liquid waste generated from the oil extraction process from FFB in palm oil mills (Borja and Banks 1995). POME is the effluent from the final stages of palm oil production in the mill. For each ton of crude palm oil (CPO) produced, about an average of 0.9–1.5 m<sup>3</sup> POME is generated. The biological oxygen demand (BOD), chemical oxygen demand, oil and grease, total solids and suspended solids of POME ranges from 25,000 to 35,000, 53,630, 8,370, 43,635 and 19,020 mg/L, respectively. Furthermore, its high solids concentration and acidity causes it to be unsuitable for direct discharge to water courses.

Sterilization and clarification are two main stages in palm oil mill which produces condensate and clarification sludge respectively basically form the wastewater otherwise known as palm oil mill effluent. POME is also known as the colloidal suspension of 95–96 % water, 0.6–0.7 % oil, and 4–5 % total solid (TS) including 2–4 % suspended solid (SS) originating from the mixing of sterilizer condensate, separator sludge and hydro-cyclone wastewater. In most mills, these three wastewater streams are combined together resulting in viscous brown liquid containing fine suspended solids (Ahmad et al. 2003). Table 6.1 shows the approximate composition (%) of major constituents, amino acids, fatty acids and minerals in raw POME (adapted from Habib et al. 1997).

Regulatory control over discharges from palm oil mills is instituted through Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977 promulgated under the Environmental Quality Act, 1974 and enforced by the Department of Environmental (DOE). The palm oil mills are required to adhere to prescribed regulations, which include laws governing the discharge of mill effluent into water course and land (Ahmad et al. 2003). On top of that, the requirement of BOD level of industrial effluent to be discharged to water course has been tightened recently by DOE where the prevailing national regulation of 100 mg/L BOD has now been reduced to 20 mg/L for mills in certain environmentally sensitive areas especially in Sabah and Sarawak (Liew et al. 2012).

Anaerobic digestion is one of the most widely used methods applied for palm oil mill effluent (POME) treatment because it digests the high-strength wastewater with lower energy consumption and generates renewable energy in the form of methane (Shanmugam and Horan 2009), thus, anaerobic digestion can be considered as one of the sources of renewable energy (Yacob et al. 2006). Anaerobic digestion is a process by which almost any organic waste can be biologically converted in the absence of oxygen (Lastella et al. 2000). In the process of degrading POME into methane, carbon dioxide and water, there is a sequence of reactions involved; hydrolysis, acidogenesis, acetogenesis and methanogenesis (Gerardi 2003).

**Table 6.1** The approximate composition (%) of major constituents, amino acids, fatty acids and minerals in raw POME (adapted from Habib et al. 1997)

Major Constituents	Composition (%)	Amino acids	Composition (%)	Fatty acids	Compositions (%)	Minerals	Compositions ( $\frac{\mu\text{g}}{\text{g}}$ dry weight)
Moisture	6.99	Aspartic acid	9.66	Caprylic acid (8:0)	2.37	Fe	11.08
Crude protein	12.75	Glutamic acid	10.88	Capric acid (10:0)	4.29	Zn	17.58
Crude lipid	10.21	Serine	6.86	Lauric acid (12:0)	3.22	P	1,4377.38
Ash	14.88	Glycine	9.43	Myristic acid (14:0)	12.66	Na	94.57
Carbohydrate	29.55	Histidine	1.43	Pentadecanoic acid (15:0)	2.21	Mg	911.95
Nitrogen-free extract	26.39	Arginine	4.25	Palmitic acid (16:0)	22.45	Mn	38.81
Total carotene	0.019	Threonine	2.58	Heptadecanoic acid (17:0)	1.39	K	8,951.55
Total	100.789	Alanine	7.70	10-Heptadecanoic acid (17:1)	1.12	Ca	1,650.09
		Proline	4.57	Stearic acid (18:0)	10.41	Co	2.40
		Tyrosine	3.16	Oleic acid (18:1n-9)	14.54	Cr	4.02
		Phenylalanine	3.20	Linoleic acid (18:2n-6)	9.53	Cu	10.76
		Valine	3.56	Linolenic acid (18:3n-3)	4.72	Ni	1.31
		Methionine	6.88	T-linolenic acid (18:3n-6)	0	S	13.32
		Cystine	3.37	Arachidic acid (20:0)	3.56	Se	12.32
		Isoleucine	4.53	Eicosatrienoic acid (20:3n-6)	2.04	Si	10.50
		Leucine	4.86	Eicosatetraenoic acid (20:4n-6)	1.12	Sn	2.30
		Lysine	2.66	Eicosapentaenoic acid (20:5n-3)	0.36	Al	16.60
		Tryptophan	1.26	Total	95.99	B	7.60
		Total	90.84			Mo	6.45
						As	0.09
						V	0.12
						Pb	5.15
						Cd	0.44

