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Baseline study of methane emission from anaerobic ponds of palm oil mill effluent treatment

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Abstract

The world currently obtains its energy from the fossil fuels such as oil, natural gas and coal. However, the international crisis in the Middle East, rapid depletion of fossil fuel reserves as well as climate change have driven the world towards renewable energy sources which are abundant, untapped and environmentally friendly. Malaysia has abundant biomass resources generated from the agricultural industry particularly the large commodity, palm oil. This paper will focus on palm oil mill effluent (POME) as the source of renewable energy from the generation of methane and establish the current methane emission from the anaerobic treatment facility. The emission was measured from two anaerobic ponds in Felda Serting Palm Oil Mill for 52 weeks. The results showed that the methane content was between 35.0% and 70.0% and biogas flow rate ranged between 0.5 and 2.4 L/min/m^2. Total methane emission per anaerobic pond was 1043.1 kg/day. The total methane emission calculated from the two equations derived from relationships between methane emission and total carbon removal and POME discharged were comparable with field measurement. This study also revealed that anaerobic pond system is more efficient than open digesting tank system for POME treatment. Two main factors affecting the methane emission were mill activities and oil palm seasonal cropping.

Keywords: Greenhouse gases (GHG); Methane; Palm oil mill effluent (POME); Anaerobic ponds/lagoons

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1. Introduction

Recent increases in the prices of fossil fuels have renewed global interest in exploring alternative renewable energy sources. Growing attention is

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given to bio-energy sources such as wood fuels, agricultural wastes, animal wastes, municipal solid wastes wastewater and effluents. In addition to being renewable and sustainable, these types of energy sources are considered as environmentally friendly. As such they have great potentials for mitigating climate change. In particular biomass fuels hold great promise as a component of Clean Development Mechanisms strategies to reduce greenhouse gases (GHG) emissions to acceptable levels (Brown et al., 1998).

Being a tropical country, Malaysia has enormous supply of biomass resources generated from photosynthetic activities throughout the year. The biomass is mainly derived from palm oil, wood and agro-industries. At present the palm oil industry generates the most biomass from the oil extraction process such as the mesocarp fiber, shell, empty fruit bunch (EFB) and palm oil mill effluent (POME). It is estimated that more than 50 million tonnes of biomass will be generated from the palm oil industry in the year 2005. This will continuously increase in proportion to the world demand of edible oils. Of all four by-products mentioned above, only POME has not been commercially re-used by the industry. The mesocarp fiber and shell are burnt within the boiler to generate steam for electricity, while the EFB is being used as fertilizer or soil mulching in the oil palm plantation. However, there is a great potential for renewable energy projects using POME. Like municipal waste, POME also produces methane gas, which can be used to generate electricity (Hassan et al., 2004).

Due to its highly polluting properties, with average values of 25 000 mg/L biochemical oxygen demand (BOD) and 50 000 mg/L chemical oxygen demand (COD), the most cost effective technology is anaerobic treatment. This concept is being applied either in the pond or open digesting tank systems (Hassan et al., 2004). Earlier studies by Ma et al. (1999) and Quah and Gillies (1984) have shown that the end-products of the anaerobic digestion of POME are mainly methane and carbon dioxide in 65 : 35 ratios (also known as GHG), and approximately 28 m^3 of gases are emitted from 1 t of POME. However, due to the variations in POME treatment practices, the methane emission may differ. As reported by Shirai et al. (2003) and Yacob et al. (2005) methane composition was between 35% and 45% for the anaerobic treatment of POME, which is significantly lower from the values reported by the earlier workers.

A few improved high rate bioreactors have been tested in the treatment of POME such as the modified anaerobic baffled bioreactor (Faisal and Unno, 2001), anaerobic filter and anaerobic fluidized bed reactor (Borja and Banks, 1995), thermophilic upflow anaerobic filter (Mustapha et al., 2003) and rotating biological contactors (Najafpour et al., 2005) in increasing the efficiency of pollution reduction and methane production. Experimental results indicated better treatment of POME compared to conventional practices. However, large scale implementation of any of the improved system is still lacking.

