UNIVERSITI PUTRA MALAYSIA

EFFECTIVE COMPOSTING PROCESS FOR LIGNOCELLULOSIC MATERIALS FROM AGRO-INDUSTRIAL WASTE IN MALAYSIA

CHAI EE WEN

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By

CHAI EE WEN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

October 2015

DEDICATION

Special dedicated to:

My Supervisor Committees
ASSOC. PROF. DR. H'NG PAIK SAN
ASSOC. PROF. DR. ARIFIN ABDU
PROF. DR. LUQMAN CHUAH ABDULLAH

My Father
CHAI SIN KEONG

My Mother
CHO SEU LAN

and

My Brothers
CHAI CHUAN CHUN
CHAI CHUAN YAU

Abstract of thesis presented to the Senate of the Universiti Putra Malaysia
in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman : Associate Professor H'ng Paik San, PhD
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Excessive chemical fertilising to soil will compromise future food production by degrading soil fertility. Organic fertilisers in the form of compost provide increased physical and biological storage mechanisms to soils, mitigating risks of over-fertilisation. However, lignocellulosic materials composting require long time to reach maturation. This study was aimed to develop an effective composting process of lignocellulosic materials from agro-industrial wastes in Malaysia. The study started from the selection of feedstock and microorganisms for composting, followed by the determination of most suitable composting environment conditions for microorganisms to degrade the selected compost feedstock. In this study, the effect of moisture content and turning frequency of composting on maturity and quality of compost feedstock were determined. Once the composting parameters are determined, the biodegradation rate of organic substances in selected compost feedstock was evaluated. Through the biodegradation rate of organic substances in selected compost feedstock, the compost feedstock can be mixed together to have effective biodegradation. The C/N ratio of compost was adjusted by having different mixing ratios of the selected compost feedstock for composting process. During composting, temperature, moisture content, pH, oxygen concentration, and colour changes were monitored while total nitrogen, total organic carbon, total organic matter, C/N ratio, chemical composition and colony forming unit were evaluated weekly to draw the trends of these substances over composting time. From the results, empty fruit bunches (EFB), coffee ground and palm oil mill sludge (POMS) were selected as compost feedstock to represent material with the high, ideal and low C/N ratio, respectively. The ratio of 60% of *Bacillus subtilis* and 40% of *Aspergillus niger* showed higher cellulose degradability in filter paper was selected as the best fungus and bacterium ratio for composting. Moisture content of the compost pile should be controlled between 50- 60% throughout the composting period. On the other hand, the measured oxygen concentration was significantly higher by increase the turning frequency in the coffee ground due to the low bulk density and vigorous microbial activity in the compost piles. It was also found out that the moisture content on the surface of compost piles dropped below 50% in 14 days with compost piles without turning and turning every 9 days. Thus,

turning every 6 days on the compost piles was selected as the most practical turning frequency for the EFB, coffee ground and POMS. The study on biodegradation rate of organic substances in the compost feedstock provides information on the composting stages and indicated the selected compost feedstock should be mixed together to enhance the biodegradation rate. Through co-composting, different mixing ratios of selected compost feedstock were composted and C/N ratio of compost piles dropped to 20 in 8 weeks. As a conclusion, effective composting process for EFB, coffee grounds and POMS was developed with 60% of *Bacillus subtilis* and 40% of *Aspergillus niger*, the compost piles should control between 50- 60%, turn the compost pile every 6 day, and through co-composting method.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PROSES PENGKOMPOSAN YANG EFEKTIF UNTUK BAHAN LIGNOSELULOSA DARI SISA INDUSTRI PERTANIAN DI MALAYSIA