It is noted that modeling of biogas production were generally based on the kinetic models (De Gioannis et al. 2009; Ueno et al. 2007; Rao and Singh 2004; Sosnowski et al. 2008; Derbal et al. 2009; Boubaker and Ridha 2008; Gali et al. 2009). Like the phase of bacteria growth, biogas production rate showed a rising limb and a decreasing limb which was indicated by the linear and exponential equation.

The objective of the current work was to study the production of biogas from typical palm oil mill effluent together with other waste supplements through the measure of volume and flow rate of the biogas production. This study also aims to promote environmental friendly and green engineering concept through the using of renewable and sustainable biogas from the POME. Besides this study also turns waste into wealth by generating energy. The abundance of POME (waste) can now be used to generate energy.

## Feedstock Preparation

### *Palm oil mill effluent (POME), Activated Sludge, Palm Fiber, Palm Kernal*

Eight liters fresh raw POME was collected from the first discharge point from the palm oil mill. The characteristic of the fresh POME was summarized in Table 6.2. The POME was preserved at a temperature less than 4 °C, but above the freezing point in order to prevent the wastewater from undergoing biodegradation due to microbial action (APHA 1985). POME was thawed at room temperature before ready to be used. 4 kg activated sludge was obtained from the aerobic pond and used without further purification. 10 g of palm fiber and palm kernel was obtained from the Lumadan Palm oil mill's laboratory.

**Table 6.2** Characteristic of the Raw POME (from Lumadan Palm Oil Mill)

Parameter	Content
pH	4.7
BOD <sub>3</sub>	25,000 mg L <sup>-1</sup>
COD	50,000 mg L <sup>-1</sup>
Suspended solids (SS)	18,400 mg L <sup>-1</sup>
Total volatile solids (TVS)	34,000 mg L <sup>-1</sup>
Oil and grease	3,800 mg L <sup>-1</sup>
Ammonical nitrogen	36 mg L <sup>-1</sup>
Total nitrogen	710 mg L <sup>-1</sup>

Source: Lumadan Palm Oil Mill, 2011

**Table 6.3** Typical characteristics of cow dung

Type of analysis	Cow manure
Total solids (% wet)	15.6
Volatile solids (% TS)	82.8
Total Kjeldahi nitrogen (% TS)	1.2
Total organic carbon (%TS)	–
Phosphorus	2.4 (g/kg)
Potassium (% TS)	–
pH	7.8

Source: Rene et al., 2005

## ***Cow Dung***

Four kilogram of fresh cow dung was collected from Desa Dairy Farm, Kundasang, Kota Kinabalu, Sabah, Malaysia. The samples were packed into 500 g polyethylene bags and stored at  $-10^{\circ}\text{C}$ . Frozen manure portions were thawed at room temperature before being used for experiment purpose. The characteristics of typical cow dung are shown in Table 6.3.

## **Experimental Design and Operation Procedure**

### ***Experimental Conditions***

Temperature:  $30^{\circ}\text{C}$ .

Pressure: 1 atm.

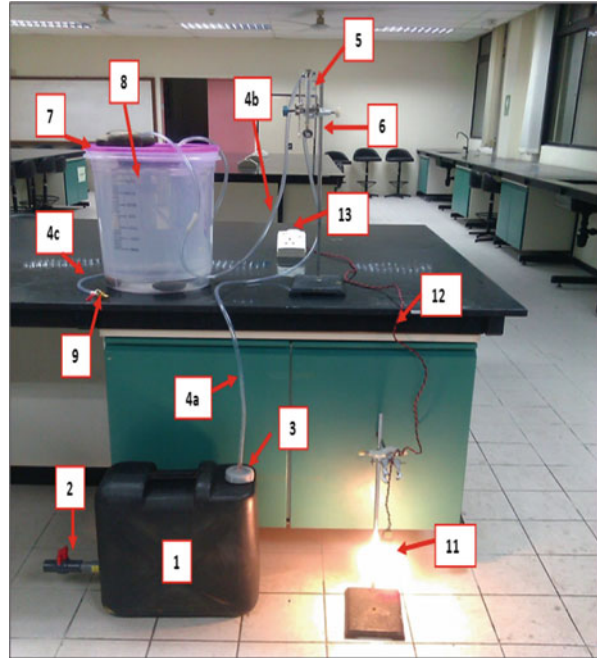
A 25 l plastic barrel for loading of the POME, activated sludge and cow dung were setup as shown in Fig. 6.1 below:

The weight of the empty 25 l barrel was measured. Before the experiment was started, the POME and the frozen manure portions were thawed at room temperature for around 5–6 h until it reached the room temperature. 8 l of POME was measured by using a measuring cylinder and weighed by an analytical balance before it was poured into the 25 L plastic barrel. Then, 4 kg of cow dung and 4 kg of activated sludge were weighed and they were diluted with 5 l of water to prepare slurry before pouring into the 25 L plastic barrel. Ten gram of palm kernel and palm fiber were added into the barrel.

The mixtures of POME, cow dung and activated sludge were mixed for 2 min. After mixing, 50 ml sample were taken out for pH sampling analysis. The pH of the mixture should be maintained at pH 7. 150 ml of 2 M NaOH was added to adjust the pH to neutral.

After setup, the barrel was stored in closed environment. The bulb was switched on to make sure the anaerobic process is maintained in mesophilic condition ( $30\text{--}35^{\circ}\text{C}$ ). Note should be taken that the bulb condition and the surrounding

**Fig. 6.1** Experimental setup. Labeling references: 1 25 L plastic barrel; 2 PVC ball valve  $\frac{3}{4}$ "; 3 Lid of the 25 L plastic barrel; 4 Leveling tube 4a, 4b, 4c (total: 3 m); 5 Flow meter (lpm); 6 Retort stand with clamp; 7 20 L plastic jar; 8 10 L plastic jar; 9 Ball valve  $\frac{1}{2}$ "; 10 Bunsen burner; 11 Bulb; 12 Wiring and plug; 13 Extension plug



temperature need to be checked two times daily (morning and afternoon) once the experiment was started to make sure the surrounding was always in mesophilic condition. The barrel complete loaded with the biomass was weighed again.

$$\text{Biomass used} = \text{weight of complete loaded barrel} - \text{weight of empty barrel} \quad (6.1)$$

Volume of biogas produced by the anaerobic digester and its flow rate were recorded daily for 44 days. The volume of biogas produced was estimated by water displacement method. pH was tested once in every 3 days to make sure it was maintained at pH 7. The organic waste was mixed by manually shaking the anaerobic digester slowly for 5 min once every 2 days to prevent the formation of thick scum layer on the surface that can hinder the biogas production.

### ***Analytical Methods***

A total of 23.214 kg of biomass was used in this experiment. Biogas production of the anaerobic digester was measured by using the water displacement method in the mesophilic condition of  $30 \pm 3$  °C and atmospheric pressure of 1 atm. Parameter such as volume of biogas produced, biogas flow rate, and pH of anaerobic digester were measured according to the standard methods.

The flow rate of the biogas was read directly from the flow meter (scale: litre per minute) daily and the data was recorded. The volume of biogas produced was read from the 10 l plastic jar by taking note how much volume of water was displaced. The reading was taken daily and all the data were recorded in a table form in a logbook completed with the date of the reading was taken.

For the pH measurement, digital pH meter was used and the pH sampling analysis was done once in every 3 days to make sure the pH of the organic waste was maintained at 7. If the pH was lower than 7 or slightly acidic, then suitable amount of 2 M NaOH was added. The surrounding temperature measured once in every 3 days with digital thermometer.

Biogas production rates were simulated using linear and exponential plots. The linear equation of the two stages in ascending and descending limbs could be expressed in (6.2). Presumably biogas production rate would improve linearly with an increasing time, and after a peak, it would decrease linearly to zero as time continuously increases.

$$y = a + bt \quad (6.2)$$

Where  $y$  is the biogas production rate ( $\text{L kg}^{-1} \text{ day}^{-1}$ ) at time  $t$  (day),  $t$  is the time over the digestion period.  $a$  is intercept ( $\text{L kg}^{-1} \text{ day}^{-1}$ ) and  $b$  is slope ( $\text{L kg}^{-1} \text{ day}^{-2}$ ). For rising limb,  $b$  is positive whereas  $b$  is negative for failing limb.