This paper will present the findings of long term observation of methane emission pattern based on methane composition and flow rate from the commercial anaerobic pond system. The research paper will also discuss factors affecting the methane emission rates and pattern from the treatment system.

2. Site descriptions and methods for monitoring

2.1. Serting palm oil mill

The mill is located in the state of Negeri Sembilan, approximately 175 km from Kuala Lumpur, Malaysia. It is owned by the Felda Palm Industries Sdn. Bhd. (a subsidiary of Felda, the largest palm oil-based company in Malaysia). It has the capacity to process fresh fruit bunch (FFB) at 54 t/h. The mill was commissioned in 1986 to receive and process the FFB from Felda plantations and its surrounding areas. Wastewater treatment facility comprises of ponding system constructed to treat POME before safe discharge.

2.2. Ponding system

The ponding system is a series of 12 ponds which consisted of a cooling pond, a mixing pond, four anaerobic ponds, two facultative anaerobic ponds and 4 algae ponds. With the current processing capacity of the mill, the total hydraulic retention (HRT) of the ponding system is more than 100 days. In this study, the focus was on the anaerobic ponds as active bubbling of biogas was visibly evident. In the facultative ponds, emission of biogas was confined to the early stage of the ponds which was minimal. Two observation anaerobic ponds were selected at random out of the four ponds for the measurement of GHG emission. The data collection was carried out for 52 weeks to evaluate the effects of seasonal cropping, mill activities and other factors. Each anaerobic pond has the capacity of approximately 7500 m^3 of POME with a total hydraulic retention time of 40 days. The dimension of the anaerobic pond (at effluent level) is $60.0 \times 29.6 \times 5.8$ m (length × width × depth).

2.3. Methane measurement from anaerobic ponds

The biogas produced was collected using a static collection chamber with a surface area of 0.7 m^2 and connected to a tube for biogas sampling and detection. In each pond four static collection chambers were positioned to measure the total biogas emission from the effluent surface. The chambers were positioned based on the effective area of active bubbling. The biogas flow rate was recorded using a wet gas meter (OSK 14608, Shinagawa Seiki Co.) with a flow rate capacity of 2 to 600 L/h, while the methane gas composition was determined using gas analyzer (XP-314A, Shin-Cosmos Electrics Co. Ltd) plugged to the tubing. Based on the average emission rate of four collection chambers, the total biogas emission per pond was calculated as shown below:

$$\begin{aligned}&(\text{Average emission rate})/0.7\,\text{m}^2\\&\quad\times \text{total effective emission}\\&\quad= \text{total biogas emission}\end{aligned}$$

2.4. Chemical oxygen demand (COD)

POME samples were collected daily from the inlet and outlet of the ponds to determine the total carbon removal. COD was measured using the *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992). At the same time the methane emission pattern was recorded as described in the previous section. Correlation between the methane and total carbon removal was established and plotted.

3. Results

3.1. Methane emission rate and composition

In deciding the location of the collection chambers, preliminary observation was carried out earlier to determine the effective biogas emission area. It was found that the emission activity was concentrated 5 m

