UNIVERSITI PUTRA MALAYSIA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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March 2014

Chairman: Azhari Samsu Baharuddin, PhD
Faculty: Engineering

Oil palm empty fruit bunches (OPEFB) are one of the most abundant lignocellulosic biomass produced in palm oil industry throughout the year. With the increasing demand for palm oil worldwide, the amount of oil palm biomass available is expected to grow and composting is one of the best approaches to solve the abundance of this waste. Palm oil mill effluent (POME) is also produced in huge quantities because the ratio of water required to the oil palm fresh fruit bunches (OPFFB) processed is usually 1:1 ratio. Hence, this project was conducted to evaluate the pressed-shredded OPEFB and palm oil mill effluent (POME) anaerobic sludge composting treatment. The project was divided with three stages: 1) Composting process by windrow system at pilot scale; 2) Combinational in-vessel and windrow system at pilot scale; and 3) Composting of OPEFB with formulating palm oil mill effluent biochar solution (POMEBS) aerobic sludge using a lab scale in-vessel composter. All the composting process was completed within 40 days. The process performance was further evaluated by structure degradation analysis using scanning electron microscopy (SEM), Fourier transform infrared (FTIR), Thermogravimetric analysis (TGA) and X-ray diffraction (XRD). The windrow system managed to produce compost with final nutrient contents of N:P:K at 2.6:0.7:3.2 and the final C/N ratio was 14.62. Combinational in-vessel and windrow system produced compost with final N:P:K which stabilized at 2.8:0.4:2.8 and the final C/N ratio was 13.85. Composting OPEFB and POMEBS aerobic sludge managed to produce compost with higher N:P:K which stabilized at 3.7:0.8:6.2 and the final C/N ratio was 10.16. For windrow system, SEM pictures showed that silica bodies were completely removed at day 10 while for combinational in-vessel and windrow system SEM showed silica bodies only partially removed after 7 days after come out from the composter and completely removed after day 20. FTIR results illustrated the chemical reaction of the composting process for transforming OPEFB into mature compost. The results from FTIR were also correlated with XRD and TGA. TGA results showed that composting of OPEFB with POMEBS aerobic sludge have a higher weight reduction of organic matter compared to composting of OPEFB with POME anaerobic sludge which were 21% and 10% respectively. Microbial community analysis by Polymerase Chain Reaction-Denaturing Gel Gradient Electrophoresis (PCR-DGGE) indicated that *bacillus subtilis strain TU2*, *bacillus Sp. MH-16*, uncultured bacterium clone, uncultured firmicutes bacterium, *bacillus Sp. Hs-v2*, *bacterium FA_149* and *bacillus subtilis strainTBR2* were the predominant species at the optimum condition of the POMEBS aerobic sludge. In conclusion, composting

OPEFB with POMEBS succeed in improving the degradation process and produced good quality compost.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN TERHADAP PENGKOMPOSAN TANDAN KELAPA SAWIT KOSONG DENGAN CECAIR ANAEROBIK ENAP CEMAR KELAPA SAWIT

