CHAPTER 2

LITERATURE REVIEW

2.1 Solid wastes

Solid wastes are the wastes arising from human and animal activities that are discarded as useless or unwanted waste from processes of agricultural and industrial production such as domestic waste, industrial waste and infectious waste etc. (Opartsiriwit *et al*., 1996).

2.1.1 Type of solid wastes

According to Yamcharoenwong (1988), municipal solid waste can be classified as follows: wet-solid waste with high moisture content which can be bio-digested for high organic content for example i.e. food waste and manure; dry-solid waste with low moisture content which can not be digested. It can be kept for longer period of time than wet-solid waste before disposal. In addition, some dry solid waste can be got rid of by burning; animal waste other harmful wet-solid waste can give unpleasant odor and risk of disease spread out to the nearby residential areas; solid waste from roads, for example leaves, paper and soil which may block the sewage pipes; and solid waste from construction site, for example wood, concrete, bricks, stone, sand and etc.

The analysis of solid waste components is important for selecting a suitable method for its volume reduction before final disposal and to improve the efficiency of solid waste management system. The physical and chemical components of solid waste would be different based on activities and generation source. Opartsiriwit *et al*. (1996) performed a study on solid waste management in Bangkok and reported that about 63 percent of total solid waste contained nearly 21 percent of food waste which can be burnt.

2.1.2 Impact of the solid wastes (Diaz and Golueke, 1985)

As solid wastes are stock of refuse and decomposed materials, they contain various types of pathogens with a high breeding rate. Wind and insects are distributing some disease to people in the community. It is the habitat of many carriers, such as files, cockroaches, mosquitoes and rat etc., which can carry disease from waste to human. Unpleasant odor and sharp materials are dangerous to public health and safety. According to Department of Environmental Quality Standard (1984), solid wastes have an impact on environment such as the following: a) the solid wastes composed of chemicals and heavy metals will destroy the structure of soil and its component. For examples, heavy metals and radioactive substances can change soil characteristics; b) The solid wastes accumulation in sewage pipe and stream cause obstructions of water flow. The leachate causes degradation of the ecology, and plants and animals are destroyed in propagation; and c) The solid wastes, which contain chemicals such as mercury, cause toxic, air pollution in burning, bio-digestion in anaerobic condition causes sulfite gas and ammonia gas emission to the atmosphere.

2.2 Composting

Composting is a biological decomposition process that during composting microorganisms use the organic matter as a food source, producing heat, carbon dioxide, water vapor, and humus as a result of their furious growth and activity. (Figure 1) Composting is generally used for the treatment of organic solid wastes from households, business centers and agriculture. It is also used in agro-industrial process to obtain products which can be applied to soil to increase soil organic matter content as well as enhance soil structure and cation exchange capacity (Haug, 1980; Ayuso *et al.*, 1996; Haug, 1996; Esse *et al.*, 2001; Contreras-Ramos *et al.*, 2004).

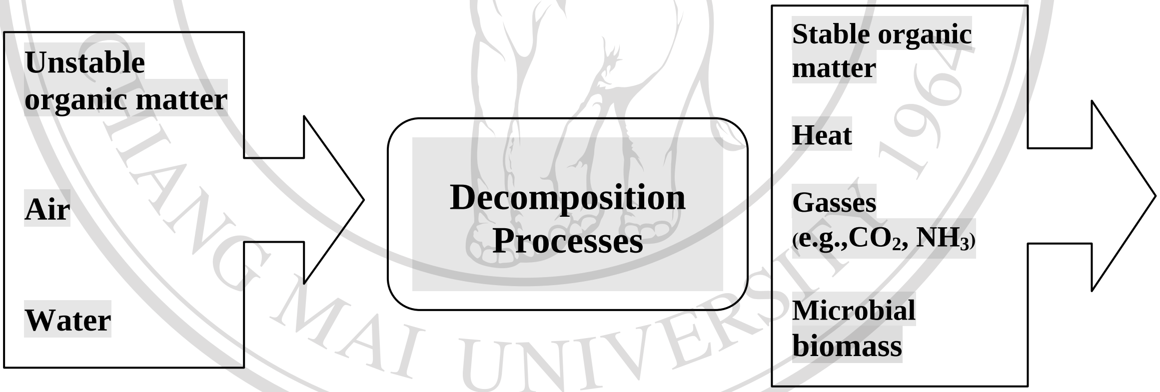

Figure 1 Inputs and outputs of the composting process

Adapted from Diaz *et al.* (1993)

2.2.1 Composting Process

Both mesophilic and thermophilic bacteria and fungi are the predominant organisms during the initial and the active stages of the compost process. The bacteria can be morphologically grouped into the "bacteria proper" and "filamentous" bacteria. In reality, the filamentous bacteria simply are "branched" bacteria, and are members of the actinomycetes. Usually the actinomycetes do not appear in sizable numbers until the close of the high-temperature active stage of the compost process. Coincidentally with their appearance there is a rapid disappearance of cellulose and lignin. The onset of the stabilisation stage of the process is attended by the appearance of saprophytic macroflora. Sources of nutrients for the macroflora are inactive microflora and the decomposing wastes.

