# THE DECOMPOSITION PROCESS OF FOOD WASTE FOR ORGANIC FERTILIZER PRODUCTION AT ENGINEERING CAMPUS, UNIVERSITI SAINS MALAYSIA

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By

MOHD FIRDAUS BIN AHMAD IDRUS

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# ABSTRAK

Teknologi pengkomposan adalah salah satu cara paling berkesan untuk meminimumkan sisa pepejal. Dalam kajian ini, teknik yang dipilih ialah kompos aerobik. Pengkomposan aerobik digunakan sebagai pendekatan untuk penyiasatan ini. Pengkomposan aerobik adalah kaedah penguraian sisa organik yang menggunakan gas oksigen. Kerana kehadiran oksigen, proses pengkomposan ini amat berkesan dalam mengurangkan bau busuk yang disebabkan oleh gas ammonia dan hidrogen sulfida. Ini, seterusnya, boleh mengurangkan kesan pencemaran alam sekitar. Kaedah pengkomposan yang digunakan dalam kajian ini ialah pengkomposan dram, di mana sisa makanan dan sisa halaman dikompos di dalam tong/kompos. Kajian ini telah dibahagikan kepada tiga peringkat iaitu peringkat 1, 2 dan 3. Peringkat 1 merupakan kajian penentuan ciri-ciri fizikal dan kimia ke atas sisa taman seperti kandungan lembapan, pH dan nisbah karbon kepada nitrogen (C: N). Dalam peringkat 2, kajian pengkomposan dilakukan terhadap campuran sisa makanan dan taman dengan nisbah 1:1. Pada peringkat ini juga, cecair rumen sebanyak 6-liter juga telah ditambah sebagai peransang dalam mempercepatkan proses kompos di dalam tong. Semasa proses pengkomposan, kompos ini akan melalui pemantauan secara berkala iaitu pemantauan dari segi suhu, kandungan lembapan, pH dan nisbah C: N. Pada peringkat 3 pula, kajian pengkomposan dilakukan terhadap campuran sisa makanan dan taman dengan nisbah 2:1. Pada peringkat ini juga, cecair rumen sebanyak 3-liter juga telah ditambah sebagai peransang dalam mempercepatkan proses kompos di dalam tong. Semasa proses pengkomposan, kompos ini akan melalui pemantauan secara berkala juga iaitu pemantauan dari segi suhu, kandungan lembapan, pH dan nisbah C: N. Kompos yang terhasil turut diuji kandungan nutrient (nitrogen dan potasium) menggunakan kaedah ICP dan kandungan logam berat (Fe, Zn, Cu, Cd) diuji menggunakan kaedah AAS. Peringkat 3 merupakan peringkat naik taraf daripada peringkat 2. Jadi keputusan yang diperolehi di peringkat 3 adalah lebih baik daripada peringkat 2. Hasil kajian mendapati

terdapat Peningkatan suhu ke fasa termofilik (> 45 °C) pada peringkat 3. Suhu tertinggi yang dicatatkan adalah 46.87°C. Pada peringkat 2, peningkatan suhu yang tinggi tak dapat dihasilkan dimana kompos peringkat ini hanya merekodkan 43.4°C. Nisbah C: N yang terhasil pada peringkat 3 adalah kurang 20:1 dimana lebih baik daripada nisbah C: N yang terhasil pada peringkat 2. Nisbah C: N yang terhasil pada peringkat 2 adalah lebih daripada 20:1. Dari segi peratus kandungan lembapan, peringkat 3 merekodkan peratus lebih baik iaitu sebanyak 61.23% berbanding 73% yang dicatatkan pada peringkat 2. Perubahan pH bagi kompos pada peringkat 3 juga berada pH yang diinginkan iaitu lebih besar daripada pH 7 iaitu 7.45 berbanding kompos yang terhasil pada peringkat 2 yang disifatkan terlalu beralkali iaitu 8.81. Keputusan dari segi nutrient dan logam-logam berat pada peringkat 3 juga disifatkan sebagai baik dan boleh digunakan sebagai bahan penambah baik kepada tanah. Berdasarkan pemerhatian kasar, didapati kompos yang dihasilkan pada peringkat 3 adalah lebih sesuai digunakan berbanding kompos yang terhasil pada peringkat 2. Ini disebabkan oleh, kompos peringkat 3 mempunyai ciri-ciri kompos yang sudah matang berbanding kompos peringkat 2. Kompos yang sudah matang mempunyai warna yang lebih gelap, baunya seakan-akan tanah dan berliang. Jadi ciri-ciri ini dapat dilihat pada kompos peringkat 3 tapi tidak pada kompos peringkat 2. Kadar pengeluaran hasil baja organik daripada $1m^3$ sisa bagi peringkat 2 adalah $0.033\ m^3$ dan bagi peringkat 3 pula adalah $0.059\ m^3$.

# ABSTRACT

Composting technology is one of the most effective ways to minimize solid waste. In this study, the technique chosen was aerobic composting. Aerobics composting was used as the approach for this investigation. Aerobic composting is a method of decomposing organic waste that employs oxygen gas. Because of the presence of oxygen, this composting process is particularly efficient in decreasing the foul odour caused by ammonia gas and hydrogen sulphide. This, in turn, can lessen the environmental impact of pollutants. The composting method utilized in this study is drum composting, in which food waste and yard waste are composted in a bin/composter. This study has been divided into three stages, namely Stages 1, 2 and 3. Stage 1 is a study to determine the physical and chemical properties of yard waste such as moisture content, pH, and carbon to nitrogen (C: N) ratio. In Stage 2, a composting study was performed on a mixture of food and yard waste in a 1: 1 ratio. At this Stage, 6 liters of rumen fluid were also added as a stimulant in speeding up the composting process in the composter. During the composting process, the compost will go through periodic monitoring in terms of temperature, moisture content, pH and C: N ratio. In Stage 3, a composting study was performed on a mixture of food and yard waste with a ratio of 2: 1. At this stage, 3 liters of rumen fluid were also added to the composter. During the composting process, the compost will go through periodic monitoring as well, namely monitoring in terms of temperature, moisture content, pH and C: N ratio. The resulting compost was also tested for nutrient content (nitrogen and potassium) using the ICP method and heavy metal content (Fe, Zn, Cu, Cd) was tested using the AAS method. Stage 3 is an upgrade Stage from Stage 2. So, the results obtained in Stage 3 are better than in Stage 2. The results showed that there was an increase in temperature to the thermophilic phase (> 45 ° C) at Stage 3. The highest temperature recorded was 46.87 ° C. In Stage 2, a high-temperature increase could not be produced where the compost of this stage only recorded 43.4 ° C. The C: N ratio produced in Stage 3 is less than