Oleh

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Tandan kelapa sawit kosong merupakan salah satu sisa lignoselulosa yang banyak dihasilkan sepanjang tahun di dalam industri kelapa sawit. Dengan peningkatan permintaan terhadap minyak kelapa sawit di seluruh dunia, jumlah biomas yang terbiar dijangka turut bertambah dan pengkomposan merupakan salah satu langkah untuk mengatasi masalah lebihan sisa ini. Cecair enap cemar kilang kelapa sawit juga dihasilkan dalam kuantiti yang banyak dimana kuantiti air yang diperlukan untuk memproses buah kelapa sawit segar adalah 1:1. Oleh itu projek ini adalah untuk menilai pengkomposan ditekan-dicincang tandan kelapa sawit kosong dengan cecair anaerobik enap cemar kilang kelapa sawit. Projek ini dibahagikan kepada tiga peringkat: 1) Pengkomposan menggunakan sistem batas berskala pilot; 2) Pengkomposan menggunakan gabungan kontena tertutup dan sistem batas berskala pilot; dan 3) Pengkomposan sisa tandan kosong dengan formulasi cecair aerobik enap cemar kilang kelapa sawit dan arang menggunakan kontena tertutup kompos berskala kecil. Kesemua proses pengkomposan lengkap dalam tempoh 40 hari. Prestasi proses dinilai selanjutnya melalui analisis struktur degradasi menggunakan *scanning electron microscopy (SEM), Fourier transform infrared (FTIR), Thermogravimetric analysis (TGA) and X-ray diffraction (XRD).* Sistem batas berjaya menghasilkan kompos dengan nutrisi akhir N:P:K pada 2.6:0.7:3.2 dan nisbah C/N ratio akhir sebanyak 14.62. Kombinasi kontena tertutup dan sistem batas berjaya menghasilkan nutrisi akhir N:P:K pada 2.8:0.4:2.8 dan nisbah C/N ratio akhir sebanyak 13.85. Pengkomposan tandan kelapa sawit kosong dan formulasi cecair aerobik enap cemar kilang kelapa sawit dan arang berjaya menghasilkan N:P:K yang lebih tinggi iaitu 3.7:0.8:6.2 dan nisbah C/N ratio akhir 10.16. Untuk sistem batas, gambar *SEM* menunjukkan badan-badan silika telah berjaya dibuang kesemuanya pada hari ke-10 sementara kombinasi kontena tertutup dan sistem batas menunjukkan hanya sebahagian badan-badan silika berjaya dibuang pada hari ke-7 selepas dibawa keluar dari kontena tertutup dan hanya berjaya dibuang keseluruhannya pada hari ke-20. *FTIR* menggambarkan tindak balas kimia yang berlaku semasa proses pengkomposan menukar tandan kelapa sawit kosong kepada kompos yang matang. Hasil dari *FTIR* kemudiannya dikaitkan dengan hasil analisis dari *XRD* dan *TGA*. Hasil *TGA* analisis menunjukkan pengkomposan tandan kelapa sawit kosong dan formulasi cecair aerobik enap cemar kilang kelapa sawit dan arang menunjukkan penguraian bahan organik adalah lebih tinggi berbanding pengkomposan tandan kelapa sawit kosong dengan cecair anaerobik enap cemar kilang kelapa sawit iaitu masing-masing 21% dan 10%. Analisis mikrobial

menggunakan tindak balas rantaian polimerasi-elektroporasis kecerunan gel denaturasi menunjukkan *bacillus subtilis strain TU2*, *bacillus Sp. MH-16*, *uncultured bacterium clone*, *uncultured firmicutes bacterium*, *bacillus Sp. Hs-v2*, *bacterium FA_149* and *bacillus subtilis strainTBR2* adalah jenis-jenis kelompok mikroorganisma mutlak yang berada dalam formulasi cecair aerobik enap cemar kilang kelapa sawit dan arang. Kesimpulannya, pengkomposan tandan kelapa sawit kosong dan formulasi cecair aerobik enap cemar kilang kelapa sawit dan arang berjaya meningkatkan proses degradasi dan menghasilkan kompos yang berkualiti.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fibre
ADL	Acid detergent lignin
BLAST	Basic local alignment search tool
BOD	Biological oxygen demand
CDM	Clean development mechanism
CFU	Colony forming unit
COD	Chemical oxygen demand
CPO	Crude palm oil
DNA	Deoxyribonucleic acid
FELDA	Federal land development authority
GHG	Greenhouse gas
ICP	Inductively coupled plasma
IRR	Internal rate return
MPOB	Malaysian palm oil board
NDF	Neutral detergent fibre
NPV	Net present value
OPEFB	Oil palm empty fruit bunches
OPFFB	Oil palm fresh fruit bunches
PBP	Payback period
PCR - DGGE	Polymerase chain reaction - Denature gradient gel electrophoresis
POME	Palm oil mill effluent
POMEBS	Palm oil mill effluent biochar solution
SEM	Scanning electron microscope
TS	Total solids
TSS	Total suspended solids
VSS	Total volatile solids

CHAPTER 1

INTRODUCTION

1.1 Treats to Climate Change

The climate change is one of critical issue affecting the world and has been reported to cause numerous adverse effects on ecosystem such as disruption of clean water and food supply, impacts on human health, natural resources and security of human settlement (Sulaiman, 2010). The increasing emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) has been considered worldwide as the major cause of global warming (Kaewmai et al., 2012).

