APPLICATION OF ENZYME-PRODUCING BACTERIA FOR MUNICIPAL SOLID WASTE BIODEGRADATION

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ABSTRACT

Population growth with increasing consumption levels leads to abundant waste in Kuantan. Jabor landfill, commonly known as Kuantan landfill, receives more than 500 tons of waste per day with a composition of 60% of domestic waste and 40% of commercial waste. The composition of domestic waste were organic waste, green waste, mixed paper, plastic, textile, ferrous, glass, rubber and leather, and others. Meanwhile, the compositions of commercial waste are food, plastic, yard waste, paper, cardboard, textile, glass, non-ferrous, rubber, wood, ferrous metals. Landfill system always produces leachate. This waste contains many types of bacteria with the potential to degrade the waste compound. Screening tests with selective media demonstrated the ability of bacteria to produce amylase, lipase, protease and cellulase enzymes. These enzymes are needed to accelerate the molecules breakdown of municipal solid waste in the biodegradation process. Samples for isolation of bacteria were taken from different places, namely landfill soil and leachate. Identification of bacteria was conducted using Gen III microplate BIOLOG microbial identification system. They were *Bacillus amyloliquefaciens, Bacillus ruris, Bacillus licheniformis, Bacillus subtilis* and *Kocuria varians*. There were 4 different treatments: composting pile without bacteria (T0), composting pile with inoculation of amylase and protease producing bacteria (T1), composting with inoculation of lipase and cellulase producing bacteria (T2), and composting with inoculation all enzyme-producing bacteria (T3). The result of biodegradation process of T3 treatment reached the highest temperature (53° C) with the longest thermophilic phase compared to other treatments. The lower value of C/N ratio, the more stable the level of maturity of compost. The lowest of C/N ratio value was T3 (10%). T3 treatment compared with other treatments can increase as much as 27% content of nitrogen, 67% of phosphorus and 33% of potassium. All the treatments with bacterial inoculation (T1, T2, and T3) are able to reduce the content of heavy metals (Fe, Zn, Cu) on municipal solid waste biodegradation. It can be concluded that the inoculation of potential enzyme-producing of bacteria on municipal solid waste biodegradation is effective to increase the nutrient content and decrease the heavy metals.

ABSTRAK

Pertumbuhan penduduk dengan tahap penggunaan yang semakin meningkat membawa kepada sisa pepejal yang banyak di Kuantan. Tapak pelupusan Jabor yang dikenali sebagai tapak pelupusan Kuantan menerima lebih daripada 500 tan sampah sehari dengan komposisi 60% daripada sisa domestik dan 40% daripada sisa komersial. Komposisi sisa domestik adalah sisa organik, sisa hijau, kertas campuran, plastik, tekstil, besi, kaca, getah dan kulit, dan lain-lain. Komposisi sisa komersial adalah makanan, plastik, sisa halaman, kertas, kadbod, tekstil, kaca, bukan ferus, getah, kayu, logam ferus. Sistem tapak pelupusan sentiasa menghasilkan larut resapan. Sisa ini mengandungi banyak jenis bakteria yang berpotensi untuk menguraikan kompaun sisa. Ujian saringan dengan media terpilih menunjukkan keupayaan bakteria untuk menghasilkan enzim amilase, lipase, protease dan selulase. Enzim ini diperlukan untuk mempercepatkan pecahan molekul sisa pepejal perbandaran dalam proses biodegradasi. Sampel untuk isolasi bakteri telah diambil dari tempat yang berbeza, iaitu tanah tapak pelupusan dan larut resapan. Pengenalan bakteria telah dijalankan oleh Gen III microplate BIOLOG sistem pengenalan mikrob. Mereka adalah *Bacillus amyloliquefaciens*, *Bacillus ruris*, *Bacillus licheniformis*, *Bacillus subtilis dan Kocuria varians*. Terdapat empat rawatan yang berbeza: kompos timbunan tanpa inokulasi bakteria (T0), kompos timbunan dengan inokulasi bakteria yang menghasilkan amilase dan protease (T1), pengkomposan dengan inokulasi bakteria yang menghasilkan lipase dan selulase (T2), dan kompos dengan inokulasi semua bakteria yang menghasilkan enzim (T3). Hasil daripada proses biodegradasi rawatan T3 telah mencapai suhu yang paling tinggi (53 ° C) dengan fasa thermophilic yang paling lama berbanding rawatan lain. Kompos yang nisbah C/N paling kecil adalah tahap yang lebih stabil dan matang, yang paling kecil daripada nilai nisbah C / N adalah T3 (10%). Rawatan T3 berbanding dengan rawatan lain boleh meningkatkan sebanyak 27% daripada kandungan nitrogen, 67% daripada kandungan fosforus dan 33% daripada kandungan potassium. Semua rawatan dengan suntikan bakteria (T1, T2, T3 dan) dapat mengurangkan kandungan logam berat (Fe, Zn, Cu) di biodegradasi sisa pepejal perbandaran. Dapat disimpulkan bahawa inokulasi potensi enzim-penghasilan bakteria di biodegradasi sisa pepejal perbandaran adalah berkesan untuk meningkatkan kandungan nutrien dan mengurangkan logam berat.

