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ABSTRACT

Composting industry is a progressive and innovative industry that has been growing worldwide, especially in the last 30 years. The objectives of this paper were to collect and analyze information about fundamentals and processes on composting and anaerobic digestion, and compiling an overview of these processes. This paper also presents the versatility and multivariable profile of these processes, showing the biological, chemical, physical, and thermodynamic fundamentals.

KEYWORDS

Composting; anaerobic digestion; composting fundamentals, composting processes

INTRODUCTION

In 2003, MSW generation was estimated to be 4.5 pounds (2.04kg) per person per day. Approximately 55% of the 240 million tons ($2.4x10^8$ kg) of MSW generated per year were landfilled, 14.0% were combusted, and 31% were recycled or composted (USEPA, 2003). Composting industry has grown in the USA in the past 20 years (Coker and Goldstein, 2004). Recycling of MSW increased 9% and composting of MSW increased 5% from 1990 to 2003, totaling 7% for composting (USEPA, 2003). Just to have an idea how much of an impact MSW has, residential waste of City of New York is approximately 28% composed of leaves, grass, yard, food, and other organic waste. New York could save $12 million per year by restoring and expanding composting programs (Goldstein and Goldstein, 2004).

There are three major biological management of MSW: biological processes occurring in landfills, anaerobic digesters, and composting facilities (Palmisano and Barlaz, 1996). In this paper, landfills will not be covered since there is a tendency of diverting biodegradable components from MSW from landfills to other alternatives, such as composting (Braber, 1995; Harrison and Richard, 1992; Komilis, 2006; New Mexico State University, 2004) and anaerobic digestion (Braber, 1995; Shin et al., 2000). This tendency is not only due to dwindling landfill space (Nichols, 2004; Shin et al., 2000; Song and Greenway, 2005; Tinmaz and Demir, 2006), but also due to certain challenges, such as emanating odors, attracting vermin, emitting toxic gases, and potentially contaminating groundwater (Shin et al., 2000). However, it is important to note that there are some studies that have proposed improvements in the challenges associated with landfills (Münnich et al., 2006).

Composting is the biological decomposition and stabilization of organic substrates that involves aerobic respiration (Palmisano and Barlaz, 1996) and produces a final product that is stable, and free of pathogens and plant seeds that can be beneficially applied to land (Haug, 1993). During the process of aerobic composting, it generates carbon dioxide, water, and heat. On the other hand, anaerobic digestion is the biological decomposition of organic substrates in the absence of oxygen. During the process of anaerobic digestion, it generates methane, carbon dioxide, and numerous low-molecular weight intermediates such as organic acids and alcohols (Haug, 1993) and humus (Chynoweth and Pullammanappallil, 1996). This implies that significantly less energy is required per mass of organic decomposed during anaerobic digestion compared to aerobic composting. Anaerobic digestion of MSW has developed more rapidly in Europe in the last decade than in the U.S. (Palmisano and Barlaz, 1996). Anaerobic digestion is also preferred in other countries, such as Korea, to manage food residuals (Shin et al., 2000). Within the projects reported in the U.S. that turn methane from anaerobic digestion into electricity, there is a very good example of the Straus Family Creamery in California that generates up 600 000 kWh/year from anaerobic digester, saving $6,000/month in energy costs (Goldstein, 2004)

FUNDAMENTALS

The maturity and stability of a compost is important because it interferes in the retardardation of plant growth due to nitrogen starvation, anaerobic conditions, phytotoxicity of NH_3, and some organics (Huang et al., 2004). It also affects the potential for odor generation, biomass re-heating, residual biogas production, re-growth of pathogens, plant disease suppression ability, and effects on other process parameters (Adani et al., 2006). Biological, chemical, physical, and thermo dynamic factors should be appropriately controlled for achieving compost maturity efficiently.

Biological Fundamentals

In anaerobic digestion, four different types of microorganisms are responsible for the the degradation of MSW: hydrolytic, fermentative, acetogenic, and methanogenic (Braber, 1995). In the first step of anaerobic digestion (depolymerization), the hydrolytic bacteria are responsible for depolymerization of polymeric solid substrates into smaller molecules such as organic acids, alcohols, and the methanogenic substrates. Some bacteria involved in this step are: Bacteroides *succinogenes, Clostridium lochhadii, Clostridium cellobioporus, Ruminococcus flavefaciens, Rumminococcus albus, Butyrivibriofibrisolvens, Clostridium thermocellum, Clostridium stercorarium,* and *Micromonospora bispora.* In anaerobic digesters with MSW, the predominant bacteria are *Clostridia*. In this stage, typically only 50% of the organic matter is degraded. Also, some intermediate reactions occur: for example, products of depolymerization reactions are converted to fermentation products (Chynoweth and Pullammanappallil, 1996).

