African Journal of Biotechnology Vol. 9(16), pp. 2427-2436, 19 April, 2010
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2010 Academic Journals

Full Length Research Paper

Effects of palm oil mill effluent (POME) anaerobic sludge from 500 m^3 of closed anaerobic methane digested tank on pressed-shredded empty fruit bunch (EFB) composting process

Azhari Samsu Baharuddin[1,3], Lim Siong Hock[2], Mohd Zulkhairi Md Yusof[2], Nor' Aini Abdul Rahman[2]*, Umi kalsom Md Shah[2], Mohd Ali Hassan[2], Minato Wakisaka[3], Kenji Sakai[4] and Yoshihito Shirai[3]

[1]Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[2]Department of Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[3]Department of Biological Functions and Engineering, Graduate School of Life Science and System Engineering, Kyushu Institute of Technology, 2-4 Hibikino, Wakamatsu-ku, Kitakyushu, Fukuoka 808-0916, Japan.
[4]Department of Plant Resources, Graduate School of Bioresources and Bioenvironmental Sciences, Kyushu University, 6-10-1, Higashi-ku, Fukuoka, 812-8581, Japan.

Accepted 11 March, 2010

In this study, co-composting of pressed-shredded empty fruit bunches (EFB) and palm oil mill effluent (POME) anaerobic sludge from 500 m^3 closed anaerobic methane digested tank was carried out. High nitrogen and nutrients content were observed in the POME anaerobic sludge. The sludge was subjected to the pressed-shredded EFB to accelerate the co-composting treatment. In the present study, changes in the physicochemical characteristics of co-composting process were recorded and evaluated. The co-composting treatment was completed in a short time within 40 days with a final C/N ratio of 12.4. The co-composting process exhibited a higher temperature (60 - 67°C) in the thermophilic phase followed by curing phase after four weeks of treatment. Meanwhile, pH of the composting pile (8.1 - 8.6) was almost constant during the process and moisture content was reduced from 64.5% (initial treatment) to 52.0% (final matured compost). The use of pressed-shredded EFB as a main carbon source and bulking agent contributed to the optimum oxygen level in the composting piles (10 - 15%). The biodegradation of composting materials is shown by the reduction of cellulose (34.0%) and hemicellulose (27.0%) content towards the end of treatment. In addition, considerable amount of nutrients and low level of heavy metals were detected in the final matured compost. It can be concluded that the addition of POME anaerobic sludge into the pressed-shredded EFB composting process could produce acceptable and consistent quality of compost product in a short time.

Key words: Pressed-shredded empty fruit bunch, palm oil mill effluent anaerobic sludge, anaerobic digester, compost.

INTRODUCTION

Malaysia is the largest palm oil producer and exporter in the world. Despite high economics return to the country, the industry also generates large amount of wastes such as empty fruit bunch (EFB) (23%), mesocarp fibre (12%), shell (5%) and palm oil mill effluent (POME) (60%) for every tonne of fresh fruit bunches (FFB) processed in the mills (Najafpour et al., 2005). In 2005, it was estimated that about 75.5 million tonnes of FFB has been processed in the country (Lau et al., 2008). Thus, the treatment of EFB and POME has gained interest from many researchers

*Corresponding author. E-mail: nor_aini@biotech.upm.edu.my. Tel: 603 8946 6669. Fax: 603 8946 7510.

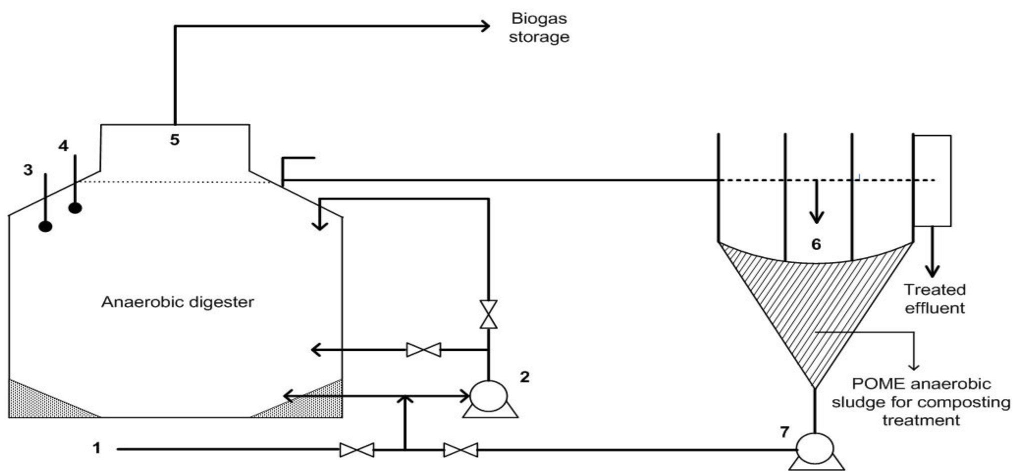

Figure 1. POME anaerobic sludge obtained from 500 m^3 semi-commercial closed anaerobic digester system. 1= fresh POME inlet; 2 = mixing pump; 3 = temperature probe; 4 = pH probe; 5 = gas collection chamber; 6 = settling tank; 7 = sludge recycling pump.

due to the abundant amount generated in the mills (Baharuddin et al., 2009a; Zakaria et al., 2008). The most common practice of EFB treatment are through soil mulching, boiler fuel and incineration, but the rest of them are left unused in the palm oil mills. However, the transportation and distribution of EFB in the plantation as soil mulching is getting more expensive due to the current labour shortage (Suhaimi and Ong, 2001). Meanwhile, the use of EFB as boiler fuel is also not efficient, due to its characteristic high moisture content (Yacob et al., 2005). The incineration of EFB in the palm oil mills is restricted by the Department of Environment (DOE) (Astimar and Wahid, 2006).

