UNIVERSITI PUTRA MALAYSIA

KINETIC STUDY OF LABORATORY SCALE COMPOSTING PROCESS

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By

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LIST OF ABBREVIATIONS

CHN	:	Carbon Hydrogen Nitrogen.
C/N ratio	:	Carbon to nitrogen ratio.
MSW	:	Municipal Solid Waste.
k_T	:	Reaction rate at T^oC.
k_{20oC}	:	Reaction rate at 20^oC.
θ	:	Temperature-activity coefficient.
T	:	Temperature.
C	:	Substrate, carbon.
X	:	Free organisms
CX*	:	Activated substrate-orgnism complex.
P	:	By product generated by endogeneous reaction.
k_i	:	Specific reaction rate constant.
R	:	Consumption rate of substrate or reaction rate.
X_T	:	Total microorganisms concentration.
K_1	:	System constant of composting system.
K_2	:	System variable of composting system.
VS	:	Volatile solids.
NVS	:	Non volatile solids or ash.
ASH	:	Ash or non volatile solids.
MC	:	Moisture content.
DR	:	Dry residue.
V	:	Volume of the reactor
dC/dt	:	Rate of change in substrate, mass/volume.time.
dx/dt	:	Rate of change in microorganism, mass/volume.time.
Q	:	Substrate incoming rate, volume/time.
C_{in}	:	Concentration of substrate in incoming stream, mass/volume.
C_{out}	:	Concentration of substrate in outgoing stream, mass/volume.
X_{in}	:	Concentration of microorganism in incoming stream, mass/volume.
X_{out}	:	Concentration of microorganism in outgoing stream, mass/volume

R_c	:	Substrate uptake rate, mass/volume.time.
R_x	:	Microorganism population growth rate, mass/volume.
Y	:	Cell synthesis efficiency or yield coefficient.
k_d	:	Endogeneous decay coefficient.
μ_{max}	:	Maximum specific growth rate constant for miroorganism, $time^{-1}$
C_{in}	:	Incoming substrate concentration.
C_{out}	:	Discharge subatrate concentration.
θ	:	Hydraulic detention time.
θ_{min}	:	Minimum detention time.

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in partial fulfilment of the requirements for the degree of Master of Science.

KINETIC STUDY OF LABORATORY SCALE COMPOSTING PROCESS

By

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May 1999

Chairman: Associate Professor Azni Bin Hj. Idris, Ph. D.

Faculty: Engineering

Solid waste generated in Malaysia constitutes of large portion of organic material that can be readily composted. Composting which dispose off the organic material, and at the same time producing usable compost as the end product is thought to be a good option for organic wastes disposal. This project accomplished kinetic study of composting process that may be of use for the design and process optimization. This study was conducted under controlled laboratory experimental set up; operated at 40^oC, equipped with aeration facility, with boiled rice and soil as the organic material. The volatile solid was employed as the process indicator throughout the course of this project. The data was manipulated and best fitted based on the procedure of Michaelis Menten model. The model resulted in an experimental exponential equation. It also enable the formulation of another linear equation therefrom, that eventually give in the value of K_1 and K_2 (whereby K_1 is the process constant and K_2 is the process variable of a composting system). The model produced has a mathematical expression of $y = 88.357x^{-0.2490}$ with R-square value of 0.8148, and gave in the value of K_1 and K_2

of 80.6102 and 1.0502. The model was verified by another set of verification data. Three verification methods were carried out, that were Differences analysis, Percent of error analysis, and Ratio of experimental data over verification data. The results showed that the model is capable of describing the actual status of the process. However, if this model is to be applied for the design of composting facility, Monod equation that governs the microbial aspect should be incorporated.