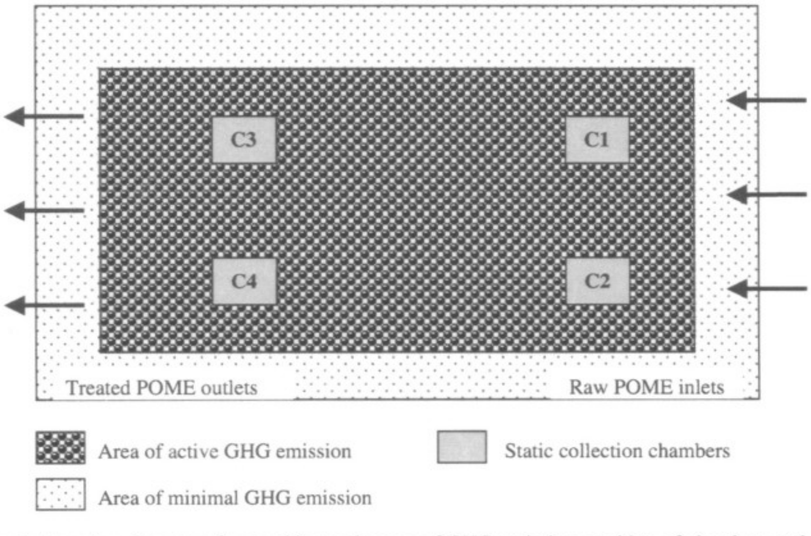

Fig. 1. Schematic top view diagram of anaerobic pond, areas of GHG emission, position of chambers and effluent flow.

Table 1
Biogas flow rates and methane emission profiles of different regions of anaerobic ponds (average values over 52 weeks observation)

Region/Chamber		Biogas flow rate (L/min/m^2)	Methane content (%)
Inlet	C1	1.64 ± 0.60	52.0 ± 6.7
	C2	1.64 ± 0.66	51.5 ± 6.2
Outlet	C3	1.27 ± 0.52	58.1 ± 6.4
	C4	1.26 ± 0.52	57.7 ± 7.0

away from the edges of the pond which was equivalent to an area of approximately 1373 m^2 or 76.3% of the whole effluent surface. Therefore all the collection chambers were positioned within the effective biogas emission area as shown in Fig. 1. The methane emission profiles of the designated chambers are presented in Table 1. There was a marginal difference in terms of the biogas flow rates and methane content for the collection chambers located in the same region (inlet and outlet of the ponds). However, significantly active bubbling was observed close to the inlet as supported by the higher biogas flow rate compared to the outlet region. Nevertheless, the methane content was higher in the outlet region. This could be explained by excess concentration of organic matter such as organic acids in the inlet region that would influence the methanogenic activities (Masse and Massé, 2005). As a result, lower methane and higher carbon dioxide were emitted from the inlet region.

The average methane composition recorded was 54.4%, ranging from 35.0% up to 70.0% (Fig. 2), while the emission rate was averaged at 1.5 L/min/m^2. The highest and lowest emission rates were 2.4 and 0.5 L/min/m^2, respectively. As seen in Fig. 2, the relationship between the methane composition and biogas emission rates is negatively correlated. Between week 8 and week 22 severe fluctuations of both emission rates and methane composition were clearly seen. During this period the emission rates dropped from 2.2 to 0.6 L/min/m^2 while methane composition reached the highest point of 67.5%. Second major trough was observed between week 39 and 42 where the lowest emission rate was recorded at 0.5 L/min/m^2 and methane content at 63.8%. Minor troughs were also evident throughout the 52 weeks study.