The microorganisms responsible for such reaction also vary, depending upon the temperature change during the course of composting. Figure 2 shows the typical temperature phase develop in composting process. They are described below in brief.

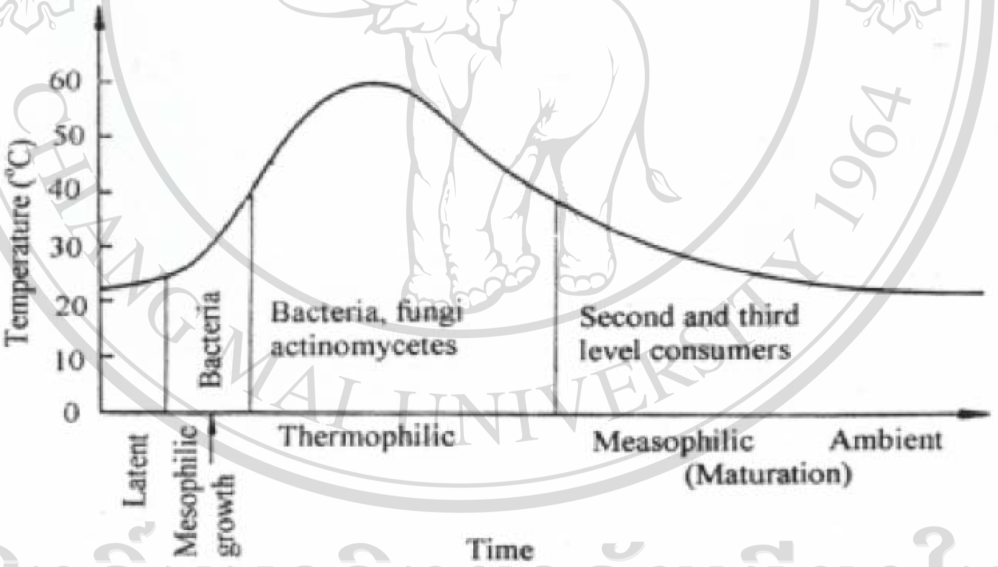

Figure 2 Patterns of temperature and microbial growth in compost pile (Polprasert, 1996)

I. The first mesophilic phase

At the beginning of composting, mesophilic bacteria and fungi degrade soluble and easily degradable compounds of organic matter, such as monosaccharides, starch, and lipids. Bacteria produce organic acids, and pH decreases to 5-5.5. Temperature starts to rise spontaneously as heat is released from exothermic degradation reactions. The degradation of proteins leads to release of ammonia, and pH rises rapidly to 8-9. This phase lasts from a few hours to a few days (Crawford, 1983; Paatero *et al*., 1984).

II. Thermophilic phase

The compost enters the thermophilic phase when the temperature reaches 40ºC. Thermophilic bacteria and fungi take over, and the degradation rate of the waste increases. If the temperature exceeds 55º-60ºC, microbial activity and diversity decrease dramatically. After peak heating, the pH stabilizes to a neutral level. The thermophilic phase can last from a few days to several months (Waksman and Cordon, 1939; Strom, 1985).

III. Cooling and maturation phase

After the easily degradable carbon sources have been consumed, the compost starts to cool. After cooling, the compost is stable. Mesophilic bacteria and fungi reappear, and the maturation phase follows. However, most of the species are different from the species of the first mesophilic phase. Actinomycetes often grow extensively during this phase, and some protists and a wide range of macroorganisms are usually present. The biological processes are now slow, but the compost is further humifiedand becomes mature. The cooling and maturation phase lasts for several months or even years (Biddlestone and Gray, 1985; McKinley and Vestal, 1985; Strom, 1985).

2.2.2 Operational parameters for composting process

Temperature

The temperature of compost is a function of the accumulation of heat generated metabolically and, simultaneously, the temperature is a determinant of metabolic activities (MacGregor *et al.*, 1981). Temperature control is important for pathogen destruction, respiration-rate optimizing, moisture removal, and compost stabilization (Soares *et al.*, 1995).

Hall (1998) and Ekinci (2001) reported that the thermophilic community in self-heating organic masses was most active at approximately 55 to 60°C, and the optimum temperature was approximately 60°C, which confirmed by Jeris and Regan (1973). While Atchley and Clark (1979) suggested 70°C, and Haug (1993) suggested 72°C as optimal temperature levels. Hall (1998) and Ekinci (2001) indicated that temperature higher than 60°C, and Jeris and Regan (1973) also hypothesized that temperatures above 70°C would produce slower respiration rates. In contrast Snell (1957) suggested that the optimum temperature for composting systems was only 45°C.

Variations in substrate composition, composting method, aeration rate and other factors could affect optimal composting temperature (Haug, 1993; Hall, 1998; and Ekinci, 2001).