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B	Boron
^{o}C	Celsius Degree
C	Carbon
Ca	Calcium
CH_4	Methane
CO_2	Carbon dioxide
Cu	Copper
Fe	Iron
g	Gram
H_2S	Hydrogen sulphate
K	Potassium
L	Litres
Mg	Magnesium
mL	Millilitres
Mo	Molybdenum
mS cm^{-1}	Millisiemens centimetre
N	Nitrogen
NH_3	Ammonia
O_2	Oxygen
P	Phosphorus
S	Sulfur
Si	Silicon
T0	Compost treatment without bacteria
T1	Compost treatment with amylase and protease enzymes producer
T2	Compost treatment with cellulase and lipase enzymes producer
T3	Compost treatment with all enzymes producer bacteria
V	Volume
W	Weight
Zn	Zinc

LIST OF ABBREVIATIONS

AAS	Atomic absorption spectroscopy
C/N Ratio	Carbon to Nitrogen ratio
CFU	Colony forming units
CMC	Carboxymethyl cellulose
DFT	Dry fermentation technology
DNA	Deoxyribonucleic acid
EC	Electrical conductivity
GHG	Green house gases
HC	Hydraulic compactor
HHE	Human health and the environment
HW	Horticultural waste
IPS	Initial particle size
JICA	Japan International Cooperation Agency
MC	Moisture content
MHLG	Ministry of housing and local government
MSW	Municipal solid waste
NA	Nutrient agar
NB	Nutrient broth
PGPR	Plant growth promoting rhizobacterium
PPSPPA	Solid Waste Management and Public Cleansing
PSA1	Pahang service area 1
SS	Sewage sludge
SWM	Southern waste management
TAD	Thermophilic aerobic digestion

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Every year, the level of waste generation continues to rise because of uncontrolled consumption due to increasing population, attitudes towards spending and high living standards. Quantities of waste generated are growing in response to the rapid increase in population, accelerated urbanisation and industrialisation. However, with the increasing population, the volume of waste generated remains abundant. Solid waste is generated from various domestic (schools, hospitals, universities, offices) and commercial (from restaurants, hotels, markets and industry) sources and consists of biodegradable matter, as well as inert non-biodegradable matter. The most dominant variable in the municipal solid waste (MSW) flow is food waste. Relatively homogeneous residential waste, some differences in the waste depends on local factors and other demographics; most households dispose of the same type of waste (Yousuf and Rahman, 2007). Trends in the composition of MSW in Malaysia showed that food, paper and plastic are the main components of waste generated in most places (Agamuthu et al., 2007). The main household waste composition includes 71% organic waste, 12% plastic, 7.5% paper and paper products, 5% dirt and construction debris and 1% hazardous waste. The highest percentage is organic waste, although the composition of the waste varies depending on the source.

The handling and separation of wastes at the source is a critical step in waste management in Malaysia. Solid waste management can be defined as a discipline related to the control of waste generated. The storage of waste used various types of bins such as a small bin for household, medium and large bin for industry or manufacture. The most used bins for residential areas are small bins. Also, the bins used are made of various materials, such as plastic, metal, rubber, mixed paper, and cardboard boxes. In the case of high-rise building, communal bins or central container is used. Waste collection activities are the most expensive activity in waste management systems. The introduction of intermediate treatment facilities such as transfer stations, composting and incinerator plants, may become the alternative treatment of waste in Malaysia. The government is also considering the various designs and modes of incineration process available in the market. One of the process is the thermal gasification process (Earth Observation Centre, 2011).