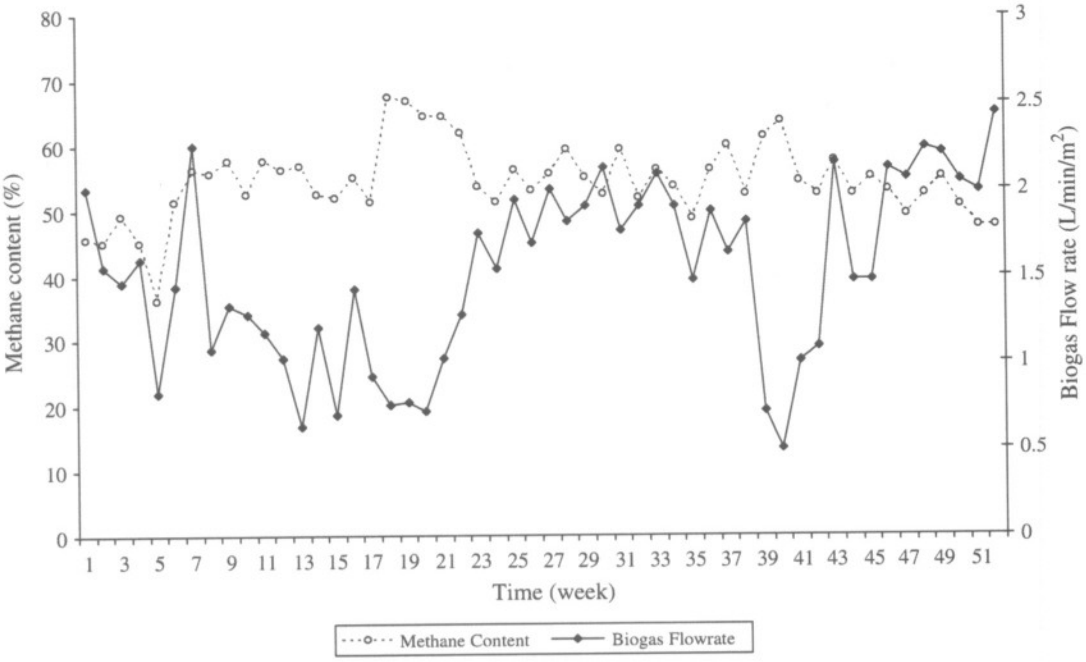

Fig. 2. Biogas emission profiles from anaerobic ponds.

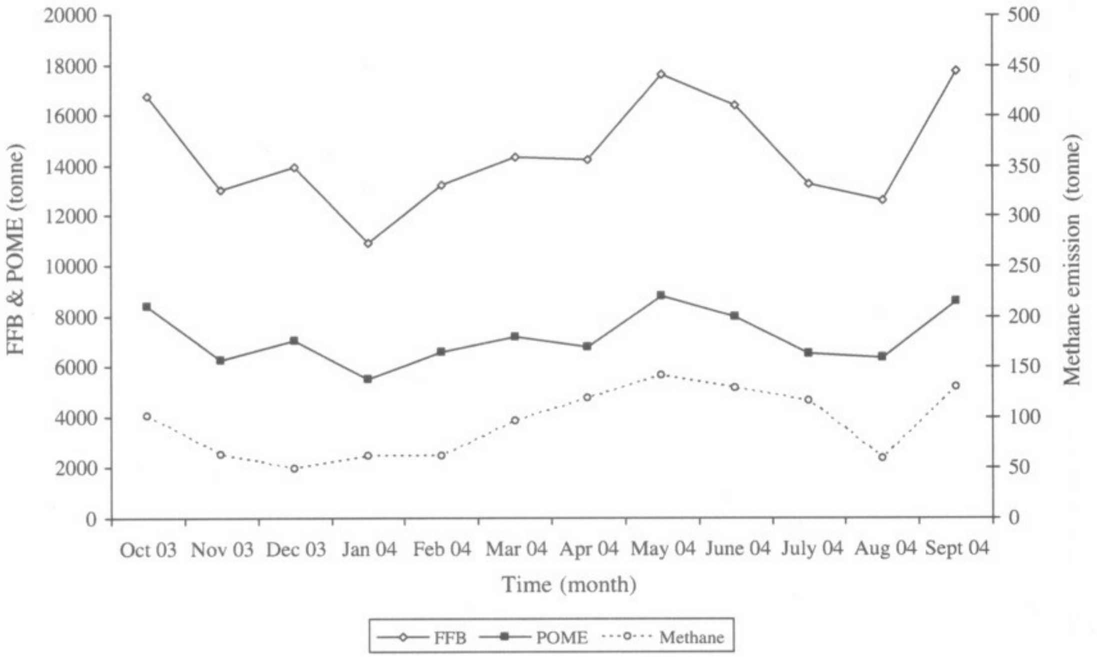

Fig. 3. Monthly profiles of FFB, POME and methane emission.