If we assume that biogas production rate would improve exponentially with an increasing period of time and after the climax, it then decrease exponentially to zero as the time continuously increases, the exponential plot for the ascending and descending limbs could be presented in (6.3) (De Gioannis et al. 2009):

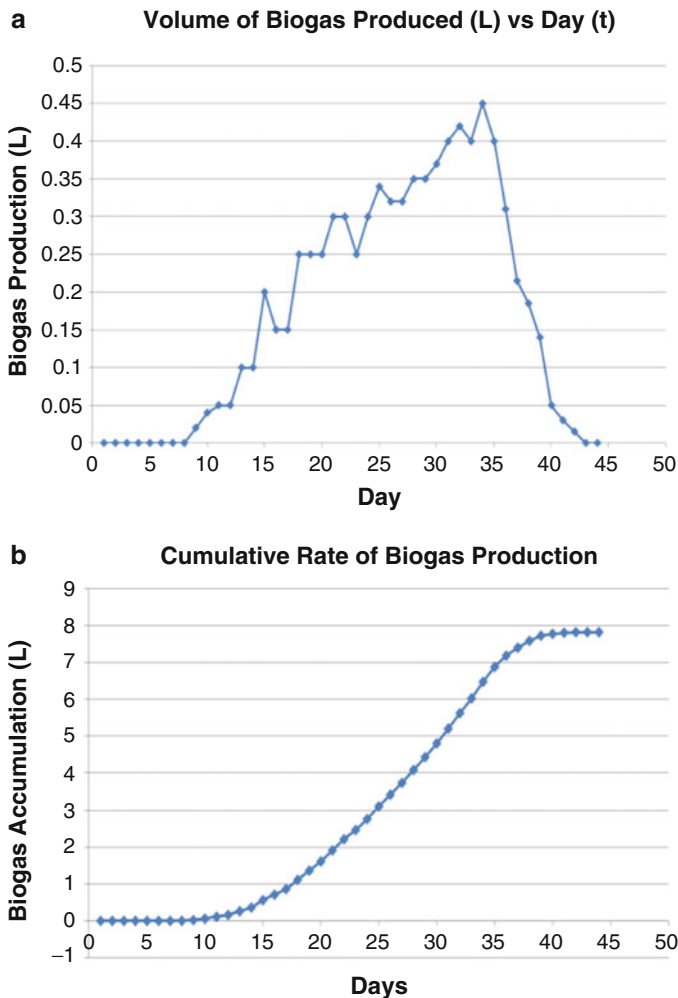
$$y = a + b \exp(ct) \quad (6.3)$$

Where  $y$  is the biogas production rate ( $\text{L kg}^{-1} \text{ day}^{-1}$ ) at time  $t$  (day),  $t$  is the time (day) over the digestion period,  $a$  and  $b$  are constants ( $\text{L kg}^{-1} \text{ day}^{-1}$ ) and  $c$  is also a constant having different unit ( $\text{d}^{-1}$ ). For rising limb,  $c$  is positive whereas  $c$  is negative for falling limb.

By using the data obtained from the experiment, scale up method could be used to estimate the amount of biogas that able to be generated by Malaysia's palm oil mill industry if all the palm oil mill effluent discharged was fully utilized with the proper anaerobic treatment technology.

## Results and Discussion

Biogas production and biogas accumulation were shown in Fig. 6.2a, b. Experimental result showed that the whole complete digestion period was 44 days with the retention time of 8 days. The peak biogas production rate occurred between day 29 and day 34. Biogas production started to decrease at day 36 until the completion



**Fig. 6.2** (a) Biogas production versus day. (b) Cumulative rate of biogas production

of the experiment. The biogas accumulation curve pattern could be explained by the typical growth curve for a bacteria population. The retention time was the lag phase of the bacteria inside the cow dung. It was the period of adaption of the bacteria cells to the digester’s environment. The exponential curve just after the retention time was due to the bacteria had adjusted to the new environment. The bacteria were multiply exponentially. This period of time was known as balanced growth. Short period linear curve was due to the endogenous metabolism of bacteria. Death phase of bacteria explained the stationary curve. No nutrients left in the digester caused bacteria to die.