The last step is the methanogenesis. Methanogic bacteria are slow-growing anaerobes that degrade acetate, methanol, carbon dioxide, formate, carbon monoxide, methylamines, methyl mercaptans, and reduced metals (Chynoweth and Pullammanappallil, 1996).

In composting, a variety of microorganisms are present in a composting system, as shown in Fig. 1.

Even though the microbial population may be vast, the main microorganisms that affect the composting system are fungi, actinomycetes, and bacteria. Also present are protozoa and algae (Stoffela and Kahn, 2001). Bacteria and fungi are the most important microorganisms for composting (Haug, 1993).

A composting system may contain three classes of microorganisms: cryophiles or psychrofiles, mesophiles, and thermophiles (Stoffela and Kahn, 2001). Cryophiles bacteria do their best work at about 13ºC, although they work even until -20ºC. Between 0ºC to 40ºC, mesophilic bacteria predominate. Above this temperature, thermophilic bacteria work faster. When the temperature of the compost comes down, mesophilic bacteria again predominate (Wassenaar, 2003).

Considering a windrow system, mesophiles and thermophiles are the most common microorganisms in composting, contributing to composting at different times of the process. This has four different stages. In the first stage, there are abundance of substrate and mesophiles that are predominant and very active. During this stage, large quantities of heat energy are generated, which increases the temperature of the compost pile. The favorable temperatures to this kind of microorganism are between 35°C and 45°C (Miller, 1996; Stofella and Kahn, 2001).

As the temperature rises, it becomes more favorable to thermophiles, for which the best temperature is higher than 45°C. The compost pile reaches about 65°C to 70°C. At this stage, the food sources decreases for microorganisms and the temperature falls, resulting in one more mesophilic stage. In the last stage, the temperature falls to ambient temperature again (Miller, 1996; Stofella and Kahn, 2001).

About 80 to 90% of the microbial activity during composting is due to bacteria (Haug, 1993; Stofella and Kahn, 2001). In composting, species were found belonging to *Bacillus, Pseudomonas, Arthrobacter, Alicaligenes* (Stofella and Kahn, 2001), as well as *Staphilococci* (Hassen et al., 2001) in the mesophilic stage. In thermophilic stage, bacteria are predominantly of the *Bacillus sp*., as *B. subtilis, B. stearothermophilic,* and *B. licheniformis*. Above 65°C, compost populations are often reduced to pure cultures of *B. stearothermophilus* (Miller, 1996). The optimum starting temperature for decomposition was found to be 40°C, considering the amount of TOC reduction (Hamoda et al., 1998).

Actinomycetes usually can be observed after five or seven days from the beginning of the composting. They are easily detected because of their grayish appearance in the compost. They are responsible for the "earthy" smell that the compost emits under favorable conditions. *Micromonospora, Streptomyces,* and *Actinomyces* are some species that can be regularly found in composting materials. Actinomycetes play an important role in composting once they have conditions to degrade cellulosic components such as bark, newspaper, and woody stems (Stoffela and Kahn, 2001, Wassenaar, 2003). Actinomycetes tend to be common in the later stages of composting. They prefer moist, highly aerobic conditions and a neutral or slightly alkaline pH (Miller, 1996).

Fungi are important because they can break down tough debris and organic residues that are too dry (fungi have a lower moisture requirement), acidic (fungi can live in a broad range of pH), or low in nitrogen, enabling bacteria to continue the decomposition process. Fungi are most common in mesophilic and thermophilic stages of composting. Species more common are *Mucor, Aspergillus,* and *Humicola* (Epstein, 1997; Miller, 1996; Wassenaar, 2003).

Ants, beetles, centipedes, green fruit beetle larvae, millipedes, mites, redworms, sowbugs, springtails, and redworms can be found in a compost pile (Wassenaar, 2003). They are important not just for decomposition of the organic matter, but as source of nutrients and biomass to the soil (Epstein, 1997).

Chemical Fundamentals

Carbon (C) and nitrogen (N) are essential to the composting process. Carbon provides the primary energy source and it is utilized for cellular growth. Nitrogen is also essential to the growth of microorganisms in order to synthesize new cellular material (Diaz et al., 1993; Epstein, 1997; Stofella and Kahn, 2001). C/N ratio is a very import parameter and expresses the effect of raw waste quality (Hamoda et al., 1998). The optimum C/N ratio was found to be in the range of 25 – 30 (Diaz et al., 1993; Epstein, 1997; Hamoda et al., 1998; Huang et al., 2004; Stofella and Kahn, 2001).

