Report:

ISSUES RELATING TO ORGANIC WASTE DISPOSAL

PART 1 – THE SCIENCE OF ORGANIC WASTE DISPOSAL

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Executive summary

The issues of waste, at a philosophical level, arise primarily from the twentieth century view of a products lifespan as being linear from creation, through use, to disposal. In earlier times, in natural systems, and in recent shifts towards sustainability, a more cyclical view prevails. There is an emphasis on reuse and recycling together with minimisation of residuals.

This philosophical shift back to recycling has been given momentum by the impact of waste and its disposal on the environment but more particularly by the voting public affected by the impacted environment. The move towards sustainability has been led from Europe but is gaining momentum in many countries, and indeed industries, around the globe. Key drivers in many countries include protection of groundwater and reduction of greenhouse gas emissions, as well as increased alternative disposal costs.

This report is the first in a series of three and covers the issues of organic waste recycling and reuse. A second report in the series provides an overview of the HotRot composting system and the third report looks at the science behind the operation of this system. Each report is complete in itself but all three combined provide a detailed reference tool for those wishing to understand organic waste composting and the HotRot technology.

The science of organic waste recycling and reuse

The cost of organic waste 'disposal'

In a natural environment most living tissue is recycled within an ecosystem. Carbon is fixed by plants, used for growth, consumed by animals and released through respiration or decay. Other elements are similarly cycled within the ecosystem. While this cycling is not perfect, many ecosystems are relatively stable for extremely long periods of time.

In the current human-manipulated environment these cycles have been largely lost or significantly disrupted with two important consequences. Firstly, essential nutrients are removed from productive land and ultimately disposed of to landfill or sewer. This causes problems of both depleted lands and enriched receiving environments. Secondly, organic matter that is necessary for effective soil function is depleted. This depletion is relatively slow with significant effects taking decades to manifest. Nevertheless, as significant depletion of productive land has been occurring for over a century very significant effects are now realised in many areas.

The first cost of landfilling organic waste is thus a loss of productive capacity of the land, a cost that is almost completely ignored. While chemical fertilisers have reduced the impact of this, their long-term use is not a sustainable option, and does not address organic matter depletion; carbon mining. A number of international studies have clearly highlighted improve productivity through replenishment of carbon in soils via the addition of compost.

The practice of landfilling organic waste is problematic because the waste is not stable. The greenhouse gas methane is produced in high quantities (up to 100 kg/tonne of waste) and ground water may be impacted by leachate. Appropriate engineering can mitigate these issues at a cost but avoidance is generally more cost effective and is without long-term risk; even the most efficient landfill gas capture systems only prevents the release of approximately 50% of greenhouse gases. A 2002 USEPA study clearly identified that composting of food waste could reduce GHG emissions by 1.0 metric tonne equivalents of CO_2 per tonne of organic waste composted when compared to disposal to landfill with gas capture[1].

Composting removes organic waste from landfill, but more importantly applying the product to land replaces organic matter and restores the carbon cycle. Soil organic matter gives the soil structure and preserves biodiversity. In purely functional terms, it improves water retention, (counter-intuitively) improves drainage, suppresses crop disease and increases productivity. Essentially the natural cycles can be restored even though they may now be discontinuous in both time and space. This is a practical and achievable sustainability solution for modern society.

[1] Solid Waste Management and Greenhouse Gases: A life cycle assessment of emissions and sinks. EPA530-R-02-006, May 2002.

Organic waste strategies

In the latter half of the twentieth century not only did waste per capita increase but also the individual's direct post-rubbish-bin involvement in its disposal became almost zero. Collection, transport and disposal systems were generally effective, but unsustainable with an obvious disconnect between the waste generator and the waste disposer.

The end of the twentieth and the early parts of the 21st century has seen a significant shift; through education community ownership of waste has become the norm. On the one hand, the *cost* of waste is being recognised and the amount of waste reduced. On the other, the *value* of waste, as a resource, is also being appreciated and appropriate systems are being put in place to ensure that this can be realised. Where waste is inevitably generated, key impediments to reuse, recycling or recovery are a lack of cleanliness, mixing and contamination.