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

KAJIAN KINETIK UNTUK PROSES PENGKOMPOSAN SKALA MAKMAL

Oleh

NG HON SENG

Mei 1999

Pengerusi: **Profesor Madya Azni Bin Hj. Idris, Ph. D.**

Fakulti: **Kejuruteraan**

Sisa pepejal yang dihasilkan di Malaysia mengandungi sebahagian besar bahan organik yang boleh diuraikan secara mikrobiologi. Pengkomposan yang boleh menguraikan bahan organik, dan pada masa yang sama menghasilkan kompos yang berguna adalah suatu pilihan yang difikirkan sesuai untuk pelupusan bahan organik. Projek ini menyentuhi aspek kinetik yang amat berguna kepada rekabentuk dan pengoptimuman proses pengkomposan. Projek ini telah dijalankan di dalam makmal di bawah keadaan eksperimen yang terkawal; iaitu suhu operasi pada 40°C, dilengkapkan dengan kemudahan pembekal udara, dengan nasi dan tanah sebagai bahan organik. Pepejal meruap telah digunakan sebagai penunjuk proses sepanjang eksperimen ini. Data yang diperolehi telah digunakan dan dipadankan berdasarkan prosedur dalam permodelan Michaelis Menten. Model ini telah menghasilkan persamaan eksponen secara eksperimen, dan membolehkan pembentukan suatu lagi persamaan linear, yang akhirnya telah memberi nilai K_1 dan K_2 (di mana K_1 adalah suatu pemalar proses, dan K_2 adalah suatu pembolehubah proses untuk sesuatu sistem pengkomposan). Model yang

dihasilkan boleh diungkapkan dalam persamaan matematik sebagai $y = 88.357 x^{-0.2490}$ dengan nilai R-kuasa dua sebanyak 0.8148, dan memberi nilai K_1 dan K_2, 80.6102 dan 1.0502 masing-masing. Model ini telah disahkan dengan suatu set data pengesahan lagi. Tiga cara pengesahan telah dijalankan, iaitu analisa perbezaan, analisa peratus kesalahan, dan nisbah data eksperimen kepada data pengesahan. Keputusan yang diperolehi menunjukkan bahawa model ini mampu menggambarkan status sebenar proses pengkomposan. Walaubagaimanapun, persamaan Monod yang merangkumi aspek mikrobiologi perlu dipertimbangkan, sekiranya model ini hendak digunakan di dalam merekabentuk kemudahan pengkomposan.

CHAPTER I

INTRODUCTION

General

Solid waste is one of the three major environmental problems faced by municipalities in Malaysia (The World Bank, 1993). The total amount of solid waste generated in Malaysia in 1994 was about 9,535 tonnes per day or 3.5 million tonnes per year (Malaysia Industry-Government Group of High Technology, 1994). The per-capita generation rate varies from 0.45 kg/cap/day to about 1.44 kg/cap/day, and the national average was estimated to be about 0.77 kg/cap/day. The organic content which is readily biodegradable are 48.4% for city area (Kuala Lumpur), 35.0% for moderate-urban area (Seremban) and 63.7% for rural area (Muar) of the total weight of solid waste generated (Nasir *et al*., 1996). Therefore, a total diversion of organic waste portion from the solid waste generated will reduce 4,675 tonnes per day or 1.75 million tonnes per year of solid waste.

In view of the high percentage of organic material in the solid waste generated in Malaysia, composting which employs a biological process to decompose organic material naturally, is thought to be a potential alternative in converting the organic materials in the solid waste to become useful compost for land applications. In fact, composting has been one of the four major waste disposal routes in many countries (Warmer, 1995).

Composting is not a common practice for solid waste disposal in Malaysia. There is no composting facility specifically designated for solid waste disposal. However, it was practised by some farmers to dispose off their post-harvest products, such as rice straws, and some small scale composting facility to produce fertiliser or soil conditioner commercially.

There are not much study been carried out by our local scientists, especially in the area of kinetics, which may be of crucial importance from an engineering point of view, because process kinetic is one of the major controlling factors in the optimisation of the process. This study is therefore initiated on this basis, to ascertain the kinetic behaviour of the composting process, and thereby provide fundamental information required for optimisation.

Objectives

This project aims to study the kinetic behaviour of composting process. The objectives of the study are as follows:

- To characterise the kinetic behaviour of composting process by using Michaelis-Menten model.
- To suggest a mathematical algorithm for the design of composter based on the kinetic model produced in the first objective.

