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Physicochemical Changes in Windrow Co-Composting Process of Oil Palm Mesocarp Fiber and Palm Oil Mill Effluent Anaerobic Sludge

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Abstract: The objective of this study is to investigate the characteristics and physicochemical changes in windrow co-composting process of oil palm mesocarp fiber (OPMF) and palm oil mill effluent (POME) anaerobic sludge at pilot scale. The addition of POME anaerobic sludge as a nutrient source and microbial seeding into the OPMF compost led to the prolonged of thermophillic condition (50 – 68°C) until day 39 of treatment. The pH value was remained stable (6.8-7.8) throughout the process whereas the moisture content was reduced towards the end of treatment with final moisture content around 50%. The final matured compost was achieved within 50 days with C/N ratio of 12.6. In addition, considerable amount of nutrients and low level of heavy metals were detected in the final matured compost. The results is indicated that windrow co-composting of OPMF and POME anaerobic sludge could produce acceptable quality of compost that can be used as fertilizer or soil amendment.

Key words: Oil palm mesocarp fibre, palm oil mill anaerobic sludge, compost

INTRODUCTION

Oil palm is one of the most economical and potential parential crops that originate from native west Africa. It has been growth as the commercial agricultural crop in the production of palm oil in several countries. Malaysia is one of the world major palm oil producing country, as it had processed around 75.5 millions tonnes of fresh fruit bunch (FFB) in 2005. From these processed FFB, 11.9 millions tonnes of oil palm mesocarp fiber (OPMF) which has constituted about 15.7% of solid biomass of FFB has been generated (Lau *et al.*, 2007). Since the worldwide demand in palm oil continue to growth, it is believed that large amount of oil palm solid biomass will be generated in the mills. OPMF usually left as the solid wastes after oil extraction process (Sreekala *et al*., 1997). According to Choo *et al.* (1996), oil losses in the fiber after screw press extraction of crude palm oil (CPO) was around 5 to 6% and most of these fiber is normally burned as fuel for boiler in the mills. Besides, the fiber also mixed with kernal shell to use as solid wastes for electricity generation in the mills (Lau *et al.*, 2007).

It is expected that mill OPMF generation will be in excess trend via limited boiler capacity and increasing demand in FFB processes in the mills. Therefore, an alternative disposal methods is essential to overcome the abundant amount of OPMF generated in the mills every year. Yacob *et al.* (2005) also reported that typical oil palm mills waste treatment system in Malaysia is one of the major sources that contributed to the emission of Green House Gas (GHG). For every tonnes of POME being treated, around 12.36 kg of methane gas was estimated to be emitted from open anaerobic ponds (Baharuddin *et al.*, 2009). Bioconversion of these biomass (OPMF and POME) into valuable product is important to minimize the biomass generation impact to the

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environment. The utilization of these biomass has offer a great commercial potential to the palm oil mill industry since its available in large quantity in the mills.

The application of POME anaerobic sludge for the production of OPMF compost promotes for the environmental solution in the palm oil mills. In addition, co-composting of these biomass could substitute and reduce the usage of inorganic fertilizer in farming. However, composting process is a dynamic process and it depends on several factors should be controlled such as temperature, moisture content, oxygen level, carbon-nitrogen ratio, and nutrient (Ruggieri *et al*., 2008; Baharuddin *et al*., 2009). This study is the first to investigate the physicochemical changes of co-composting process using OPMF and POME anaerobic sludge at pilot scale. The characteristics of the compost product was also determined.

MATERIALS AND METHODS

Pilot Scale Composting Site:

This research was conducted under shade and cement base in Faculty of Biotechnology and Biomolecular Sciences, University Putra Malaysia, 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:

The composting materials were obtained from Felda Serting Hilir Palm Oil Mill, Negeri Sembilan, Malaysia. The Oil Palm Mesocarp Fiber (OPMF) was collected from palm oil extraction process whereas POME anaerobic sludge was obtained from Anaerobic Methane Closed Digesting Pilot Plant (500 m^3). OPMF typically were left as the burning material for electicity generation. The wastewater treatment facilities that available in Felda Serdang Hilir palm oil mill comprises of ponding system and Closed Digesting Tank (CDT). The thicken POME anaerobic sludge used in this study was collected from the settling tank for the sludge recycling system (Yacob *et al*., 2006).