20: 1 which is better than the C: N ratio produced in Stage 2. The resulting C: N ratio in Stage 2 is more than 20: 1. In terms of the percentage of moisture content, Stage 3 recorded a better percentage of 61.23% compared to 73% recorded in Stage 2. The change in pH for compost in Stage 3 is also the desired pH which is more significant than pH 7 which is 7.45 compared to the compost produced in Stage 2 which is considered too alkaline which is 8.81. The results in terms of nutrients and heavy metals at Stage 3 are also considered good and can be used as an enhancer to the soil. Based on the rough observation, it was found that the compost produced in Stage 3 is more suitable for use than the compost produced in Stage 2. This is due to, Stage 3 compost having the characteristics of mature compost compared to Stage 2 compost. Mature compost has a darker color, smells like soil and is porous. So, these characteristics can be seen in Stage 3 compost but not in Stage 2 compost. The production rate of organic fertilizer from 1m3 of waste for stage 2 is 0.033 $m^3$ and for stage 3 is 0.059 $m^3$.

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# LIST OF ABBREVIATION

| Acronym | Description |
|---|---|
| AAS | Atomic Absorption Spectrometry |
| C | Carbon |
| Cd | Cadmium |
| CCD | Charge Coupled Device |
| $CH_4$ | Methane |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cu | Copper |
| Fe | Ferrous |
| HCl | Hydrochloric acid |
| $HNO_3$ | Nitric Acid |
| $H_2O_2$ | Hydrogen Peroxide |
| ICP-MS | Inductively Couple Plasma Mass Spectrometry |
| K | Potassium |
| N | Nitrogen |
| $NH_3$ | Ammonia |
| $NO_2$ | Nitrogen dioxide |
| pH | Potential of Hydrogen |

| | |
|---|---|
| USM | Universiti Sains Malaysia |
| Zn | Zinc |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background Study

The issue of solid waste management is the most difficult for authorities in both small and major cities in developing countries. This is mostly owing to the rising generation of such solid waste and the resulting financial load on municipalities (Abdel et al., 2018). The generation of solid waste is proportional to the population size. In Malaysia, insufficient garbage collection equipment, a lack of appropriate waste management rules, and technological constraints such as solid waste management planning and operation are all issues associated with inefficient waste management (Jaafar et al., 2018). Solid waste can be categorized into many materials such as paper, glass, metal, yard trimmings, food waste, etc. For this study, food waste will be more emphasized as it has great potential to be converted into organic fertilizer. Food waste is generated at a rate of 16,688 tons per day in Malaysia. Even though it is biodegradable and has a high potential for composting, nearly 80% of all food waste is still disposed of in landfills (Hashim et al., 2021). There are many adverse effects of letting food waste increase from year to year. For instance, food waste will cause a greenhouse effect from methane ($CH_4$) emissions (Omoleye et al., 2020). It occurs from aerobic decomposition which creates very little $CH_4$ for the first month after food waste has been thrown out at the landfill. But within a year, anaerobic conditions in the landfill will take place and bacteria decompose the waste and produce $CH_4$ as a by-product (Omoleye et al., 2020).

Composting initiatives are a fantastic way to reduce the amount of solid waste in landfills. Besides that, it also can improve human health, reduce erosion as well as saves time and money. For instance, composting is the natural process of converting organic matter, such as leaves and food scraps, into a beneficial fertilizer that may be used to improve the quality of soil and plants (Cheong et al., 2020). From that, organic fertilizer from food waste will allow for quicker vegetation growth and then make the structure of the plant strong (Rastogi et al., 2020). Then, erosion incident risk can be reduced. Many technologies can be used to treat organic waste (e.g., food waste, yard waste) such as anaerobic digestion, aerobic composting, and chemical hydrolysis (Wang et al., 2019). In this study, aerobic composting was selected to treat food waste based on several advantages over other methods. When compared to anaerobic treatment, aerobic composting is quick, with the decomposition process completed in eight to twelve weeks and no foul-smelling gases produced. (Mehta et al., 2018). Organic waste composting is currently acknowledged as a viable approach for improving soil health, developing soil ecosystems, and ensuring agricultural output sustainability. Stable compost products aid in the replenishment of plant nutrients, the preservation of soil organic matter, and the enhancement of soil's physical and microbiological properties. For this study, 8 cafeterias in Universiti Sains Malaysia (Engineering Campus) area were chosen which is in Nibong Tebal, Pulau Pinang.

## 1.2 Problem Statement

Universiti Sains Malaysia (Engineering Campus) has 8 cafeterias operated by different contracted food companies which are under Teratai Madu Trading, MMI Global Empire, Sa'ayah Yusoff, Yiezie Empayar Enterprise (Burger), Rosnaida Hambali, Mohd Asmawi Abdul Rahman, Katering Selera Mutiara, and Airieda Enterprise. These contracted companies have a responsibility to provide food and beverage to students as well as staff working on campus. In general, food waste in the Engineering Campus is generated daily if the cafeteria is operating. This can be supported based on the sampling of food waste research conducted by Kamaruddin et, al. (2017) in the USM cafeteria. The total amount of food waste created within 30 days of the sampling period was 3,402.2 kg or 113.4 kg per day. The average quantity of food waste generated by eight cafeterias was computed based on seven consecutive days of total food waste generated by eight cafeterias in four weeks for each day. From the food waste characterization works, they found that bones had the largest percentage of the total, followed by vegetables and grains, with 39, 27, and 10 %, respectively (Kamarudin et al., 2017). Based on the data on food waste generation and characterization, it can be concluded that food waste is the best candidate to produce organic fertilizer and can provide benefits by converting it into beneficial products instead of being disposed of directly at the landfill (Cheong et al, 2020). Thus, Universiti Sains Malaysia (Engineering Campus) can collaborate with the owner of contracted food companies at that campus to produce organic fertilizer from food waste generated and then use them to replace existing fertilizer in USM (Engineering Campus).