Phosphorus (P) and potassium (K) are also important to the growth of the plants. Substrates such as biosolids, yard debris, and animal manure may have sufficient P, but Municipal Solid Waste (MSW) may not have enough P if it is high in cellulose. Cisteine and methionine - both aminoacids found in protein materials - are the main sources of sulfur (S) in substrates, which in sufficient quantities may generate volatile and odorous compounds (detected by people even at a low-level of concentrations). In well-aerated process, sulfites are oxidized into the sulfates by combining with oxygen in well-aerated zones. However, in anaerobic conditions, volatile organic sulfides and H_2S vaporize into the atmosphere, being responsible for many of the malodor associated with composting. In regard to heavy metals, some countries have established compost quality standards that limit the concentration of heavy metals (arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, and zinc). This refers to the heavy metal concentration of the substrate and the final compost (Stofella and Kahn, 2001).

Many organic substances, including MSW, sewage sludge, and other industrial waste are being introduced to composting, which increases the level of heavy metals when compared to the traditional “green” waste compost (Song and Greenway, 2005). However, heavy metals do not seem to be an obstacle to composting. For example, the US Environmental Protection Agency (US-EPA) considers that the levels of trace elements found in MSW compost do not represent a significant risk in terms of human health and impacts to the environment. In addition, the separation of MSW into compostable and non-compostable fractions reduces the level of heavy metals. Another concern about the presence of heavy metals in compost is the possibility of their leaching to groundwater or runoff to surface waters. It has been reported that the leaching of heavy metals increases with application rate of the compost in the soil. However, the concentration of some heavy metals has been reported to be lower than that by the US-EPA drinking water limits (Epstein, 1997).

Composting process is relatively insensitive to pH because it has a wide range of microorganisms that work in different pH (Diaz et al., 1993; Stofella and Kahn, 2001). For example, bacteria acidophiles need pH 5 or less for maximal growth; bacteria alkalophiles need a range of pH between 7 and 12; and bacteria neutrophiles need pH about 7.0 (Epstein, 1997). However, the optimum pH generally is considered to be between 6.5 and 8.5. In aerobic composting an oxidation process occurs where O_2 is consumed and CO_2 is produced. Thus, controlling the level of these two gases during the composting process can provide an indication of composting activity. For an efficient composting, an adequate aeration is required, which is based on temperature, free air space, and moisture (Stoffela and Kahn, 2001). Aeration is important to obviously satisfy the O_2 level, to remove water from wet substrates, and to remove the heat generated by organic decomposition in order to control the process temperature (Haug, 1993).

Physical Fundamentals

Moisture content is an important variable in composting process in order for the bacteria to assimilate their nutrients that could be dissolved in water. Moisture comes from the original moisture of substrates and from the biological oxidation of organic matter. It is lost through evaporation. Diaz et al. (1993) have stated that the microbial activity ceases when the moisture is less than 8% to 15%. It is reported that it may start to occur when the moisture content is about 12% to 15% (Stofella and Kahn, 2001). The desirable moisture content is between 50% and 60% (Epstein, 1997; Hamoda et al., 1998; Stofella and Kahn, 2001); although, for domestic waste, the optimum moisture is between 52% and 58% and for food waste it is 60%. Lower moisture levels can make composting facility operators prematurely conclude that their compost process has stabilized. In addition, microbial activity decreases when moisture is below 40%. On the other hand, high moisture levels (above 60%) can block the air passageways, enabling anaerobic conditions with the potential for odor formation. Composting containing materials with structural strength, with a degree of resistance of individual particles to consolidate under compression, (e.g., woodchips, straw, hay (dried grass), rice hulls, and corn stover) can tolerate high moisture of about 75% to 80%. On the other hand, if particles are structurally weak, they are deformed and compressed upon compression, and the volume of interstices is proportionally reduced, which means that it reduces the available space for air and water; so, the permissible water content is lower. Fig. 2 shows a schematic of interstices in composting material. Fruit wastes, caning process wastes, sludge, and manures are example of materials that have little or no structural strength. In this case, it is necessary to add a bulking material, which will improve the strength of the compost material. Any material can be added with a high degree of structural strength or even finished compost material (which is usual), or some amorphous material can be added after undergoing a specific process (Diaz et al., 1993).

Particle size affects moisture retention, free air space, and porosity of the compost mixture. Large particle size materials imply more free air space and high porosity. On the other hand, small particle size materials increase the surface contact between O_2 and compost material, increasing the aerobic composting activity. Hamoda (1998) showed that the rate of organic matter decomposition is higher for material of 40 mm particle size due to the fact that the voids between such larger waste particles are bigger than with smaller sizes (5, 10, and 20 mm size), where the oxygen may not access particles easily.