Nevertheless, it should not have forgotten that at extremely high temperatures, proteins may be denatured and biological activity may decline as populations die. Maintaining a consistent optimal temperature in thermophilic range is therefore necessary to provide not only for faster and more complete composting, but also a safe product by pathogen destruction.

Turning a pile can release heat from the inner core and temporarily cool it down (points A and B in Figure 3). As the food is available and a thermophilic organism becomes depleted, their rate of growth slows and the temperature begins to drop. Turning the pile at this point may produce a new temperature peak (points C and D in Figure 3). This is because relatively undecomposed organic matter gets mixed into the center of the pile, where temperature and moisture conditions are optimal for rapid decomposition. In addition, mixing loosens up the compost ingredients, which increases the infiltration of oxygen that is needed by aerobic microorganisms.

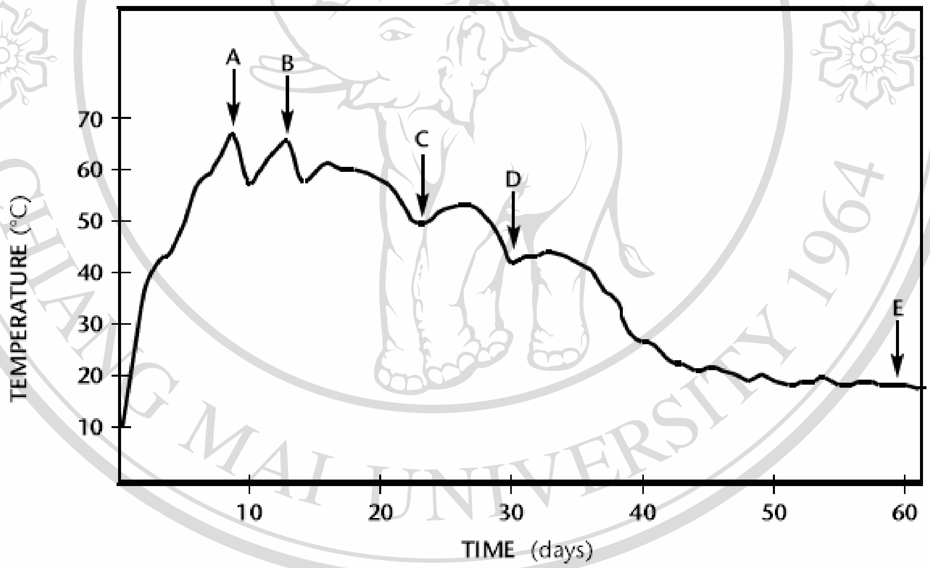

Figure 3 The effects of turning on compost temperature

A typical temperature change as a function of time is presented in Figure 3. The temperature of the material to be composted begins to rise shortly after the establishment of composting conditions. The initial change in temperature parallels the incubation stage of the microbial populations. If conditions are appropriate, this stage is succeeded by a more or less exponential rise in temperature to 60° to 70°C. During this period that the microbial populations increase exponentially in population size, the temperature remains at this level (plateaus) over a period of time. Thereafter, the temperature begins to drop gradually until it reaches the ambient level.

The maturation stage is indicated by the completion of the compost process resulting increase in stability and the compost mass can be safely used or stored after the temperature has finally dropped to about 40°C.

However the duration of the high-temperature plateau may be prolonged if the substrate is largely refractory, or if conditions are less than satisfactory. Or, if the wastes have a significant concentration of inert material, the intensity of the rise is much reduces. Such a condition would be indicated by a low volatile solids concentration. In these cases, the temperature level probably would be lower and the maturation stage will be prolonged as well.

Oxygen/Aeration

Gas exchange supplies oxygen and removes carbon dioxide, heat, and water vapor. The significance of supplying oxygen is that aerobic respiration generates heat at a rate sufficient for self-heating (Cooney *et al*., 1968; Atchley and Clark, 1979; Rynk, 1992; Sesay, 1998). Furthermore, for temperature control which is accomplished by varying aeration rate, the relationship between heating due to high oxygen conditions and cooling due to convective and phase-change phenomena is critical. A number of researchers considered oxygen or carbon dioxide levels as feedback variables (Jeris and Regan, 1973; Nakasaki and Shoda, 1987; deBertoldi *et al*., 1983; Haug, 1993, 1996; Vinci *et al*.,, 1996; Bodelier and Laanbroek, 1997; Richard *et a*l., 1999; Zhang, 2000; Ekinci, 2001). With a known flow rate, measurement of carbon dioxide or oxygen should be sufficient to define the rate of degradation (Jeris and Regan, 1973). It was generally accepted that oxygen levels below 5% might limit aerobic activities (Haug, 1993) rops, and it is not restored by turning or mixing (point E in Figure 3).

Microorganisms

Measurements of microbial community have shown that enormous changes in population distribution occur during composting (Table 1). Table 2 shows some of the major microbial participants as composting progresses from the mesophilic stage into the thermophilic stage and then through a gradual cooling period.