POME is the most polluted organic residues generated from palm oil mills. POME is compose of high organic content mainly oil and fatty acids and are able to support bacterial growth to reduce its pollution strength. Anaerobic process is the most suitable approach for its treatment (Mumtaz et al., 2008). Unfortunately in Malaysia, the most popular treatment method for POME which is utilized by more than 85% of the mills is the open pond system. This is due to its low capital and operating costs (Alawi et al., 2009). In our previous work (Baharuddin et al., 2009a), shredded EFB and partial treated POME from an open anaerobic pond was used for co-composting treatment in open windrow system at field scale. The composting treatment was completed within 80 days with final C/N ratio of 12.5. The quality of the final matured compost was difficult to maintain due to the variation of partial treated POME characteristics in the open pond system. Therefore, it is essential to provide the EFB composting treatment with a consistent nitrogen and microbial source from POME in order to produce a good quality of compost product besides overcoming the problem of POME treatment. In the year 2005, the anaerobic treatment of POME and methane production for clean development mechanism (CDM) project using a 500 m^3 closed anaerobic digester (CAD) was developed at Felda Serting Hilir Palm Oil Mill, Malaysia (Yacob et al., 2006). The settling tank was installed and sludge was recycled to provide a balance microbes population for the treatment of POME and methane gas production (Alawi et al., 2009). Besides biogas generation from the treatment of POME, POME anaerobic sludge from the digester can also be used for EFB composting treatment. The addition of thicken POME anaerobic sludge into EFB compost might enrich the composting materials with high nutrient and microbial sources.

Therefore, the aim of this study is to accelerate and improve the co-composting process of pressed-shredded EFB with POME anaerobic sludge. Physicochemical changes during the composting process and characteristics of the compost product were evaluated.

MATERIALS AND METHODS

Composting Site

The composting treatment was conducted under shade and cement base at the Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia. The brick blocks with length of 2.1 m, width of 1.5 m and height of 1.5 m were used as composting blocks.

Raw materials and composting process

The EFB was obtained from Seri Ulu Langat Palm Oil Mill, Dengkil, Selangor, Malaysia. POME anaerobic sludge was obtained from a 500 m^3 semi-commercial CAD system at Felda Serting Hilir, Negeri Sembilan, Malaysia. The EFB was pressed and shredded in the mills for the recovery of remaining crude palm oil (CPO). The size of pressed-shredded EFB was estimated about 15 to 20 cm length. The pressed-shredded EFB was applied directly onto the composting site. Figure 1 shows the POME anaerobic sludge in the biogas treatment which has been previously reported (Alawi et al., 2009) as sludge recycling. The thicken POME anaerobic sludge from the bottom part of the clarifier tank was used for the composting treatment in the present study.

One tonne of pressed-shredded EFB was loaded into the composting block by using a loader. About 50 kg of recycled EFB compost was added to facilitate the composting process. In order to maintain the moisture content of pile within 55 to 65%, POME anaerobic sludge was added at three days interval using a motor pump. The addition of POME anaerobic sludge was terminated a week before harvesting. Windrow turning was conducted one to three times a week for sufficient aeration and material mixing. The turning rate was dependent on temperature and oxygen level in the composting pile. Each composting cycle was completed within 40 days. The total POME anaerobic sludge added into the EFB compost throughout the process was about one tonne (1: 1 ratio).

Sampling and analysis

One kilogram (1 kg) of samples was collected at different depth and points in the pile (surface and core). The samples were divided into two parts. One part was stored at 4°C while the other part was stored at -20°C until further analysis. All analysis was done in triplicates. Changes of the texture, colour, odour and size of the samples were recorded based on physical observation.

The temperature and oxygen level at the top, middle and bottom layers of the interior of the heaps was monitored by using temperature and oxygen monitoring device. Moisture content was determined by drying 10 g of sample at 120°C (AND MX/MF moisture analyzer) until a constant weight was attained. CNHS analyzer 2000 (Leeco, USA) and Inductively Coupled Plasma (OES, Perkin Elmer, USA) was used to determine carbon, nitrogen, nutrients and heavy metal elements. Plate count method was done to measure viable bacterial count according to Brock and Madigan (1991). The analyses for chemical oxygen demand (COD), biological oxygen demand (BOD), volatile suspended solid (VSS), total solids (TS), total suspended solids (TSS), oil and grease, pH and electrical conductivity (EC) were conducted according to American Public Health Association (APHA) methods (1998). Meanwhile, analysis of cellulose, hemicellulose and lignin content were determined according to Gorring and Soest (1970). Scanning electron microscope (Philips XL 30 ESEM, Holland) was used to view the structure of pressed-shredded EFB, POME anaerobic sludge and compost sample.

RESULTS

Characteristics of raw materials

Table 1 shows the characterization of pressed-shredded EFB and POME anaerobic sludge used in the composting treatment. Characteristics of fresh raw POME was also determined as a comparison in the present study.

Pressed-shredded EFB

Pressed-shredded EFB was used as a main carbon source for the composting treatment due to its high cellulose (52.81 ± 8.1%) and hemicellulose (14.83 ± 2.3%) content (Table 1). The pressed-shredded EFB was brownish in colour with the length size of 15 to 20 cm. The fibrous form of pressed-shredded EFB might act as a good bulking agent for the composting treatment. The EFB used in the present study has been pressed in the mill to recover the remaining CPO left and then it was shredded into a loose fibrous material. The fibrous were stick together to form vascular bundles with 29.3 ± 3.8% of moisture content (Figure 2a). The pH of pressed-shredded EFB was 6.9 ± 0.2 which is slightly acidic. Scanning electron microscopy (SEM) observation of pressed-shredded EFB also suggested that some silica body on the surface of EFB structure were removed as shown in Figure 3a. However, the structure still consisted of firmly bound threads of lignin with smooth surface along the structure (Figure 3a). This might be due to the strong combination of lignin (13.71 ± 0.9%) and hemicellulose around the cellulose linkages (Table 1). The C/N ratio of pressed shredded EFB was 54.4 with carbon and nitrogen content at 43.49 ± 3.1% and 0.8 ± 0.1%, respectively. Moreover, high K (2.01 ± 0.3 mg/L) was detected in the pressed-shredded EFB as compared to other nutrient elements (Table 1).