Usually the temperature profile of the composting system is shown as a simple curve, as shown in Fig. 3. The control of the temperature in composting process is important to maximize the decomposition rate and to inactivate pathogenic organisms (Epstein, 1997; Martin, 1991; Stofella and Kahn, 2001). For substrates that do not contain human pathogens, a certain desirable temperature is necessary to inactivate plant pathogen or to destroy weed seed. Temperature also affects the moisture content, which affects microbiology activity (Epstein, 1997). The best temperature varies according to the type of substrate that is being used and according to the microorganism population that is desired; for example, there is different optimum temperature to mesophilic bacteria and to thermophilic bacteria (Stoffela and Kahn, 2001).

Thermodynamics Fundamentals

Thermodynamics is the branch of science that deals with energy and its transformation. All life forms can be viewed as chemical machines, which must obey the laws of energy and heat. The designer of a composting plant needs to understand the microbes involved, reactions they mediate to obtain energy, environmental conditions required for growth and metabolism, and, in certain cases, conditions required to kill organisms such as pathogens (Haug, 1993).

The First Law of Thermodynamics is the law of the conservation of energy. The concepts of heat, work, internal energy, and enthalpy are related to the First Law. The Second Law of Thermodynamics resulted from a search to explain the direction in which spontaneous process would occur. The concept of free energy was developed from the First and Second Laws. Free energy gives the useful work, which can be derived from a chemical reaction that occurs under constant pressure and temperature conditions (most microbial reactions occur under such conditions). The water and solid fractions of a composting material can be treated as separate components from a thermodynamic standpoint, which allows calculating the energy balance of a composting process (Haug, 1993).

Interesting studies were done in this area very recently. For instance, mass and energy balances of four alternatives strategies were examined for energy recovery from MSW by dedicated waste-to-energy plants generating electricity through a steam cycle. The largest energy savings were achieved by combusting materials recovery without treatment in large scale plants (Consonni et al., 2005). In another study, energy conservation and carbon dioxide emission reductions due to recycling in Brazil were estimated, given the amount and the composition of waste recycled and the scenario for the energy generation expansion in that country (Pimenteira et al., 2004).

PROCESSES

Composting

Composting may be performed in various ways. Currently, the leading concepts are: non-reactor systems (windrows and static pile) and reactor systems (vertical flow, horizontal and inclined flow processes, and nonflow processes).

Windrow

Windrow is the most common composting method practiced (Diaz et al., 1993; Haug, 1993; Stofella and Kahn, 2001) and is a potential treatment technique for MSW (Komilis, 2006). Mixed feedstocks are placed into long narrow piles and turned periodically, usually by mechanical equipment.

Height, width, and shape of the windrows vary depending on the nature of the feed material and the type of equipment used for turning (Haug, 1993). Windrow process can be naturally aerated. In this case, the oxygen is supplied primarily by natural ventilation resulting from the buoyancy of hot gases in the windrow system and, to a lesser extent, by gas exchange during turning. Another variation of the windrow process is the one with forced aeration. In this case, oxygen transfer into the windrow is aided by forced or induced aeration from blowers (Haug, 1993; Manser and Keeling, 1996).

Turning feedstocks aerates the windrow, although not for a long time because microorganisms consume the oxygen within hours (Epstein, 1997; Stofella and Kahn, 2001). Another effect of turning is the loss of water. It can be good, if the substrate has high moisture content. On the other hand, because the turning process makes it easier to add water, it is a good opportunity if the moisture level of the feedstock is low. The frequency of turning is indicated by the ratio of oxygen availability to oxygen demand and it depends on many factors: nature of the material, its structural strength and moisture content, pathogen kill, uniformity of decomposition, and the rapidity of the composition desired by the operator. Turned windrow systems have some limitations. The first is that temperatures lethal to pathogens do not prevail throughout a windrow. Another disadvantage is that the turning procedure can contaminate the sterilized material with nonsterile material in the outer layers of the windrow in which bactericidal temperatures did not develop. Repeated turnings can reduce the pathogens populations to less than affective concentrations. In addition, turning improperly or insufficiently leads to malodors. Reduced frequency, increased space requirement, intensity and frequency of turnings, have also been listed as disadvantages (Diaz et al., 1993).

Static piles

This process may be passively aerated, assisted passive aerated, and aerated. The passively aerated process is based on passive aeration, natural decomposition, to produce compost. It is normally used to slowly decompose cellulostic feedstocks, such as leaves, brush, bark, wood chips, and some agriculture residues. Feedstocks may be combined and mixed to adjust moisture, porosity, density, and/or C/N ratio. After the pile is formed, this is turned with a bucket loader every one to three month, resulting in one or two turnings during the composting cycle (Stoffela and Kahn, 2001).