In Malaysia, serious efforts are being taken to reduce greenhouse gas (GHG) emissions because the major increasing emissions of CO_2, CH_4 and N_2O comes from oil palm industry. The oil palm industry is one of the biggest commodity producers in Malaysia. Malaysia has become the world's second largest oil palm producer and exporter after Indonesia (Shuit et al., 2009). The total oil palm planted area in 2011 reached 5 million hectares, an increase of 3% from the previous year (MPOB, 2011). The primary sources of GHG from palm oil production are: 1) emissions from operations during oil palm growing and oil palm fresh fruit bunches (OPFFB) processing; 2) emissions from changes in carbon stocks, during the development of new plantations and the operations of plantations (RSPO, 2009). The main emissions from operations during oil palm growth is the use of artificial fertilisers such as nitrogen fertilisers which contributed to N_2O emissions. Oil palm is the largest consumer of fertiliser in Malaysia which about 80% of industrial crop's fertiliser used in Malaysia (Sabri, 2009). In addition, the expansion of oil palm plantations increases the usage of fertilisers. Besides that, the escalating increase of world fertiliser price gives attention to find other alternative fertilisers such as compost.

In the meantime, OPFFB processing capacity is 54 tonnes per hour and approximately 300,000 tonnes can be processed in a year (Yoshizaki et al., 2012). It generates a large amount of oil palm biomass and waste materials (Abdul Khalil et al., 2012). In oil palm processing mills, each tonne of processed oil palm fresh fruit bunches (OPFFB) produces OPEFB (23%), oil palm mesocarp fibre (OPMF) (12%), shells (5%) and palm oil mill effluent (POME) (60%) (Baharuddin et al., 2010). Overall, oil palm fronds (OPF) (70%) make up most of the biomass produced, followed by oil palm empty fruit bunches (OPEFB) (10%) and oil palm trunks (OPT) (5%) (Ratnasingam, 2011). This biomass is utilised in many ways, including ruminant food (Abu Hassan et al., 1994), bioplastic (Chen et al., 2009), biochar (Mohd Salleh et al., 2010), composting (Baharuddin et al., 2010), pulp and paper (Wan Rosli et al., 2007) and automotive components (Shuit et al., 2009); waste water which generally refers as palm oil mill effluent (POME) is used to capture biogas (Ahmad et al., 2011; Sulaiman et al., 2009). However, there are still an abundance of biomass left in palm oil mills and the most notable is OPEFB. Therefore, OPEFB still used as mulch in the plantation which leads to CH_4 emissions, as a result of anaerobic decomposition (RSPO, 2009). Whereas, pond treatment system is still being used due to excessive POME generates by palm oil mills besides not all palm oil mills in Malaysia have installed the digestive system to capture biogas. The POME has high biodegradable organic material and the naturally available oxygen in pond treatment system is generally insufficient to cater all aerobic decomposition of the organic material (RSPO, 2009). As a result, the decomposition of the organic material turns anaerobic hence produced biogas which cause the CH_4 emissions into the atmosphere. Therefore, compost is one of the promising ways to utilise this biomass while enabling low-cost production.

1.2 Overview on Composting of Organic Waste

Composting is a biological process of breaking up organic waste such as food waste, landscaping waste and agricultural waste by various microorganisms into a humus like substance product (Ali Tweib et al., 2011). The decomposition process can naturally happen almost everywhere even without exerting too much effort because it is an element of ecosystem life cycle. However, without the perfect mixture and proper control, the process slows down and eventually results to unpleasant compost. Olive oil industry in the Mediterranean countries also having a similar situation to palm oil mill in Malaysia where the residues derived from olive oil processing namely olive pomace and olive mill wastewater are generated in great amounts, thus making their disposal a major environmental problem (Plaza et al., 2007). According to Vlyssides et al. (1996), the annual olive oil production is in the range of 0.35 to 0.40 million tonnes, resulting in the generation of about 1.5 million tonnes of olive oil wastewater in Greece while Muktadirul Bari Chowdhury et al. (2013) reported that the annual olive oil wastewater worldwide be over 3 million tonnes. Normally, olive oil waste water treatment is based on evaporation in open air ponds system yielding a sludge residue which is rich in readily decomposable organic matter and plant nutrients (Hachicha et al., 2009). Therefore, in order to overcome the problem, olive oil waste water is being mixed with other organic waste such as tree cuttings, wheat straw, wool waste and animal manure to produce compost (Muktadirul Bari Chowdhury et al., 2013).