POME anaerobic sludge

POME anaerobic sludge used in the present study has an opposite characteristics compared to the pressed-shredded EFB with lower C/N ratio (8.0) and high water content (94.0 ± 2.3%). The POME anaerobic sludge was used as nutrient source for the composting treatment as it has high composition of phosphorus (1.2 ± 0.1 mg L^{-1}), potassium (5.1 ± 1.2 mgL^{-1}), calcium (2.5 ± 0.9 mg L^{-1}) and magnesium (1.4 ± 0.2 mg L^{-1}) as shown in Table 1. The treatment of fresh raw POME for biogas production in the system contributed to the low level of oil and grease (183.0 ± 10.1 mg L^{-1}) and very low level of heavy metals (Ni < 15 mg kg^{-1}) in the sludge (Table 1). Although the pH of fresh raw POME was in the acidic condition (4.3 ± 0.3), the pH of POME anaerobic sludge was almost neutral (7.4 to 7.6). Figure 3b shows the structure of the dried POME anaerobic sludge. The POME anaerobic sludge contained high BOD (15180 mg L^{-1}) and COD level (40563 mg L^{-1}) indicating high amount of organic matter (Table 1). Interestingly, the VSS level in POME anaerobic sludge was also higher compared to the fresh raw POME. Therefore, the POME anaerobic sludge might be suitable for used as microbial seeding in the composting treatment. In this study, thicken POME anaerobic sludge with TS and TSS value at 55,884 mg L^{-1} and 34,720 mg L^{-1}, respectively was used.

Physiological and biochemical changes during composting process

POME anaerobic sludge and pressed-shredded EFB had

Table 1. Characteristics of pressed-shredded EFB, fresh raw POME and POME anaerobic sludge.

Parameters	Pressed shredded EFB	Fresh raw POME	POME anaerobic sludge
Moisture (%)	29.3 ± 3.8	98.21 ± 0.2	94.03 ± 2.3
pH	6.90 ± 0.2	4.33 ± 0.3	7.41 ± 0.2
C(%)	43.49 ± 3.1	36.36 ± 3.8	37.51 ± 5.1
N(%)	0.8 ± 0.1	2.71 ± 0.9	4.68 ± 0.7
C/N	54.4	13.4	8.0
Oil and grease (mg L^{-1})	-	2151.0 ± 50.1	183.0 ± 10.1
Electrical conduct. (dS m^{-1})	-	-	-
COD (mg/L^{-1})	-	113191.0	40563.0
BOD (mg/L^{-1})	-	35580.0	15180.0
Volatile suspended solid (mg L^{-1})	-	14530.0	21110.0
Total suspended solids (mg L^{-1})	-	18980.0	34720.0
Total solid (mg L^{-1})	-	41022.0	55884.0
Cellulose (%)	52.81 ± 8.1	38.36 ± 5.0	10.45 ± 5.1
Hemicellulose (%)	14.83 ± 2.3	23.21 ± 2.9	6.01 ± 1.8
Lignin (%)	13.71 ± 0.9	26.72 ± 3.4	48.13 ± 9.2
Composition of nutrients and metal elements			
Phosphorus (%)	0.08 ± 0.02	1.01 ± 0.2	1.25 ± 0.1
Potassium (%)	2.01 ± 0.3	2.49 ± 0.2	5.16 ± 2.2
Calcium (%)	0.26 ± 0.07	1.56 ± 0.1	2.55 ± 0.1
Sulphur (%)	0.19 ± 0.1	0.57 ± 0.2	1.21 ± 0.3
Ferrum (%)	0.07 ± 0.02	1.03 ± 0.3	1.09 ± 0.4
Magnesium (%)	0.12 ± 0.05	1.21 ± 0.2	1.41 ± 0.2
Zinc (mg kg^{-1})	33.0 ± 7.1	118.82 ± 22.1	151.0 ± 14.5
Manganase (mg kg^{-1})	28.78 ± 9.1	339.0 ± 20.0	495.24 ± 48.3
Copper (mg kg^{-1})	25.52 ± 5.3	73.24 ± 8.1	174.9 ± 20.3
Boron (mg kg^{-1})	26.97 ± 4.9	95.59 ± 8.2	65.0 ± 10.1
Molibdenum (mg kg^{-1})	1.0 ± 0.08	n.d	5.0 ± 1.0
Cadmium (mg kg^{-1})	n.d	1.2±0.1	n.d
Nickel (mg kg^{-1})	6.1 ± 1.7	n.d	14.0 ± 2.2

n.d., Not detectable (all percentages are in dry weight).

(a) (b) (c)

Figure 2. Physical appearance of (a) raw pressed-shredded EFB, (b) compost (day 20) and final matured compost (day 40).