For the static pile process, it is difficult to maintain the aerobic condition; usually, aerobic condition exists only within one to three meters from the pile surface and perhaps along air channels that form within the pile. However, oxygen conditions can be improved with well-mixed feedstocks and with the increasing of porosity.

One of the most common assisted passive aerated methods is the Passively Aerated Windrow System (PAWS). This method involves short windrows with one to three meters height and they are not turned. There are some characteristics usually common for any variation of this method: feedstocks have homogeneous and relatively porous mixture; a delivery system for passive air flow; a base layer of stable absorbent material like straw or compost; and an exterior layer (approximately 150 mm thick) of stable coarse material that retains heat, moisture, odor, and NH_3.

In the aerate static piles method, fans aerate the composting materials. It improves aeration, reduces the processing time, and reduces the potential to produce odors, while providing oxygen, cooling the pile and removing water vapor, carbon dioxide, and other products. There is no intentional turning or agitation; it occurs just when materials are moved (Stofella and Kahn, 2001).

Some advantages of this method are that it is simple, requires less area than passively aerated methods and turned windrows, while aerating is better. In addition, it can be enclosed within a building because it is a more compact process and require less space (Stofella and Kahn, 2001). Additionally, static piles are not required to be turned regularly (Manser and Keeling, 1996). This method, however, requires attention due to compaction, short circuiting of air, and inconsistent decomposition within a batch of compost (Stoffela and Kahn, 2001). Moreover this system needs a power supply for the fans, and a control system to alternate the fans between suction and blowing. Another problem is that the air pipe could be in the way of handling equipment inside a plant, interfering in the process (Manser and Keeling, 1996).

Within the vertical processes, there are agitated solids bed and packed bed. Agitated solids beds have multiple hearths; solids are agitated during movement down the reactor, with forced aeration. Feeding can be continuous or intermittent and there is some mixing in reactor. A very good example of this type of reactor is the NGK reactor that began operation in 1989 in Japan. This reactor can be seen in Fig. 5. In this system, two reactors are provided, each with six cells arranged vertically. The facility composts slightly over two dry tons/day (2,000 kg/day) of lime and ferric conditioned, raw sewage sludge, filtered press cakes. Packed bed (silo reactors) are usually used for composting of sludge cake amended with sawdust and other materials (Haug, 1993). Periodic transfers of solids from the bottom to the top of the reactor occur (Haug, 1993; Stofella and Kahn, 2001), allowing agitation of the solids. Feedstocks must be mixed before loading. The time that the material remains in the silo ranges from 10 to 30 days, depending on the application (Stofella and Kahn, 2001).

Within the horizontal and inclined solids flow, there are the tumbling solids bed, agitated solids bed, and static solids bed. Tumbling solids bed (rotary drums or kilns) have drums usually slightly inclined, rotating slowly (continuously or intermittently), tumbling the material inside. With this movement, the material is mixed, agitated, and moved through the drum or kiln. Feedstocks are feed at the top of the drum and the compost is removed at the opposite side (Stoffela and Kahn, 2001), as can be seen in Fig.5. Agitated solids beds have two variations (agitated bins or open channels). One has cylindrical tanks with a set of screws that allows air to be discharged into composting material. If retention time is less than two or three weeks, the material must be finished in windrows (Diaz et al., 1993). The other has rectangular bins. Feedstocks are placed into designated cells along the bin length, and they are turned about once a week. They remain in the system for about six days and the material is allowed to mature in windrows over one to two months. This system combines forced aeration with tumbling; the air is forced through the composting mass at least once each day (Diaz et al., 1993; Stofella and Kahn, 2001). For the static solids bed there are two types: tunnel reactor and conveyor type. This system has been applied to a variety of feedstocks, for example: sludge, manure, and MSW fractions. The vessel is essentially a plug flow, tubular reactor or tunnel of rectangular cross section. One design uses a pusher plate with forward and backward movement which is situated at the feed end of the tunnel. Air can be supplied and gases can be removed along the length of the reactor (Haug, 1993).

Nonflow reactors (compost boxes) are very simple systems in which materials are loaded in the box reactor and remain there for 7 to 14 days. Aeration is usually controlled and curing is usually conducted in windrows for several months afterwards (Haug, 1993).