## 1.3 Objectives

This study aims to convert food waste into a product that is more environmentally friendly and can be widely used in agriculture, namely as compost. The main method that has been used is aerobic composting i.e bin composting.

The main objectives of this study are:

1) To determine the quality of organic fertilizer in terms of factors influencing the composting process (pH, C: N ratio, temperature, moisture), nutrient content (nitrogen, potassium), heavy metal content (Fe, Zn, Cu, and Cd), and the characteristics of the final compost.
2) To determine the production rates of the yield of organic fertilizer from $1m^3$ of waste.

## 1.4 Scope of work

This study covered laboratory determination of pH, temperature, moisture content, and C: N of main raw materials such as food waste (rice, vegetable, and fruit waste) and yard waste. Rumen fluid was added to the composting mixture to speed up the decomposition process and improve the quality of nutrients. Some microorganisms in the rumen fluid, such as bacteria, fungi, and protozoa, can aid in decomposition. The parameters such as pH, temperature, moisture content, and C: N determination are the first laboratory determination that has been done routinely (except on weekend days) during the composting process until mature compost can be identified. It can be identified if the final compost obtained was dark-colored (dark brown or black), with an earthy smell, and porous.

After that, ICP (Inductively Coupled Plasma) Spectroscopy methods were utilized to measure potassium (K) contents. Next, the heavy metal determination (Fe, Zn, Cu, and Cd) will be proceeded using Acid Digestion *(EPA 3050B).* After the acid digestion, Atomic Absorption Spectrometry (AAS) was used to analyze the heavy metal contents in the final compost. The result will be compared with the existing standard of fertilizer used in Malaysia. To determine the production rate of organic fertilizer from $1m^3$ of organic waste, the height of the initial compost in the compost bin will be identified. So, the volume of the final compost can be determined by subtracting the height of the initial and final compost marked on the compost bin. The resulting compost will be used as organic fertilizer.

**1.5 Layout of Dissertation**

This study is divided into five chapters: introduction, literature review, methodology, results and discussion, and conclusion. Chapter 1 covers the overview or research background of the study, the problem statement, the scope of study to be covered, the specific objectives to be achieved as well as the dissertation layout. Chapter 2 reviews thoroughly the technical aspects of composting process involved including the factors affecting the composting process (temperature, C: N, pH, and moisture content) and types of composting systems. Previous results and analysis were discussed and compared for a better understanding of the directions of this present work. The information related to the composting of food waste was also defined in this chapter. A general overview of methodologies used throughout the research is presented in Chapter 3. In this chapter, an overall experimental design flowchart including raw material preparation until determination quality and quantity of fertilizers are elaborated. Chapter 4 further outlines the results obtained as well as a discussion of the results that are obtained from the experiments concerning the objectives of the study. Chapter 5 presents the conclusion of the overall findings from the current study. In addition, some recommendations for future research related to this area to give the implication and importance for further study will be covered in this chapter. The contribution of this study to civil engineering will be discussed.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This research focuses on food waste composting. This chapter discusses the theoretical foundation of the composting process, as well as the parameters influencing the composting process (temperature, C: N, pH, and moisture content) and types of composting systems. The information related to the composting of food waste was also explained in this chapter

## 2.2 What is composting?

The use of composting technology for plant growth is thought to be as old as agriculture itself. Composting was discovered in clay tablets around 2300 B.C. during the Akkadian empire (Rodale et al., 1960). In the early 20$^{th}$ century, controlled studies about compost making and compost use has been discovered. In the same century, numerous projects have been conducted and making composting technology has been approved successfully based on its effectiveness in terms of improvement of horticultural crops (Wang et al., 2019).

Composting technology is largely based on an empirical approach to intensively managed organic waste biodegradation (Fan et al., 2021). Composting has traditionally been defined as the use of thermophilic conditions and thermophilic microbial consortia to biodegrade organic wastes in a matrix enriched with readily degradable organic substrates, bulking agents, nutrients, and moisture (Elliot, 1988). To retain heat, the process relied on the exothermic reactions of the microbial consortium and the insulating properties of the compost matrix. Retaining the heat produced over a given time does eliminate human pathogens from the compost product (Ayilara et al., 2020). Microorganisms have been linked to the composting of munitions-contaminated soils (Fayiga et al., 2018).

### 2.3 Classification of the composting process

Composting is the biological decomposition of organic matter. Microorganisms play an important role in this process by breaking down organic matter into a more stable material known as compost. There are two types of composting processes: aerobic and anaerobic.

#### 2.3.1 Aerobic composting process

The decomposition of organic matter in the presence of oxygen is involved in this process. This reaction produces $CO_2$, $NH_3$, water, and heat as a by-product. The input-output analysis of the aerobic composting process is depicted in Figure 2.0.

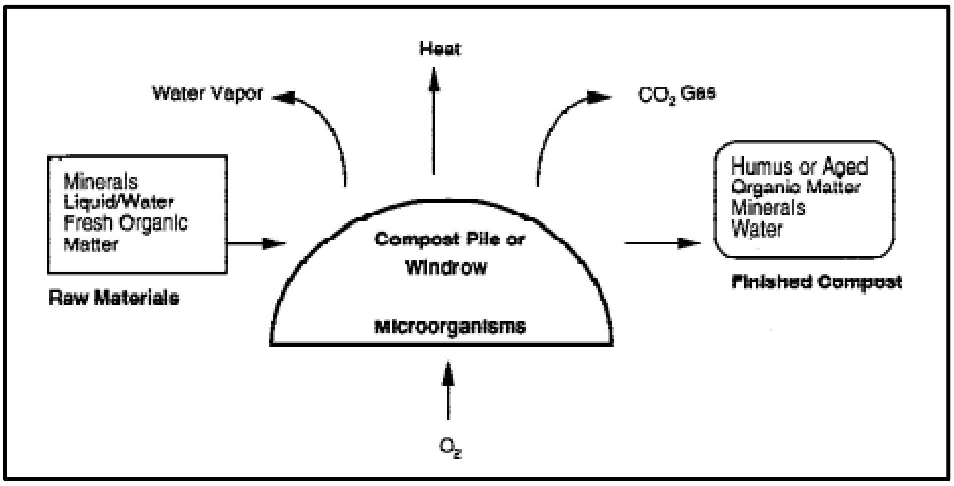


Figure 2.0: Input-output analysis of the aerobic composting process (Source: Pace et al., 1995)

The amount of oxygen consumed is high at the start of the process and then decreases as the compost matures (Wang et al., 2021). Aerobic bacteria will also consume carbon more quickly than nitrogen. If the ratio is insufficient, the nitrogen will be depleted while some carbon will remain, causing bacteria to die. Excess nitrogen would result in ammonia formation, which would stymie digestion. This process will use organic waste as an energy source, while nitrogen will be recycled (Paritosh, et al., 2017).

