COMPOSTING AGRICULTURAL AND INDUSTRIAL WASTES

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Contents

Summary

The quantities of solid wastes produced by the societies of both industrialized and developing countries can no longer be ignored. These wastes are increasing in quantity

and their safe disposal is an urgent necessity. Without careful consideration of disposal options, the health of ecosystems and ultimately human society itself will suffer. Reducing the volume of solid wastes prior to disposal is one of a number of strategies that can be used to limit the pollution that follows uncontrolled solid waste dumping. However, volume reduction is only a partial solution to this problem. What is needed in addition is the conversion of the waste to a form that at least is non-harmful to the environment. Much to be preferred, however, is volume reduction coupled with a conversion of the material to a form that is beneficial to the receiving environment. The composting of biodegradable solid wastes offers these two distinct advantages over the uncontrolled dumping of organic material which is then left to rot. The vast quantities of biodegradable materials produced globally on a daily basis can be processed to reduce its volume, inactivate many hazardous or unwanted agents, and provide valuable nutrients to the soil on which it will be finally disposed as a bio-fertilizer. Examined below will be some of the process configurations used in composting operations. An outline of the biochemical processes that take place will be provided as well as a brief description of the various organisms that are responsible for the processes that take place. Attention is also drawn to the human health hazards associated with the process as well as to the environmental problems associated with large-scale composting operations.

1. Introduction

The enormous quantities of waste discarded into the environment is of ongoing concern to us all. We think about the environment in which we live, and lament its slow and steady deterioration. We are appalled at the quantities of “solid residues” that we buy and need to discard often only moments later, and wonder whether there is a better way. Many communities and individuals, for some years now, have embraced the practical option for disposing of solid wastes in terms of the “4-R” strategy. Materials for discard, under this scheme, are considered in terms of their “re-use”, their “recycle”, their “recovery,” or perhaps whether or not they can be “reduced” in quantity, volume or with respect to their danger to humankind and the environment. It is this last category, reduction of waste material, that will be considered here, and the specific example for discussion is the biodegradation of organic matter using the composting process. The natural re-cycling of the atoms of biological materials occurs during composting; the process contributes powerfully to the re-cycling and conservation in the soil of carbon, nitrogen, phosphorus, sulfur, potassium, and a variety of naturally important metal atoms. Biodegradable material that is so processed offers a product, the *humus* or *compost*, that can be returned safely to the earth where it has a nourishing and conserving impact rather than the destructive one, so often typical of much of the waste solids that are frequently dumped onto the land and into landfills.

Historically, many civilizations have known about procedures that can be employed to ensure soil fertility, although the Mayas of meso-America seem to be the exception here. The ancient Chinese, Greeks, and Minoans, as well as various European cultures, realized the value of returning to the soil degradable organic matter to re-kindle soil fertility. The advances made in composting in India during the early part of the previous century have led to composting operational procedures that now bear the name of those cities where researchers, both Indian and European, perfected the methods, namely

Bangalore and Indore. Composting methods have been re-examined in recent years in many countries around the world, and integrated into the “4-R” strategy. The adoption of composting has been stimulated by a growing realization that land dumping of solid wastes or their incineration is not offering a real solution to the growing problem of increasing quantities of solid wastes accompanied by decreasing land availability for waste disposal.

The process of composting will be outlined in this article within the Topic area of Agricultural Biotechnology. After defining “composting” and “compost”, a discussion on compostable materials will be followed by an outline of operations. The important process variables will be outlined, after which a review will be presented of the scientific principles of bio-oxidation and compost ecology, together with comments on hazardous agents that may be present.

2. Defining Composting

It is useful to define two terms that will be used in this section; firstly “composting,” and secondly the product of this process, which is “compost”.

2.1. What is Composting?

Composting is the controlled microbial bio-oxidative process involving biodegradable organic matter, conducted under controlled environmental conditions. The oxidation produces a transient thermophilic stage which is followed by a period of cooling of the now degrading organic matter. The material is held at ambient temperatures for maturation purposes which results in a stable, volume reduced, hygienic, humus-like material—the compost—that has retained mineral elements beneficial to soil and plants.