3.2. *Total methane emission from anaerobic ponds*

The one year observation at the anaerobic ponds has clearly shown that the methane emission pattern was governed by the oil palm seasonal cropping and mill activities. As seen in Fig. 3, the commencement of low crop season in November 2003 was marked by a lower volumetric discharge of POME followed by a decline in methane emission. The trough was prolonged until February 2003 before an increase in FFB, POME discharge and methane emission were observed. During this period, a long year-end public holiday resulting in the closure of palm oil mill for a few days extended the trough. Similar phenomenon was also observed in August 2004, where a continuous reduction of

Table 2
Monthly data collected from serting palm oil mill

Month	No. of days	FFB processed (t)	POME discharge (t)	Average POME COD (ppm ± SD)	Methane emission (t)
Oct 03	23	16760	8377	59619 ± 2765	100.82
Nov 03	19	13030	6275	51967 ± 9434	63.17 ✓
Dec 03	26	13940	7001	52792 ± 9026	48.99 ✓
Jan 03	21	10910	5516	51993 ± 10025	61.33 ✓
Feb 03	22	13240	6574	55481 ± 4880	61.79 ✓
Mar 03	22	14360	7188	54625 ± 2398	95.94
Apr 04	23	14250	6768	56275 ± 4200	118.68
May 04	25	17620	8770	55456 ± 2838	141.20
June 04	25	16410	7955	59385 ± 4106	128.26
July 04	22	13260	6490	55458 ± 3784	116.41
Aug 04	24	12640	6340	54856 ± 2824	58.73 ✓
Sept 04	25	17770	8580	62685 ± 6296	129.91
Total	277	174190	85834		1125.22

POME discharge from June 2004 until August 2004 had resulted in a reduction in the methane emission rate. As shown in Fig. 3, the lowest methane emission per tank was recorded in December 2003 and August 2004 at approximately 49 and 59 t/mth, respectively.