Table 1 Microbial population changes during composting

Organisms	**Mesophilic Stage**	**Thermophilic Stage**	**Curing Stage**	**No. Species Present**
	(CFU g^{-1} Dry Mass)			
Bacteria				
Mesophilic	10^8	10^6	10^{11}	6
Thermophilic	10^4	10^9	10^7	1
Actinomycetes				
Thermophilic	10^4	10^8	10^5	14
Fungi				
Mesophilic	10^6	10^3	10^5	18
Thermophilic	10^3	10^7	10^6	16

Adapted from Poincelot (1977)

Table 2 Species diversity of the dominant microorganisms isolated during different composting phases (Heerden *et al*, 2002; Ryckeboer and Mergaert, 2003)

Composting phase	Prokaryotes	Fungi
Mesophilic phase	*Bacillus macerans*	*Aspergillus flavus*
	Staphylococcus saprophyticus	*Aspergillus niger*
	Flavobacterium sp.	*Aspergillus ustus*
	Streptomyces sp.	*Penicillium sublatilitum*
	Rhodococcus rhodochrous	*Eupenicillium cinnamopurpureum*
	Micrococcus sp.	*Cladosporium cladosporioides*
	Nocardia otitidiscaviarium	
Thermophilic phase	*Enterobacter cloacae*	*Absidia corymbifera*
	Coryneform sp.	*Penicillium diversum*
	Paenibacillus macerans	*Paecilomyces variotii*
	Bacillus licheniformis	*Rhizomucor pusillus*
	Staphylococcus capitis	*Thermomyces lanuginosus*
	Brevibacillus agri	*Thermomyces ibananensis*
Cooling and Maturation phase	*Alcaligenes denitrificans*	*Fusarium solani*
	Proteus vulgaris	*Paecilomyces lilacinus*
	Pseudomonas aeruginosa	*Coprinus lagopus*
	Serratia marcescens	*Mucor* sp.
	Cellulomonas cellulans	*Trichothecium* sp.
	Bacillus sphaericus	*Geotrichum candidum*
	Flavobacterium mizutaii	*Memnoniella echinata*

The resident microbial community in compost consists of bacteria, actinomycetes and fungi, Resident microbial communities have recently been reviewed by Tuomela *et al*. (2000). During the various composting phases different microbial communities predominate, each of which is adapted to the particular environment (Ryckeboer and Mergaert, 2003). Among microbial organisms, microfungi play a very important role. They can use many carbon sources including lignocellulose polymers and they can survive in variable conditions. Therefore, microfungi are mainly responsible for compost maturation (Maheshwari *et al*., 2000; Tuomela *et al*., 2001) and compost seems to be an excellent habitat for them since it contains all organic substrates necessary for microbial growth and reproduction. During the composting process temperature, pH and nutrient availability constantly change therefore these factors influence the types of microorganisms, species diversity and the rate of metabolic activities.

Moisture content

Sufficient moisture in the solid waste is required for maximum efficiency of microbial stabilization (Dirksen and Dasberg, 1993; Iriarte and Ciria, 2001). At low moisture contents (below 30%), microbial activity may be greatly reduced (Nakaya, 1999; Iriarte and Ciria, 2001). Conversely, when the moisture content is excessive, the interstices within the organic mass become filled with water and aeration is restricted. The moisture content between 50 and 70% is most suitable for composting and should be maintained during the periods of active bacterial reactions, i.e. mesophilic and thermophilic growth (Polprasert, 1989; Robinson and Stentiford, 1993; Zhang, 2000). Moisture content is typically reduced during the maturing process from about 60% to about 30%, which provides a stable compost product.

Other objectives of moisture management may include (Zhang, 2000): a) maintenance of optimal composting conditions, b) decreasing the amount of amendment required in agricultural applications, and c) elimination of excess water. In addition, moisture in compost may be increased by respiration and decreased by evaporation (with energy loss as well).

C/N ratio

With respect to the nutrient needs of the microbes active in composting, the C/N of the waste to be composted is the most important factor that requires attention. A large percentage of the carbon is oxidized to carbon dioxide by the microbes in their metabolic activities. The remaining carbon is converted into cell wall or membrane, protoplasm, and strong products. The major consumption of nitrogen is in the synthesis of protoplasm. Consequently, much more carbon than nitrogen is required. The ratio is on the order of 20 to 25 parts of carbon to 1 of nitrogen. Therefore, the C/N of the substrate ideally should fall within the same range. Departures from the ratio of 20 to 25:1 lead to a slowing of decomposition of composting. On the other hand, nitrogen will be lost as ammonia-N if the C/N is lower than those levels. The reason for the loss is that nitrogen in excess of the microbial needs is converted by the organisms into ammonia. A combination of high pH level and elevated temperature very likely leads to volatilization of the ammonia.Alexander (1961) also mentioned that the low C/N ratios will slow decomposition and increase nitrogen loss.