Composting Establishment:

One tonnes of OPMF was loaded into composting block using loader. In order to maintain pile moisture content within 55 to 60%, POME anaerobic sludge were added of three days interval time using a motor pump. The addition of POME anaerobic sludge were stopped a week before harvesting process. 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 50 days. The total of POME anaerobic sludge added onto the OPMF compost throughout the process was about one tonnes (1:1 ratio).

Sampling:

One kg of samples were collected at different depth and points in the pile (surface and core). The samples were divided into two parts. One part was stored in 4°C while the other part was stored in -20°C until further analysis. All experiments were done in triplicates.

Sample Analysis:

CNHS analyzer and Inductively Coupled Plasma (ICP) were used to determine the carbon, nitrogen, nutrients and heavy metal elements. Plate count method was used to measure viable microbial count (Baharuddin *et al.*, 2009). Meanwhile, oil & grease, ammonium, and electrical conductivity analysis of compost samples was conducted according to APHA methods (1998).

RESULTS AND DISCUSSION

Characteristics of Raw Materials and Final Compost:

Raw OPMF contain relatively high level of cellulose (21.3%), hemicellulose (31.9%) and lignin content (26.9%) (Table 1). Therefore, longer composting duration is required to decompost the raw materials. Changes in colour and texture properties of composting material was observed throughout the composting process (Fig. 1). The matured compost exhibited blackish in colour, soil texture and earthy smell. Since POME anaerobic sludge contained high level of moisture content with low carbon to nitrogen ratio, while OPMF has an opposite characteristics, the addition of POME anaerobic sludge into the OPMF compost would enriched the composting process with the sources of nitrogen and microbial seeding. The water content in POME anaerobic sludge could also maintain the moisture condition that is crucial for microbial growth. OPMF act as a main carbon sources for microbial consumption and it also could facilitated as a bulking agent for composting treatment. POME anaerobic sludge with BOD (15,100 mg L^{-1}) and COD (40,563 mg L^{-1}) concentration were used in this study. The POME anaerobic sludge has undergone a complete treatment for methane production in a closed anaerobic digester tank system and its characteristics was considerably consistent (Table 1). In addition, the POME anaerobic sludge was a thicken sludge due to the sedimentation in the clarifier tank. The total solid content of POME anaerobic sludge was about 55,884 mg/kg (Table 1). In this study, the nitrogen and nutrients level of the compost product were found comparable to Baharuddin *et al.* (2009) which used empty fruit bunch (EFB) and partially treated POME. The N, P, and K level in the compost product were 2.0 %, 0.3 % and 1.2%, respectively. Baharuddin *et al.* (2009) reported that compost product in previous study consisted of 2.2% N, 1.5% P and 2.8% K, respectively. Although the N, P and K content was lower than reported by Baharuddin *et al.* (2009), the results obtained in this study may suggested that OPMF and POME anaerobic sludge were the potential materials for the compost product. This composting study may also become an alternative for the utilization of excess mesocarp fibres in the palm oil mill.

Table 1: Properties of Oil Palm Mesocarp Fiber (OPMF), treated POME Sludge, and Final compost at day 60