Oleh

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Penggunaan baja kimia berlebihan kini telah merosakkan strutur kesuburan tanah seterusnya menjejaskan pengeluaran makanan pada masa depan. Baja organik atau baja kompos dapat meningkatkan fizikal dan biologi mekanisme penyimpanan dalam tanah, dan mengurangkan risiko yang diakibatkan oleh baja terlebih. Walau bagaimanapun proses pengkomposan yang panjang menyebabkan pengkomposan tidak dapat dipraktikkan secara berluas-luasan. Kajian ini bertujuan untuk membangunkan satu proses pengkomposan berkesan untuk bahan lignoselulosa dari sisa buangan industri pertanian di Malaysia. Kajian ini bermula dengan pemilihan bahan mentah dan mikroorganisma untuk kompos, diikuti dengan penentuan keadaan persekitaran yang paling sesuai untuk mikroorganisma untuk mendegradasikan bahan-bahan mentah kompos. Dalam kajian ini, kesan kandungan lembapan bahan mentah kompos dan kekerapan pembalikan kompos atas kualiti dan masa matang kompos ditentukan. Apabila kandungan lembapan dan kekerapan pembalikan kompos ditentukan, kadar biodegradasi dan corak biodegradasi bagi unsur-unsur organik dalam bahan-bahan kompos dikaji. Melalui kajian tentang kadar biodegradasi unsur-unsur organik dalam bahan-bahan mentah kompos dipilih, bahan-bahan mentah kompos ini dicadang untuk dicampur bersama agar meningkatkan kecekapan biodegradasi. Nisbah C/N kompos telah diubahsuaikan dengan mencampurkan bahan-bahan mentah kompos yang dipilih untuk proses pengkomposan. Semasa pengomposan dijalankan, suhu, kelembapan, pH, aras oksigen, dan perubahan warna dipantau manakala jumlah nitrogen, jumlah karbon organik, jumlah bahan organik, C/N nisbah, komposisi kimia dan populasi mikroorganisma dalam kompos dinilai setiap minggu untuk mendapatkan kadar degradasi bahan-bahan ini. Tandan buah kosong (EFB), serbuk kopi dan sisa pepejal buangan kolam minyak sawit (POMS) telah dipilih sebagai bahan mentah bagi kompos berdasarkan ciri-ciri fizikokimia yang diperolehi dalam kajian ini. Ketiga-tiga bahan lignoselulosa ini menunjukan nisbah C/N yang tinggi, baik dan rendah untuk proses pengkomposan. Campuran bakteria dan kulat dengan nisbah 60% *Bacillus subtilis* dan 40% of *Aspergillus niger* menunjukkan degradasi selulosa yang paling tinggi dalam kertas penapis. Selain itu, tiga kandungan lembapan yang berbeza telah diuji ke atas bahan-

bahan lignoselulosa yang dipilih. Ia dicadangkan bahawa kandungan kelembapan longgokan kompos perlu dikawal antara 50- 60% sepanjang tempoh pengkomposan supaya dapat mengelakan bahan lignoselulosa dalam loggokan kompos kering dengan mudah sekiranya tempoh pengompos terlalu panjang. Di samping itu, didapati kepekatan oksigen dalam kompos serbuk kopi terjejas dengan ketara dengan kadar pembalikan kompos yang berlainan. Ini disebabkan oleh serbuk kopi mempunyai ketumpatan pukal yang rendah dan aktiviti mikroorganisma yang aktif dalam kompos. Ia juga mendapati bahawa kandungan kelembapan pada permukaan kompos jatuh ke bawah 50% dalam 14 hari bagi bahan-bahan kompos tanpa pembalikan dan bagi bahan-bahan kompos yang membalik setiap 9 hari. Oleh itu, pembalikan kompos setiap 6 hari dianggap paling sesuai pengomposan bahan lignoselulosa yang dipilih dalam kajian ini. Kajian pada kadar biodegradasi unsur-unsur organik dalam bahan lignoselulosa memberi maklumat tentang peringkat pengomposan dan ia menunjukkan bahan lignoselulosa harus dicampurkan untuk meningkatkan kadar degradasi. Ketiga-tiga bahan lignoselulosa dicampurkan dengan nisbah C/N yang berlainan dan didapati nisbah C/N kompos menurun ke 20 selepas pengomposan selama 8 minggu. Kesimpulannya, proses pengkomposan berkesan bagi EFB, serbuk kopi dan POMS telah dibangunkan dengan 60% *Bacillus subtilis* dan 40% *Aspergillus niger*, kandungan kelembapan longgokan kompos perlu dikawal antara 50-60%, membalikan kompos setiap 6 hari dan ketiga-tiga bahan lignoselulosa harus dicampurkan sekali.