Compost is the product of the controlled microbial degradation of heterogeneous organic matter into a safe and beneficial humus-like material. Emphasizing a “controlled” process distinguishes composting from “uncontrolled” rotting or the simple putrefaction of organic matter. Furthermore, bio-oxidative metabolism of the microorganisms involved ensures that the bulk of the biodegradable carbonaceous matter will be dissimilated completely to CO_2 and water. Other components or organic matter, such as nitrogen and sulfur, will be assimilated into microbial cell mass, only to be liberated again after the cells die and degrade.

The oxidative metabolism of microorganisms is exothermic, and the heat produced is sufficient to increase the temperature of organic matter to between 60 and 75°C over a period of up to 10 days. This so-called “thermophilic stage” offers a self-sanitizing mechanism by which pathogens, seeds and heat-labile microbial and plant toxins (phytotoxins) will be destroyed. Not all organic matter will be degraded completely. For example, lignin in plant material will be modified and become part of the final stable product. These modification processes are slow and occur during the maturation stage. The final humus-like material, the compost, is a dark, crumbly, earthy material usually containing less than 2% (w/w) each of nitrogen, potassium, and phosphorus (N:P:K). When applied to soil, these minerals are available to plants while at the same time the compost offers improved soil structuring characteristics (conditioning).

The related process of vermicomposting (i.e. composting which involves the use of earthworms to act in conjunction with aerobic microorganisms (bacteria, actinomycetes, and fungi) to bring about the bio-oxidation and subsequent stabilization of biodegradable organic matter) is also finding increasing applications on a large scale.

2.2. Compostable Materials

In theory any naturally synthesized material can be composted. However, some materials can be stabilized much faster than others. Soluble plant exudates and sap will be bio-oxidized much more rapidly than lignin and ligno-cellulosic materials. These latter components of vegetable matter will be modified by the composting process and will thus contribute to the texture and plant-nutritive value of the final product. Crop residues are compostable, but although high in carbon they are deficient in nitrogen (see *Recycling of Agro-industrial Wastes through Cleaner Technology)*. Animal wastes (faeces and urine) offer rich sources of nitrogen but are often low in carbon content, especially in the case of omnivorous animals. Herbivores, being incapable of digesting all of their cellulose intake, will excrete compostable carbon in addition to the above mentioned nitrogenous material.

Food industries processing agricultural produce generate compostable wastes, although possibly the most difficult to process are solid wastes and waste waters from vegetable oil extraction presses. Treatment of solid wastes arising from slaughterhouses and meat-packing facilities also represent a special problem since this waste material is almost devoid of carbohydrate material, and yet is rich in fat and protein. With these wastes, every care is needed to facilitate controlled bio-oxidation and to avoid anaerobic putrefaction (Figure 1).

Figure 1. Household food wastes being collected for transfer to central composting facility.

(Photo courtesy of the Craig Coker Composting Council of Canada (info@compostingcouncil.org)

To be compostable, municipal solid wastes require processing such that the biodegradable material is separated from all other solids (glass, metal, plastic, and other non-biodegradable substances) likely to be present in such wastes (see *Recycling of Organic Waste Using Urban Rooftop Integrated Microfarming*). Size reduction is generally used to maximize the surface area available to attack by microorganisms. This also assists in obtaining a uniform particle size in the final compost. There is always the likelihood that classified and pulverized compostable municipal solid wastes may be contaminated with hazardous materials (for example, pesticide residues and traces of heavy metals). This is of concern to the relevant authorities, since compost could be a route whereby toxic materials are returned to the environment. Municipal sewage sludge is also compostable. High in nitrogen as it is, it requires augmentation with carbon and adsorbtion onto a carrier material (e.g. wood chips or bark) to facilitate free movement of air through the sludge. (Refer to Table 1, Section 3.3.4 for the C:N ratio values of selected organic wastes).

3. An Outline of the Composting Operation

3.1. Process Considerations

Composting offers a waste management system that reduces the volume of wastes, stabilizes otherwise putrefactive organic substances and recovers some of the nutrient value of biodegradable solids. Three broad stages of the process can be identified. These are: firstly, preparation of the waste solids; next, bio-oxidative stabilization of the organic material by the composting ecosystem; and finally, preparation of the matured compost for commercial sale as a biofertilizer.