It is reported that an initial C/N ratio of 25-30 is suitable for microbial activities during the nitrification process. Then, the C/N ratio can be used as an indicator for compost maturity. If the initial C/N ratio is greater than 35, the microorganisms must go through many life-cycles, oxidizing off the excess carbon until a more convenient C/N ratio for their metabolism is reached. In case of the C/N of a waste is too high, it can be lowered by adding a nitrogenous waste. Conversely, if the C/N is too low, a carbonaceous waste can be added (Diaz *et al*, 1993). The nitrogen content and the C/N ratio of various wastes and residues are listed in Table 3.

Table 3 Nitrogen content and C/N of various wastes and residues

Wastes	**Nitrogen content (%)**	**C:N**
Sawdust	0.1	200-500
Straw, wheat	0.3-0.5	128-150
Straw, oats	1.1	48
Straw, rice	0.5-1	120-150
Mixed grasses	214	19
Non legume vegetable wastes	2.5-4	11-12
Poutry manure	6.3	15
Cow manure	1.7	18
Horse manure	2.3	25
Activated sludge	5	6

pH level

The initial pH depends on the composition of the ingredients. In the early stages of composting, organic acids may accumulate as a by-product of the digestion of organic matter by bacteria and fungi. The resulting drop in pH encourages the growth of fungi, which are active in the decomposition of lignin and cellulose. Usually, the organic acids break down further during the composting process, and the pH rises. This is caused by two processes that occur during the thermophilic phase: decomposition and volatilization of organic acids, and release of ammonia by microbes as they break down proteins and other organic nitrogen sources. Later in the composting process, the pH tends to become neutral as the ammonia is either lost to the atmosphere or incorporated into new microbial growth.

Nakasaki *et al*. (1994) found that the degradation rate of organic matter in the pH controlled experiment was faster than that in the experiment without pH control and found an optimum pH range of 7–8, while the decomposition of glucose proceeded rapidly in a pH range of 6–9. Moreover, Nakasaki *et al*. (1996) found that inoculation with *Bacillus licheniformis* clearly enhanced the carbon turnover by shortening the low pH phase when composting in a laboratory-scale composting reactor at 60 °C.

Generally, organic matter with a high range of pH (from 3 to 11) can be composted. However, optimum values are between pH 5.5 and 8.0. Whereas bacteria prefer a nearly neutral pH, fungi develop better in fairly acid environment.

Finished compost generally has pH between 6 and 8. If the system becomes anaerobic, it will not follow this trend. Instead, acid accumulation may lower the pH to 4.5, severely limiting microbial activity. In such cases, aeration usually is sufficient to return the compost pH to acceptable ranges.

Nitrogen content

The nitrogen content of composts will vary according to the source material and how it is composted. In general, nitrogen becomes less available as the compost matures with nitrogen-rich feedstock but more available with carbonaceous feedstock. Nitrogen in the form of ammonium (NH^{4+}) or nitrate (NO^{3-}) is readily available for plant absorption. However, these constituents are low in composts. A finished compost has little ammonium, as it is oxidized to nitrate during composting and curing, and any nitrate that is produced could be leached, lost to the air, or consumed by the organisms performing the composting. The majority of the nitrogen in finished compost (usually over 90%) has been incorporated into organic compounds that are resistant to decomposition. Rough estimates are that only 10% to 30% of the nitrogen in these organic compounds will become available in one growing season. Some of the remaining nitrogen will become available in subsequent years and at much slower rates than in the first year (Lossin, 1970).

Macronutrients and micronutrients

The macronutrients include carbon (C), nitrogen (N), phosphorus (P), calcium (Ca), and potassium (K). However, the required amounts of Ca and K are much less than those of C, N, and P. Because they are required only in trace amounts, they are frequently referred to as the "essential trace elements". In fact, most become toxic in concentrations above trace. Among the essential trace elements are magnesium (Mg), manganese (Mn), cobalt (Co), iron (Fe), and sulphur (S). Most trace elements have a role in the cellular metabolism. The substrate is the source of the essential macronutrients and micronutrients. Even though an element of uncertainty is introduced into an operation, economic reality dictates that wastes constitute most or all of the substrate in compost practice. Any uncertainty is due to variation in the availability of some nutrients to the microbes. Variation in availability, in turn, arises from differences in resistance of certain organic molecules to microbial attack. Variations in resistance lead to variations in rate at which the process advances.

Examples of resistant materials are lignin (wood) and chitin (feathers, shellfish exoskeletons), and several forms of cellulose (Regan and Jeris, 1970).