The first 2 weeks of the digestion indicated slow production of biogas concurring with the first phase of biomass decomposition via acetogenesis process. Addition of NaOH was intensive during this time because the pH of the biomass dropped dramatically. The production of biogas increased rapidly until it reached the peak production phase where methanogenesis phase took place. Only small increment was observed after week 4 until the end of the run at day 44. The bacteria activities began to cease during this time possibly due to toxicity of high ammonia nitrogen content above  $1 \text{ g L}^{-1}$ . The nutrient provided for the bacteria also decreased when the time passed. The plots showed that the production rate was inconsistent. This could be explained by the fluctuation of temperature which caused the microorganisms' metabolism activities were varying far from the optimum condition. In addition, pH value increment gave more acidic environment which decelerated the activities of microorganism in methane production. High value of acid could cause death. The total yield of biogas was 7.825 l. Figure 6.3a, b show the temperature and pH measurement during the experiment period.

The average value of the pH during the experiment period was  $6.96 \cong 7.0$  while the temperature was maintained at the average value of  $30.75 \text{ }^\circ\text{C}$ .

From the Fig. 6.2a, the increasing and decreasing biogas production rate curve pattern was more towards either linear or exponential pattern. Hence linear and exponential equations as discussed in the analytical methods were to be used confidently. Model simulations were shown below:

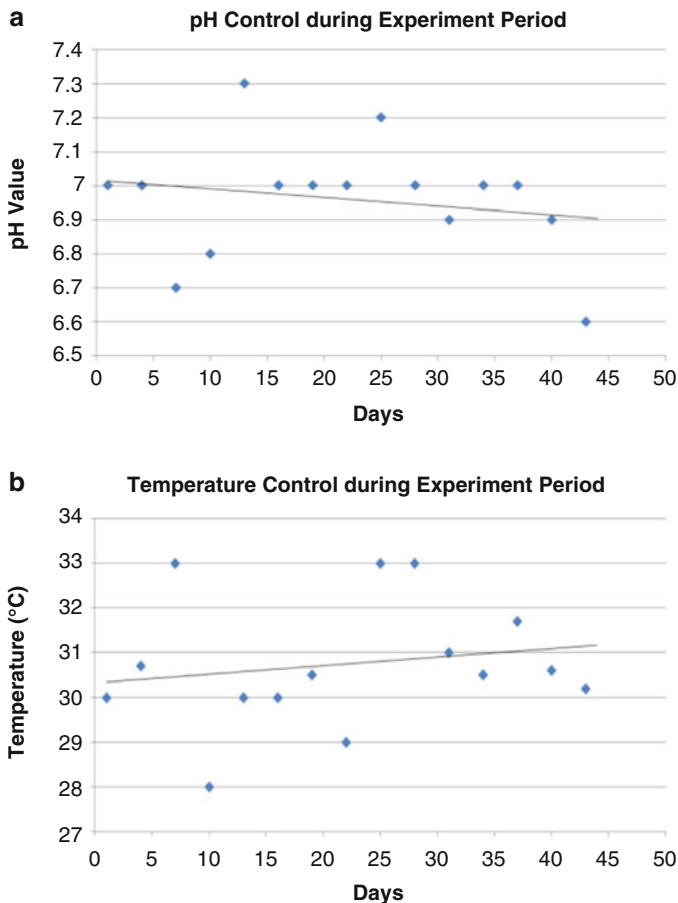
### ***Linear Plots of Biogas Production***

From Fig. 6.4a, the rising limb of the biogas production rate gave the equation of  $y = 0.006 t - 0.003$ . The graph intercepted at  $a = -0.003 \text{ L/kg day}$  with the slope of  $b = 0.006 \text{ L/kg day}^{-2}$ . Rising limb of biogas production indicated the microbial population growth was increasing.

For Fig. 6.4b, the falling limb of the biogas production rate gave the equation of  $y = -0.002 t + 0.087$ . The graph intercept at  $a = -0.002 \text{ L/kg day}$  with the slope of  $b = -0.002 \text{ L/kg day}^2$ .  $R^2$  of the production rate in the rising and falling limb ranged from 0.926 to 0.954. The falling limb of biogas production rate was due to the decaying of microbial kinetic growth (death phase).