Treatment and reuse of organic waste via composting is an established and effective technique. Despite this, relatively little organic waste, especially in terms of food, animal and sewage wastes, is dealt with in this way. The impediments are two-fold. Firstly, organic waste is frequently mixed with inorganic and non-compostable materials, resulting in composting being impractical, or the compost product being of low value. Secondly, the costs of alternative disposal options such as landfill have been low. In recent years landfill charges have risen and composting is now usually a cost competitive option but access to clean waste streams remains problematic.

Waste treatment of all types has tended towards large centralised facilities where economies of scale in processing can be realised. This is not without cost however. Transport charges can be significant, and the 'out of sight, out of mind' mentality engendered in the waste producer is unhelpful. We believe that in many cases community or business ownership of smaller composting facilities to deal with organic waste will be a more effective solution. This offers a number of advantages.

- Transport costs and issues are eliminated.
- Waste contributors have ownership of the solution - this is beneficial in achieving a clean organic waste stream through source separate collection.
- The costs of waste management are internalised within the business or community with advantages for control and management.

A number of examples of this approach are in operation around the world. This approach may be less applicable in densely populated areas, but we still argue that decentralised composting (satellite facilities) where waste generation and compost utilisation are geographically close is a sensible option.

Similarly, collection of source separated waste should be a goal. Often it is argued that collection of separate waste streams is more expensive than collection of mixed waste. However, this does not take into account the additional cost (both capital and operating) of a much larger processing plant that needs to not only to separate but also treat the waste. Again collection of source separate waste streams is transferring ownership back to the generator, where it realistically belongs. More recently we have seen a backlash from traditional waste recyclers refusing to process dirty or contaminated recyclables (plastic, glass and metal); this is clear evidence of a maturing industry and is a pointer to the future for all recyclables (organic and inorganic materials).

Composting defined

There are a number of published definitions of composting, with several of these defining composting as: '*The controlled biological decomposition and stabilisation of organic substrates, under conditions that are primarily aerobic and that allow the development of thermophilic temperatures as a result of biologically produced heat. It results in a final product that has been sanitised and stabilised, is high in humic substances and can be beneficially applied to land.'*

Or, less formally - composting is a natural process that turns organic waste into a clean, stable and useful product. It is worth emphasising a few key words in these definitions:

- Biological process – composting is a living process.
- Aerobic – in the presence of oxygen, this separates the process from anaerobic digestion.
- Heat is produced – heat is a by-product of composting, it does not cause composting of and in itself.
- Result in a product than can be beneficially supplied to land – while not strictly part of the process it should be a key goal of any composting operation.

This process can be effectively accomplished in the backyard by occasional application of a fork. This option should not be discounted, as home composting can effectively contribute to waste reduction in some circumstances, but for collected waste in commercial or municipal quantities, a rather more engineered solution is required.

The composting process

Composting is an application of the natural processes of decay. The distinction being that sufficient organic material is gathered so enough energy (food) is available to support a large and active microbial population, which, through respiration, generates sufficient heat to accelerate the process. This also achieves a selective sterilisation of potential pathogens and seeds that is variously known as sanitisation, pasteurisation or disinfection. Recognition of the process goes back to ancient times, and it is readily achieved on a small scale although often not very efficiently.

Composting is traditionally driven by a succession of microbial processes. Broadly the process may be considered as comprising four phases: heating, thermophilic decomposition, mesophilic decomposition and curing. In the heating phase microbial respiration in the presence of oxygen causes the temperature in the compost mass to rise. As this occurs there is a change in the microbial population from organisms that thrive at ambient temperatures to those that prefer elevated temperatures up to around 55-60°C (thermophiles)[2]. While sufficient readily metabolisable material (energy) remains in the waste, the action of the thermophiles maintains the high temperature. From a practical standpoint this ensures that pathogens and weed seeds are destroyed and results in rapid waste treatment. It is important to note though that temperature is a function of microbial activity and heat removal from the process; a balance must be struck between allowing sufficient heat to accumulate to provide optimal conditions for compost microbes, and the elimination of seeds and pathogens, and removing sufficient heat to prevent overheating. While very high temperatures can be generated in composts, these are not particularly beneficial as very few organisms are able to function above 65°C; various publications list the optimum temperature for composting as being between 53 and 65°C, with a number indicating that the temperature should not exceed 60°C.