Parameters	OPMF	POME anaerobic sludge	Final Compost
Moisture (%)	33.7	95.4	49.3
pH	5.9	7.4	7.50
C(%)	42.7	32.5	24.8
N(%)	0.8	3.9	1.9
C/N	56.9	8.3	12.6
Ammonium(%)	-	-	0.1
Oil and Grease (mg/L^{-1})	-	183.0	50.0
Electrical Conductivity (Mmhos/cm)	-	-	6.0
Total solid (mg Kg^{-1})	-	55,884.0	-
COD (mg/L^{-1})	-	40,563.0	-
BOD (mg/L^{-1})	-	15,100.0	-
Cellulose (%)	21.3	-	-
Hemicellulose (%)	31.9	-	-
Lignin (%)	26.9	-	-
Composition of nutrients and metal elements			
Phosphorus (%)	0.1	1.2	0.3
Potassium (%)	0.5	2.0	1.2
Calcium (%)	0.2	1.6	0.9
Sulphur (%)	0.1	4.6	20.6
Magnesium (%)	0.1	0.9	0.3
Zinc (mg/kg^{-1})	9.8	157.8	189.5
Manganase (mg/kg^{-1})	n.d	549.6	151.4
Ferrum (%)	0.2	1.9	1.0
Copper (mg/kg^{-1})	27.1	243.1	57.4
Boron (mg/kg^{-1})	n.d	180.4	7.0
Molibdenum (mg/kg^{-1})	1.0	n.d	n.d
Cadmium (mg/kg^{-1})	n.d	n.d	n.d
Chromium (mg/kg^{-1})	10.7	23.3	19.0
Plumbum (mg/kg^{-1})	0.5	0.1	32.2
Nickel (mg/kg^{-1})	4.0	n.d	3.46

n.d.: Not detectable

Co-composting of OPMF can be accomplished by the addition of thicken POME anaerobic sludge prior to it microbial seeding capability and nutrient sources. Since the thicken POME anaerobic sludge was used in this study, the amount of POME added onto the OPMF compost was lower than reported by Baharuddin *et al.* (2009). Moreover, acceptable level of potassium and phosphorus were detected in compost product and this may due to the existance of these elements in OPMF and POME sludge. Low heavy metals concentration were detected in all compost samples (Table 1).

Physiological and Biochemical Changes in Composting Process:

Temperature variation:

Temperature is an important parameter indicating the rate of composting process and compost maturity (Luo *et al.*, 2007). The POME anaerobic sludge used in this study contained high level of organic matter as indicated by high BOD level (Table 1). Therefore, when the highly organic matter material added into highly cellulosic material like OPMF, heat was generated in the piles due to metabolic heat generation from biodegradation (Miyatake and Iwabuchi, 2005). It was observed that the temperature of the compost increased sharply to around 60°C within 24 hours and this reflecting microbial decomposition activity in the compost piles (Fig 2). Moreover, the piles dimension of 2.1 m length, 1.5 m width and 1.5 m height could preserved pile heat by limiting heat loss to the surrounding due to low surface to volume ratio. From day 1 to day 40, the temperature was maintained around 50-68°C indicating long thermophillic phase. This prolonged thermophillic phase may likely caused by the existence of oily substances in OPMF which would release complete oxidation energy that aid the co-metabolism of more stable molecules like lignin (Manious *et al*., 2006).

Fig 1: Physical changes during composting; (a) raw OPMF, (b) compost (day 20), and final compost (day 50)

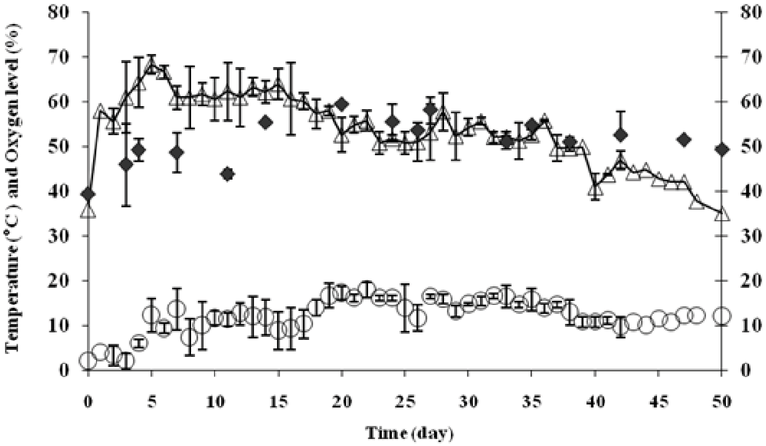

Fig. 2: Profiles of compost temperature (△), Oxygen level (○) and moisture content ◇) during co-composting of OPMF and treated POME sludge