### 2.3.2 Anaerobic composting process

Anaerobic composting is the decomposition of organic matter that takes place in the absence of oxygen. This procedure takes longer than aerobic composting. The product is typically composed of $CH_4$, $CO_2$, $NH_3$, acidic gases, and a foul odour. Decomposing substances tend to become more acidic under anaerobic conditions.

## 2.4 Composting methodology

The composting method is classified into two types: open method and mechanical method (Diaz et al., 1993). The open method is composed of two methods: the static stack method (windrow) and the aerated static pile method (aerated static pile). In-vessel mechanical methods include vertical reactors, horizontal reactors, and rotary drums. Aside from these two main methods, two others are becoming increasingly popular in organic waste composting: vermicomposting and thermophilic composting.

### 2.4.1 Open method

This method is simple and does not necessitate a high level of technological expertise. It can process any type of organic waste, including animal feces, sewage sludge, and yard waste, and can convert large amounts of waste into compost. The material to be composted is mechanically agitated to introduce oxygen as well as to (and thus) control the temperature and mixing effect of the material in the former. The substrate in the latter is static and the air is blown through it. The agitated and static bed aeration systems are represented by the windrow and static pile processes, respectively.

**a) Windrow Composting System**

Windrow composting involves placing raw materials in long, narrow piles or windrows that are turned regularly. Aeration is introduced into the setup due to the mixing of the materials. A typical windrow composting setup should begin at 3 feet for dense materials such as manures and 12 feet for fluffy materials such as leaves (Gonawala and Jardosh, 2018). It is difficult and costly to support, but it is rapid and retains heat. If such a windrow is left without mechanical agitation or turning, natural aeration occurs through diffusion and convection currents, but composting proceeds very slowly, taking more than a year to complete. The process is greatly accelerated by periodic turning, which not only aerates but also homogenizes the waste, resulting in a more uniform breakdown. Turning can be done by anything from front-end loaders on small sites to self-propelled specialized turners that straddle the windrows at larger facilities, depending on the size of the operation. Windrows necessitate a large amount of land and can cause odour issues, particularly during turning operations. They may also expel fungal spores and other bioaerosols. Despite these disadvantages, windrow composting accounts for most centralized composting systems, possibly because windrow composting is frequently carried out as an addition to existing landfill operations or on the outskirts of towns and cities, reducing nuisance to people living nearby.

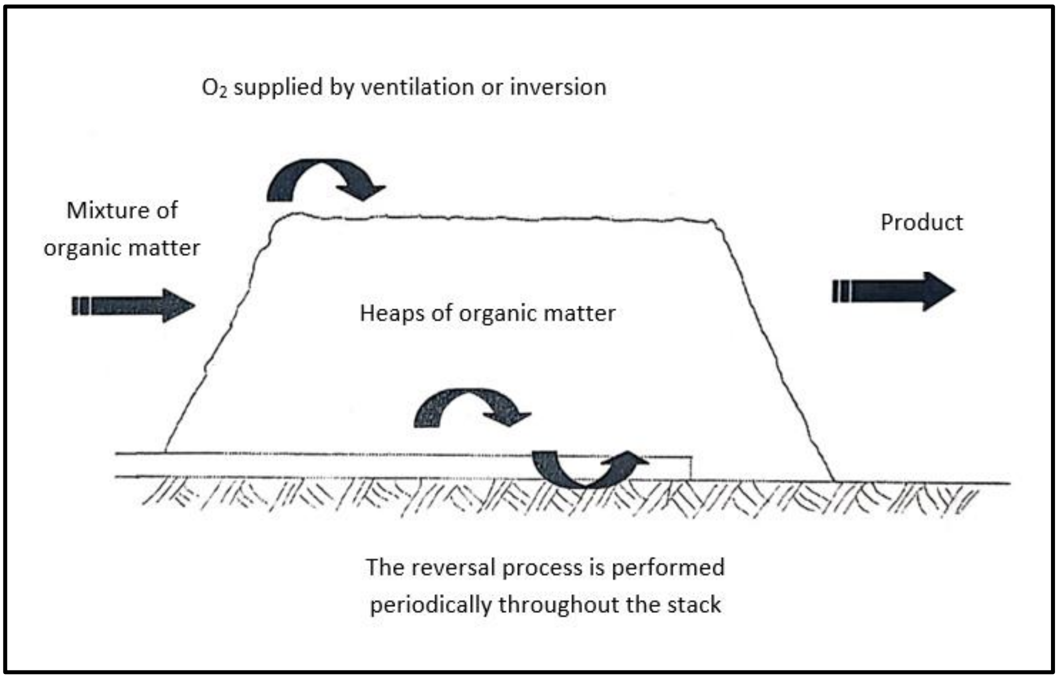

Figure 2.1: Windrow composting system (Source: Tchobanoglous et al., 1993).

**b) Aerated static pile**

A static pile system, like windrows, is made up of waste that is laid out in parallel rows. The air blower and a network of porous pipes used in the aerated static pile method are used to ventilate the pile of organic waste (Figure 2.2). The air is pumped in to provide oxygen to aid in the breakdown of organic waste and regulate the temperature in the pile (Tchobanoglous et al., 1993). Because the mixing required can be accomplished with standard agricultural equipment, these systems are significantly less expensive in terms of equipment, manpower, and operating costs. They do, however, increase the land requirement because decomposition occurs at a slower rate, causing the material to remain on-site for a longer period.

