QUALITY CONTROL AND MANAGEMENT

BIOLOGICAL COMPOSTING

Undoubtedly composting was practiced in ancient times in different parts of the world. The Israelites, Greeks, and Romans used organic waste directly or composted them. Initially, the composting process was anaerobic, but later it was modified to an aerobic process and renamed the Bangalore process. The basic concept was to utilize vegetable and animal wastes and night soil (human excrement), mixing them with an alkaline material for neutralizing acidity, and managing the mass through turning for aeration and water addition.

The second half of the 1970s witnessed a drastic shift in the emphasis of composting. Facilities were designed to treat a number of substrates ranging from manures to the organic fraction of MSW to bio solids. Now it is an important method employed in several industries to address the problem of solid waste generated.

Compost resembles humus but is comprised of materials in various stages of decomposition. Some may be broken down quickly; others may require multiple rounds of destruction from varied specialized microorganisms and soil invertebrates. A pile of compost may contain some humus, but there's still plenty of work available in the heap for the decomposers.

In this episode we understand the process of biological composting in following topics

1. Factors influencing composting
2. The composting process
3. Types of composting
4. Phases of composting
5. Role of micro organisms in composting

FACTORS INFLUENCING COMPOSTING

Understanding the basic principles of composting can have a significant bearing on the process and product. There are several factors which influence the composting process in different stages. The major factors that affect the rate of decomposition of the organic matter during composting are oxygen and moisture. Many technologies are better at providing and maintaining proper oxygen and moisture.

Oxygen and Aeration

Composting is an aerobic process and therefore requires oxygen. Oxygen is provided through aeration. The provision of oxygen depends on the aeration process, which is a function of the system. Windrow composting provides oxygen through the turning process and by convection. Aerated static pile (ASP), agitated bed, and other systems provide oxygen through blowers. For oxygen to reach the microbial population there needs to be sufficient porosity through the matrix. The porosity is dependent on the feedstock, its moisture content, and particle size.

Biosolids and food waste are dense and have high moisture content. Therefore, bulking agents are usually used. These can either be natural materials, such as wood chips, sawdust, and yard waste, or artificial material, such as shredded rubber tires. Oxygen levels above 10% are usually provided. When the oxygen level is below 5%, it can become limiting to the aerobic microorganisms. At this level anaerobic gases such as methane are generated.

Moisture

Moisture can be a limiting factor in the composting process. Generally, the rate of microbial activity decreases when the moisture level in compost is below 40%. At 20%, microbial activity is essentially ceased. When moisture content in the compost exceeds 60%, the pore space can be filled with water; then oxygen can become limiting and overall microbial activity decreases. Generally, bacteria are more sensitive to soil moisture than actinomycetes and fungi. Both actinomycetes and fungi tend to predominate in dry soils since they form resisting structures. Since the composting process is a drying process, as water is lost due to the increased temperature, moisture control is essential. The optimal moisture level during the composting process appears to be near 50%. However, the control of moisture is also important from a processing point of view. Many facilities prefer to screen the compost and recover the bulking agent immediately after composting and before curing. Most screens are effective at moisture contents below 45%. Therefore maximum composting is carried out at moisture contents between 50 and 55%.

Temperature

Changes in temperature are the result of microbial activity. Temperatures rise from ambient to mesophilic and then to thermophilic. During these temperature variations, the microbial population also subjected to change. These changes are very important as they enable the different microorganisms to metabolize the various components of the feed stocks.

Temperature is also important to control pathogens as well as to destroy weed seeds. As the process progresses and the available nutrients for the microorganisms are consumed or metabolized, temperatures will drop and at some point return close to ambient. The rate of heat production is proportional to the available organic material for microbial consumption.

The decline of temperature to near ambient is an indication that the process is near completion and that the material, probably, is stable and mature.

Maintaining temperature is often a function of operating conditions. These can include:

- Pile structure
- Pile volume
- Pile insulation
- Pile moisture
- Pile oxygen
- Ambient environmental conditions
- Turning frequency

Carbon and Nitrogen (C:N)

Carbon

The two most important nutrients for microbial activity and growth that affect the composting process are nitrogen and carbon. A high carbon-to-nitrogen ratio will slow the composting process. A high nitrogen-to-carbon ratio will release ammonia. Although the ideal carbon-to-nitrogen ratio is approximately 27 to 30:1, the composting process is effective within carbon-to-nitrogen ratios of 22 to 40. It can proceed at lower C:N ratios. However, there will be a release of ammonia. At higher C:N ratios, the process slows down.