Jabor Landfill is the only landfill in Kuantan, which is located in Pahang Service Area 1 (PSA1) covering the district of Kuantan in the state of Pahang. It is approximately 300 km away from Kuala Lumpur and 25 km from the city of Kuantan. The total site area is 30 hectares. There is also a system of leachate containment, leachate collection system, leachate treatment plant and landfill gas management (Alam flora, 2006). Approximately 500 tons of waste are collected at Jabor landfills every day, using the concept of semi aerobic recirculatory system treatment or Fukuoka methods as a solid waste management.

Leachate production is one of the biggest problems associated with the operation of environmental sanitary landfill, because the liquid waste can cause harmful pollution problems by contaminating surfaces and ground water as well as surrounding soil surfaces. *Clostridium perfringens* and fungal filaments are usually contaminated leachate. In addition, there are bacteria, which includes aerobic, coliform and fecal coliform, psychrophilic and mesophilic bacteria, and spore-forming bacteria (Matejczyk et al., 2011). The two bacterial groups that showed a good adaptation and critical participation in the leachate treatment for almost the entire duration of treatment are *Actinomycetes* and *Bacillus* (Yahmed et al., 2009). Analysis of individual substrate utilisation patterns of bacteria isolated from the leachate collected at successive sampling dates showed a decrease in the percentage of Gram-negative bacteria, which are able to metabolize sugar selected by increasing the percentage of Gram-positive bacteria that are capable of metabolizing sugar (Hale Boothe et al., 2001). Therefore, one of the objective in this study is to identify and to compare the number of species of bacteria that live in landfill soil and leachate, which have the potential to produce amylase, protease, cellulase and lipase enzymes. The bacteria could be the agent of biodegrader for municipal solid waste treatment. With that abundant amount, it needs various efforts to reduce the high production of waste. Sanitary landfills and incinerators cause further effects that are more harmful to living beings and environment. Biodegradation is one of the waste managements that can produce a product that are beneficial to plants. It can convert up to 50-60% of the waste into biofertilizer. The product will be richer in microbes, thus can improve plant nutrient uptake, which is also effective in increasing agricultural production.

Biodegradation process involves biological and chemical processes. The enzyme activity is affected by the type of substrate, temperature and microbiological activity to degrade waste. Monitoring enzyme activity during the composting process can provide valuable information related to the dynamics of essential nutrients such as C, N or P, and contribute to developing a better understanding of the transformation that occurs during composting (Vargas-García et al., 2010). Microorganism-induced degradation of organic materials depends on the activity of various hydrolytic enzymes (Raut et al., 2008). Each material source will demonstrate different enzyme activities. The rate of decomposition is highly dependent on the quality of the organic substrate, environmental conditions, the chemical nature of the substrate, and the activity of microorganisms (Jurado et al., 2014).

1.2 PROBLEM STATEMENT

To identify the trend of the various types of waste that goes into landfills each year, it is necessary to conduct waste classification update. This is useful to determine what management will be implemented to resolve the problem of municipal solid waste in Kuantan. Food is the majority biodegradable component of municipal solid waste, which consists of more than 50%. Municipal solid waste management costs are expensive and require other alternative management for example incineration, sanitary landfill and their technologies. Composting is one of solid waste management that is economical, convenient and can produce useful organic fertiliser for crops. However, Jabor landfill never applied this treatment as a combination for the waste treatment.

Biodegradable waste in landfill is the substrate for composting. In this study, the biodegradation method will be conducted by using bacterial consortium. The isolated bacteria in this research are indigenous bacteria that are expected to be utilised for the municipal solid waste degradation. The method uses a combination of microbes that have different abilities to produce enzymes to degrade organic waste. Therefore, it can accelerate the decomposition process to be more effective and efficient.