Scope of Study

This project will study the composting process to dispose off food waste. The raw material used was rice. There is no prior amendment on the chemical composition of the composting materials been attempted, neither did any bulking agents that may change the physical properties of the composting materials been added. However, rich topsoil was added for microorganism innoculation. The characterisation of the composting process was carried out for the first 10 days after the raw material was innoculated; as most of the domestic food wastes can completely be composted within 7 days (Golueke, 1977). There is also no temperature dependent term been included in the model, primarily due to the fact that composting is a self heat generating process, temperature for the process may change from ambient temperature for the process to thermophilic temperature, and eventually back to the ambient temperature again upon maturation. The main focus of this project is to study the kinetic of composting process by using volatile solids as the indicator.

Rationale of the Study

Composting process which decomposes organic material microbiologically can best be characterised by the organic content of the waste material. Organic content can in turn be quantified by measuring the carbon content. In the previous study done by Whang and Meenaghan (1980), the carbon concentration was measured by using CHN analyser, which performed very well for the raw material used. The raw material used was cattle manure and sawdust, which are considered as quite homogenise compared to other domestic waste. Whang and Meenaghan, (1980) did not mention the amount of sample collected to perform the analysis. However, most of the CHN analyser requires only minute amount of sample, which is as minute as 0.5 mg or less (for the model of CHN analyser available in Soil Science Department and Chemistry Department in UPM, and Chemistry Department in UKM). The precision of the technology is undoubtedly high. However, minute amount of sample collected for analysis in the case of composting, which deals mostly with heterogeneous waste, may not be as appropriate as it is for the case of homogenised sample.

In view of the shortcoming observed for CHN analysis, volatile solids content, which can be measured by heating up the sample to 550^{o}C, was therefore used to characterise the kinetic behaviour of composting process in this project.

CHAPTER II

LITERATURE REVIEW

This chapter discusses the principles of composting process from all aspects. The microbiology and limiting factors were highlighted. Brief introduction on the study of reaction kinetic from chemical engineering aspect had also been included to facilitate further discussion on the kinetic model adopted for this study.

Definition

'Composting is a method of solid waste management whereby the organic component of the solid waste stream is biologically decomposed under controlled conditions to a state in which it can be handled, stored, and/or applied to the land without adversely affecting the environment' (Golueke, 1977). Golueke had defined composting in such a way to distinguish it from other biological decomposition processes, with emphasis on the controlled conditions, the state of composted materials and the usage of compost.

In addition, Haug (1993) elaborated the conditions in which composting is differed from the natural decomposition process. He defined composting as 'the biological decomposition and stabilisation of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land'.

Classification of Composting Process

Composting process can be classified from the aspect of aeration, temperature, and technology. According to Golueke (1977), there are three types of classification, which are:

1. Aerobic or anaerobic
2. Mesophilic or thermophilic
3. Mechanised or non-mechanised (synonyms for closed or open system)

Aerobic composting is the designation given to those composting processes that involve decomposition in the presence of air. Conversely, anaerobic composting implies decomposition in the absence of air.

Generally, there are some typical temperature ranges for various microorganisms, namely psychrophilic, mesophilic and thermophilic. However, there are only mesophilic and thermophilic microorganisms which are of importance in composting. Mesophilic microorganisms are those organisms that have an optimum temperature range within 8 to 45°C or 10 to 50°C. Thermophilic microorganisms develop when the temperature exceeds about 45 to 50°C and they thrive best in the range of 50 to 60°C (Golueke, 1977).

Haug (1993) addressed the third classification as reactor and nonreactor processes. Reactor system is also popularly termed as in-vessel system (Walker *et al.*, 1986), enclosed system (Anderson *et al.*, 1984), and mechanical (as classified by Golueke, 1977). This classification is based on the technology involved. According to Golueke (1977), mechanical composting as its name implies, involves the use of mechanized, enclosed units equipped to provide control of the major environmental factors. However, non mechanized composting is generally referred to the open or windrow composting, whereby the raw materials are stacked in elongated piles (windrows) and allowed the composting process to proceed therein.

Principles of Composting

In the aerobic process, oxygen will be utilised by living organisms to decompose and assimilate organic matter together with some of the carbon, nitrogen, phosphorus, sulphur and other elements for synthesis of their cell protoplasm. Carbon is a source of energy and protoplasm is a building material