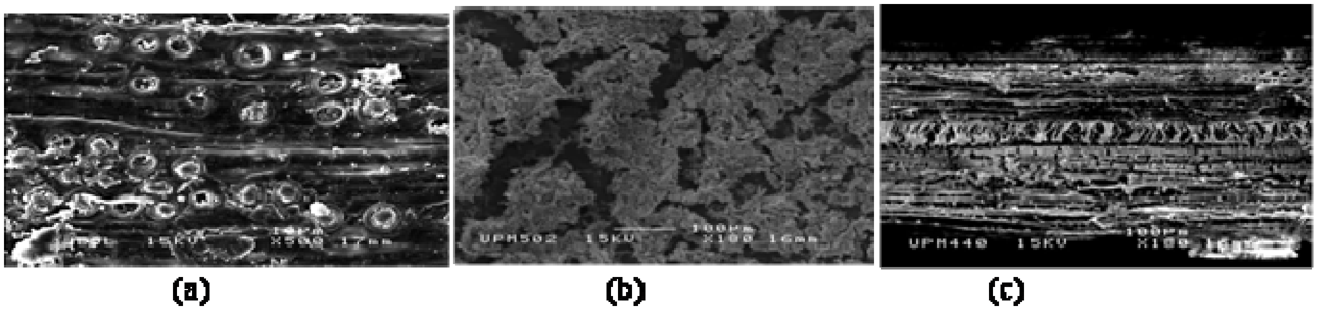

Figure 3. SEM analysis (a) Pressed-shredded EFB (500 x magnification), (b) POME anaerobic sludge (180 x magnification) and (c) final matured compost at day 40 (180 x magnification).

opposite characteristics (Table 1); thus the combination of these materials would be suitable substrates for the composting treatment. The final matured compost in the present study was blackish in colour, soil texture and earthy smell (Figure 2c). In addition, it was also suggested that the structure of pressed-shredded EFB was altered during composting treatment with the presence of many holes indicating that the cellulose and hemicellulose linkages was disrupted (Figure 3c). This phenomenon might be due to the action of cellulolytic and lignolytic microbes throughout the treatment.

Temperature profile

During the composting period, the ambient temperature was observed around 29 to 32°C. In the present study, the temperature of composting piles was increased sharply at 50°C after 24 h and maintained between 60 to 67°C from day 2 until day 19 of treatment (Figure 4). The rapid increase in temperature might be due to the turning process. Moreover, large amount of readily digestible components in the POME anaerobic sludge were available for microbial utilization. The thermophilic phase in the present study was continued until day 25 of treatment before gradually decreased to below 40°C after day 28 when the curing phase was started. During the curing phase, the C/N ratio tends to stabilize. At the end of treatment, the average temperature inside the pile was 32°C. The temperature profile showed in this study (Figure 4) met the sanitation requirement without external exertion of heat energy to the composting pile. It was also suggested that the capacity of piles could preserve heat by limiting heat loss to the surrounding. The oil and grease content of composting material was reduced from 1340.0 ± 20.0mg.kg^{-1} at day 2 of treatment to the value of 140.3 ± 17.5 mg.kg^{-1} in the final matured compost (Table 2).

Moisture content and oxygen level

In this study, POME anaerobic sludge was added to the composting piles to maintain the optimum moisture content (55 - 65%) throughout the treatment (Figure 4). The moisture content of the final matured compost (51.8 ± 3.7%) was slightly lower than the initial materials (64.5 ± 2.2%). High thermophillic temperature and frequent turning in the composting piles contributed to water loss. Therefore, the addition of POME anaerobic sludge was essential to sustain the microbial activity as well as provide nitrogen source. In this study, the oxygen level in the composting piles (Figure 4) was maintained in the thermophilic phase (10 - 15%) before slightly reduced (5 - 10%) during the curing phase. The reduction of oxygen level in the curing phase might be due to the compaction of degraded composting materials, although frequent turning was conducted.

pH and electrical conductivity

The initial pH of composting pile was slightly increased from 7.6 to 8.5 within the first 2 days of treatment and this was probably due to the POME anaerobic sludge added (Figure 5). The value of pH showed almost constant after day 3 until day 28 of composting treatment. The pH detected was in the range of 8.5 to 8.7, indicating a weak alkaline condition of the system (Figure 5). The slight declined in pH after day 29 (pH < 8.5) was probably due to the volatilization of ammonium and released of hydrogen ions from the nitrification process. The pH of the final matured compost was pH 8.1 ± 0.8. Moreover, the initial EC value was increased from 4.8 ± 1.0 to 7.0 ± 0.3 dS m^{-1} of the final matured compost (Table 2). This result might be attributed to the release of several ions during the mineralization of organic matter.

Bacterial count

Based on temperature profile during composting, two stages in the treatment process can be observed; thermophilic (from day 2 to day 27) and mesophilic (from day 28 to day 40). The initial total bacteria count was

Table 2. Characteristics of EFB compost at initial (day 2) and final matured compost (day 40).

Parameters	EFB compost (initial - day 2)	EFB compost (final - day 40)
Moisture (%)	64.5 ± 1.2	51.8 ± 3.7
pH	8.56 ± 0.2	8.12 ± 0.8
C(%)	42.49 ± 5.2	28.81 ± 3.3
N(%)	0.93 ± 0.05	2.31 ± 0.08
C/N	45.6	12.4
Oil and Grease (mg kg^{-1}))	1340.0 ± 20.0	140.0 ± 27.5
Electrical Conduct. (dS m^{-1})	4.87 ± 1.0	7.02 ± 0.3
Cellulose (%)	51.31 ± 5.0	33.86 ± 4.7
Hemicellulose (%)	21.81 ± 2.6	15.92 ± 2.5
Lignin (%)	20.24 ± 3.1	38.14 ± 3.1
Composition of nutrients and metal elements		
Phosphorus (%)	0.86 ± 0.1	1.36 ± 0.5
Potassium (%)	1.52 ± 0.3	2.84 ± 0.6
Calcium (%)	0.61 ± 0.1	1.04 ± 0.3
Sulphur (%)	0.13 ± 4.3	0.18 ± 6.5
Ferrum (%)	0.04 ± 0.1	0.98 ± 0.2
Magnesium (%)	0.38 ± 0.08	0.90 ± 0.1
Zinc (mg kg^{-1})	12.91 ± 3.7	157.32 ± 56.0
Manganase (mg kg^{-1})	11.88 ± 2.3	151.2 ± 30.8
Copper (mg kg^{-1})	11.71 ± 2.8	74.30 ± 10.2
Boron (mg kg^{-1})	4.00 ± 1.1	11.01 ± 2.6
Molibdenum (mg kg^{-1})	n.d	n.d
Cadmium (mg kg^{-1})	n.d	n.d
Nickel (mg kg^{-1})	12.24 ± 1.1	19.32 ± 2.4

n.d., Not detectable (All percentages are in dry weight).