The carbon provided to the microorganisms on the feedstock is utilized for cellular growth. During microbial metabolism, carbon dioxide is evolved and released to the atmosphere. As the process progresses, the rate of microbial activity decreases and carbon dioxide evolution decreases. It is the relationship between the volatile solids content of a feedstock and carbon dioxide evolution: the higher the volatile solvents content of organic matter, the greater the production of carbon dioxide. Starches, sugars, and fats decompose or mineralize much faster than proteins or cellulose, whereas lignin is very resistant to mineralization.

I) THE COMPOSTING PROCESS

Regardless of the system selected, the elements of the composting process are essentially the same. Configurations vary since each system attempts to optimize the unit processes to achieve the system objectives.

The major steps in the composting process are as follows

Preprocessing

1. Feedstock delivery and handling

2. Feedstock preparation

Composting

1. Composting phase or active composting
2. Curing phase

Postprocessing

1. Refining
2. Product preparation

During these steps it is necessary to screen the waste, particle size of the waste need to be reduced, undesirable materials such as ferrous and nonferrous metals, plastic etc., has to be removed. It is also important to mix the solid waste because mixing is often necessary to obtain a homogeneous matrix for proper composting.

However, several other elements such as feedstocks, bulking agent or amendments and final product distribution and marketing need to be considered prior to reviewing the composting process.

Feedstocks

The type of feedstock and its physical properties affect the delivery process, storage, and handling of the feedstock prior to the composting process. The primary feedstock characteristics affecting the delivery process are:

- Moisture content or its solids content
- Putrescibility
- Physical properties

Numerous feedstocks have been composted. These include:

- Sewage sludge, biosolids, septage, and night soil
- Municipal solid waste, biowaste (source-separated organics)
- Yard waste
- Food waste—grocery, institutional, industrial etc.,
- Animal waste, fish waste
- Animal mortalities
- Industrial wastes—pharmaceutical, pulp and paper, food processing

Food wastes are generally putrescible, but their odors must be contained or treated, otherwise it will attract vectors such as flies. In addition to being a health issue since vectors can carry and transmit pathogens, they are also a nuisance source. One large biosolids/yard waste facility in California was shut down because of the nuisance source of flies and odors. In Michigan, several facilities handling large volumes of grass were shut down due to odors.

In both these cases, proper delivery, storage, and handling as well as an understanding of the basic concepts of composting could have avoided many of the problems.

Bulking agent or amendments

A bulking agent, as the name applies, is a material generally used to control the moisture content or provide porosity to the feedstock. It can be organic or inorganic to provide structural support to enhance aeration or air movement through the matrix. For example, many of the sewage sludges, biosolids, or manures are in cake form, i.e., mud-like consistency. These materials need to be converted into particle-like material for air to move through the matrix. If the feedstock is very wet, i.e., greater than 65% moisture (35% solids), the addition of sawdust or previously prepared dry compost could be used to reduce the moisture content but the resultant matrix may not provide sufficient porosity. An organic or inorganic bulking agent could then be used to provide the porosity and even wood chips or shredded rubber tire chips would provide porosity. These later bulking agents could be screened out and reused in the process.

Various different bulking agents have been used. The following is a list of the bulking agents which are used during composting

- Wood chips
- Wood shavings
- Rice hulls
- Straw
- Bagasse
- Water hyacinths
- Yard waste, tree trimmings
- Shredded rubber chips
- Agricultural wastes
- Pelleted refuse
- Peanut hulls

Bulking agents or amendments are often needed to be able to process the feedstocks in an aerobic and efficient manner. The bulking agents serve several purposes such as feedstock moisture content adjustment, provide porosity to the matrix, adjust the carbon-to-nitrogen ratio, product quality, stacking (structural stability) and storage.

Producing hygienic, stable, and mature compost enhances its marketability and affects the economics of composting. Pathogen destruction and minimizing vector attraction depend on achieving the time-temperature relationships. Regardless of the feedstock, achieving the

U.S. Environmental Protection Agency (USEPA) 40CFR503 regulations will result in a hygienic product. A well-cured product will result in a stable and mature product.