Particle size

The size of particles in the waste is a nutrient-related factor, because the waste is the substrate in composting and the substrate is the source of nutrients. The relation to nutrition is the effect of size of the individual particles on the physical availability of nutrients, i.e. accessibility to the nutrients. Particle size determines the ratio of mass-to-surface and, hence, amount of a particle's mass that is exposed to microbial attack. In as much as the ratio increases with decrease in size, the rate of decomposition (composting) theoretically should increase with decrease in particle size. However, the theoretical increase does not always materialise in practice. The failure may be due to one or more factors. For example, the physical nature of the substrate may impose constraints in terms of minimum permissible size. The permissible minimum size is the one at which any further reduction would adversely affect the compost process. Ultimately, the criterion for determination of minimum permissible size is the ability to establish a substrate porosity that is consistent with necessary aeration. Porosity is largely a function of the structural strength of the particle material. Structurally strong, crush-resistant waste materials, such as wood, straw, and paper, remain porous at very small particle sizes. Any size reduction needed would be determined by the characteristics of the bedding material. Size reduction is usually accomplished with a shredder or grinder, which is a large, expensive piece of equipment. A possible alternative might be to rely upon some form of tumbling to accomplish the relatively limited tearing, breaking, and maceration that would be required (Nakaya, 1999; Iriarte and Ciria, 2001).

2. 3 Bio-degrading microorganisms

The microorganisms needed for composting are found throughout the natural environment. They are present in compost feedstock as well as in the water, air, soil, and machinery the feedstock and compost are exposed to during processing. These sources ensure a high diversity of microorganisms, which helps to maintain an active microbial population during the dynamic chemical and physical processes of composting, such as shifts in pH, temperature, water, organic matter, and nutrient availability.

Microbe Types and Requirements

The microbiological components of compost consist of bacteria and fungi. Because of their unique nature, actinomycetes are discussed here as a third microbiological component, though in actuality actinomycetes are a particular kind of bacteria. The majority of microorganisms responsible for the formation of compost are aerobes.

Fungi

Fungi form their individual cells into long filaments called hyphae. They penetrate throughout the composting material, decomposing both chemically and mechanically the more recalcitrant organic matter fraction such as lignins and cellulose. Fungal hyphae physically stabilize the compost into small aggregates, providing the compost with improved aeration and drainage. Ecologically, fungi play a vital role in breakdown of dead plant materials.

Bacteria

The most numerous biological component of compost is the bacteria. They also contribute to the stabilization of aggregates through the excretion of organic compounds that bind adjacent organic matter and soil particles together. Bacteria are typically associated with the consumption of easily degraded organic matter. They are the dominant population throughout the entire composting process, whereas the actinomycetes and fungi typically proliferate in the later stages.

Actinomycetes

Actinomycetes are visually similar to fungi in that they have networks of individual cells that form filaments or strands, they are actually a type of bacteria. These filaments allow for a colony of actinomycetes to spread throughout a compost pile, where they are typically associated with the degradation of the more recalcitrant compounds. Their filaments contribute to the formation of the stable organic aggregates typical of finished compost. Actinomycetes are tolerant of lower moisture conditions than other bacteria and are responsible for the release of geosmin, a chemical associated with the typically musty, earthy smell of compost (Biddlestone and Gray, 1985; McKinley and Vistal, 1985; Strom, 1985).

Cellulose decomposition

A prominent carbonaceous constituent of plants and probably the most abundant organic compound in nature is cellulose (Table 4). The cellulose content of plants is never fixed and the concentration changes with age and type of plant. A concentration range of 15 to 50 percent includes most of the common crop species (Maheshwari *et al.*, 2000; Golueke and Diaz 1990). Both starch and cellulose are polymers of the same building block, glucose, but the individual peculiarities of the two molecules permit ready microbial attack of the former substance while the latter is far more resistant to microbiological and enzymatic breakdown.

Table 4 Percentage of cytoplasmic and cell wall components in plants

Plant component	% of total
Waxes and pigment	1
Amino acids, sugars, nucleotides, etc.	5
Starch	2-20
Protein	5-7
Cellulose	15-50

Adapted from Tengerdy and Szakacs (2003)

Cellulolytic microorganisms are common in field and forest soils, in manure and on decaying plant tissue. The physiological heterogeneity of the responsible microflora permits the transformation to take place in habitats with or without O_2, at acid or at alkaline pH, low or high moisture levels, and from temperatures just above freezing to the thermophilic range. Among the cellulose-utilizing species are bacteria, filamentous fungi and actinomycetes. Although many of these organisms have been studied only in pure culture, the action in nature is clearly the result of a complex community. At best, it is difficult to compare pure cultures with the many populations active *in vivo* since there is an intense microbiological competition for nutrients and sequential changes in the composition of the microflora with time.

Cellulose is on occasion degraded more rapidly in mixed than in pure culture, even when the associated organisms are unable by themselfes to attack the poly saccharide. The secondary population probably favors the primary flora by removing the breakdown products and thereby preventing the metabolic wastes from causing inhibitions.