1.3 OBJECTIVES

The objectives of this study include:

1) To characterise the municipal solid waste in Jabor landfill, Kuantan, Pahang.
2) To isolate and identify the potential bacteria from Jabor landfill to those are able to produce amylase, protease, cellulase and lipase enzymes.
3) To determine the efficiency of municipal solid waste degradation by bacterial consortium.

1.4 SCOPE OF STUDY

Based on the objectives, the major scope of this experiment is to find out the effectiveness of bacteria consortium from landfill soil and leachate that are capable to degrade municipal solid waste. To achieve the objective of this research, four scopes have been identified:

1. Characterisation of municipal solid waste using hand sorting methods. Generally MSW consists of different categories: food waste, green waste, paper (mixed), cardboard, plastic (rigid, film and foam), textile, wood waste, metals (ferrous or non-ferrous).
2. Isolation of bacteria using the standard serial dilution procedure and identification of bacteria using Gram staining and BIOLOG automated system.
3. To study the ability of bacterial consortium to produce lipase, protease, amylase and cellulase enzymes with selective media. The types of agar used are: skim

milk agar for protease, starch agar for amylase, rhodamine B agar for lipase and carboxymethyl cellulose agar (CMC) for cellulase activity.

4. Application of bacterial consortium for municipal solid waste degradation with small scale composting in a plastic container with duplicate sub sample were taken for the monitoring composting process. The monitored parameters were total carbon, total nitrogen, C/N ratio, temperature, pH, electrical conductivity, moisture content, phosphorus, potassium, and heavy metal content (Cu, Fe, Zn).

CHAPTER 2

LITERATURE REVIEW

2.1 MUNICIPAL SOLID WASTE

Municipal solid waste (MSW) is a term often used for the solid heterogeneous by-product of different human activities in the municipal area of the city. The waste generally contains discarded material like papers, plastic, glass, metal fine earth particles, ash, sewage sludge, dead animals, etc. (Thitame et al., 2010). Solid wastes are all the waste originating from human and animal activities that are normally solid and are discarded as useless or unwanted. It encompasses the heterogeneous mass of discarded residence and commercial activities as well as the more homogeneous accumulations of single industrial activities. The characteristics and composition of this waste depend on every activity and the amount varies by source, season, geography and time (Robert, 1999; Thitame et al., 2010). There are three primary purposes for solid waste characterisation. First, the data became the basis for planning economic analysis, design and subsequent management and operation of a disposal system or material – energy resource recovery facilities. Secondly, the solid waste characterisation for rehabilitation or retrofit of facilities redefines the quantity and type of waste for disposal. Third, plant optimisation and emission monitoring can be expedited by the characterisation of solid wastes being processed (Robert, 1999).

Three primary sources of waste are classified as municipal solid waste. These are residential, institutional and commercial waste, and municipal services wastes (street sweeping). Residential wastes are high in quantity and vary with time and season. Over time, municipal solid waste is not only increasing but the composition is also changing. The organic wastes are decreasing and the paper and plastics are increasing in the waste stream, indicating the growing preference for consumption of packaged food in recent years (Yousuf and Rahman, 2007). According to Saeed (2009), the sources of municipal solid waste are street cleansing, landscape and garden, industrial & constructional, institutional, residential and commercial (Table 2.1). The generation of municipal solid waste by the public is a function of socio-economic background, i.e. the buying power, cultural background, locality i.e. urban or rural setting and the environment awareness (Johari et al., 2012). Analysis of the composition of the waste comes from restaurants, hotels, schools and roads (Dangi et al., 2011).

Table 2.1: Source Sector of MSW

Sector	**Percentage**
Street Cleansing	11%
Landscape & Garden	7%
Industrial & Constructional	4%
Institutional	6%
Residential	48%
Commercial	24%

Source : (Saeed et al., 2009)

2.2 CHARACTERISTIC OF MUNICIPAL SOLID WASTE

Generally, the solid waste composition in most Asian countries is highly biodegradable with high moisture contents such as food waste, paper, plastic/foam, agriculture waste, rubber/leather, wood, metal, glass and textiles. Basically, municipal solid waste is a heterogeneous mixture of waste; organic and inorganic, rapidly and slowly biodegradable and hazardous generated from various sources due to human and industrial activities. In major cities, it showed that food and vegetables wastes are the major components in the waste stream.