II) TYPES OF COMPOSTING

Haug (1993) classified composting systems according to reactor type. The classification which is simplified is as follows

A. Static systems

a. Passively aerated windrows

b. Forced aeration—static pile

c. Bin/container/bag/tunnel

d. Silo/vertical reactors

B. Turned or agitated systems

a. Windrow

b. Drum/kiln

c. Agitated bed

III) PHASES OF COMPOSTING

However, it is generally accepted that composting is essentially a four-phase process that may be summarized as follows.

Mesophilic Phase (25–40 °C)

In this first phase (also called starting phase), energy-rich, easily degradable compounds like sugars and proteins which are abundant are subjected to degradation by primary decomposers such as fungi, actinobacteria, and bacteria along with worms, mites, millipedes, and other mesofauna. Depending on the composting method, the contribution of these animals is either negligible or, as in the special case of vermicomposting, it is considerable. It has been demonstrated that the number of mesophilic organisms in the original substrate is three orders of magnitude higher than the number of thermophilic organisms, but the activity of primary decomposers induces a temperature rise.

Thermophilic Phase (35–65 °C)

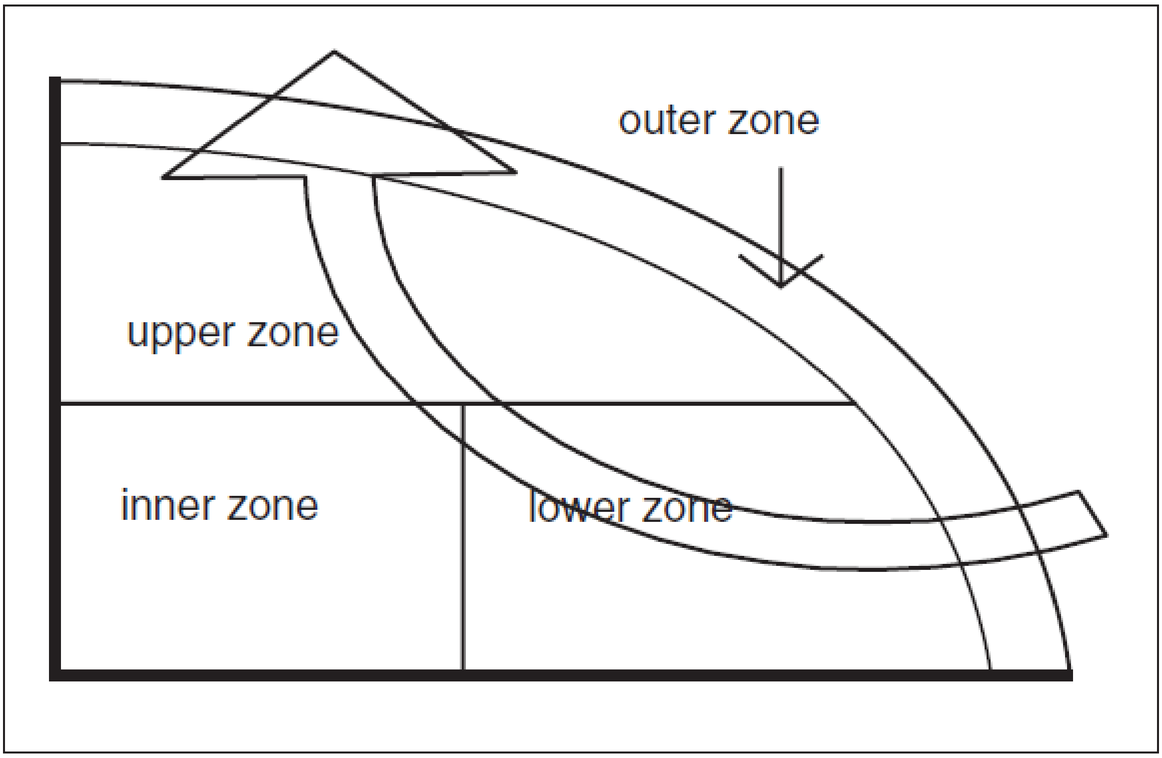
Organisms adapted to higher temperatures gradually replace the entire mesophilic flora. Mesophilic organisms die off and are eventually degraded by the succeeding thermophilic organisms, along with the remaining, easily degradable substrates. The decomposition continues to be fast, and accelerates until a temperature of about 62 °C is reached. Thermophilic fungi do have growth maxima between 35 and 55 °C, while higher temperature usually inhibits fungal growth. Thermotolerant and thermophilic bacteria and actinobacteria are known to remain active even at higher temperatures.