The preparation of organic solids for composting attempts to ensure that optimal conditions exist for the bio-oxidative reactions that are required for organic matter stabilization. Surface area of the compostable solids must be maximized to allow oxygen availability and enable rapid microbial action. Mechanical shredding or pulverizing of agricultural residues and of biodegradable municipal wastes is practiced. Other wastes may not need this preparatory treatment. For example, wastes from meatworks and meat-packing houses are usually composed of paunch contents, stock-pen wastes (faecal), meat, skin, and hide scraps, and sludge from primary and sometimes secondary biological treatment systems. Mechanical size reduction of these materials is usually not required. Biosolids (sludges) arising from sewage treatment plants pose a different problem. Biosolids are characterized by their small particle size, and because of their density and water content they tend to pack down. This impedes ventilation. Consequently a “bulking agent“ is required.

Mixing the biosolids with a bulking agent leads to the adsorption of the particles onto the surfaces of the latter. The available area of substrates exposed to bio-oxidizing microorganisms is thus increased. Large chips of wood or bark (from 3 to 5cm long and 0.5 by 3cm in cross-section) facilitate air-flow through the pile. However, finer cuts of wood such as wood-shavings and coarse sawdust allows better access to the carbonaceous material by actinomycete bacteria and fungi. Bulking agents and biosolids are mixed in a ratio of 1 part bulking agent to 2 parts compostable waste. Figure 2 illustrates the adsorption of a fine-particle waste on the bulking agent and the spaces between fragments of bulking agent to facilitate ventilation.

Chimney fly ash has also been added to bulking agents as an inert extension to the agent. The role of the bulking agent is to:

- increase the surface areas available for bio-oxidation, especially when the organic substrate to be stabilized is composed of particularly fine particles;
- assist ventilation of the mass to facilitate bio-oxidation. About 30% of the pile volume should be air spaces. Good ventilation will also purge metabolic CO_2;
- produce a dark, loam colored final product, especially from using wood or bark chips;
- ensure that moisture is available for the metabolic processes;
- maintain the structural integrity of the windrow and static pile.

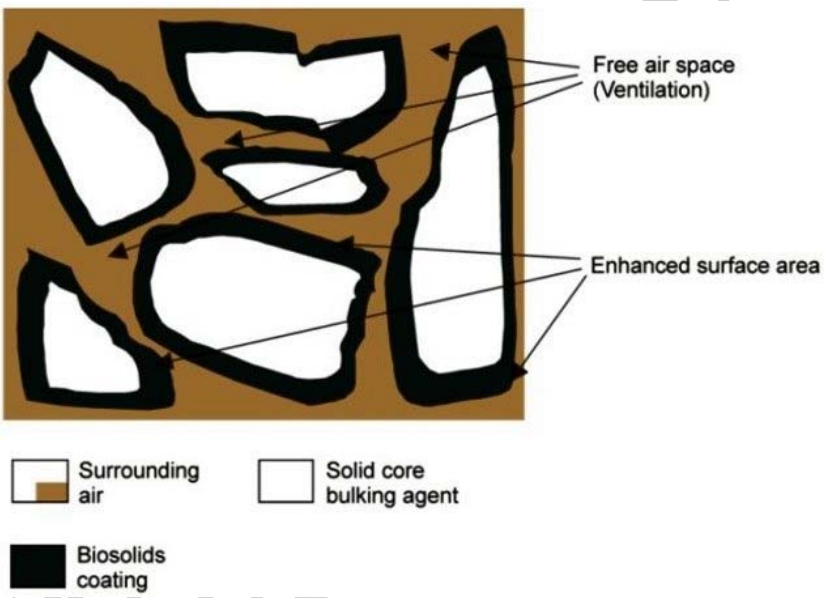

Figure 2. Role of bulking agent in composting. Free air spaces facilitate gas exchange between compost material and external environment.

Thus the bulking agent can be regarded as a regulator of the bio-oxidative process rate, and also assists in balancing the ratios of biodegradable organic matter, moisture, and available oxygen. Use of bulking agents is particularly important in the stabilization of secondary (biological) treatment sludges and other wet compostables. Dry-material wastes (e.g. agricultural residues) may not require a bulking agent.