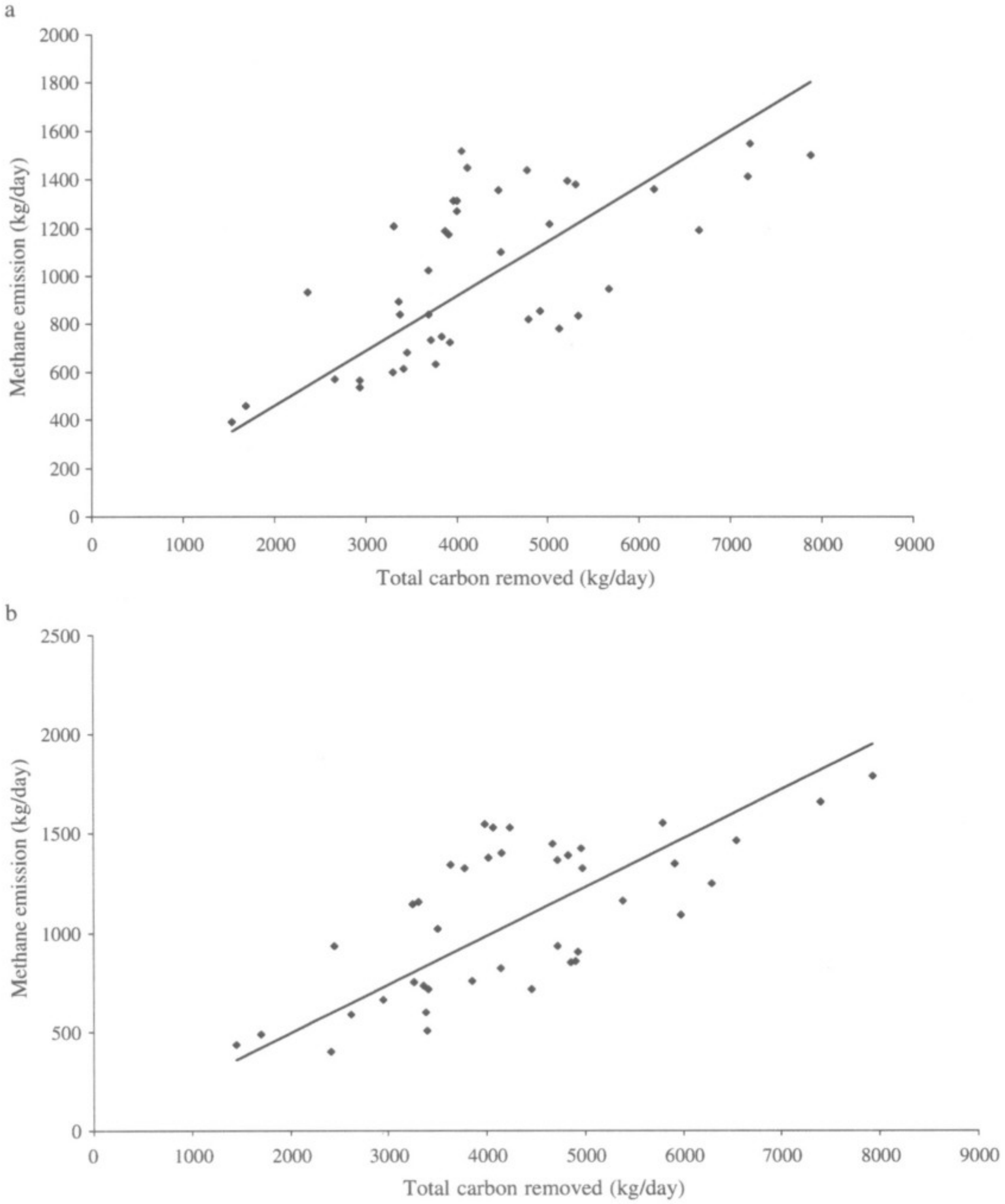

Fig. 4. (a) Relationship between methane emission and total carbon removed from pond A. (b) Relationship between methane emission and total carbon from pond B.

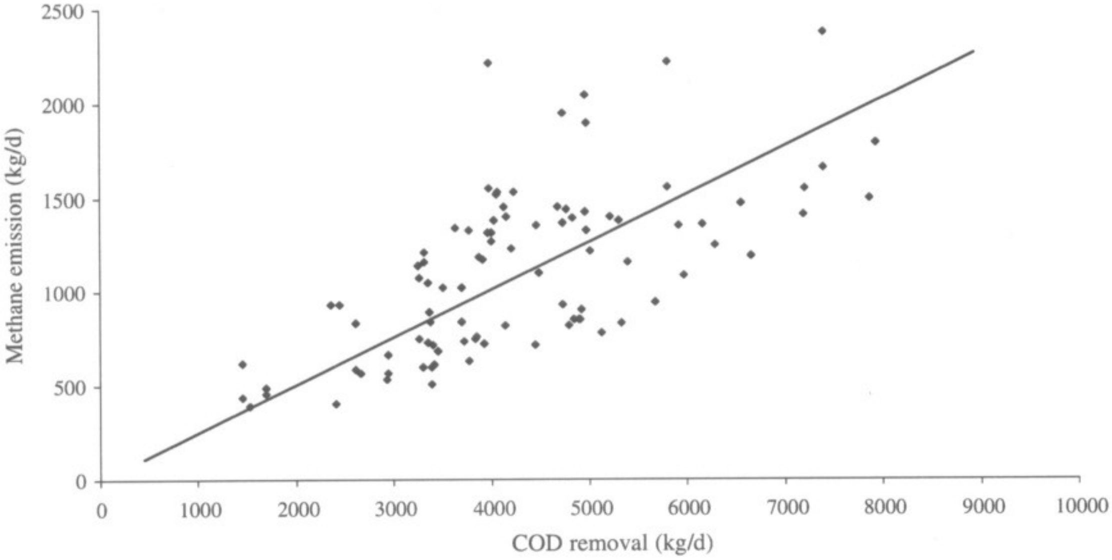

Fig. 5. Average methane emission and COD removal relationship.

An average of 1043.1 kg of methane was emitted from each pond at the mill daily. With a total of 277 days of operation and four anaerobic ponds, based on field measurement from October 2003 until September 2004, it is estimated that 1125.2 t of methane was released to the atmosphere (Table 2).