Other waste components are paper, paper product, polyethylene, plastics, textile, wood, rubber, leather, metal, tins, glass, ceramics, brick, concrete, dust, soil and etcetera (Yousuf and Rahman, 2007; Tsiko and Togarepi, 2012). Table 2.2 shows that the characteristic of municipal solid waste in Malaysia is organic waste as the major component, which includes paper, plastics, textiles, rubber & leather, wood, garden waste, dust and incombustibles (Muhd Yunus, 2012).

Table 2.2: Characteristic of MSW in Malaysia

Characteristic of MSW	**Percentage**
Organics	58.30%
Paper	8.20%
Plastics	13.10%
Textiles	1.30%
Rubber & leather	0.40%
Wood	1.80%
Garden Waste	6.90%
Dust	0.40%
Incombustibles	11.50%

Source : (Muhd Yunus, 2012)

The characteristics or the composition of Malaysian MSW is different from other countries. Due to its tropical climate with heavy rainfall, the Malaysian MSW contains high moisture content ranging from 52.6 % to 66.2 %, (Hassan et al 2001). Daniel and Laura summarize the sources and types of municipal solid waste in Table 2.3.

Table 2.3: Type and source of MSW

Source	Typical waste generators	Types of solid wastes
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, and household hazardous wastes
Industrial	Light and heavy manufacturing, fabrication, construction sites, power and chemical plants	Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes, ashes, special wastes
Commercial	Stores, hotels, restaurants, markets, office buildings, etc.	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Institutional	Schools, hospitals, prisons, government centers	Same as commercial
Construction and demolition	New construction sites, road repair, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, etc
Municipal services	Street cleaning, landscaping, parks, beaches, other recreational areas, water and wastewater treatment plants	Street sweepings, landscape and tree trimmings, general wastes from parks, beaches; and other recreational area, sludge
Process	Heavy/light manufacturing, refineries, chemical plants, power plants, mineral extraction and processing	Industrial process wastes, scrap materials, off specification products, slag, tailings
Agriculture	Crops, orchards, vineyards, dairies, feedlots, farms	Spoiled food wastes, agricultural wastes, hazardous wastes (e.g. pesticides)

Source: Daniel and Laura, 1999.

2.2.1 Biodegradable Municipal Solid Waste Content

Biodegradable wastes in the MSW also consist of vegetable kitchen waste. The various feedstocks could be classified into four groups according to nutrient composition (protein, fat, cellulosic materials and easily degradable carbohydrates). The various types of biodegradable municipal solid waste content are described in Table 2.4 according to Kobayashi et al., (2012).

Table 2.4: Different composition from various type of municipal solid waste

Volatile Solid (g/100 g wet)		Concentration (g/100 g VS)					
		Protein	**Fat**	**Carbohydrates**	**Cellulose**	**Hemicellulose**	**Carbohydrates except cellulose and hemicellusose**
AKW	33.3	54.4	35.7	9.9	3.9	n.d.	6.0
VKW	13.4	21.6	19.4	59.0	21.6	9.0	28.4
OKW	25.5	23.1	19.2	57.6	7.5	2.7	47.5
MP	31.7	7.3	20.8	71.9	59.9	4.1	7.9
CW	32.8	10.4	3.4	86.3	n.d.	n.d.	86.3
TCD	28.3	21.9	11.3	66.8	20.5	17.7	28.6
NP	33.6	5.7	7.1	87.2	66.4	5.1	15.8
WPC	63.4	2.1	2.1	95.9	91.0	5.0	0.0
UAKW	38.6	59.8	27.2	13.0	1.6	n.d	11.4
UVKW	10.8	19.4	11.1	69.4	19.4	n.d.	50.0
UP	59.2	2.0	7.4	90.5	75.5	6.4	8.6
VW	22.1	30.8	15.4	53.8	45.7	13.6	0.0
Mix	-	-	-	-	-	-	-
HQP	82.9	0.1	0.2	99.6	83.2	7.2	9.2
EGG	96.5	66.6	33.5	n.d.	n.d.	n.d.	0.0
WEO	28.5	0.2	94.5	5.3	n.d.	n.d.	5.3
ISC	66.9	5.4	1.0	93.6	n.d.	n.d.	93.6
FDN	98.2	-	-	-	-	-	-
BP	99.9	-	-	-	-	-	-
PGB	95.5	-	-	-	-	-	-