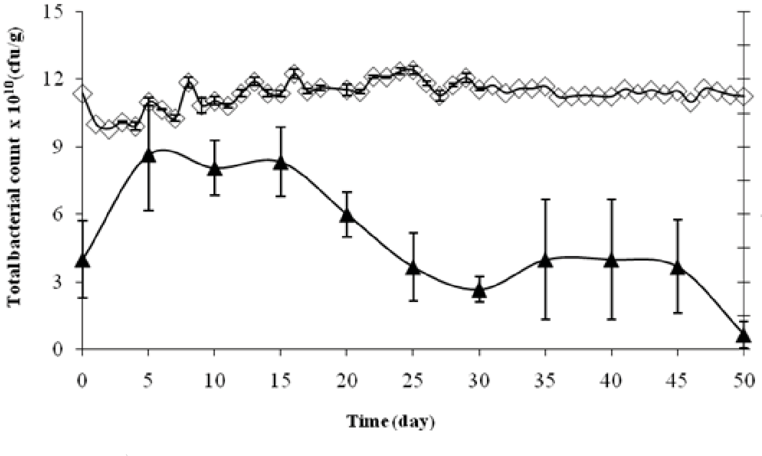

Fig. 3: Total bacterial count (△) and pH (◇) profiles thoughout composting process

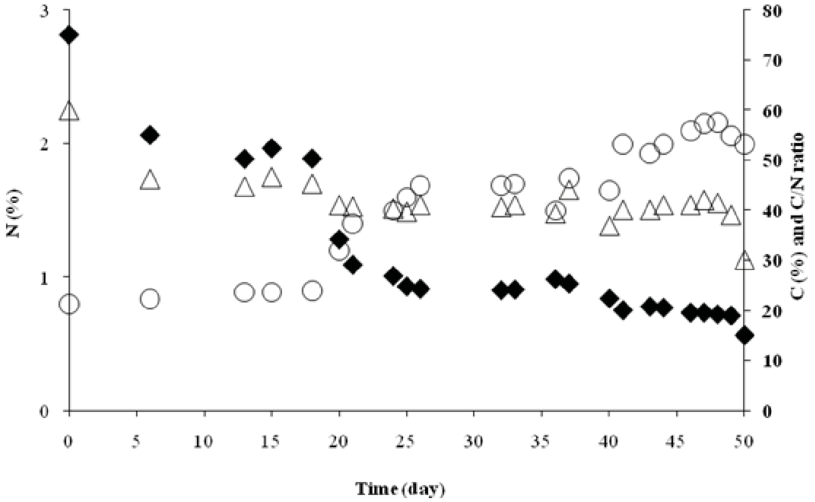

Fig. 4: Changes of nitrogen content, carbon content and C/N ratio throughout composting process (○ : nitrogen; △ : carbon; ◇ : C/N ratio)

According to Margesin *et al*. (2006), the optimum temperature range for composting process was within 50-70°C with 60°C was the most satisfactory temperature whereas prolonged high temperature within 70-75°C might inhibited some of the beneficial microbial action and increased nitrogen loss due to vaporization. The temperature rose sharply during the beginning of composting process and it was suggested on the existent of indigenous bacteria in raw materials (Fig. 3). These indigenous bacteria would progressively oxidised easily degradable carbohydrate and peptin at initial of thermophillic phase, whereas more stable material such as lignin being oxidized in prolonged thermophillic stage (Baffie *et al*., 2006). Meanwhile, it was reported that high temperature ranges between 50°C to 70°C is required to destroy the pathogen exist in pre-mature compost (Oinam *et al.*, 2008).

Lafond *et al*. (2002) also stated that temperature more than 55°C for 3 conservative days would result in compost sanitation. Therefore, the temperature profile obtained in this study (Fig. 2) met the sanitation requirement without external exertion of heat energy to the compost pile. The temperature of compost pile reduced gradually after it reached the maturing phase at day 40 of the treatment. At the end of the composting process, the compost pile shown a significant decreased of temperature (35°C). This indicated that microbial activities had been reduced due to the depletion of biodegradable substrates for the growth and survival.