Anaerobic Digestion

Anaerobic digestion has been used for food residuals in Europe for over 30 years (Nichols, 2004). In the U.S., this technology has been growing since 1990 due to increased technical reliability, growing concern of facility owners about environmental quality, increased number of federal and state funds available for cost share, and emergence of new state energy policies (Mattocks and Wilson, 2005). Digestion has been even moved from "unthinkable" to "Best Management Practice" in the West Coast (Mattocks, 2004). This process is used mostly for treatment of municipal sludges and industrial wastes. Some countries such as China and India use the biogas generated for cooking, lighting, and operation of small engines, using the residues as soil amendment (Chynoweth and Pullammanappallil, 1996). Currently, the leading concepts of anaerobic digestion are dry continuous system, dry batch systems, wet continuous systems, and co-digestion (Braber, 1995). In a continuous system, the dry matter varies between 20% and 40% and fresh substrate is added continuously and an equivalent amount is withdrawn once each day or two. In the dry batch system, material is not added or withdrawn from the digester till the digester process has been completed (Diaz et al., 1993). In addition, each batch lasts for two to three weeks and percolate is recirculated to stimulate mixing and digestion (Braber, 1995).

The wet continuous system is subdivided into conventional slurry systems and anaerobic filters. Conventional slurry system usually works with codigestion of animal manure, MSW and other wastes, and a dry matter of about 10%. Anaerobic digesters usually have two- or multi-phases systems. In the first reactor, hydrolysis and acidification of the substrate occur (Braber, 1995). Organisms decompose lipids, cellulose, and protein and generate soluble compounds. Acid bacteria work on theses compounds, producing organic acids. This is known as the acid-former phase (Diaz et al., 1993). Methane fermentation occurs in the second reactor. Bacteria either work on organic acid producing methane and carbon dioxide or reduce carbon dioxide into methane by using hydrogen or formate produced by other bacteria. The very final products of this stage are methane, carbon dioxide, trace gases, and a stable residue. This is known as the methanogenic phase (Diaz et al., 1993). About 90% of the facilities in Europe use the one-stage reactor (Vandevivere, De Baere, and Verstraete, 2002).

The advantages of wet processes over dry processes are: higher homogeneity of wastes and possibility of separating out contaminants, floating matter, and sediments. On the other hand, the disadvantages are: greater reactor capacity; large material flows to be transported, treated, and heated; higher cost for water supply and dewatering; and slightly lower gas yield since heavy inerts and scum layer need to be removed (Nichols, 2004).

The digestion procedures are plugflow, completely mixing, or anaerobic filters. Plugflow is a very simple system: it is lined in an excavated pit with a wall of native materials; the interior of this wall is lined with an impervious material such as a plastic sheet. Suitable provision must be made for capping the pit and collecting and storing the gas. Availability of a suitable lining material may be an issue for some situations. For example, the durability and degree and permanence of impermeability of the plastic sheet are difficult (Diaz et al., 1993). The mixing can be done either mechanically or by gas injection (Braber, 1995). Mixing is important to achieve an efficient operation of a digester, avoiding sedimentation, and breaking up the scum layer.

Anaerobic digesters may be run at mesophilic or thermophilic temperatures. Mesophilic process has higher operational reliability as the microorganisms are less sensitive to temperature and concentration fluctuations; less energy required for heating up wastes; and higher percentage of methane in biogas. However, the residence time is higher, the volume of gas produced is lower, and the sanitation is not certain (Nichols, 2004). Thermophilic process has been suggested for anaerobic co-digestion of substrates such as mixed municipal and industrial waste (Oleskiewicz and Poggi-Varaldo, 1997), anaerobic co-digestion of coffee waste and sewage sludge (Neves et al., 2006), co-digestion of paper mill sludge, biosolids, and MSW (Poggi-Varaldo et al., 1997), and co-digestion of paper mill and MSW (Poggi-Varaldo et al., 1999).

Other Processes

Home Composting

A bin or some type of container is used to keep the composting material within a confined space. The feedstocks that can be used are: garden trimmings, manures, garbage, vegetable trimmings, paper and cardboard, and various absorbent materials. Any decomposable organic material can be used, except human feces, diseased animals, and plant debris heavily dosed with pesticides and other toxic material in general, for reasons of public health (Diaz et al., 1993).

The maximum C/N requirement should be 25:1 to 30:1. For home composting, this ratio can be adjusted considering the relation of “green” debris or garbage to “dry” garden debris. Green debris, e.g., lawn clippings, fresh leaves or plants, green plant stems, roots, flowers are rich in nitrogen. Dry debris, e.g., dried grass (no longer green), matured flowers stalks, branches (excluding leaves), straw, and fall leaves are rich in carbon (Diaz et al., 1993; Hanson, 1997).

Vermicomposting

This is an aerated composting system in which redworms process the feedstock, and they excrete vermicasts at the soil surface. Compost worms do best under moist conditions, but are very sensitive to elevated temperatures (Dominguez et al., 1997). The best temperature for worms is between 13°C and 29°C (Pittaway, 2001), although maintaining moderate bed temperatures can significantly increase performance of the process (Frederickson and Howell, 2003). This system can be processed in bed or in windrows, indoor or outdoor.