Despite the destruction of most microorganisms beyond 65°C, the temperature may rise further and may exceed 80°C. It is probable that this final temperature rise is not due to microbial activity, but rather is the effect of abiotic exothermic reactions in which temperature-stable enzymes of actinobacteria might be involved.

The thermophilic phase is important for hygienization. Human and plant pathogens are destroyed; weed seeds and insect larvae are killed. Not only the temperature during the thermophilic phase, but also the presence of a very specific flora dominated by actinobacteria, are important for hygienization through the production of antibiotics. The disadvantage of temperatures exceeding 70 °C is that most mesophiles are killed, and thus the recovery is retarded after the temperature peak. This may, however, be avoided by appropriate measures for recolonization.

The same temperatures are not reached in all zones of a compost pile; thus, it is important that, through regular turning, every part of the substrate is moved to the central, hottest part of the pile. From a microbiological point of view, four major zones may be identified within a pile (as shown in figure below).

- The outer zone is the coolest, and well supplied with oxygen
- The inner zone is poorly supplied with oxygen
- The lower zone is hot, and well supplied with oxygen
- While the upper zone is the hottest zone, and usually fairly well supplied with oxygen.



Cross section of a compost windrow (major zones and convection stream are indicated)

Cooling Phase (Second Mesophilic Phase)

Temperature starts decreasing when the activity of the thermophilic organisms ceases due to exhaustion of substrates. Mesophilic organisms recolonize the substrate, either originating from surviving spores, through spread from protected microniches, or from external inoculation. While in the starting phase organisms with the ability to degrade sugars, oligosaccharides and proteins dominate, the second mesophilic phase is characterized by an increasing number of organisms that degrade starch or cellulose. Among them are both bacteria and fungi.

Maturation Phase

During the maturation phase, the quality of the substrate declines, and in several successive steps the composition of the microbial community is entirely altered. Usually, the proportion of fungi increases, while bacterial numbers decline. Compounds that are not further degradable, such as lignin–humus complexes, are formed and become predominant.

Overall important characteristics during pre and main composting and postcomposting, mature phase can be summarized as follows

During pre and main composting **(1-6 weeks)**

- Degradation of easily degradable compounds such as sugar, starch, pectin, protein etc.,

- Inactivation of pathogenic microorganisms and weed seeds
- High oxygen demand
- Emissions of odor and drainage water

During postcomposting, mature phase **(3 weeks to 1 year)**

- Degradation of difficult-to-decay degradable compounds such as hemicelluloses, wax, fat, oil, cellulose and lignin
- Composition of high molecular weight compounds (humus)
- Low oxygen demand
- Low emissions

5. ROLE OF MICRO ORGANISMS IN COMPOSTING

Composting induces high metabolic activities of microorganisms at high densities (up to 10^{12} cells g^{-1}). The constant change in conditions (temperature, pH, aeration, moisture, availability of substrates) results in stages of exponential growth and stationary phases of various organisms. The microbial consortia present at any point of time are replaced by others in short intervals. The problem, however, is that despite their viability, only a minor fraction of the microbes can be cultivated.

Biodegradation processes in nature are commonly comparable to a continuous culture (from a microbiological view), and the most important determinant factors are external (substrate quality, temperature, moisture, etc.). Composting, in contrast, resembles a batch culture with steady changes in substrate composition and biochemical conditions.

Wide range of microorganisms play important role in decomposing the organic waste in the compost during different stages. For example, cellulolytic, ligninolytic, *Thielavia thermophilia*, *Armillaria mellea*, *Clitopilus insitus*, *Pleurotus ostreatus*, *Lentinus lepideus*, *Fomes* sp., are found during composting processes.

Composting has many benefits:

- Many community wastes can be composted. Thus, a single composting facility can handle municipal and industrial organic biosolids, MSW, yard wastes, food wastes, etc.
- A composting facility can be designed and operated to minimize environmental impacts. Odors and bioaerosols can be controlled. With today's technology, facilities and operations should not produce offensive odors.
- Composting can help to meet landfill reduction and recycling goals.
- Composting can decompose or degrade many organic materials.