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This thesis is only a beginning of my journey.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the Doctor of Philosophy. The members of the Supervisor Committee were as follows:

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LIST OF ABBREVIATIONS

α	Alpha
%	Percentage
AIA	Actinomycete Isolation Agar
ANOVA	Analysis of variance
As	Arsenic
°C	Degree Celsius
C	Carbon
Cd	Cadmium
CDM	Clean Development Mechanism
CEC	Cation exchange capacity
CER	Certified Emission Reductions
CFU	Colony forming unit
CG	Coffee ground
CH_4	Methane
cm	Centimeter
cm^3	Cubic centimeter
CMC	Carboxyl methyl cellulose
C/N	Carbon to nitrogen
CO_2	Carbon dioxide
Cr	Chromium
DC	Decanter cake
DOE	Department of Environment
DRIFTS	Diffuse reflectance infrared fourier transform spectroscopy
DTA	Differential thermal analysis
EC	Electrical conductivity
EFB	Empty fruit bunches
FA	Fulvic acid
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FELDA	Federal Land Development Authority
g	Gram
h	Hour
H	Hydrogen

H_2SO_4	Sulphuric acid
HA	Humic acid
HCl	Acid hydrochloric
Hg	Mercury
HNO_3	Nitric acid
K	Pottasium
kg	Kilogram
MC	Moisture content
mg	Milligram
min	Minute
ml	Milliliter
MOA	Ministry of Agriculture
MPOB	Malaysia Palm Oil Board
N	Nitrogen
NA	Nutrient agar
NaOH	Sodium hydroxide
NH_3	Ammonia
NH_4	Ammonium
Ni	Nickel
N_2O	Nitrous oxide
NO_3	Nitrate
O	Oxygen
OPF	Oil palm frond
OPT	Oil palm trunk
P	Phosphorus
Pb	Lead
PDA	Potato Dextrose Agar
PKC	Palm kernel cake
POME	Palm oil mill effluent
POMS	Palm oil mill sludge
RISDA	Rubber Industry Smallholders' Development Authority
s	Second
SPSS	Statistical Package for the Social Sciences
TGA	Thermogravimetric

TN	Total nitrogen
TOC	Total organic carbon
TOM	Total organic matter
w	Weight

CHAPTER 1

INTRODUCTION

1.1 General

Agricultural sector is one of the major pillars of the national economy in Malaysia. In 2014, about 24%, 7.9 million hectares of land areas were dedicated to agriculture alone (Hamid and Wan Ahamad, 2014). Evidences of reduction in soil fertility and water quality were rampant due to the chemical intensive culture since 1990 (Pingali *et al*., 2012; Bala *et al*., 2014). In an effort to reduce the dependence on chemical fertilisers and to move towards more natural and healthier approach in food production, government has adopted a range of policies and programs to promote sustainable land management practices. The new National Agro-Food Policy (2011-2020) is aimed on high productivity while ensuring conservation and utilisation of natural resources on a sustainable basis (MOA, 2012). To meet this policy, there is now a concerted effort to use organic fertiliser for essential nutrients in the crops production, while providing a protection to soils for further depletion in nutrients. Composting is defined as a control decomposition that transforms the biodegradable organic materials into a stable and humus-like substance for soil application (Lashermes *et al*., 2012; Coelho *et al*., 2011; Tiquia, 2010). It is an efficient idea to control the quality of the soils in the country.

Agriculture residues accounted nearly 70% of the total 70 million tons of the organic materials discharged per year in the country (Chai *et al*., 2013). The agriculture residues are mostly leftover from primary crops such as oil palm, paddy, cocoa, coffee, pepper, and sugar cane. The residues are derived from plant; composed of a mixture of cellulose, hemicellulose, and lignin which label as lignocellulosic materials. Nutrients present in lignocellulosic materials represent a low-cost, environmentally friendly alternative to inorganic fertilisers for crops' growth. Although the density of nutrients in lignocellulosic materials is comparatively modest, nonetheless, the compost contains insoluble nitrogen and can act as a slow-release fertiliser (Bokhtiar and Sakurai, 2005).