Moisture content and Oxygen level:

The moisture content was a critical factor to optimize the composting system. According to Lue *et al*. (2008), microbial dependability of water to support growth could affect biodegradation of organic matters. In this study, POME anaerobic sludge was added to the compost materials (OPMF) in order to maintain the optimum moisture content (50-60 %). Tiquia *et al*. (2002) also reported that moisture content around 40 to 60 % was required for microbial survivality while moisture content exceeded 80 % could killed aerobic microorganism due to suffocation. However, high thermophillic phase temperature together with frequent aeration turning in composting process could caused water constantly loss in the form of evaporation. Therefore, the addition of POME anaerobic sludge was crucial to sustain bioactivity as well as supplied nitrogen sources.

In this study, the initial moisture content (Fig. 2) was around 40% and it took around 2 weeks to achieve optimum moisture content (50-60 %). According to Choo *et al.* (1996), oil losses in the fiber after screw press extraction of crude palm oil (CPO) was around 5 to 6%. It is suggested that the oil residue in OPMF compost may restrained the water absorption in the fiber. Lin (2008) reported that thermophillic temperature would assisted decomposition of oil and grease left in the substrates. The moisture content could be maintained after decomposition of oil and grease. The oil and grease content in OPMF compost was reduced from 2597 mg kg^{-1} at day 0 to about 50 mg kg^{-1}, respectively at the end of composting treatment. Oxygen demand was usually high during composting process. The oxygen level profile (Fig. 2) indicated the rapid depletion of oxygen was observed during initial decomposition phase although frequent turning was provided. The rapid expension of microbial population due to active consumption of readily degradable material had contributed to low initial oxygen level (Baffi *et al*., 2006). Besides, oil degradation and slow "burning" of composting materials also contributed to oxygen depletion (Manios *et al*., 2006). The "burning" of oily residues may produced ash that could inhibit microbial growth as well as restrain electical conductivity (EC) increment. However, after depletion of readily degradable material, the oxygen level had increased and maintained till the end of composting process.

Effect of pH:

Fig 3 shows the pH values thoughout the composting process. The reduction of pH observed during initial composting phase was likely caused by the formation of intermitted organic acids and anoxic fermentation due to large consumption of oxygen by oxic bacteria (Lin, 2008). Later, the pH was gradually increased on day 5, which is likely to be the consequences of rapid metabolic degradation of organic acid and intense proteolysis of liberating alkaline ammonia compound due to protein degradation (Guerra-Rodriguez *et al*., 2001; Satijah and Devarajan, 2007). Moreover, addition of treated POME sludge into compost materials (OPMF) also contribute to slightly alkaline condition. In maturity phase, the pH was almost neutral and stabilized, which probably due to buffering nature of humic substances (Satijah and Devarajan, 2007).

Bacterial Count:

The decomposition of the organic materials was performed by microorganism. Therefore, bacteria population profile thoughout the process reflecting microbial activity and compost stability. In this study, the initial total bacteria count was around 4×10^{10} CFU g^{-1} in wet substrates (Fig 3). As the process entered thermophillic phase, it was observed that total bacterial count increased sharply and remain constant for 10 days. This probably due to the domination of thermophillic bacteria and availability of easily degradable materials. However, between day 15 to day 30, the microbial population reduced gradually. This phenomenon might be due to ash formation from prolonged high temperature which indirectly inhibit microbial growth. According to Wong *et al*. (1997), high pH in ash will inhibit microbial growth. Besides, Fig.3, shows that microbial population increased again after thermophillic phase (day 40). This maybe caused by domination of mesophillic microorganism with respect to decrease in compost pile temperature.