### ***Exponential Plots of Biogas Production***

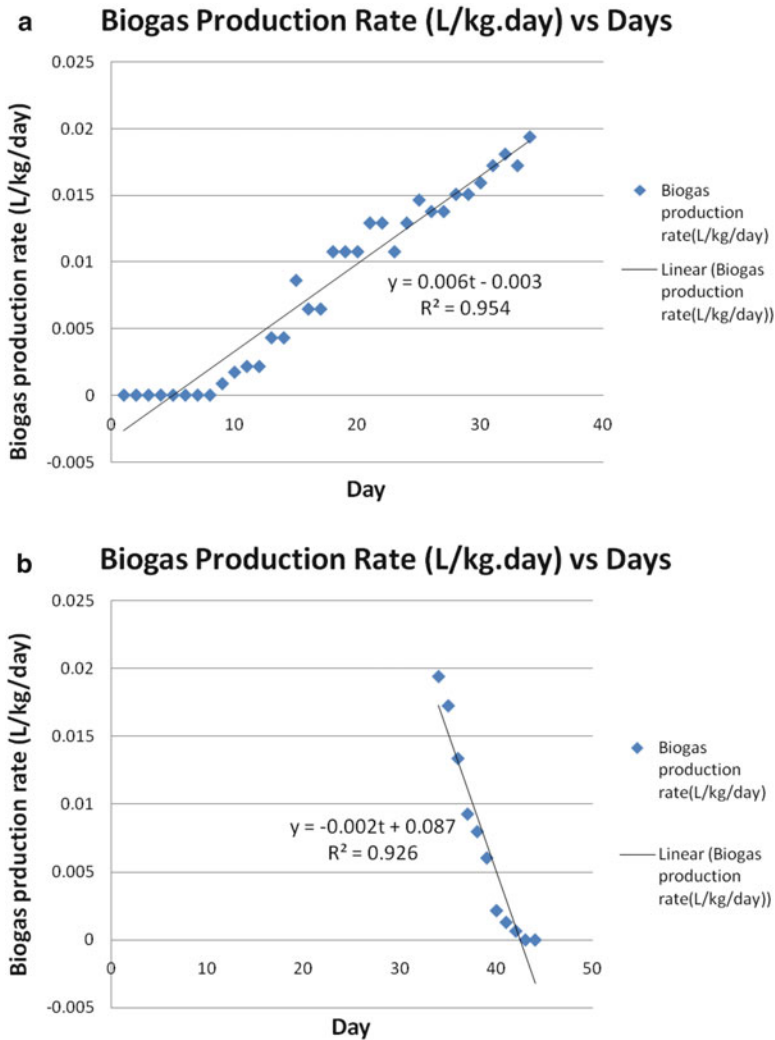
Figure 6.5a, b depicted the exponential plots of biogas production rates. For the rising limb of the biogas production rate, the plot gave the equation of  $y = -0.001 + 0.001 \exp(0.099 t)$ . The constant value of  $a = -0.001 \text{ L/kg day}$ ,  $b = 0.001 \text{ L/kg day}$  and  $c = 0.099 \text{ day}^{-1}$ . Rising limb of biogas production indicated the microbial population growth was increasing.