Vermicomposting supplies mineral balance, improves nutrient availability, and could act as complex-fertilizer granules. In addition, vermicomposting allows a great reduction of pathogenic microorganisms. Vermicomposting may also bring a decrease of bioavailable heavy metals than in the composting process, and there is evidence that the final product may contain hormone like compounds that accelerate plant growth (Dominguez et al., 1997).

CONCLUSIONS

Composting and anaerobic digestion are multivariable processes, based on microbiological, chemical, physical, and thermodynamic fundamentals. They have several variations; they may be operated in open or closed reactors. They represent intelligent options for processing MSW, converting organic matter into soil amendment, managing dwindling landfill space, and be a potential source of renewable energy.

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FIGURES

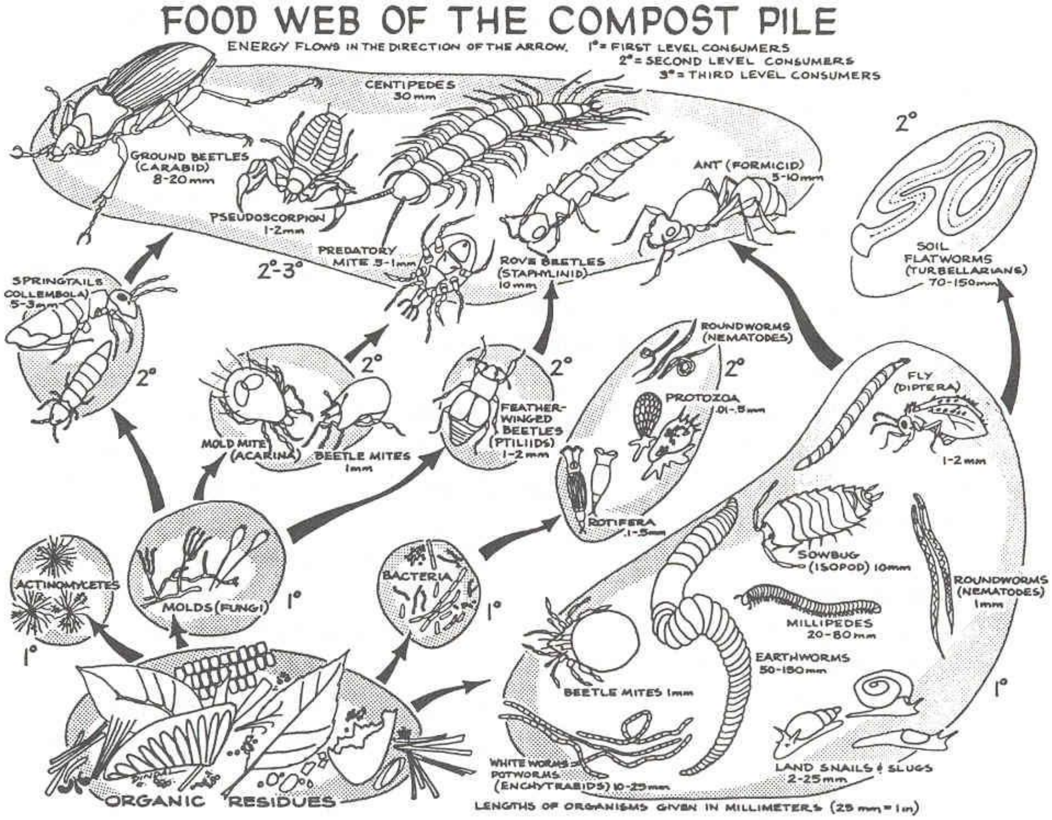

Fig. 1 - Variety of microorganisms of the compost pile (Epstein, 1997)

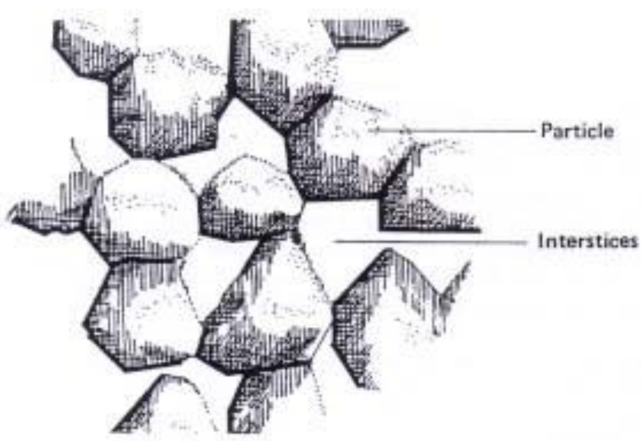

Fig. 2 - Schematic of interstices in composting material (Diaz et al., 1993)