C/N ratio:

In this study, nitrogen content was increased steadily whereas carbon content was gradually reduced (Fig. 4). This was attributed by the active microbial cellulolytic degradation and microbial proliferation which immobilize nitrogen (Satisha and Devarajan, 2007). The stability of the compost can be defined as the degree of which organic material have been stabilized by the composting process. According to Ajay *et al*.(2007), compost was consider stable if it contained humus-like product which was not suitable to sustain microbial activity. While, Tiquia *et al.* (2002) reported that drop in C/N ratio, temperature and oxygen consumption reflect the compost maturity. Despite the high C/N ratio of OPMF used in this study, the addition of POME anaerobic sludge could reduced initial C/N ratio of composting material to the acceptable level. The initial C/N ratio of composting material was around 78. Although Ma *et al*. (2003) proposed that the ideal C/N ratio to initiate composting process was 30:1, small and oily OPMF structure may inhibited the addition of POME anaerobic sludge prior to oxygen level limitation.

It was observed that C/N ratio decreased gradually for the first 2 weeks of composting process (Figure 3). This might caused by prolonged thermophillic phase and oily residues in OPMF. The oily OPMF surface could inhibit nitrogen absorption capability of OPMF whereas prolonged high temperature would increased nitrogen loss in the form of evaporation. However, high temperature and aerobic condition could promote oil oxidation. It can be observed that C/N ratio decreased dramatically after removal of oily residues at day 20 (Fig 4) and continued to decrease afterwards. According to Satisha and Devarajan (2007), C/N ratio below 20 was considered as acceptable maturity compost whereas Baharuddin *et al*. (2009) reported that C/N ratio less than 15 was more preferable. In this study, the compost with C/N ratio around 20 was obtained in curing phase after day 40 while C/N ratio around 13 was obtained in day 50. The final C/N ratio was comparable to that mentioned by Baharuddin *et al*. (2009), which used 60 days to compost empty fruit bunch (EFB) to achieve final C/N ratio of 12.

Nutrient changes (Macro and Micro changes):

A high quality compost product was obtained when the compost contains considerable amount of nutrients particularly potassium, phosphorus, ferum, calcium and magnesium. Table 1 shows the nutrients detected in the raw materials and final matured compost. The critical nutrient elements such as potassium (K) and phosphorus (P) were increased with the final concentration of 1.2% and 0.3% , respectively. The K and P detected in the final compost were higher than sludge compost (<0.1%) (Li *et al.*, 2008). The concentration of magnesium (Mg), calcium (Ca), and ferrum (Fe) also increased prior to POME anaerobic sludge addition. The final Ca and Fe concentration were comparable to the result obtained from EFB-POME compost, which were 0.7% and 1.2%, respectively. Furthermore, sulfur content changed slightly probably due to minor consumption by microorganisms and total dry mass rapid decreament (Lu *et al.*, 2009). The micronutrients are essential for plant regrowth and plant healthy (McCrimmon, 2002). The micronutrient elements detected in the compost (Table 1) were zinc (< 200 mg kg^{-1}), manganese (< 200 mg kg^{-1}), copper (< 60 mg kg^{-1}), and boron (< 10 mg kg^{-1}). It is suggested that most of these micronutrients were derived from organic-bound compounds in POME anaerobic sludge.

Heavy Metal:

The heavy metals content (Cr, Cd, Pb, and Ni) in the compost is shown in Table 1. It can be observed that the heavy metals in the final compost was in acceptable level and meeting the USEPA standards. The final heavy metals such as lead (<40 mg kg^{-1}) and chromium (<20mg kg^{-1}) were much lower than oily sludge compost (>70 mg kg^{-1}) (Bengtsson *et al.*,1998). Meanwhile, nickel concentration was lower than 10 mg kg^{-1} and Cadmium was not detectable. This indicated that final compost was below toxicity limit and safe to use as fertilizer.

Conclusions:

Co-composting of OPMF and POME anaerobic sludge was suggested as a feasible approach under controlled conditions. In this study, the oily residues in OPMF had inhibit moisture absorption in composting process as well as promote prolonged thermophillic phase. The compost obtained in this study had achieved C/N ratio around 12 with considerable amount of macronutrients and micronutrients and the heavy metals content were below the toxicity level.

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