Aerated static pile systems are used to accelerate composting. These are made up of aeration or exhaust piping grid over which substrate piles are formed. The piles' initial height should be 2-2.5m (Tchobanoglous et al., 1993), depending on the porosity of the material, weather conditions, and the reach of the pile-building equipment. In the winter, extra height helps to keep the heat in. The finished compost topping protects the pile's surface from drying, insulates it from heat loss, deters flies, and filters ammonia and potential odours generated within the pile.

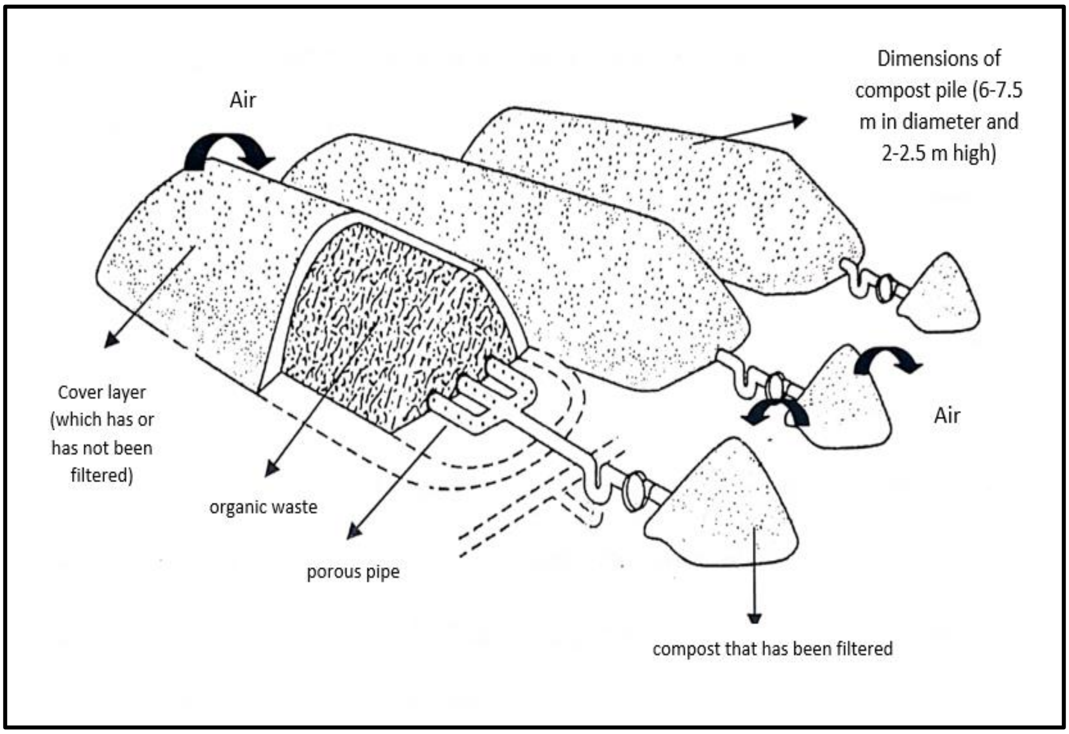


Figure 2.2: Aerated static pile system (Source: Tchobanoglous et al., 1993).

### 2.4.2 In-vessel mechanical methods

In-vessel composting systems can be designed and engineered with greater precision than conventional systems. This contributes to improved process efficiency, control, and optimization. By regulating airflow, temperature, and oxygen content, for instance, this approach can reduce odour issues and speed up the composting process (Tchobanoglous et al., 1993). The disadvantages of this method are the high capital and operating costs associated with the use of computerized equipment, as well as the requirement for skilled labour. In general, this method can be divided into three types: vertical, horizontal, and rotary drum reactors.

**a) Vertical reactor**

Organic materials are fed into the reactor through the top and distributed to the bottom in Stages in this method. Forced aeration was performed on the composted organic waste from the reactor's bottom, as shown in Figure 2.3. These reactors are typically taller than 4 m. Because high air flow rates are required to be uniformly distributed over the surface of the composted organic matter waste, the height of this reactor makes process control difficult. However, this situation can be improved by increasing the uniformity of airflow distribution in both the reactor and the collection system. This method involves changing the direction of the air flow between the inlet flow and the blower pipes from vertical to horizontal.

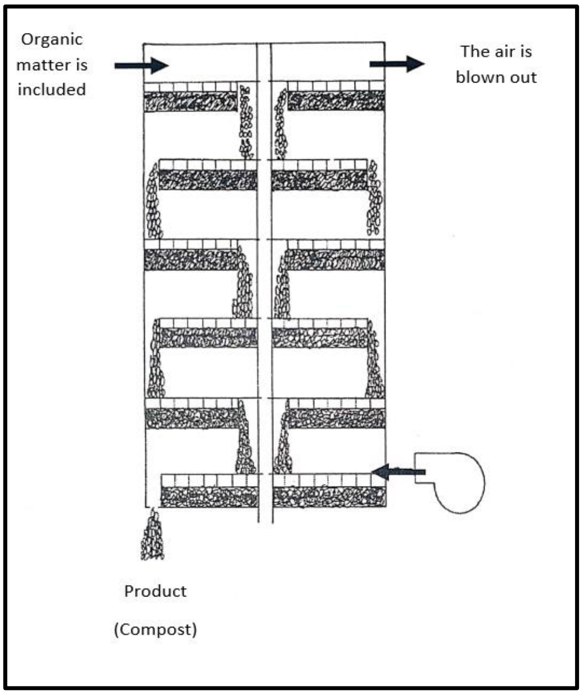


Figure 2.3: Organic matter flow and air flow
in a vertical reactor (Source: Haug, 1993).

**b) Horizontal reactors**

This reactor has a mechanism that is very similar to the vertical reactor; the only difference is the direction of organic matter feed. As shown in Figure 2.4, organic matter is inserted horizontally, which shortens the airflow path as well as the composted material until the end of the process. This short path can indirectly avoid the problem of oxygen deficiency that occurs in the peak reactor. Static methods are used to design this type of reactor. The static method necessitates the use of a mechanism for inserting and removing waste from the reactor. Temperature and oxygen content are used as control variables in the ventilation system located at the reactor's base. This method appears to be capable of decomposing organic matter from the municipality's non-uniform solid side.