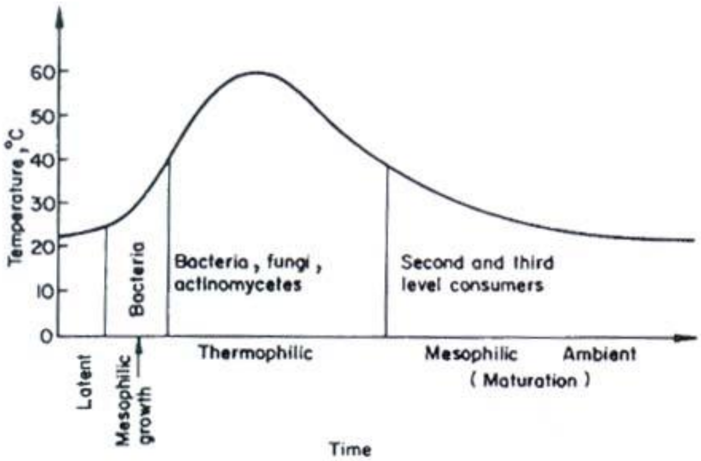

Fig. 3 - Patterns of temperature and microbial growth in compost piles (Stoffela and Kahn, 2001)

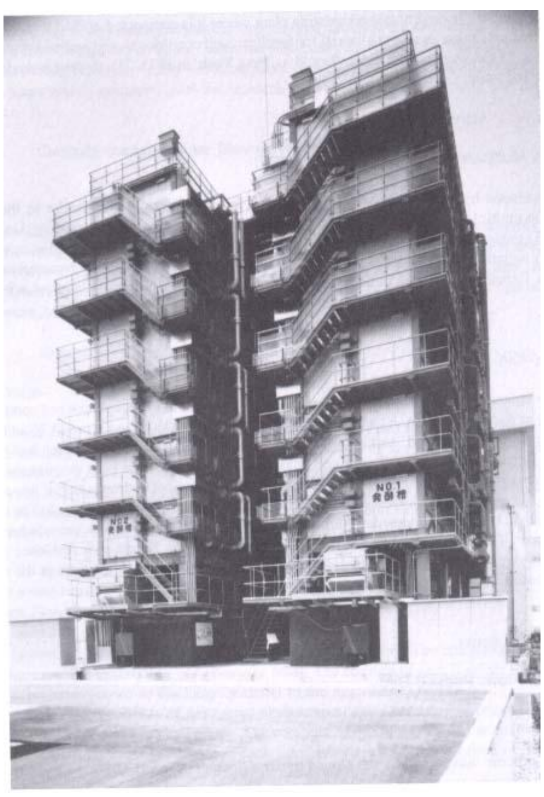

Fig. 4 - NGK vertical, multistage, agitated bed-composting system (Haug, 1993)

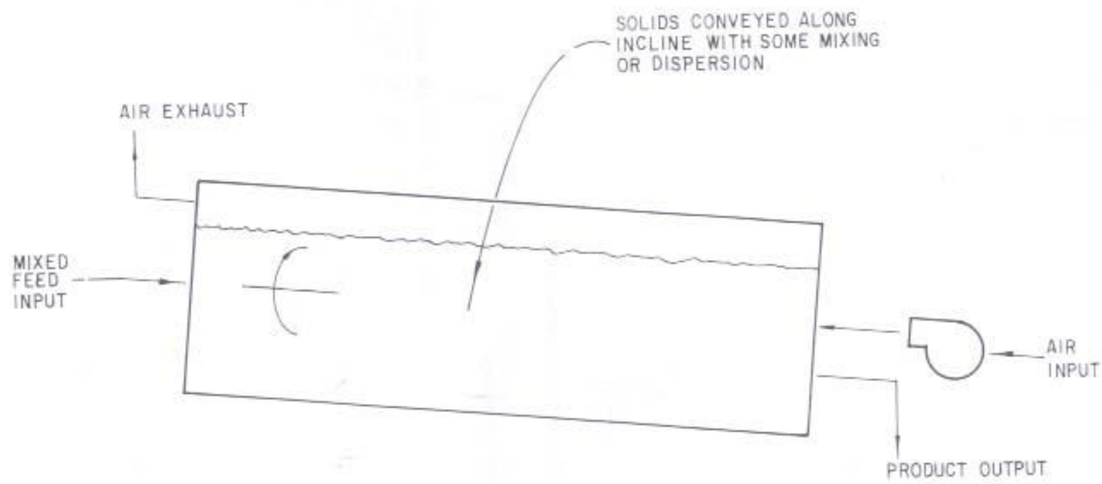

Fig. 5 - Tumbling solids bed reactor, rotating drum or kiln (Haug, 1993)