Table 1.1: Mechanical properties of some important natural fibre

Fibre	Tensile Strength (MPa)	Elongation (%)	Toughness (MPa)
OPEFB	248.0	14.0	2,000
OPMF	80.0	17.0	500
Coconut coir	140.0	25.0	3,200
Banana	540.0	3.0	816
Pineapple leaf	640.0	2.4	970

Source: Hock (2011)

In Malaysia, besides oil palm industry, there are many other organic waste that has been produced in high amount such as from sugarcane, coconut, pineapple and banana (Alwani et al., 2014). These organic wastes can be considered as carbon to produce compost. Composting usually takes months to complete, depending on characteristic materials used and the composting system. Table 1.1 below shows the mechanical properties of some important natural fibre. OPEFB have moderate tensile strength, high percentage of elongation and toughness compared to other natural fibre. It indicates OPEFB is a strong and tough fibre as high energy is required to break the OPEFB fibre. According to Baharuddin et al. (2013), the longer treatment in the composting process corresponds to the phenolic compound in the OPEFB cell walls which could restrict the rate and extent of polysaccharide degradation. There are four types of widely-applied composting systems, namely open statics piles, turned windrow and piles, aerated static piles, and the in-vessel system (Hubbe et al., 2010).

The success of the compost stabilisation process depends on a suitable environment created by controlling the moisture content, oxygen level, carbon-nitrogen ratio and temperature (Baharuddin et al., 2009). Furthermore, good quality microbe seeding can fasten the degradation rate of organic waste. According to Zainudin et al. (2014), the continuous supply of microorganisms and also nutrients is one of the factors that promote rapid composting through the effective degradation of lignocellulosic materials.

1.3 Problem statements

Nowadays, much attentions are given towards long standing issued such as improvement in palm oil effluent treatment, better handling and utilisation of oil palm biomass, zero-discharge, water conservation and recycling due to greater demands on the environmental protection issues from the environmentalists, non-government organisation and Federal Land Development Authority (FELDA) (Sulaiman, 2010). FELDA have been implemented Clean Development Mechanism (CDM) Projects consisted three parts which are biomass power plant, compost plant and biogas plant. CDM is supervised by an executive board under the guidance of the United Nations Framework Convention on Climate Change (UNFCCC) and certified emission reduction (CER) could be claimed and converted it into a monetary value (Sulaiman, 2010). Introduction of compost derived from the aerobic degradation process OPEFB and POME was one of the waste management measures to reduce environmental impact in palm oil mills. Compost plant was first commissioned in FELDA Maokil, Malaysia and can produce up to 18,000 tonnes of compost annually. Furthermore, Sime Darby Plantation reported that up to 2012, there were 22 composting plants being operated with the potential production capacity up to 600,000 tonnes of compost annually (Yacob et al., 2010).

Table 1.2: Chemical fertiliser consumption and OPEFB compost production estimation quantity

Nutrients	Chemical fertiliser dry weight basis (tonnes)	Chemical fertiliser consumption (tonnes)	OPEFB compost dry weight basis (tonnes)	OPEFB compost produced (tonnes)
Nitrogen, N	1,448	3,842	488	1,295
Phosphorus, P	858	2,276	76	202
Potassium, K	3,348	8,882	1,065	2,825
Total	5,654	15,000	1,629	4,322

(Source: Yoshizaki et al., 2012)

Table 1.2 shows the chemical fertiliser consumption and OPEFB compost production quantity for 300,000 tonnes OPFFB harvested in the year 2010. The consumption of chemical fertiliser is 15,000 tonnes which comprise 1,448 tonnes of nitrogen, 858 tonnes of phosphorus and 3,348 tonnes potassium in dry weight basis (Yoshizaki et al., 2012). On the other hand, composting of 69,000 tonnes OPEFB with the addition of 207,000 tonnes raw POME as microbial seeding produce 488, 76 and 1,065 tonnes of N, P, and K respectively on dry weight basis (Yoshizaki et al., 2012). The amount of compost produced can only cover 4,322 tonnes of chemical fertiliser which is partly the nutritional demand in the plantation. Thus, 10,678 tonnes are still needed to meet the original demand of chemical fertiliser. Table 1.3 shows the capital cost of chemical fertiliser and revenue made by OPEFB compost production. The current market price for chemical fertiliser are RM1,150/tonnes, RM600/tonnes and RM1,040/tonnes of urea (21%N), phosphate rock (28-30% P_2O_2) and potassium chloride (60% K_2O) respectively. Then, the compost price is estimated based on the N:P:K amount of compost. OPEFB compost is estimated can save up to RM4,548,450 annually the capital cost to buy chemical fertiliser. Economic analysis reported by Yoshizaki et al. (2012) shows that the internal rate return (IRR) for compost project is 31%, RM 10.87 million of net present values (NPV) and it takes 2.9 years for payback period (PBP). High IRR and NPV shows that the project is highly profitable to reduce the abundance of biomass produced in palm oil mills and also reduce the capital cost of chemical fertiliser.