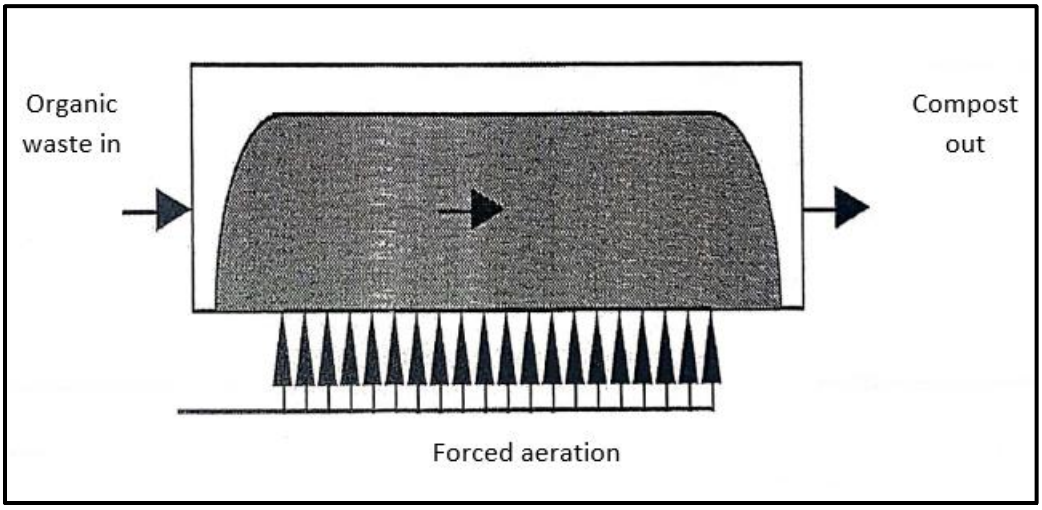


Figure 2.4: Horizontal reactor (Source: Haug, 1993).

**c) Rotary drum reactors.**

Organic matter will be mixed, aerated, and moved throughout the system using this method. The composting process is accelerated in the drum. The organic materials in the drum that have been inverted and crushed are then removed and allowed to decompose and mature using the stacking or aerated static stacking method.

During the turning process, air will be introduced into the reactor and mixed with organic materials. Air moves in the opposite direction of organic matter, as illustrated in Figure

2.5. Outside air will cool the resulting compost in the reactor's outlet section. Meanwhile, in the middle of the reactor, the organic materials will be exposed to relatively hot air to promote aerobic decomposition. Warmer air will be introduced into the reactor to begin the aerobic decomposition process of the newly introduced organic materials. Drums for small-scale composting can be made from recycled materials such as concrete mixing containers or old cement furnaces, or perforated barrels can be used to create natural ventilation.

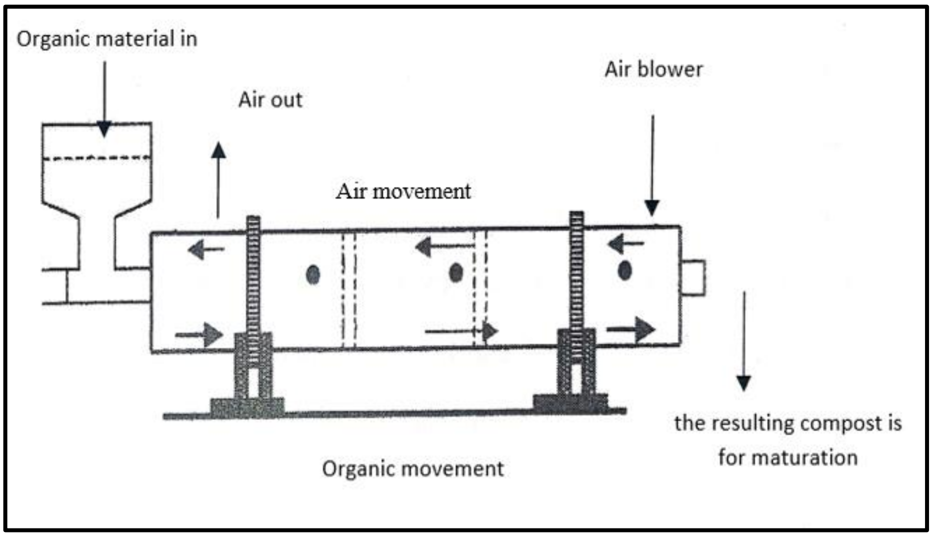


Figure 2.5: Rotary drum (Source: Diaz et al., 1993)

## 2.5 Composting of food waste

Numerous types of food waste can be composted. In general, if it is not contaminated and comes from the ground, is vegetative, or animal in nature, it can be composted (Haug, 1993). Food waste is classified as follows:

i) Wasted fruits and vegetables

Peelings, outer skins, pomace, cores, citrus culls, leaves, fruit twigs, filter cake, and sludge are all included.

ii) Animal waste

Lobster shells, crab scraps (shell and viscera), scallop viscera, whole fish scraps, blood, fats, intestine residues, and manure are all included.

iii) Mixed food waste

Food waste comes from cooked/prepared (at a restaurant, home, etc) and expired food.

## 2.6 Factors influencing the composting process

Composting has its requirements, which are a determining factor in the compost's outcome. These factors also influence the rate and extent of decomposition (Diaz et al., 1993). In general, the closer they get to the optimum levels, the faster they degrade. If these factors are not at their optimum, the degradation process will be slowed. These are referred to as limiting factors. As a result, it is critical to understand the limiting factors of decomposition for a specific type of waste to produce good, mature compost. The following are some of the limiting factors used in this study:

i) Temperature

ii) pH

iii) Moisture content

iv) C: N ratio

### 2.6.1 Temperature

In a specific temperature range, biochemical functions in the composting process can be performed well. If the compost is in low and high temperatures, the process kinetics is limited. In aerobic composting systems, two temperature zones can be achieved. The thermophilic region and the mesophilic region. According to Caetano et al. (2020), the temperature for mesophilic composting is 20 to 40°C, while the temperature for thermophilic composting can be reached 80°C. According to Pace et al. (1995), the temperature for mesophilic composting is 40 to 45°C, while thermophilic composting is 45 to 70°C.