As the readily available sources of energy (nutrients) decline the compost cools (as the rate of microbial respiration slows) and a new population of mesophilic microbes, preferring warm temperatures, becomes established. The compost remains warm and active, and considerable degradation can still occur. Indeed, where there is a high proportion of cellulosic material (wood, etc.) the mesophilic phase of composting is likely to be the longest and support the greatest numbers and diversity of microbes. Eventually, all the readily degradable material has been utilised, the temperature returns to ambient, and active composting has ceased. At this stage the compost is usually referred to as 'immature'. This is because it contains relatively high levels of ammonia and other compounds that are toxic to plants. Microbes able to oxidise ammonia to nitrate are not able to survive at elevated temperature. During curing these microbes recolonise and phytotoxic compounds are dissipated and stabilised.

Depending upon the goals of the process, and end use of compost, the curing stage can often be omitted. Where a compost-rich plant growing medium is produced, curing (and appropriate validation) is essential. Where compost is spread broadly to land, curing can often be dispensed with.

Good engineering can optimise the composting process, but it must be recognised that the process is driven by the biology of microbial degradation. With a well-engineered system it is possible to generate semi-mature compost in around 15-20 days[3]. From a processing point of view it may be possible to reduce the time within the composting unit below this but processing conditions such as moisture, pH, aeration and heat (temperature) must be actively managed. Very short residence times of a few days are sometimes used, but these achieve only sanitisation through the thermophilic composting phase, and the resulting material remains highly biologically active and in need of further composting.

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[2] While it is recognised that compost piles may achieve temperatures higher than this, this is generally associated with poor heat removal and will lead to inhibition of the true composting process.

[3] Shorter times are possible with higher proportions of putrescible (food) waste

Optimising the composting process

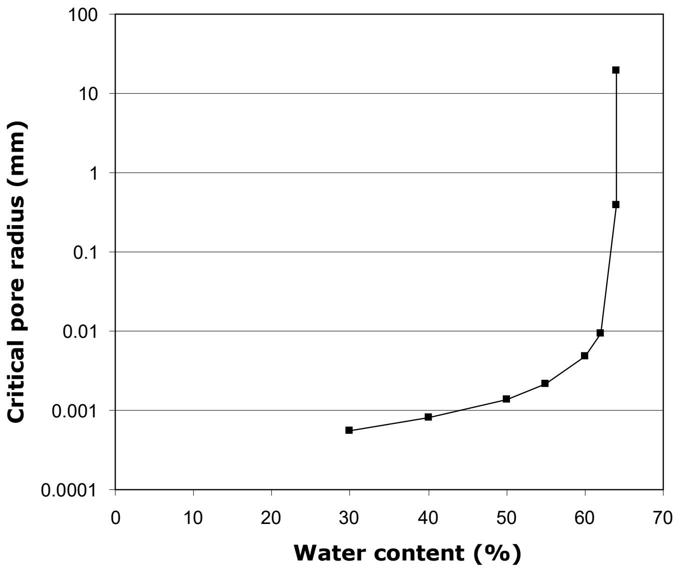
1.1.1 The microbial environment

Effective composting requires appropriate feedstock, as this is the 'food' for the microbes that drive the process. A sufficient level of readily degradable carbon is required. This is sometimes expressed as 'volatile solids content' and is essential for rapid microbial growth, which in turn promotes heating. A balance of other nutrients, principally nitrogen is also required. The requirement is often expressed as a C:N ratio. Workable ratios are quite broad, with the range 25:1 – 40:1 often quoted as ideal but these figures are generally applicable to passive composting systems (windrows and static piles), lower C:N ratios can be acceptable in well-engineered and aerated processes (see Part 3 for more details on C:N ratios and how HotRot deals with low ratio wastes).

Composting is an aerobic process; sufficient oxygen must be supplied to allow the process to proceed. Air must be able to penetrate to all parts of the pile. At the gross level this means mechanisms for turning and air-injection is required. At a lower level, it also requires that attention be given to particle size (porosity or bulk density), avoidance of accretions or conglomerates, and prevention of preferential air flow (channelling).

Water content is also a critical factor. Moisture needs to be kept at between 40 and 60%. At higher moisture levels free airspace essential for aeration is usually adversely affected (pore spaces become flooded), in these situations it becomes impossible to maintain oxygen levels. The issues underlying air (oxygen) penetration are structure, moisture and heat release. Fast composting requires oxygen delivery to the microbial cells. This is optimal when there is an interlinked network of relatively small open pores. Oxygen movement through water is around 10,000 times slower than oxygen movement through air. If pores are filled with water, the rate of oxygen transport will be too slow to sustain thermophilic composting. Richard (2000) explains the theoretical relationship between water content and the size of air-filled pores (http://compost.css.cornell.edu/oxygen/capillary.html).