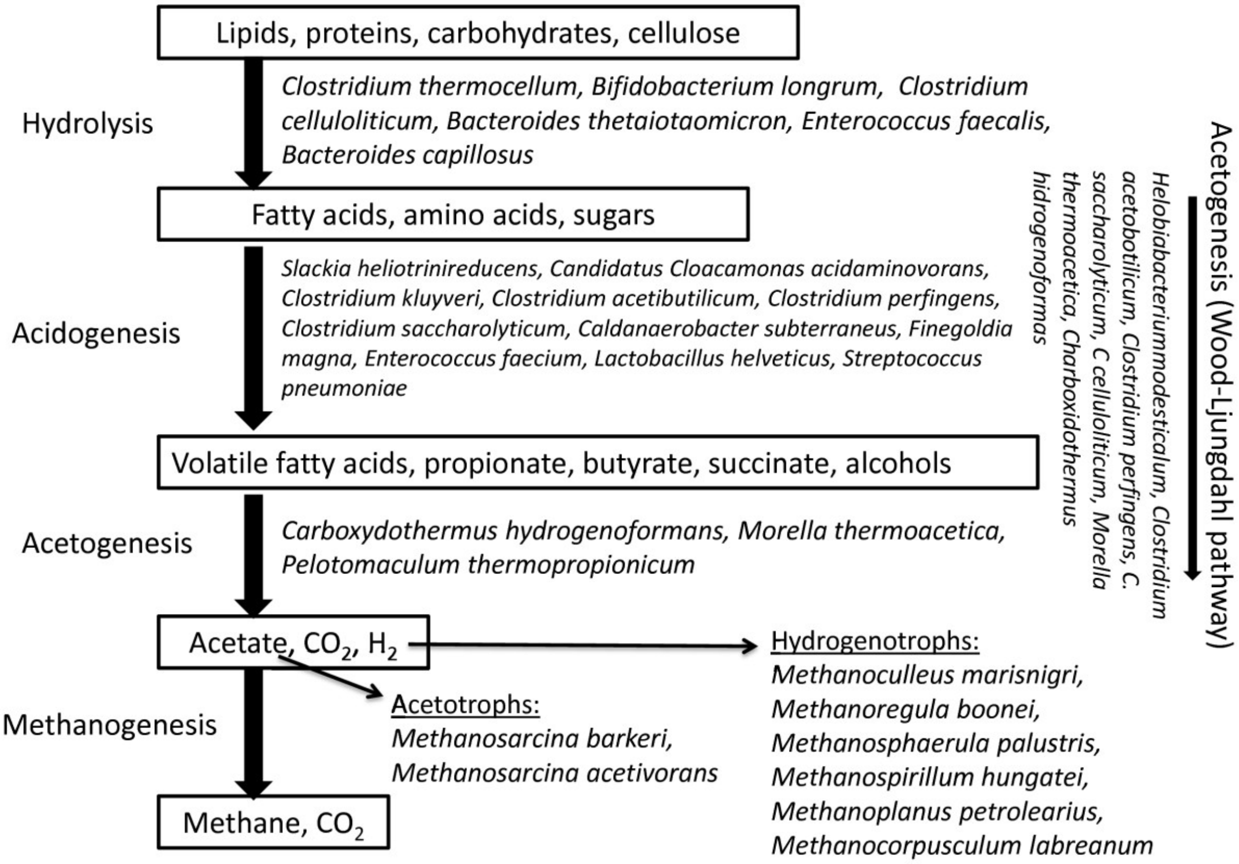
- Composting produces a usable product. Not only is the product usable, but as a soil conditioner, it can conserve soil moisture, reduce erosion by improving infiltration, and reducing runoff.
- Compost adds carbon to the soil. It thus sequesters carbon, reducing greenhouse gas.