**Fig. 6.3** (a) pH control during experiment. (b) Temperature control during experiment

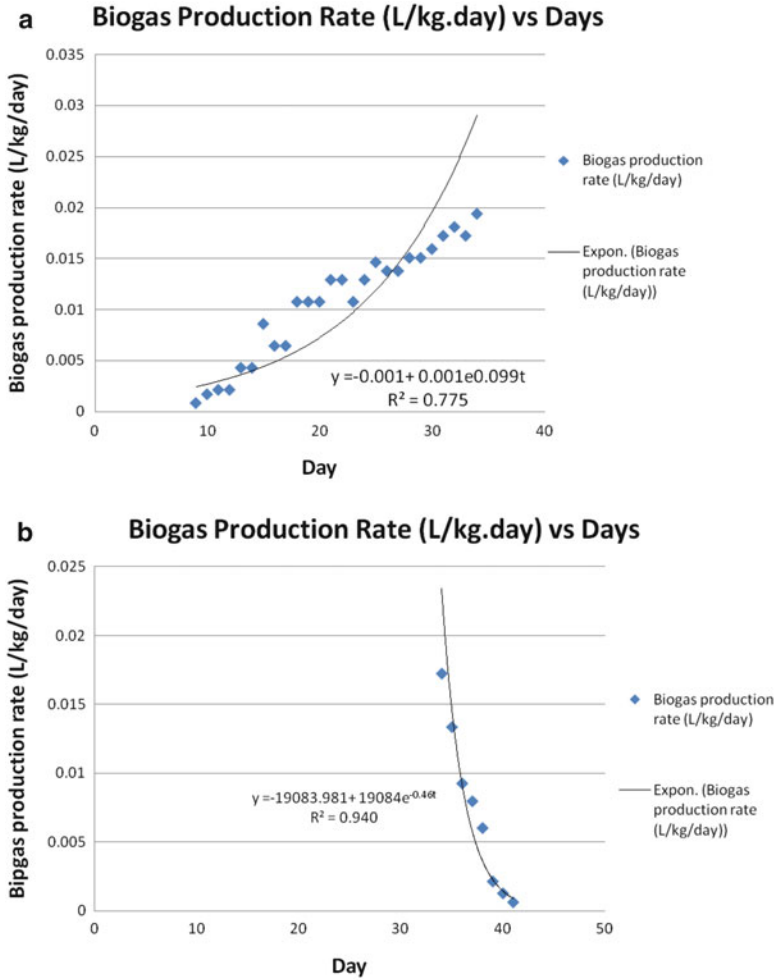
For the falling limb, the plot of the biogas production rate gave the equation of  $y = -19,083.881 + 19,084 \exp(-0.46 t)$ . The constant value of  $a = -19,083.881$  L/kg day,  $b = 19,084$  L/kg day and  $c = -0.46 \text{ day}^{-1}$ .  $R^2$  of the production rate in the rising and falling limb ranged from 0.775 to 0.940. The falling limb of biogas production rate was due to the decaying of microbial kinetic growth (death phase).

$R^2$  of for the rising limb of the linear plot shows better simulation than those of exponential; while for the falling limb, exponential plot shows slightly better simulation than the linear regression. Hence the biogas production rate could be best modeled with the combination of both linear and exponential models, where rising limb was best fitted by linear model ( $R^2 = 0.954$ ) while falling limb by the exponential model ( $R^2 = 0.940$ ).



**Fig. 6.4** (a) Biogas production linear plot (rising limb). (b) Biogas production linear plot (falling limb)

The experiment shows that 23.214 kg of total biomass (which contained 8 l POME) would produce 7.825 l of biogas. 62.5 % of the biogas production was estimated to be the methane gas while the rest was the carbon dioxide. Malaysia POME production was estimated to be 53 million tones/year ( $6.6250 \times 10^{10}$  kg/year). From the experiment, 10 kg POME was used and it managed to produce 7.825 l ( $0.007825 \text{ m}^3$ ) of biogas. Thus  $6.6250 \times 10^{10}$  kg/year POME will be able to produce  $6.8864 \times 10^7 \text{ m}^3$ /year of biogas. Table 6.4 below summarize the estimated biogas production from palm oil mill industries Malaysia.



**Fig. 6.5** (a) Biogas production exponential plot (rising limb). (b) Biogas production exponential plot (falling limb)

**Table 6.4** Malaysia’s palm oil mill effluent biogas production estimation

Malaysia palm oil mill: Total POME generated per year = 53 million m<sup>3</sup>

Unit	Mass (kg)	Volume (m <sup>3</sup> )
Total biogas production	$5.93 \times 10^7$	$6.8864 \times 10^7$
Methane	$3.71 \times 10^7$	$5.7664 \times 10^7$
Carbon dioxide	$2.22 \times 10^7$	$1.12 \times 10^7$

## Conclusions

The study proves that biogas is able to be produced from POME with an anaerobic digestion method by using cow dung and activated sludge. There is no doubt that biogas produced from POME in anaerobic digestion facilities are becoming favorably utilized to replace energy derived from fossil fuels. The overall biogas production was 0.7825 l per kg of POME mixture slurry. However, the average methane produced is only about 62.5 % with 37.5 % Carbon dioxide and traces of H<sub>2</sub>S concentration. Biogas production by using POME and cow dung with the appropriate compositions gave a better linear plot curve fitting compared to the exponential curve fitting. From the scale up calculation, a potential of  $5.93 \times 10^7$  kg of biogas could be produced each year from  $5.30 \times 10^7$  m<sup>3</sup> POME volume production in Malaysia. Further investigation is yet to be carried out to finalize the optimization of the parameters involved in this study.

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