Table 1.3: The capital cost of chemical fertiliser and revenue made by OPEFB compost production

Nutrients	Market price RM/tonnes	Chemical fertiliser consumption (tonnes)	OPEFB compost production (tonnes)
Urea (21% N)	1,150	3,842	1,295
Phosphate rock (28-30% P_2O_2)	600	2,276	202
Potassium chloride (60% K_2O)	1,040	8,882	2,825
Total amount		15,000	4,322
Total price		RM15,021,180	RM4,548,450

(Source: Yoshizaki et al., 2012)

However, the main problem facing by these compost plants was low and inconsistent quality of compost in term of N:P:K values. According to Baharuddin et al. (2010), the quality of the final matured compost was difficult to maintain due to the variation of POME characteristics in the open pond system. Therefore, it is essential to provide consistent nitrogen and microbial source which can contribute to a higher N:P:K values. In biogas plant, the treatment of POME by closed anaerobic digester system generates biogas and at the same time it produces POME anaerobic which is high in nutrient content (Sulaiman et al., 2009). Hence, the quality of compost can be improved by the addition of thicken POME anaerobic sludge during OPEFB composting process (Baharuddin et al., 2010). Moreover, the fluctuation of moisture content due to excessive moisture from high rainfall may extend the composting period. Currently, the OPEFB composting project is conducted by using a windrow system and it required a large space to fully utilised OPEFB generated by the palm oil mill. Alternatively, many palm oil mills are near to oil palm plantation, which can provide enough space for the OPEFB windrow composting process. However, the main concern is the transportation and labour costs to transfer OPEFB and POME from palm oil mills to composting sites. On the contrary, if the main carbon source changes to OPF which is most abundant, high cost is still needed for pre-treatments and collection so that it can be suitable as composting material (Shuit et al., 2009).

Hence, in this study POME anaerobic sludge was mixed with pressed-shredded OPEFB to produce compost. The pressed-shredded OPEFB was used as a main carbon source for the composting process because it was available to be used in oil palm mills.

On the other hand, POME anaerobic sludge generated from biogas production provided consistent nitrogen and microbial source for the composting process. During composting, bacteria obtain their carbon through oxidation of the organic materials. With the consistent nitrogen and microbial source, the degradation can be fastened and the matured and stabile composts will be produced. This thesis attempts to contribute to better scientific understanding of OPEFB composting and degradation process and assist in the development of a management system to maximise agronomic benefit and reduce environmental risk.

1.4 Objectives

The objectives of this study are:

1) To correlate stability and maturity determined using biological and physicochemical parameters with functional group structure changes during OPEFB composting treatments by windrow system at pilot scale operation.
2) To evaluate the changes in lignocellulosic structure of OPEFB during composting by combinational in-vessel and windrow system at pilot scale operation.
3) To evaluate the palm oil mill effluent biochar solution (POMEBS) aerobic sludge as microbial seeding for OPEFB composting process by a lab scale in-vessel system.

1.5 Scope of Research

This project was principally concerned about the strategy to produce OPEFB compost with high degradation rate and good quality compost. During the composting process by windrow system at pilot scale, the final ratio of OPEFB to POME anaerobic sludge was 1:2 after having optimise the important factors that affects composting process. While for composting process by a pilot scale combinational in-vessel and windrow system at pilot scale, the ratio of OPEFB to POME anaerobic sludge was initially set 1:3. This is due to the ability of in-vessel system that can fully control the important factors that affect composting process. In the third part of the experiment, the POME anaerobic sludge was formulated and changed to POMEBS aerobic sludge to improve the OPEFB composting process in terms of degraded performance and final compost quality. The ratio of OPEFB and POMEBS aerobic sludge was initially set 1:3. The degradation performance and final compost quality was compared to OPEFB composting with POME anaerobic sludge which was set as control experiment.

1.6 Thesis Structure

Following this brief introduction to the research, Chapter 2 reviews currently available knowledge on pressed-shredded OPEFB and POME anaerobic sludge composting process. Information about composting systems considered in this research is presented in Chapter 3 along with methodology. Based on the objectives, the experimental design was divided into three parts: 1) The first part of the experiment which represent the first objective was the OPEFB composting process by windrow system at pilot scale; 2) the second part which represents the second objective examined the OPEFB composting process by combinational in-vessel and windrow system at pilot scale; and 3) the third part which represents the third objective was effect of POMEBS aerobic sludge for the OPEFB composting process by a lab scale in-vessel system that were detailed discourses in Chapters 4. Final conclusions and recommendations are summarised in Chapter 5.

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