A diverse group of fungi utilizes cellulose for its carbon and energy sources (Table 5). Following treatment of soil with cellulose, there is a significant increase in the numbers of fungi, particularly if the nitrogen supply is adequate. Plate counts of filamentous fungi in excess of 10^6 CFU g^{-1} of soil during the decomposition of straw plus $NaNO_3$ are not uncommon. Strongly cellulolytic fungi are represented by species of the genera *Aspergillus, Chaetomium, Curvularia, Fusarium, Memnoniella, Phoma, Thielavia* and *Trichoderma*. It has been proposed that fungi are the main agents of cellulose degradation in humid soils while bacteria are of greater significance in semiarid localities. In the destruction of forest litter, wood and woody tissues, cellulolytic fungi are especially predominant. Indeed, many fungi seem able to decompose cellulose. This is in great contrast to the bacteria, a group in which possession of the requisite enzymes is a comparative rarity.

Table 5 Representative cellulase-producing microorganisms

Fungi	**Bacteria**	**Actinomycetes**
Acremonium cellulolyticus	*Bacillus*	*Streptomyces* sp.
Aspergillus acculeatus	*Cellulomonas*	
Aspergillus fumigatus	*Clostridium*	
Aspergillus niger	*Corynebacterium*	
Fusarium solani	*Cytophaga*	
Irpex lacteus	*Polyangium*	
Penicillium funmiculosum	*Pseudomonas*	
Phanerochaete chrysosporium	*Sporocytophaga*	
Schizophyllum commune	*Vibrio*	
Sclerotium rolfsii	*Clostridium thermocellum*	
Sporotrichum cellulophilum	*Ruminococcus albus*	
Talaromyces emersonii		
Thielavia terrestris		
Trichoderma koningii		
Trichoderma reesei		
Trichoderma viride		

Occasional species of *Pseudomonas*, *Vibrio* and *Bacillus* utilize cellulose but this physiological attribute is uncommon to most species of these genera. *Bacillus* contains aerobic, spore-forming, gram-positive rods while the other genera include non-spore-forming, gram-negative aerobes. *Cellulomonas*, on the other hand, is a cellulolytic genus made up of short, gram-negative rods commonly producing yellow, water-insoluble pigments; these organisms are straight or somewhat curved, but occasional pleomorphic forms are found. In addition, some cellulolytic bacteria are long, slender rods that exhibit a slight curving and others are characterized by spindleor sickle-shaped cells (Hatakka, 1994).

Actinomycetes that grow on cellulose have received little attention despite their presence during the decay of cellulosic materials. Many *Streptomyces* isolates develop, frequently with conspicuous pigments, on cellulose agar supplemented with inorganic nutrients. In addition to *Streptomyces*, species of *Micromonospora*, *Streptosporangium* and *Nocardia* are cellulolytic. That the activity is common to this actinomycetes found to have the capacity to attack cellulose (Eriksson *et al*., 1990; Dix and Webster, 1995). Nevertheless, although many actinomycetes have the necessary complement of enzymes, they are much slower in attacking the polysaccharide than most fungi and true bacteria and may not be good competitors for the substrate.

Starch Decomposition

Starch disappears rapidly when subjected to the activity of soil community and its decomposition proceeds at a greater rate than the microbiologically induced losses of cellulose, hemicellulose and a variety of other polysaccharides.

Bacteria, fungi and actinomycetes have the capacity to hydrolyze starch and the physiological heterogeneity of the active flora suggests that the decomposition can take place in diverse environments. From 3 to 90 percent of the bacteria and actinomycetes appearing on dilution plates can utilize the polysaccharide. Some of the more ubiquitous genera implicated in starch utilization are listed in Table 6.

Table 6 Some microbial genera have capability of utilize starch

Bacteria	**Actinomycetes**	**Fungi**
Bacillus	*Micromonospora*	*Aspergillus*
Chromobacterium	*Nocardia*	*Fomes*
Clostridium	*Streptomyces*	*Fusarium*
Cytophaga		*Polyporus*
Flavobacterium		*Rhizopus*
Micrococcus		
Pseudomonas		

Starch-hydrolyzing enzymes are usually inducible but the ability of microorganisms form amylolytic enzymes depend on the type of starch. Many amylolactic isolates are capable of growing on the polysaccharide obtained from one plant but not from another and some bacteria are highly specific for one or a few related starches (Takada *et al.*, 1996).

Protein decomposition

The protein molecule is composed of a long chain of amino acids. In the process, the proteolytic enzymes cleave the protein molecule to polypeptides, simple peptides and finally to free amino acids that are the end products of protease action. The reaction is a hydrolysis as the enzyme ruptures the peptide bond by the addition of water. Many microorganisms utilize polypeptides, simple peptides and amino acids in contrast to the few genera degrading native proteins.

The activity of proteolytic enzymes in soil is evaluated by incubating test samples with proteins or peptides and measuring amino acid formation in short periods of incubation. These activities are markedly affected by temperature and pH, with the optimal temperature for hydrolysis being in the thermophilic range (Pandey *et al*., 2000). Different proteins are cleaved by these catalysts and their activity is enhanced by the addition not only of proteins but also of sugars that bring about extensive microbial proliferation.