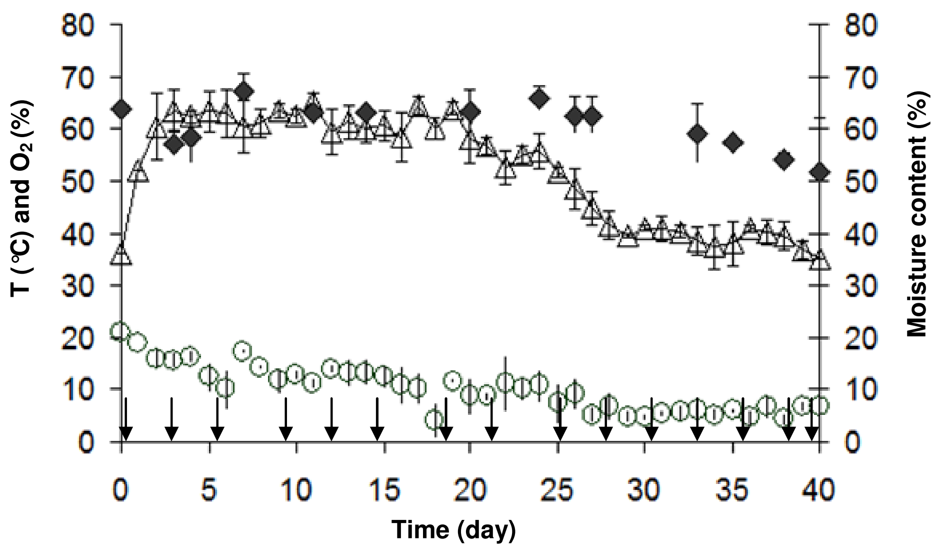

Figure 4. Profiles of compost temperature (Δ), oxygen level (○) and moisture content (♦) throughout composting treatment (arrow indicate turning process).

about 11.3 × 10^{10} CFU g^{-1} wet substrate. As the process entered thermophillic phase, it was observed that the total bacterial count increased sharply and then slowly decreased when the temperature dropped (Figure 5). The

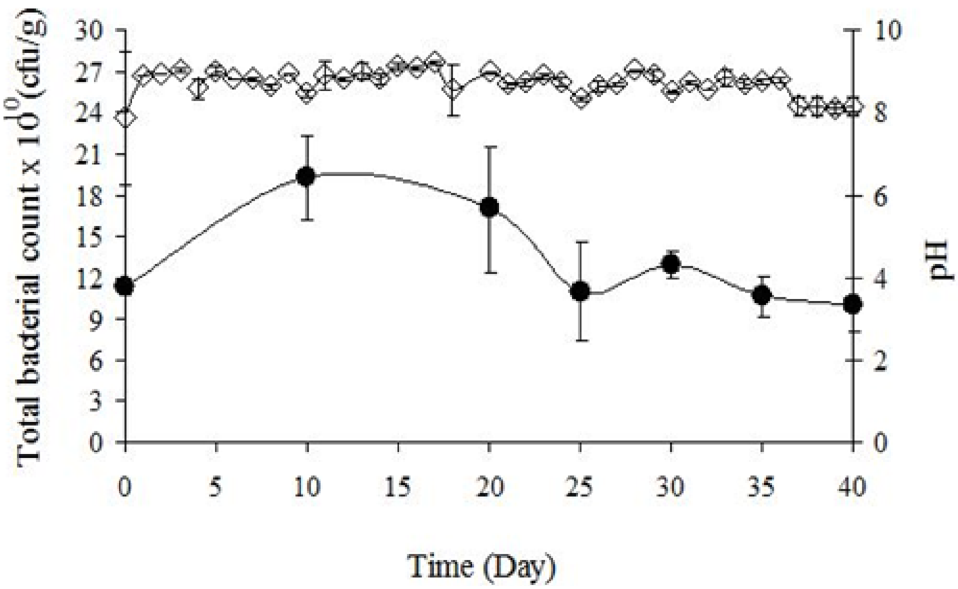

Figure 5. Total bacterial count (●) and pH (◊) profiles throughout composting process.

total bacterial count shows an abrupt increased when the treatment entered the mesophilic stage after day 25 and then gradually decreased towards the end of treatment (Figure 5). In the present study, POME anaerobic sludge consisted of high VSS content (Table 1), therefore it was added to the composting materials as microbial seeding for the composting treatment and thus the requirement of the effective microbes (EM) supplementation could be avoided.

Substrate degradation and C/N ratio

Analysis of cellulose, hemicellulose and lignin composition in the compost samples was conducted to evaluate the relative degree of decomposition during the process. It was observed that cellulose (34.0%) and hemicellulose (27.0%) content were reduced in the final matured compost; whereas lignin content had an opposite profile (Table 2). The reduction of cellulose and hemicellulose content implies the active utilization of these substances during the treatment. Meanwhile, the increment of lignin content in the final matured compost might be due to the accumulation of non degradable lignin from EFB and POME anaerobic sludge added. POME anaerobic sludge in the present study comprise of high lignin content (48.13 ± 9.2%), compared to cellulose (10.45 ± 5.1%) and hemicellulose (6.01 ± 1.8%) composition (Table 1).