(1) Animal kitchen waste (AKW)
(2) Vegetable kitchen waste (VKW)
(3) Other kitchen waste (OKW)
(4) Miscellaneous paper (MP)
(5) Cereal waste (CW)
(6) Tea and coffee dregs (TCD)
(7) Newspaper used for wrapping (NP)
(8) Wrapping paper and container (WPC)
(9) Uneaten animal kitchen waste (UAKW)
(10) Uneaten vegetable kitchen waste (UVKW)
(11) Used paper (UP)
(12) Vegetation waste (VW)
(13) Mixture of 12 wastes (Mix)
(14) Waste high quality paper (HQP)
(15) Waste egg (EGG)
(16) Waste edible oil (WEO);
(17) Waste of Japanese style confection (JSC)
(18) Fiber drain net made of kenaf (FDN)
(19) Biodegradable plastics (BP)
(20) Paper garbage bag (PGB)

Source: Kobayashi et al., 2012.

2.3 MUNICIPAL SOLID WASTE MANAGEMENT

One of the characteristics of modern society is its ability to produce waste. Most human activities generate large amounts of waste that are apparently useless and can cause serious problems from both environmental and economic perspectives. Waste is generated in the human activity, such as municipal solid waste or sewage sludge, while the other, associated with certain economic activities, is recorded only in a few areas. Knowledge of quantity and composition of municipal solid waste is fundamental for the planning of waste management system. Most previous studies looked at the characteristics of municipal solid waste at the final disposal sites. For example, there is a case of horticultural waste in Southeastern Spain, a region with a strong agricultural sector that produces more than one million tons of organic waste per year. Many alternatives for the disposal of organic waste has been proposed, with composting being one of the most effective one due to low environmental impact and cost (Bustamante et al., 2008; Canet et al., 2008; Lu et al., 2008), capacity of composting to produce a valuable product used to improve soil fertility (Weber et al., 2007) or as a growing medium in horticulture. Common waste was used for composting are agricultural waste/plant residues, livestock/poultry waste, sewage sludge (SS) and municipal solid waste (MSW).

According to Atkinson and New (1993) regarding waste management strategies, shifting towards more recycling as well as determining the quantity and composition of waste at the sources of generation are getting more attention and concern. Therefore, in Malaysia, according to the report by the Ministry of Housing and Local Government, waste generation has been increasing gradually since 2000 (Table 2.5). These circumstances require the main focus to be placed on managing the solid waste and mitigating the negative environmental effects (Badgie et al., 2012). There are common municipal solid waste managements. Those are composting, landfill, and incineration.

Table 2.5: Generation on MSW in Malaysia according to states (1996-2009)

States	**Solid waste generated (tons per day)**							
	1996	**1998**	**2000**	**2002**	**2004***	**2006***	**2008***	**2009***
Johor	1613	1786	1915	2093	2255	2430	2578	2655
Kedah	1114	1215	1324	1447	1559	1680	1782	1835
Kelantan	871	950	1034	1131	1213	1302	1382	1423
Melaka	433	480	515	563	605	650	690	711
N. Sembilan	637	695	757	828	890	957	1015	1046
Pahang	806	879	957	1046	1125	1210	1284	1322
Perak	1286	1402	1527	1669	1375	1930	2048	2109
Perlis	165	180	196	214	3573	247	262	270
P. Pinang	916	999	1088	1189	1116	1375	1458	1502
Selangor	2380	2595	2827	3090	3322	3573	3790	3904
Terengganu	743	811	883	965	1038	1116	1184	1219
K. Lumpur	2105	2305	2520	2755	3025	3323	3525	3631
WP Labuan	NA	NA	46	70	74.3	81.2	86.1	88.7
Sabah	NA	NA	NA	2490	2642	2887	3062	3154.3
Sarawak	NA	NA	NA	1905	2021	2208	2343	2413
Total	13070	14589	15587	21452	23073	24969	26489	27284

Source: (MHLG, 2003; Agamuthu et al., 2009)

2.3.1 Composting

The presence of mixed organic substrates is a prerogative of composting. More specifically, according to its etymological meaning, composting (from the Latin compositum, meaning mixture) refers to a biodegradation process of a mixture of substrates carried out by the microbial community composed of various populations in aerobic condition and in the solid states. Microbial transformation of pure substrates goes under the name of fermentation or bio-oxidation, but not composting. The main product is called compost, which may be defined as the stabilized and sanitized product of composting that is compatible and beneficial to plant growth. Compost has undergone: (1) an initial, rapid stage of decomposition; (2) a stage of stabilization; and (3) an incomplete process of humification, (Bertoldi and Insam, 2007).