The amino acids liberated by proteases serve as carbon and nitrogen sources for innumerable heterotrophs, each of which may be able to utilize one or several of these compounds. The nitrogen of most amino acids is removed as ammonia prior to significant decomposition of the carbon-containing portion of the molecule and the microorganism gets its nitrogen by assimilation of the ammonia. The common mechanisms for the initial degradation of amino acids are deamination, the removal of ammonia and decarboxylation, in which the carboxyl is removed.

The amino acids produced from the proteins are mineralized at different rates. Some amino acids are resistant and others are highly susceptible to decomposition. Ammonia is formed readily from some, while others have a more extended persistence in compost. After deamination, the carbon residue is attacked aerobically to yield CO_2 and various organic products.

Several microbial strains including fungi (*Aspergillus flavus*, *Aspergillus melleu*, *Aspergillus niger*, *Chrysosporium keratinophilum*, *Fusarium graminarum*, *Penicillium griseofulvin*, *Scedosporium apiosermum*) and bacterial (*Bacillus licheniformis, Bacillus firmus, Bacillus alcalophilus, Bacillus amyloliquefaciens, Bacillus proteolyticus, Bacillus subtilis, Bacillus thuringiensis*) (Rodriguez *et al*., 1998) are reported to produce proteases.

Lipid decomposition

The average lipid content of most plants is about 5% of dry weight, with leaves containing the greatest amount. The lipid content depends highly on the plant species. The lipid content of high, cutin-containing plants, such as conifers and succulents, may reach 10% or more of the dry weight. The durability of lipids depends on their chemical complexity. Long chain aliphatic fatty acids and phospholipids, component of membranes, are degraded relatively quickly depending on the degree of saturation or double-bond content. Microbial lipases have been produced by yeasts, fungi, and bacteria as extracellular, intracellular, and cell-bound enzyme. The extracellular lipases from yeast and bacteria are interesting because of easier application. Yeasts produced extracellular lipase are *Candida deformans* (Muderwa and Ratamahenina, 1985), *C. rugosa* (Rao *et al*., 1993) while bacteria are *Pseudomonas aeruginosa* EF2 (Gilbert *et al*., 1991), *P. fragi* CRDA 323 (Pabai *et al*., 1995) and *Alcaligenes* sp. Strain No. 679 (Kokusho *et al*., 1982).

2. 4 Inoculums

Inoculum are an adding proportional of microorganisms to decompose the substrate for compensation of lacking of indigenous microorganisms and macro-organisms. Characteristically, most wastes in compost practice have such an indigenous population, and inoculation would be unnecessary. On the other hand, inoculation would be useful with wastes that either lack an indigenous population or have one that is deficient. Examples of such wastes are pharmaceutical manufacturing wastes, wastes that have been sterilized or pasteurized, and wastes that are homogeneous in composition (sawdust or wood chips, rice hulls, petroleum wastes, etc.). If the need for an inoculum is indicated, then the decomposed horse manure, finished compost, or a rich and loamy soil can serve the purpose. All three materials contain an abundance of microflora. A form of inoculation often used in compost practice is the “inoculum”, accomplished by reproducing special microorganisms and making formulation with certain proportion of substrates (Ogram and Feng, 1996).

To produce the inoculum begins with the first step of isolation and selection of microorganisms for the target decomposition (i.e. thermophilic bacteria, bacteria producing cellulase). The selected microorganisms will be scientifically identifed and produced pure strains. The cultivation of pure strains in optimal medium will be processed to obtain the massive production. Finally, the formulation of inoculum will be carried out by mixing the microorganisms massive produced with the appropriate kind and proportion of some substrates.

To be effective, the organisms in the inoculum must be able to successfully compete with organisms indigenous to the waste. The competitive ability of introduced organisms is adversely affected by the repeated subculturing involved in culture maintenance. In conclusion, little is gained from the abundant indigenous population of microorganism characteristic of most inoculated wastes destined to be composted. Before being accepted, claims for an inoculum must be demonstrated to be valid by the way of unbiased conducted tests or demonstrations. Moreover, it should be noted that, generally, inoculated microbes do not compete well under practical conditions (Pelaez and Planas, 2001).

Many researchers and companies suggest they can determine the “health” of a compost product and recommend inoculants to improve its quality or performance. However, there is no conclusive evidence that the addition of any specific microorganism to cured compost will improve any characteristic of compost. Native microorganisms may quickly dominate introduced microorganisms. The introduced microorganisms may provide possibly nothing more than additional nutrients to organisms already in the compost. Inoculants, if desired, can be added just prior to application of the compost.

The University of California indicates that treatments with inocula have not represented an acceleration of the process, neither an improvement in product quality. Even natural inocula have presented better results than isolated microorganism formulations (Golueke, 1981; Gouin, 1992).

Thus, to determine the decompose ability of microorganisms introduced in the process, the optimal time which results in a significant reduction in production cost, can also be one parameter to considered (Rynk *et al*., 1991).