Disadvantages

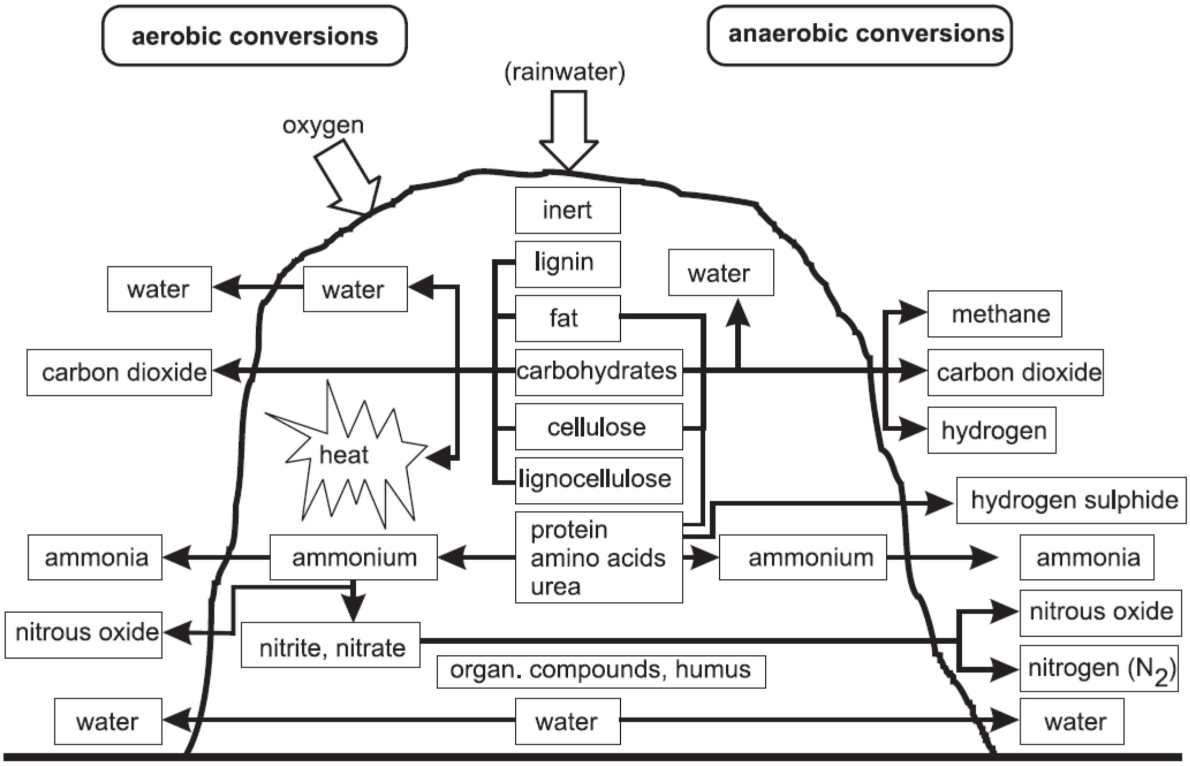
- Odor, dust, and bioaerosol emissions can occur during the process. These odors and bioaerosols can be controlled through better facility design and operations management.
- Composting facilities take up more space than some other waste management technologies. Space requirements are often related to storage and market demand.
- A product must be marketed.

Conclusion

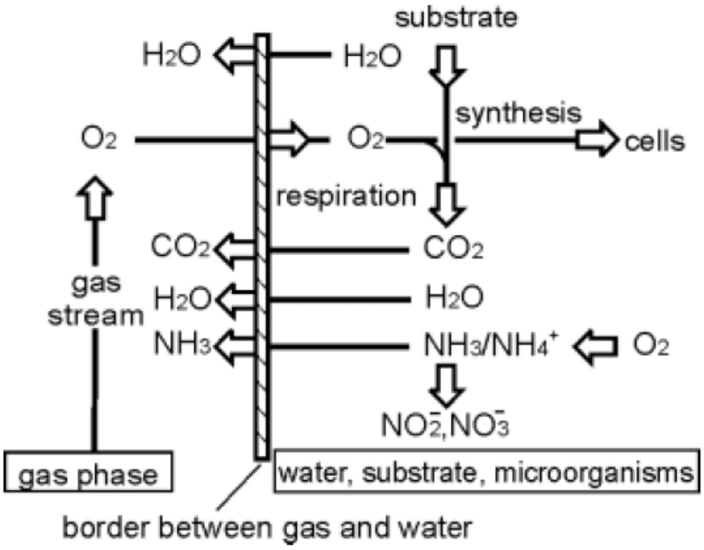
The use of compost sequesters carbon and reduces carbon dioxide emissions. Composting is the ultimate in recycling. Functionally, the only use of compost is to the benefit of our society. Composting reduces dependence on landfills, incineration, and other non friendly environmental technologies. The use of compost improves our soils to reduce runoff and erosion, increases the organic content of the soil for better water utilization by plants, and improves soil structure for better soil aeration for better plant development.