At any water content below saturation, capillary action within the waste will exert a negative pressure on free water in contact with the waste. This pressure can be related to a "critical pore radius". This critical pore radius is of great importance, as it describes the size of the waste pores that will be air-filled – pores less than the critical radius will be water-filled and those above will be air-filled. This is shown in the graph below for a model waste. The shape of the curve is expected to be similar for all wastes, although the water levels at which saturation occurs will vary considerably.



The importance of moisture content is seen in the shape of the curve and the sudden change in free air space as saturation approaches. In the example above, at 62% water, pores with a radius above 0.01 mm are air-filled. At 64% water, the waste is effectively saturated. This phenomenon illustrates the very sharp cut off between acceptable and unacceptable water levels that is not appreciated by many operators

In addition, moisture is a major heat sink – high moisture levels result in cooler temperatures and insufficient heat for evaporation. At lower moisture levels biological activity is insufficient for the process to proceed.

Not only is the overall moisture content valid but so also is moisture distribution within the pile. As composting proceeds areas will become dry through evaporative losses and simple movement of air and other areas may become excessively wet due to leachate drainage or preferential airflow. Consequently, areas will also become too hot or too cold. For efficient microbial activity optimal conditions need to be present at the micro level, evenly throughout the mass, rather than as a gross average. Thus mixing of the waste is critical and the smallest particle size compatible with good aeration should be sought.

While achieving an ideal composting mix may appear intensive, much of this work is done during plant design and commissioning. Where waste streams are reasonably consistent, relatively little effort is required to maintain successful feedstock and microbial environments.

1.1.2 Process engineering

The practical requirements for composting are relatively simple. However, in addressing large volumes of waste there are problems of hazards, vermin control, odour, leachate, dust and aerosols that need to be addressed. The process needs to be monitored and controlled, and standards met. Any process needs to be cost and energy effective. In large scale composting, therefore, the process is engineered to address the requirements of human society, business and regulation, as well as providing appropriate conditions for biological activity (sometimes balancing these requirements can be difficult – often as a result of ill-conceived legislation, i.e., legislation that is process rather than results orientated). Any system that does not pay attention to all of these factors will not be sustainable (in the broadest sense of the term).

Composting technologies

A range of composting-based solutions are available for the treatment of municipal wastes. These are distinguished by the goal of the process and the mechanism for achieving treatment. Two approaches to organic waste are taken: sustainable reuse and waste treatment. In the former, composting is used to produce a useful product that is beneficially reused on land. The wastes processed are separated or selected to ensure that contamination levels are low. This approach is compatible with our previous definition.

In using 'composting' as a waste treatment technology, separation of waste prior to the composting stage is less important and the goals are stabilisation and volume reduction. The final product is of little or no value, and may have to be landfilled.

Clearly a sustainable reuse approach is most desirable, but this is only achievable where the means and will for an uncontaminated organic waste stream exist, and where appropriate markets for the composted product can be developed. These issues are discussed further below.

Composting technologies can be split into three broad categories: open windrow, within building and in-vessel.

- ### Open windrows

Open windrows are long piles of compost that are turned occasionally by appropriate equipment. There is no containment (for all or critical parts of the process such as turnings and handling) so odour, dust, leachate and the potential for pathogenic aerosols are uncontrolled. Aeration is limited, turning infrequent and composting generally occurs at very slow rates (composting times are protracted at around 120-360 days depending on climate). Siting and the range of wastes that can be processed are therefore often constrained. Typically open windrow is restricted to green waste composting where there is no requirement for pathogen control. In this application some unevenness of treatment is not problematic. Climatic impacts can be significant but cost is low. In some parts of the world regulatory approval for windrowing is becoming hard to obtain.

- ### Within building systems

In-building systems bring composting inside. The composting process is contained with respect to the environment, but workers and equipment are exposed to potentially damaging aerosols. There is scope for much higher levels of monitoring and process control when compared with windrow composting. In-building systems are generally suited for larger scale installations but are relatively inflexible. The direct processing cost is usually high due to the large amounts of air that need to be moved and treated. Installations are capital intensive and maintenance costs may be significant. Building design must take into consideration the corrosive atmosphere, odour containment and extraction, and the operation of heavy machinery.