The biodegradable solid waste, however, is increasingly being viewed to be unsuitable for disposal through non-biological treatment technologies. Eventually, composting is one of the promising methods of Dry-Fermentation Technology (DFT) to handle a large amount of biodegradable waste (Baig et al., 2010). This process of biological treatment of wastes is also known as composting. It is a self-heating, aerobic solid phase biodegradative process of organic materials under controlled conditions, which distinguishes it from natural rotting (Sarkar et al., 2011).

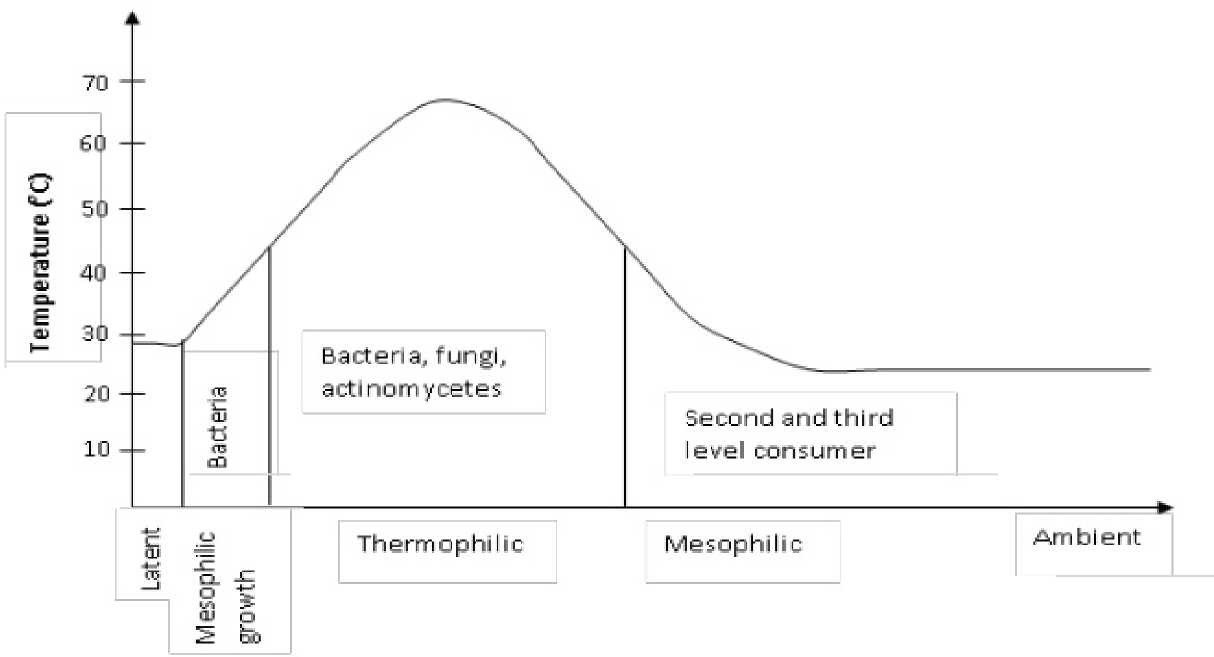

Figure 2.1: Pattern of temperature and microbial growth during composting process.

Source: Nangalia, 2013.

However, it is generally accepted that composting as a discontinuous process is essentially a four-phase process that is summarized in Figure 2.1. The first phase is the mesophilic phase (25-40°C) that is rich in energy, where easily degradable compounds like sugar and proteins are degraded by bacteria. The second phase is the thermophilic phase (35-65°C), the decomposition continues to be fast by fungi, actinomycetes, and bacteria, generally referred to as primary decomposers, and accelerates until a temperature of about