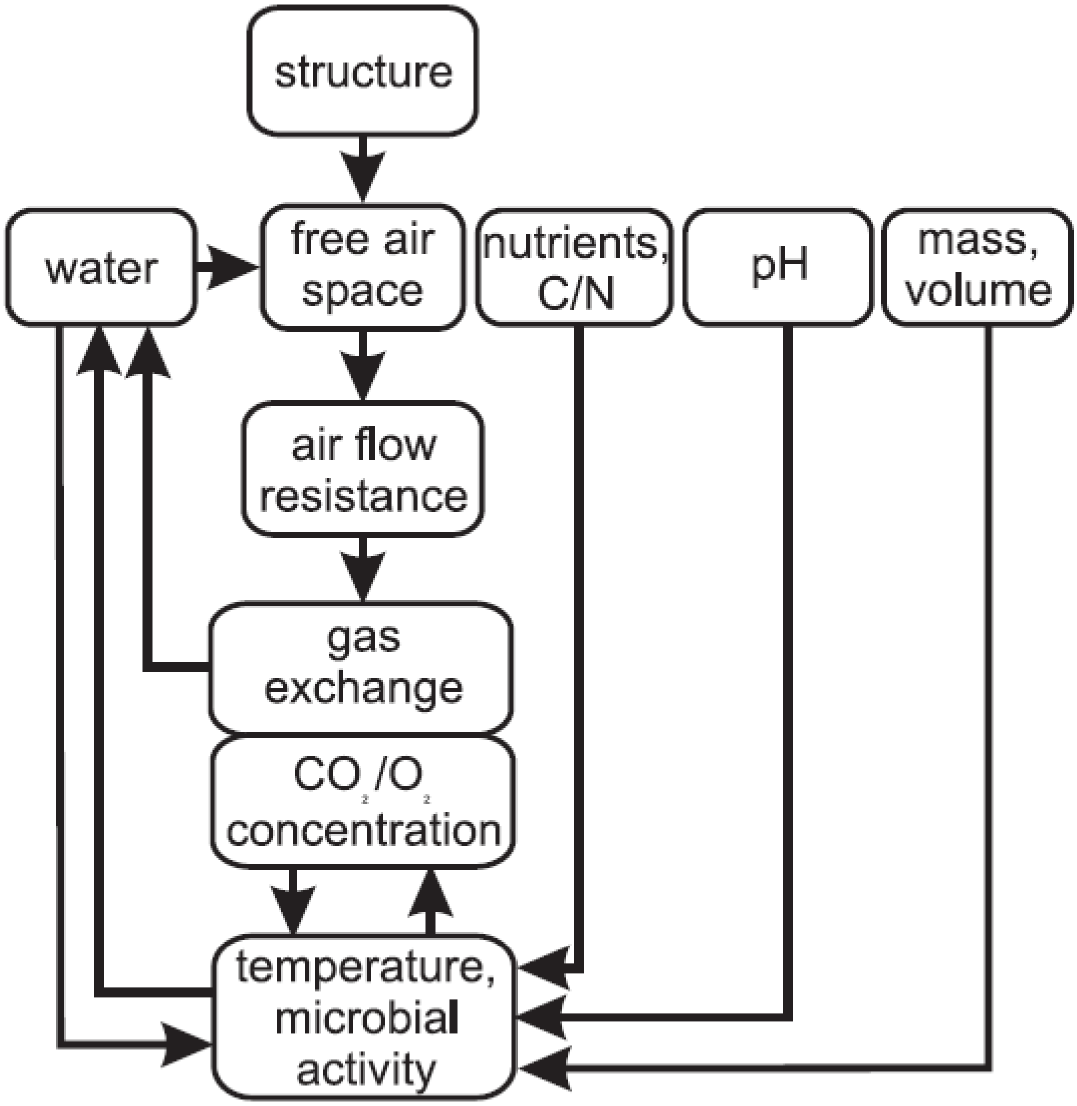
The general pathway of microbial biodegradation leading to methane production