A good quality of compost can promote good soil structure, improves nutrients and water holding capacity, and helps to control soil erosion. With the rise of environmental concerns, composting has emerged as a potential viable mean. It is about producing food in an environmentally sound manner. Composting is the best known environmentally appropriate technology to recycle varieties of lignocellulosic materials with different natures into valuable product. It can bring tremendous benefits to agriculture and land management in the long run and also reduces indiscriminate disposal problems as the agriculture waste residues will create unwanted odour and landfill issues to the nearby stream.

1.2 Statements of Problem

Composting is not a new technology and compost practice has been carried out for centuries. The evolution of compost technology and the feedstock availability have led to the expansion of composting industry in the developing countries. However, when the process moved forward, it was clear that there is lack of comprehensive understanding on the fundamentals, including the properties of feedstock, factors affecting composting process, quality and maturity of compost.

In Malaysia, a lot of local industries fail to do composting in large scale. Failures have been attributed to many reasons; one of the core reasons is the lignocellulosic materials composting required very long time to fully decompose. Several researchers reported that the time taken for lignocellulosic materials to reach maturity stage was about four months and above (Lopez-Gonzalez *et al*., 2014; Paradelo *et al*., 2013; Oviasogie *et al*., 2010; Thambirajah *et al*., 1995). The long term of composting process will directly affect the production cost which is no economic value. In addition, big space is required to store the compost piles due to the lengthy composting process.

1.3 Justification

Compost feedstock has major impacts on the composting process and the quality of final compost due to the multiple ranges of physicochemical properties of the lignocellulosic materials (Chai *et al*., 2013; Makan *et al*., 2013; Singh *et al*., 2011). Variation of organic substances in compost feedstock arise the resistance of certain organic substances to microbial degradation. This will affect the composting rate in different types of materials. In general, composting is a microbial decomposition process, lignocellulosic material is degraded into stable substances with the cooperation of many species of microorganism. Right ratio of microorganisms in compost pile is able to increase the biodegradation rate of lignocellulosic materials.

In addition, proper moisture content and aeration are vital for microorganisms to grow and survive. The effect of moisture content and turning frequency on the biodegradation rate has been investigated by many researchers. It has been reported that the microbial activity will slow down or will stop if the moisture content and aeration in the compost pile out of the optimum range (Makan *et al.*, 2013; Lim *et al*., 2009; Rasapoor *et al*., 2009; Lin *et al*., 2008;Tiquia *et al*., 2002). Hence, different moisture conditions and turning frequency on the compost feedstock were selected as variable in this study.

The degradation of lignocellulosic materials by the microorganisms depends largely on sufficient nutrients available in the materials. Carbon and nitrogen content are the important elements for microorganisms to grow and survive. In

order to increase the effectiveness of biodegradation, C/N ratio of compost need to be adjusted correctly (Sigh *et al*., 2010; Haug 1993). All these nutrients are not present in the available forms for the microorganisms to consume. Further breakdown of the organic substances by the different types of microorganisms is essential for effective composting. Therefore, it is important to understand the biodegradation rate of the organic substances. In this study, it can be hypothesized that with the proper selection of compost feedstock and microorganisms, optimum moisture content, turning frequency and C/N ratio, one is able to increase the efficiency of composting process.

1.4 Objectives of the Study

The general objective of this study is to determine an effective composting process for lignocellulosic materials that available in Malaysia into mature and quality compost.

The specific objectives of this study include;

1. To select suitable compost feedstock and microorganisms for composting based on the physicochemical properties of lignocellulosic materials and cellulose degradation ability by selected microorganisms.

2. To evaluate the effects of moisture content and composting turning frequency of selected feedstock on maturity and quality of compost.

3. To determine the biodegradation rate of organic substances in selected feedstock composted under controlled environment.

4. To accelerate the composting process through co-composting of selected feedstock.

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