3.3. Relationship between methane production rate, COD removal and POME discharged

A correlation between methane production rate and total COD removal was established and plotted for individual anaerobic pond. As shown in Fig. 4a and b

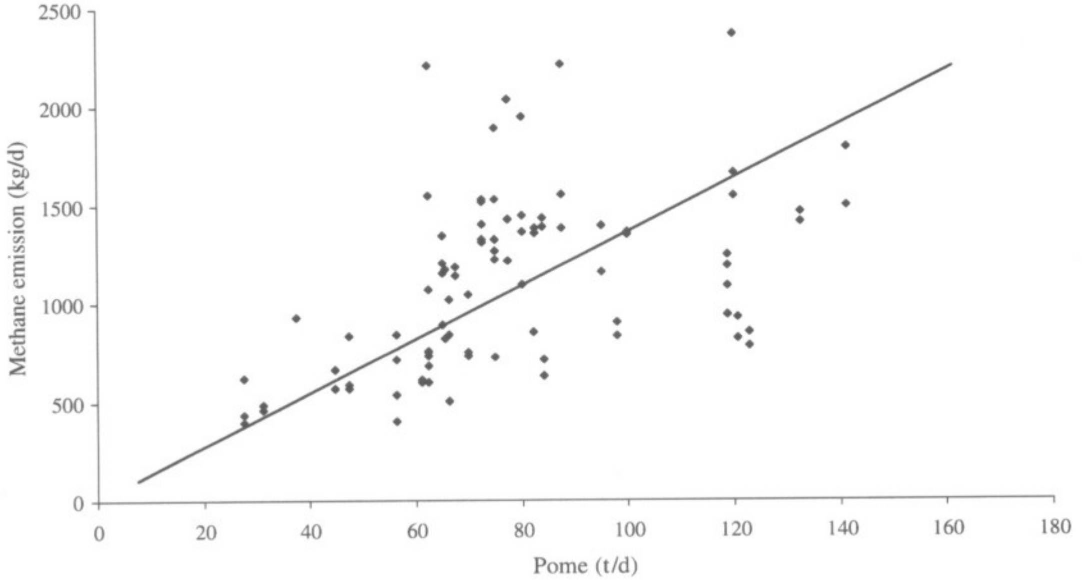

Fig. 6. Methane emission and POME relationship.

methane emission from anaerobic ponds A and B were 0.223 and 0.247 kg of methane per kilogram of COD removed. Using these values, an average of 0.238 kg of methane was emitted per kilogram of carbon removed from the anaerobic pond treatment for POME (Fig. 5). During this observation an average COD of raw POME was 55990 ± 6126 mg/L while the treated POME was 1204 ± 292 mg/L. Hence the anaerobic pond system was able to remove 54.8 kg of COD/1 m^3 of POME. This indicated that approximately 97.8% of COD was removed before the treated POME was channeled into the facultative ponds for further treatment.

98% eff.

As shown in Fig. 6, for every tonne of POME treated, an average of 12.36 kg of methane was emitted from the anaerobic ponds. Based on the two relationships methane emission and COD removal, and methane emission and POME treated, 1119.5 and 1060.9 t methane emitted were calculated, respectively. These values are not far from the methane field measurement of 1125.2 t.

4. Discussion

In 1999, Ma et al. reported that anaerobic digestion of POME produced 65% of methane from the total biogas mixture. In our study, POME digestion in the anaerobic ponds recorded an average of 54.4% methane. Lower methane composition was believed to be attributed by the large variation in the chemical properties of POME and the volume discharged to the ponds, resulting in the daily variation of organic loading rate and hydraulic retention time. POME is generated mainly from the oil extraction, washing and cleaning up processes in the mill containing and hence would contain cellulosic material, fat, oil and grease (Agamuthu, 1995). As shown in Table 2, the measured quantity and quality of POME discharge varied from time to time. This in turn will affect the growth and activity of microorganisms especially the methanogens and hence the methane emission rate. Nevertheless, in several occasions high methane composition (>65%) was measured in week 18 until 21 and in week 40. Lower methane composition was also reported from the anaerobic treatment of POME in open digesting tanks (Yacob et al., 2005). In contrary, Ma et al. (1999) was able to fully control the anaerobic digestion of POME at lab scale thus achieving higher methane composition. Over the period of 52 weeks the average was higher than data collected in the preliminary study carried out in October 2001 (Shirai et al., 2003) which did not quantify the long term effect of mill operation and FFB yield.