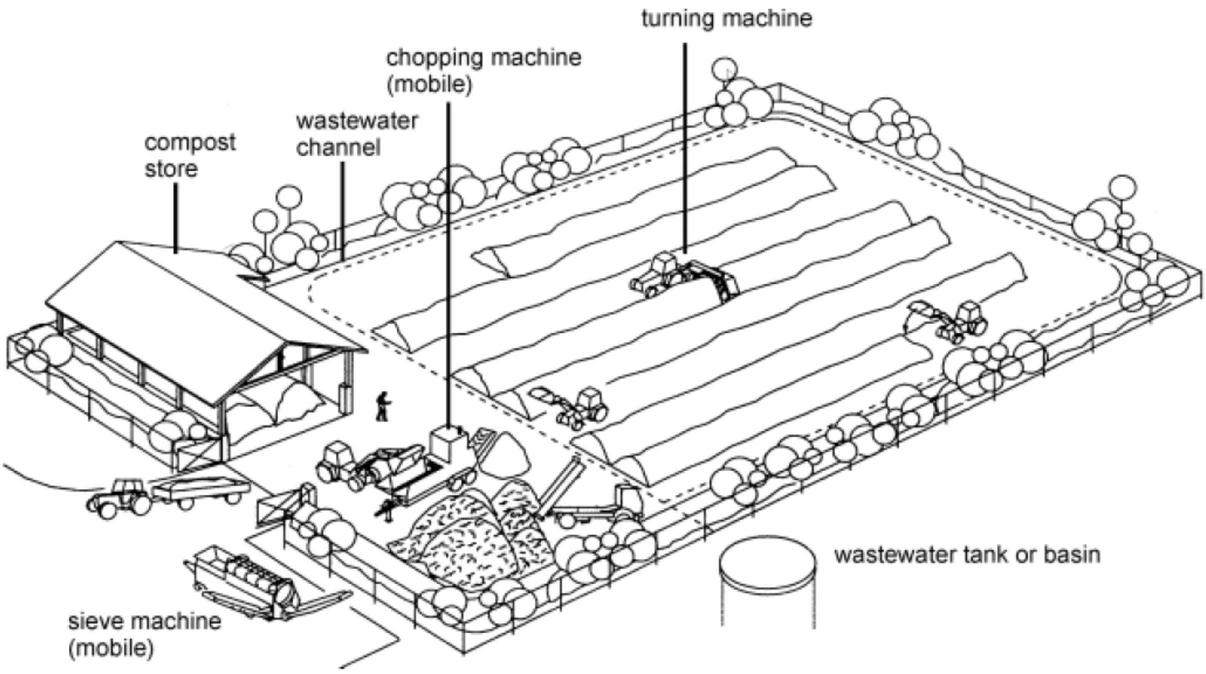
Substrates and products of microbial activity in a compost heap



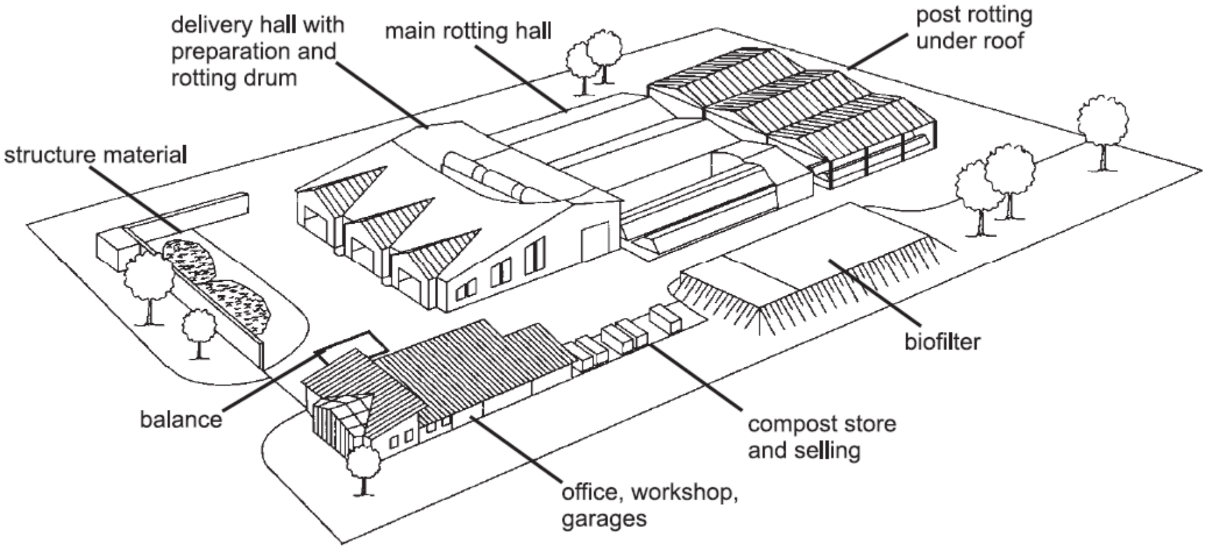
Metabolism of aerobic microorganisms at the gas/water interface



Factors influencing the composting process



Open windrow composting plant with turning machine



Composting plant with rotting drum in closed shed