In the present study, nitrogen content was increased steadily whereas carbon content was reduced gradually throughout the composting process (Figure 6). Despite high C/N ratio of pressed shredded EFB, the addition of POME anaerobic sludge reduced the initial C/N ratio of composting material to the acceptable level. The initial C/N ratio of composting material was about 45.6 at day 2 and then decreased gradually in the latter stage of treatment. The C/N ratio of 20 was obtained in the curing phase after day 27 and continued to decrease until it achieved the final C/N ratio of 12.4 at day 40. The POME anaerobic sludge consisted of high nitrogen content (4.6%). The co-composting process in the present study showed an improvement when it was completed within 40 days at a final C/N ratio of 12.4.

Nutrients (macro and micro)

Table 2 shows the nutrients changes during the composting process. In addition to carbon and nitrogen, the matured compost also contained a variety of nutrients such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe) and trace amount of zinc (Zn), manganese (Mn), copper (Cu) and boron (B). The N, P, K, Ca, Mg and Fe level in the final matured compost were 2.31, 1.36, 2.84, 1.04, 0.90 and 0.98%, respectively. The micronutrient elements detected in the final matured compost (Table 2) were zinc and manganese which were about 150 mg kg^{-1}, copper (74 mg kg^{-1}) and boron (11 mg kg^{-1}). It is also suggested that most of these nutrients were derived from organic-bound compounds in the POME anaerobic sludge added. Since, the composting treatment was conducted under shade and cement base, no leachate or run-off occurred throughout the composting treatment. The final matured compost contained a low level of nickel (Ni) (< 20 mg kg^{-1}), whereas cadmium (Cd) element was not detected in all compost samples (Table 2). The low level of heavy

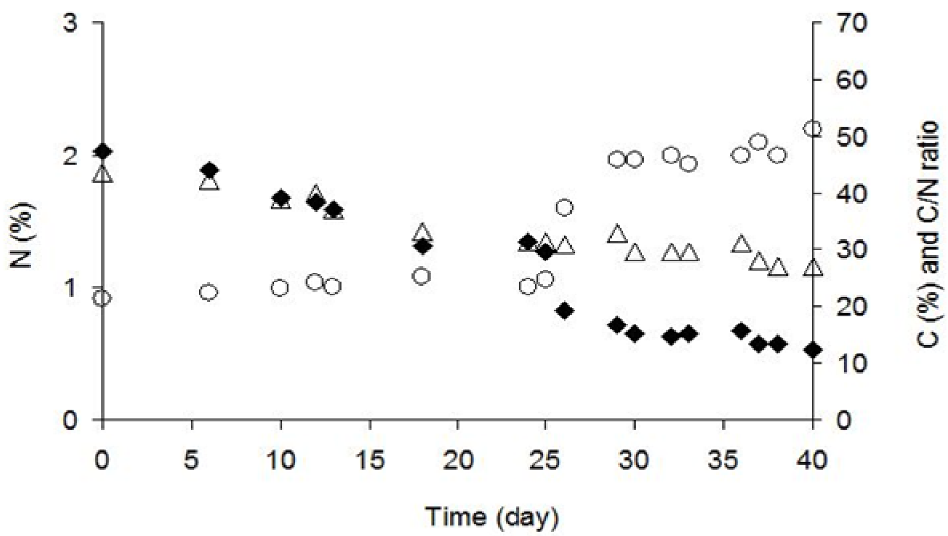

Figure 6. Profiles of nitrogen content, carbon content and C/N ratio throughout composting process (○: nitrogen; ∆: carbon; ♦: C/N ratio).

metal elements in POME anaerobic sludge might be due to the direct treatment of fresh raw POME for methane production in the digester. The results obtained in the present study also proved that the final matured compost was safe and suitable to be used as fertilizer.

DISCUSSION

The size of pressed-shredded was smaller compared to the EFB used in the previous work (Baharuddin et al., 2009a) and thus increased the surface area for microbial consumption during the composting treatment. Mohamad et al. (2002) reported that the fresh sterilized EFB usually contains about 2% of remaining CPO. According to Manios et al. (2006), oil degradation and slow 'burning' of composting materials contributed to the oxygen depletion. Interestingly, in the present study, oil was successfully removed from the EFB. Thus, the EFB mill pressing is not only for the CPO recovery but also to minimize the depletion of oxygen level in the composting treatment.