The bio-oxidative reactions necessary to stabilize the compostable material will be discussed in detail below (see Section 4). The final stage of the process is to prepare the material for commercial sale. At the end of the maturation phase the bulking agent is recovered by screening. It can be reused. The mature product may be milled to ensure uniformity of particle size and packed into bags (usually plastic) for commercial sales. Bulk quantities may also be offered to horticultural interests.

3.2. System Configuration

There are many configurations of the composting systems and a number of "classifications" are used to describe them. For example, "static", "agitated", "open", "closed", "unconfined" and "confined" are terms used to describe the various configurations. A number of these systems are described and the terms briefly explained.

Static systems are those that heap the mass of waste and bulking agent into a long pile or *windrow*. However, the windrow may or may not strictly be static because the entire mass may be re-mixed (or turned) twice a week to ensure a renewal of the oxygen supply for bio-oxidative reactions, or it may be ventilated artificially by running perforated air-pipes longitudinally along the base of the pile. This system, using forced aeration of the static pile, was developed by the US Department of Agricultural Research Station in Beltsville, Maryland, and has been referred to as the ARS process or Beltsville process (see Figure 3). These static systems are batch operations, although in large operations the pile may be extended and thus allowed to lengthen. The mature compost is removed from the oldest end while new material is continually added at the other end of the pile. Piles will have a trapezoidal longitudinal shape, and a triangular cross-section where the base width is approximately twice the height. An optimum base width is 3 to 4m. Windrows and static aerated piles are regarded as "open" or "unconfined" systems. For industrial scale operations considerable land area is required especially in the case of windrow processing where the material is to be turned regularly.

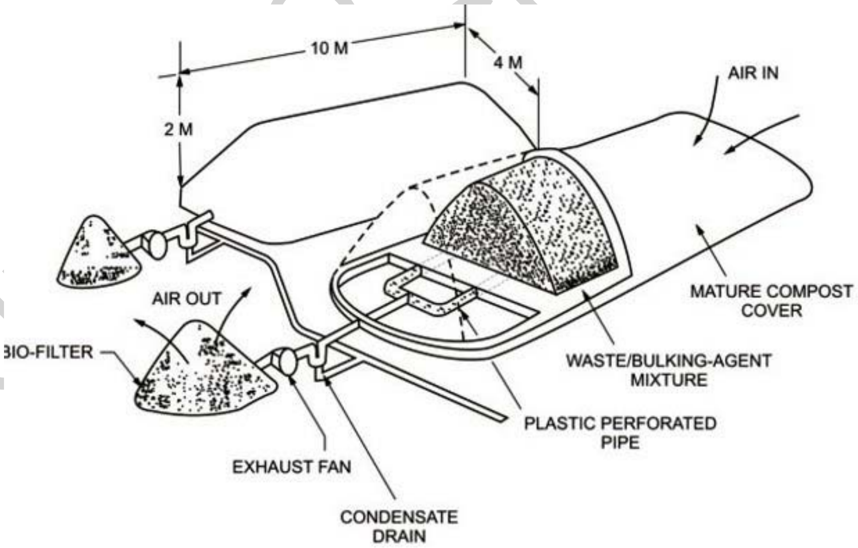

Figure 3. The Agricultural Research Station (ARS) Beltsville Aerated Static Pile. (From Anon (1979). Process Design Manual for Sludge Treatment and Disposal, U.S. Environmental Protection Agency Publication EPA 625/1-79-011, p.12-22. Washington, D.C.).

Passive Aerated Windrows. Natural convection of air within a static pile brought about by temperature gradients is the basis of the Passive Aerated Windrow (PAW) system. A series of rows of plastic pipes with holes drilled in the top are arranged on a bed of mature compost or peat and the pile built on top of them. The pipe ends protrude outside the pile, allowing air access into them. As was the case with other static piles, the heap is covered in an envelope of mature compost. Heat generated by bio-oxidation heats the middle and upper regions of the pile, warming air trapped in the air spaces. As this warm air rises and circulates outwards (but within the pile), it is replaced by cool air drawn from the bottom of the heap through the holes in the pipes. While bio-oxidation proceeds and generates heat, ventilation is sustained at rates that vary with the amount of convection present (i.e. with heat generated). This system has been applied successfully to the composting of proteinaceous wastes where there is the likelihood of ammonia and amine odors developing. These gases are trapped in the compost and turning (as is the case for the traditional windrow) is undesirable. Forced stabilization of the pile may cause loss of ammonia. In this PAW system, any ammonia escaping into the mature compost envelope covering the pile may be stabilized to nitrate by bacterial nitrification. Thus, the N content would be retained within the pile.