Mesophilic bacteria oversee decomposition in its early Stages. When microbial activity is active in the primary Stage, the temperature rises and eventually exceeds the mesophilic range. The decomposition process will then be taken over by thermophilic bacteria. During the initial Stage of high-rate substrate degradation, thermophilic temperatures are required to reduce pathogenic bacteria, weed seeds, and other undesirable organisms to tolerable levels (Canadian Council of Minister of the Environment, 1996). Compost must be maintained at temperatures above 55 °C for 3 to 15 days, depending on the composting system used, just to ensure this Stage occurs (Sai et al., 2020). The temperature drops as this Stage progress, and mesophilic microorganisms take over the process (decomposition) at a slower rate.

### 2.6.2 pH

The pH of composting typically drops in the early stages of the process, where it can be as low as pH 4 - 5 (Diaz et al., 1993). As the temperature rises, organic acids are formed, resulting in a pH drop (Tchobanoglous, 1993). The pH of composting material will vary as the process progresses, but the pH will generally begin to rise and may reach levels as high as pH 8-9. (Khalib et al., 2018). Inadequate aeration of the compost will cause the pH to drop to as low as 4.5 due to anaerobic conditions, preventing organic matter decomposition. Ideally, the highest rate of decomposition should be achieved in the pH range of 6–8. If the pH is out of range, microbial activity will be inhibited or halted (Pace et al., 1995).

### 2.6.3 Moisture content

Moisture is required for heat storage in compost bulk. The moisture content should be kept between 40 and 60 % (Jeevahan et al., 2021). If the moisture content is too high (greater than 50 – 60 %), the pore spaces become occupied with water, leaving less room for oxygen, resulting in anaerobic decomposition and temperature reduction (Diaz et al., 1993). When the moisture content falls below 40 %, the rate of biodegradation slows, and when it falls below 12 %, biological activity ceases (Diaz et al. 1993).

### 2.6.4 C: N ratio

Carbon to Nitrogen ratio is an important parameter in composting of decomposition of organic material. The ideal C: N ratio for composting is 30:1, but values between 25:1 and 35:1 are usually acceptable (Narayan et al., 2018). Carbon provided energy for microorganisms to decompose organic material, while nitrogen is used to generate new cells. Carbon material can be identified by its dry and brown colour, such as (dry dead leaves, sawdust, and so on), whereas nitrogen material is wet and green in colour, such as (meat, leafy materials, etc). If the C: N ratio is too low, which means that nitrogen is more abundant than carbon materials, and biological activity is hampered. If the carbon content is high, it indicates that the nitrogen material has decomposed before the carbon material has decomposed completely.

# CHAPTER 3

# METHODOLOGY

## 3.1 Elements of the Research

In this Chapter, the overall flow of the study starting from the desk study toward the composting analysis has been summarized and can be seen in Figure 3.0. In this study, there are 3 Stages involved which are Stages 1, 2 and 3. Stage 1 includes the determination of physical and chemical properties of raw material (food waste and yard waste), the composition of organic waste used, as well as the determination of preliminary data on food waste and yard waste, including moisture, pH and carbon to nitrogen (C: N) ratio.

Stage 2 involves monitoring physical and chemical parameters that affect the composting process such as temperature, moisture content, pH, and C: N ratio. The ratio of food waste and yard waste used at this stage is 1: 1 (wet weight) which involves using a relatively small composter with a height of 470 mm and diameter of 460 mm and a small composting mixture (10 kg with 5 kg each type of waste). In this Stage, 6L of rumen fluid was mixed with the composting mixture to assist the composting process. The mixture of composting material that is introduced into the composter covers 75% - 80% of the total volume of the composter. A little space has been provided to allow air to enter the composting mixture, ensuring an aerobic environment and an efficient composting process. The decrease in compost height in the composter was also investigated to determine the reduction in organic waste volume after the composter process. The monitoring of the composting process and experiments on compost such as temperature, pH, moisture content and C: N ratio were carried out outside of the

Environmental Engineering Laboratory 1 and 2, School of Civil Engineering, USM. In stage 2, takes 2 weeks' time to undergo the experiment.

In Stage 3, the composting process is carried out at a 2: 1 (food waste: yard waste) ratio, with a larger quantity of organic waste (60 kg with 40 kg of food waste and 20 kg of yard waste.) and a larger composter size (height: 790 mm, Diameter: 200 mm). At the initial Stages of composting, 3L of rumen fluid was added to the composting mixture. This just to avoid excessive moisture because if rumen fluid happened again. During this Stage, composting parameters such as temperature, moisture content, pH and C: N ratio were monitored. The finished compost was also evaluated for nutritional content such as nitrogen (N) and potassium (K) as well as heavy metal content (Fe, Zn, Cu, and Cd). After the maturation process was completed, the characteristics of the finished compost were investigated. The decrease in compost height in the composter was examined similarly to Stage 2 to evaluate the reduction in organic waste volume following the composting process. At this stage, some modifications or upgrades will be performed, such as improving the existing composter (composter size) and increasing the amount of composting material. The study location remains the same as in Stage 2. In stage 3, takes 40 days' time to undergo the experiment.