Based on SEM observation, it may be suggested that the outer structure of pressed-shredded EFB was better in terms of silica body removal as compared to the previous shredded EFB used for the composting treatment (Baharuddin et al., 2009b). The intact structure of EFB might be due to the combination of lignin and hemicellulose which provides a protective sheath around the cellulose (Kuhad et al., 1997). Wong et al. (2008) also reported that lignin is not attacked by enzymes and it shields the cellulose during the hydrolysis. The composition of lignin and hemicellulose in the pressed-shredded EFB was slightly lower compared to the shredded EFB used in the previous work (hemicellulose: 28.8%; lignin: 17.1%). The POME anaerobic sludge consists of lower C/N ratio and consistent characteristics compared to the partial treated POME. The characteristics of partial treated POME was always varied and difficult to maintain in the open pond system which was influenced by weather condition and mill operation (Baharuddin et al., 2009a). POME anaerobic sludge in the present study was clarified in the settling tank before used as sludge recycling in a closed anaerobic digester tank system and its characteristics was considerably consistent (Alawi et al., 2009). The macro and micronutrients detected in POME anaerobic sludge was also higher than the previous work. The higher VSS value in the POME anaerobic sludge might be due to the presence of beneficial predominant microbes for the composting treatment such as uncultured *bacteroidetes* which was previously detected in partial treated POME through the denaturing gradient gel electrophoresis (DGGE) analysis (Baharuddin et al., 2009b). In the present study, composting treatment could be completed within 40 days as much faster than the previous work (60 - 80 days) (Baharuddin et al., 2009a). Yaser et al. (2007) reported that the composting treatment of POME sludge from anaerobic digestion pond mixed with sawdust can be completed after 200 days at final C/N ratio of 19. Temperature is an important parameter to monitor the composting efficiency, as it does not only affect the biological reaction rates and population dynamics of microbes, but also the physico-chemical characteristics of compost (Luo et al., 2008). The co-composting treatment in this study demonstrated a higher temperature (60-67℃) compared to the previous work (Baharuddin et al., 2009a). Ayed et al. (2007) reported that the temperature above 60℃ affected the decomposition rate of the organic waste. The prolong thermophillic phase might be caused by the existence of the remaining CPO left in the EFB and POME anaerobic sludge which would release complete oxidation energy that aid the co-metabolism of more stable molecules such as lignin (Manious et al., 2006). Besides, moisture content also has significant effect on enzymes activities and microbial respiration in the composting process (Hu et al., 2008). In general, 50% of moisture content was the minimum requirement for maintaining high microbial activity (Liang and Das Mcclendon, 2003).

According to Satisha and Devarajan (2007), the increase of pH in the composting process was likely to be the consequences of rapid metabolic degradation of organic acids and intense proteolysis of liberating alkaline ammonia compound due to protein degradation. Ammonium released during the composting process may also contribute to the increase of pH because ammonia is the principle nitrogenous compound in the composting material. Similar pattern of pH profile was obtained in the previous work (Baharuddin et al., 2009a). Saidi et al. (2008) reported that increase in alkalinity could inhibit some pathogen such as fungi since a large number of fungi grow only under acidic condition. In addition, the increase of electrical conductivity in the present study was likely due to the loss of weight and release of other mineral salts such as phosphate and ammonium ions through the decomposition of organic substances as reported by Wong et al. (2001). High bacterial number was observed during the first 20 days of treatment (Figure 5). In the previous work, most pre-dominant microbes for composting were obtained from the raw materials as analyzed by DGGE (Baharuddin et al., 2009b). These indigenous bacteria would progressively oxidised easily degradable carbohydrate and pectin at initial thermophillic phase, whereas more stable material such as lignin were being oxidized in prolonged thermophillic phase (Baffi et al., 2006). There is an early thermophilic attack by bacteria and actinomycetes that easily converts degradable substrates such as sugars and proteins, whereas fungi are the major micro-organisms in the following part of the process when cellulose, hemicellulose and lignin are available substrates and humification takes place (Ayed et al., 2007). The reduction of carbon content was attributed by the active microbial cellulolytic degradation and microbial proliferation which immobilize nitrogen (Satisha and Devarajan, 2007). Meanwhile, the preservation of nitrogen was due to the utilization and incorporation of the decomposed nitrogen by the microbial biomass during the composting process (Tang et al., 2004).

The final matured compost comprises consistent and comparable amount of nutrient content. Since the thicken POME anaerobic sludge was used in this study, the ratio of POME added into the EFB compost was lower than reported by Baharuddin et al. (2009a). The ratio amount of POME anaerobic sludge added was similar to the ratio of pressed-shredded EFB and the treatment was accomplished within 40 days.

Conclusion

Co-composting of pressed-shredded EFB and POME anaerobic sludge showed a feasible approach under controlled conditions. The microbial seeding and nitrogen source from POME anaerobic sludge speed up the EFB composting period within 40 days with the final C/N ratio of 12.4. The final matured compost comprised consistent and considerable amount of nutrients, low heavy metals and met the United States Environmental Protection Agency (USEPA) standard to be used as soil amendment and fertilizer. This study also proved the conversion of oil palm wastes into a high value added product such as compost through the integration of POME treatment in biogas generation and available EFB at palm oil mills.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Putra Malaysia, FELDA Palm Industries Sdn. Bhd., Kyushu Institute of Technology and Malaysian Technology Development Corporation, Malaysia for the financial and technical support of this research.

Abbreviations

EFB; Empty fruit bunches, **POME;** palm oil mill effluent, **FFB;** fresh fruit bunches, **CDM;** clean development mechanism, **CAD;** closed anaerobic digester, **CPO;** crude palm oil, **COD;** chemical oxygen demand, **BOD;** biological oxygen demand, **VSS;** volatile suspended solid, **TS;** total solids, **TSS;** total suspended solids, **EC;** electrical conductivity, **EM,** effective microbes; **C/N;** carbon nitrogen ratio; **DGGE,** denaturing gradient gel electrophoresis.

REFERENCES

APHA (1998). Standard methods for examination water and wastewater. 20^{th} edition. American Public and Health Association, Washington D.C. American Public Health Association.

Alawi S, Busu Z, Tabatabaei M, Yacob S, Abd-Aziz S, Hassan MA, Shirai Y (2009) The effect of higher sludge recycling rate on anaerobic treatment of palm oil mill effluent in a semi-commercial closed digester for renewable energy. Am. J. Biochem. Biotechnol. 5: 1-6.

Ayed LB, Hassen A., Jedidi N, Saidi N, Olfa B, Murano F (2007) Microbial C and N dynamics during composting of urban solid waste. Waste Manage. Res. 25: 24-29.

Astimar AA, Wahid MB (2006). Supply outlook of oil palm biomass in Malaysia. Proceeding of the seminar on ecomat research and promotion. Beijing, China, 24-25 July 2006: Towards Enrichment of the Environment.