Agitated, Closed, Confined, In-vessel are terms used to describe batch or continuous composting that can be achieved using a closed, large vessel. Furthermore, these configurations when operated continuously can be regarded as either plug-flow or fully mixed systems. The Danish "Dan" system provides an example of a continuous plug-flow system. Materials to be composted are fed into the top of a "biostabilizer", which is a 3 to 4m diameter downward-slanting cylindrical chamber up to 30m long rotating at about 1rpm. Forced air ventilation is provided and metabolic gases, steam, and unused air are extracted by fans.

Temperatures can reach 55° to 65°C within the tumbling material, and the bottom-exiting hot mixture is screened and conveyed to maturation beds. Retention times in the biostabilizer vary from 3 to 5 days. Alternative plug-flow systems use a hydraulic ram to slowly push the composting material along a closed, ventilated, tubular reactor. In contrast to these plug-flow composters, there are the fully mixed systems in which material to be composted is fed into a large vessel and mixed by an array of vertical augers (vertical mixed reactor) or mixed by an inclined conveyor belt (horizontal mixed reactor). These systems are thoroughly ventilated to ensure that bio-oxidative reactions occur at optimal rates.

Both the plug-flow and fully mixed configurations are completely enclosed and not subject to variations in weather conditions, as is the case with windrows. Closed composting systems are experiencing increasing interest because the compactness of the operational units and diminished land requirements. Furthermore, better control of processing conditions is possible, especially feed rates, temperatures, aeration, and odor control. Retention times in the reactors may vary from a few days to 2 weeks. A further 3 month period for curing can be conducted off-site if necessary.

Large scale vermicomposting is carried out in vessels raised off the ground (to facilitate controlled drainage) with the material to be stabilized and the bulking agent loaded to a depth of about 1 meter. At ambient temperatures earthworms bring about aeration and mixing of the material, and its bio-oxidation and stabilization over a period of about 30 days.

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Tchobanoglous G., Theisen H., and Vigil S. (1993). Biological and chemical conversion technologies. *Integrated Solid Waste Management, Engineering Principles and Management Issues*, pp. 671-715, Boston: Irwin McGraw-Hill. [This chapter offers a quantitative insight into aerobic composting, providing a number of worked mathematical examples needed to establish operational values for the process parameters.]

World Wide Web pages of interest include:

Cornell University, Cornell Composting at http://www.cfe.cornell.edu/compost [Offers an excellent technological overview of both science and engineering design aspects. An excellent site.]

The industrial heavy equipment and engineering firm of Sandberger (Austria) at www.sandberger.com [Presents a catalogue style yet informative overview of the company's equipment and services. A well developed site.]

Composting Council of Canada at http://www.compost.org [This is the website for the Composting Council of Canada. Useful information].

Vermicomposting, Redland Bay, Queensland, Australia at http://www.vermitech.com [Information about a large, commercial scale processing of biosolids arising from secondary biological treatment systems. Photographs. Provides an excellent insight.]

Biographical Sketch

Graham J. Manderson is Senior Lecturer in Industrial Microbiology in the Institute of Technology and Engineering at Massey University. Born in Brisbane, Queensland his early education was at what is now the Queensland University of Technology and he later earned an Honours Degree and Ph.D. in Microbial Physiology at the University of Queensland. Since then he has been at Massey University, New Zealand, where he teaches undergraduate and postgraduate courses in general microbiology, meat microbiology, biotechnology, environmental management, and biological and ecological systems. His current research interests embrace protein fouling of hot surfaces, ozone treatment of paper mill effluents and potable aquifer waters, and the removal of phenolics from industrial wastewater streams. He describes himself as a keen music lover and reader of Australian literature.