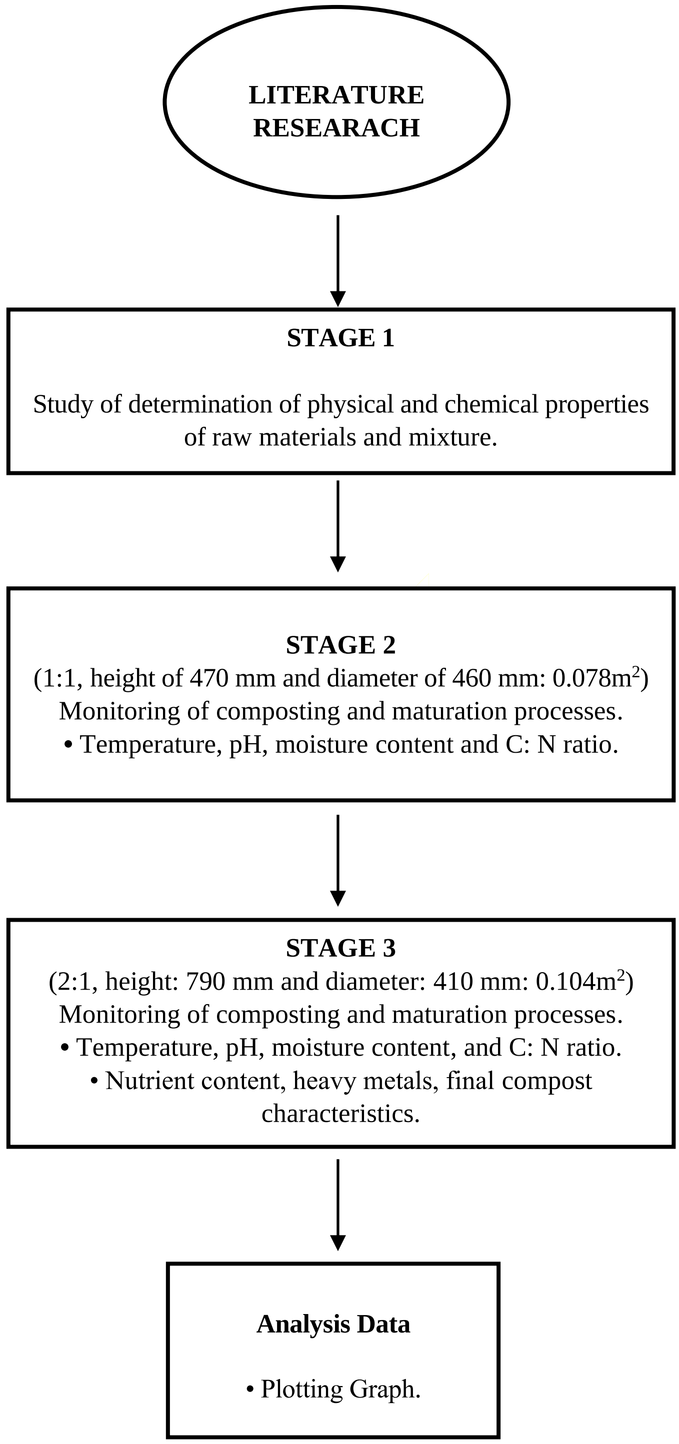


Figure 3.0: The experimental design and flow of study.

### 3.2 Determination of physical and chemical properties of raw material (Stage 1)

#### 3.2.1 Food wastes

In Universiti Sains Malaysia (Engineering Campus), there are 8 cafeterias are operating which are under different contracted companies. Physical identification has been done to identify the cafeterias operating on this campus. Starting with food contracted companies under Teratai Madu Trading, MMI Global Empire, Sa'ayah Yusoff, Yiezie Empayar Enterprise, Rosnaida Hambali, Mohd Asmawi Abdul Rahman, Katering Selera Mutiara and Airieda Enterprise. The collection for this type of raw materials was carried out after peak hour was operated which was between 1- 2 pm. The collection was carried out per day including weekends. During the collection, unwanted materials such as plastics, straws, tissues, candy wrappers, chicken bones, etc. were separated first before putting them all together into a garbage bag for the composting work soon. After the collection, food waste will go through the shredding process. This is important to make sure the food waste involved in the composting process is small. Thus, it will help to maximize the reaction between bacteria/microbe presented in the bin composter during the composting process. Food waste was collected and cut into small pieces and will be weighed. To be more accurate, the food waste has been weighed three times and the actual weight will be calculated based on the average. Each time it is weighed, the scales will be set to zero to prevent zero errors from occurring during the weighing process. The total weight of food waste collected is around 80 kg. The food waste was collected in 7 days straight.

### 3.2.2 Yard waste

Yard waste was obtained from the backside of the Development Department, Universiti Sains Malaysia, which is where yard waste from landscaping and cleaning activities on campus is collected. This location usually will be used by contractors on duty after doing public cleansing work. There are new and old layers of yard waste with the new layer of yard waste dominating the top of the pile. For composting, yard waste collection is done by collecting yard waste that is in the bottom layer of the pile using a shovel. To collect old yard waste, a small amount of digging around the new layer is required. This is because older yard waste has already degraded slightly more than newer yard waste. Older yard waste is slightly blackish and quite soft when cut. As many as three garbage bags were used to collect yard wastes. The procedure of weighing yard waste is like that of weighing food waste. The total weight of yard waste collected is around 40 kg.

### 3.2.3 Rumen Fluid

In this study, rumen fluid was obtained from cattle breeders in the Sungai Kechil Hilir area. Rumen fluid contains nutrients that microbes use as a source of energy. The rumen fluid also acts as a bio–activator and hastens the maturation of organic compost (Bernal et al., 2009) because the rumen contained numerous microorganisms, including bacteria (109 mL$^{-1}$ to 1012 mL$^{-1}$ rumen fluid), protozoa (105 mL$^{-1}$ to 106 mL$^{-1}$ rumen liquid), and a variety of fungi (Suhardjadinata et al., 2018). The total volume of rumen fluid collected is around 16 liters. Organic farms benefit greatly from an abundant population of microorganisms living in the rumen. Even though it is high in nutrients, the rumen contents of ruminant slaughterhouses such as cattle and goats are usually discarded. The waste has a high potential for use in the production of liquid and solid organic fertilizer, as well as a bio-activator in the production of goat manure fertilizer. After the collection, the rumen fluid will be measured so the volume of rumen fluid collected will be known.

### 3.3 Monitoring of composting and maturation processes (Stage 2)

This Stage involves mixing compost samples as well as monitoring composting process parameters such as temperature, pH, moisture content, and C: N ratio. The aerobic composting method was used in this study with a composter size of (Depth: 470 mm, Diameter: 460 mm). The size of the composter used is depicted in Figure 3.1. Holes made on the composter body just to make sure good aeration happened in the composter.

#### 3.3.1 Mixing process

In this Stage, composting was done by mixing the food waste and yard waste at an early stage before being transferred into the composter. The browns and greens come from yard waste and food waste collected before will be mixed alternately until it reaches 75-80% of the composter. The steps as below.

Step 1: All raw materials (food waste and yard waste) were placed on canvas (excluding rumen fluid). The raw material is then mixed uniformly using a shovel. The mixing process can be referred to in Figure 3.2.

Step 2: A total of 6L of rumen fluid was then added to the composting mixture. Figure 3.3 shows the rumen fluid used in this study.

Step 3: Hence, the mixing material was transferred into the composter. Make sure mixing material in the composter is not fully compacted. This will allow air to enter the composting mixture, ensuring an aerobic environment and an efficient composting process.