Baharuddin AS, Wakisaka M, Shirai Y, Abd-Aziz S, Abdul Rahman NA, Hassan MA (2009a) Co-composting of Empty Fruit Bunch and Partially Treated Palm Oil Mill Effluent in Pilot Scale: Intern. J. Agric. Res. 4: 69-78.

Baharuddin AS, Nakamura M, Tabatabaei M, Abd-Aziz S, Abdul Rahman NA, Wakisaka M, Hassan MA, Sakai K, Shirai Y (2009b).

Characteristics and microbial succession in co-composting of oil palm empty fruit bunch and partially treated palm oil mill effluent. The Open Biotechnol. J. 3: 92-100.
Brock DT, Mdigan TM (1991). Biology of microorganism. 6th edition Englewood Cliffs, N.J, Prentice Hall.
Baffi C, Abate MTD, Nassisi A, Silva S, Benedetti A, Genevini PL, Adani F (2006). Determination of biological stability in compost: A comparison of methodology: Soil Biol. Biochem. 39: 1284-1293.
Gorring HK, Van Soest PJ (1970). Forage Fiber Analysis (Apparatus, Reagents, Procedures and Some Applications). Agric. Handbook No. 379 pp. 1-20. Agric. Research Service-United States Department of Agric. Washington D.C.
Hu Z, Lane R, Wen Z (2008). Composting clam processing wastes in a laboratory and pilot-scale in-vessel system. Waste Manage. 29(1): 180-185.
Kuhad RC, Singh A, Erikson K (1997). Microorganisms and enzymes involved in the degradation of plant fiber cell walls. Advances in Biochemical Engineering: Biotechnology in the Pulp and Paper Industry, Springer-Verleg, New York, pp. 45-125.
Lau HLN, YM Choo, AN Ma, Chuah CH (2008). Selective extraction of palm carotene and vitamin E from fresh palm-press mesocarp fiber (*Elaeis guineensis*) using supercritical CO_2. J. Food Eng. 84: 289-296.
Liang C, Das Mcclendon KC (2003). The influence of temperature and moisture content regimes on the aerobic microbial activity of a biosolids composting blend. Bioresour. Technol. 86: 131-137.
Luo W, Chen TB, Zheng GD, Gao D, Zhang YA, and Gao W (2008). Effect of moisture adjustments on vertical temperature distribution during forced-aeration static-pile composting of sewage sludge. Resour. Conserv. Recycling, 52: 635-642.
Mohamad H, Ridzuan R, Anis M, Hasamudin W, Kamaruddin WH, Ropandi M and Astimar AA (2002) Research on development of oil palm biomass utilisation in wood-based industries. Malaysian Palm Oil Board, pp. 1-5.
Mumtaz T, Abd-aziz S, Abdul Rahman NA, Phang LY, Shirai Y, Hassan MA (2008). Pilot-scale of recovery of low molecular weight organic acids from anaerobically treated palm oil mill effluent (POME) with energy integrated system. Afr. J. Biotechnol. 21: 3900-3905.
Manious T, Maniadakis K, Kalogeraki M, Mari E, Stratakis E, Terzakis S, Boytzakis P, Naziridas Y, and Zampetakis L (2006). Efforts to explain and control the prolonged thermophillic period in two-phase olive oil mill sludge composting. Biodegradation, 17: 285-292.
Najafpour GD, Zinatizadeh AAL, Mohamed AR, Isa MH, Nasrollahzadeh H (2005) High-rate anaerobic digestion of palm oil mill effluent in an up-flow sludge-fixed film bioreactor. Proc. Biochem. 41: 370-379.
Saidi N, Cherif M, Mahrouk M, Fumio M, Boudabous A, Hassen A (2008). Evaluation of biochemical parameters during composting of various wastes compost. Am. J. Environ. Sci. 4: 332-341.
Suhaimi M, Ong HK (2001). Composting empty fruit bunches of oil palm. The Food and Fertilizer Technology centre (FFTC), 1st November 2001. [Online]. Available at http://www.agnet.org/library/eb/505a/ (Accessed on 1st January 2008).
Satisha GC, Devarajan L (2007). Effect of amendments on windrow composting of sugar industry pressmud. Waste Manage. 27: 1083-1091.
Tang JC, Kanamori T, Inoue Y, Yasuta T, Yoshida S, Katayama A (2004). Changes in the microbial community structure during thermophilic composting of manure as detected by the quinone profile method. Proc. Biochem. 39(2): 1999-2006.
Wong JWC, Mak KF, Chan NW, Lam A, Fang M, Zhou LX, Wu QT, Liao XD (2001). Co-composting of soybean residues and leaves in Hong Kong. Bioresour. Technol. 76: 99-106.
Wong KM, Abdul Rahman NA and Abd-Aziz S (2008). Enzymatic hydrolysis of palm oil mill effluent solid using mixed cellulases from locally isolated fungi. Res. J. Microbiol. 3(6): 474-481.
Yacob S, Shirai Y, Hassan MA, Wakisaka M, Subash S (2005). Baseline study of methane emission from open digesting tank of palm oil mill effluent. Chemosphre, 59: 1575-1581.
Yacob S, Shirai Y, Hassan MA, Wakisaka M, Subash S (2006). Start-up operation of semi-commercial closed anaerobic digester for palm oil mill effluent treatment. Proc. Biochem. 41: 962-964.
Yaser AZ, Abd Rahman R, Kalil MS (2007). Co-composting of palm oil mill sludge-sawdust. Pak. J. Biol. Sci. 10: 4473-4478.
Zakaria MR, Abd-Aziz S, Ariffin H, Abdul Rahman N, Yee PL, Hassan MA (2008). *Comamonas* sp. EB172 isolated from digester treating palm oil mill effluent as potential polyhydroxyalkanoate (PHA) producer. Afr. J. Biotechnol. 7(22): 4118-4121.