Another finding of the study was the higher emission of methane from the anaerobic ponds of approximately 1125 t compared to only 849 t from open digesting tank (Yacob et al., 2005). Despite having lower emission rates, anaerobic ponds emitted higher and consistent methane composition in the biogas mixture while severe daily fluctuations of methane emission pattern were observed in the open digesting tanks. More stable and conducive conditions for methane fermentation were evident in the anaerobic ponds as the untreated POME was introduced continuously at lower loading rates throughout the mill operation. This minimizes the introduction of oxygen into the ponds and the effect of loading shock from single loading pattern as experienced by the open digesting tanks.

Stagnant conditions of the effluent inside the ponds also helped to increase the methane fermentation as carbon dioxide and hydrogen produced from the process are being retained longer in the liquid phase. This would enable the hydrogen-utilizing methanogens to convert these gases into methane (Lay et al., 1998). On the other hand, fast rising bubbles inside the open digesting tanks due to vigorous mixing reduce the concentration of carbon dioxide and hydrogen in the liquid phase. This was supported by higher biogas emission rates in the open digesting tanks at 5.4 L/min/m^2 and lower methane content at 36% (Yacob et al., 2005). Localized mixing through rising bubbles that bring sludge to the surface was the only mixing observed in the anaerobic ponds.

As observed in the open digesting tank system, methane emission from the anaerobic pond was also affected by the seasonal cropping of oil palm. Similar relationships between the FFB processed, POME discharged and methane emission were observed in the anaerobic ponds. This finding is important as future estimations of methane emission should take into account the seasonal cropping as every tonne of FFB processed will generate 0.5 t of POME. The lowest methane emission was seen during November

2003–February 2004 and August 2004 during which a reduction of FFB processing and POME discharge tonnages as the yield cycle of oil palm in the surrounding plantations experienced strong depression after a peak yielding period for the previous 6 months. It was also demonstrated that the long public holidays in December 2003, when the mill was closed for a few days, affected the methane emission.

Apart from establishing the factors affecting the methane emission, we can also conclude that the method tested to establish the linear equation between COD removal and methane emission methane emission could be used to estimate methane production as the value derived from the equation is marginally lower than the actual methane field measurement. The information is useful as a lot of resources and time are required to carry out field measurement to quantify the total methane emission from all the 360 operating mills in Malaysia. In addition, the information presented would give a guideline in establishing a sound methodology in quantifying the methane emission from palm oil industry. Particularly at present, the recommended methodology (AM0013) by Intergovernmental Panel for Climate Change was derived from other sources such as landfill and wastewater methane emission.

5. Conclusion

Higher methane emission was recorded from the POME wastewater treatment facility using anaerobic ponds of 1043.1 kg/day/pond compared to open digesting tank. This was attributed to higher methane composition in the biogas mixture of 54.4%. However, lower emission rates were recorded at an average of 1.5 L/min/m^2 under normal mill operation. Anaerobic pond system also recorded higher organic conversion efficiency which for every kilogram of COD removed 237 g of methane will be emitted or 12.36 kg of methane/t of POME. The findings indicated that the anaerobic pond system is a better treatment system for POME. This is supported by its application to almost 90% of the palm oil mills in Malaysia. The long term study to establish the methane emission baseline has shown that the methane emission pattern is influenced by the oil palm seasonal cropping and mill activities, which is reflected by the quality and quantity of the POME discharge. Linear equation established from the study could be useful in quick estimation of the total methane emission from the palm oil industry.

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