- ### In-vessel composting systems

In-vessel systems are varied but generally offer the following features:

- The compost is retained within some sort of vessel and the environmental and human impacts can therefore be more tightly controlled.
- Most organic wastes can be handled – although only with considerable care in some systems.
- There are opportunities for strict monitoring although this is often misdirected with measurement of parameters such as oxygen or temperature only rather than heat release or respiration (see Part 3 of this series).

- The thermal properties of the system generally ensure rapid and sustained heating, although in some cases this is simply a reflection of low rate composting generating modest levels of heat that is not removed from the process; in this case the equipment appears efficient but is in reality poor.
- Air delivery can be well controlled, although many systems do not include mixing or turning thus resulting in channelling which often results in uneven temperature and moisture. This can lead to a product that is relatively heterogeneous despite meeting overall process requirements.
- Systems are generally scalable.

In-vessel solutions are relatively capital intensive, and total processing costs reflect this, but they offer the most comprehensive control and containment options. Systems are generally suited to small to medium sized installations. However, their modularity and cost advantage when compared to in-building systems means that several satellite plants can be established to serve very large populations. The advantage of satellite plants is that waste and product transportation costs can be minimised.

The HotRot system can be considered a “new generation” in-vessel composting system that has been developed to overcome many of the design short-comings of traditional in-vessel systems (see Parts 2 and 3 of this series).

Standards

Given the diversity of feedstock and technologies to process them, it will be apparent that the composted product is potentially variable. Standards differ according to their intent, but generally seek to ensure that the product is safe for people who come into contact with it and the environment receiving it. Standards may also have components that indicate quality or fitness for purpose. In many cases a number of compost classes are recognised, and there may often be restrictions on the use to which some of these can be put.

Common components of standards include:

- Heavy metals are ubiquitous in the environment, but may be problematic in composts, particularly those derived from biosolids and processing sludge. However, it must be recognised that it is the overall concentration that is important and even compost containing significant quantities of some elements should be able to be used as long as application rates are monitored. It should also be recognised that many heavy metals are in fact trace nutrients in agricultural systems; chromium and zinc for example are critical for wool growth.
- Chemical contaminants such as pesticides are also subject to limits in some standards but most modern compounds degrade during the composting process; there are some key exceptions that operators should be aware of.
- Human pathogens, typically *Salmonella* and faecal coliforms, are given limits. While this requirement can be met by direct testing, it is common to demand specific temperature performance for the composting process. Typically this is 3 days above 55°C or a shorter time at a higher temperature; however, as noted, temperature measurement alone is not a good indicator of compost performance.
- Weed seeds: The composting process should kill most plant propagules, and again this aspect is controlled in some standards.
- Vector attraction reduction (VAR): Putrescible waste is usually attractive to a range of nuisance animals including flies, birds and rodents (vectors). Full composting eliminates the attractiveness of the material by reducing the volatile solids content (converting readily degradable compounds to more stable ones). Legislative requirements are usually based on time at temperature requirements or a measured reduction in volatile solids content.
- Plant growth inhibitors: As discussed above, uncured compost can be toxic to plants. Herbicide carryover is also an occasional problem. Obviously this is a significant factor where the product is used as a component of plant growth medium.
- Physical contaminants: Metal, glass, plastic and stones are all potential contaminants of compost and their prevalence will reflect the feedstock.

Not all standards control all variables, as purposes vary. Some, for instance, are relatively unconcerned with product performance and focus on safety, while in others the opposite can be true.

Some significant standards are:

- AS/NZ 4454 (Australian and New Zealand standard – safety and performance)
- USEPA Rule 503 for the safe disposal of biosolids (US. Safety bias)
- Australian state EPA guidelines (these are varied and cover safety and performance and well as plant operations, many are based on AS 4454)
- BS-PAS100 (UK performance bias)
- UK and EU Animal By-Products Regulations (pathogen elimination but a heavy focus on process rather than product)
- Canadian CCME Guidelines (product stability)

Composting feedstock issues

The need for relatively uncontaminated feedstock that is compositionally appropriate for microbial degradation has already been highlighted. In a large community it is likely that various waste streams will be balanced and that the resulting mix will be compostable. Where composting is practiced for industrial wastes, it is possible a number of complementary industries will have to combine wastes to produce a suitable mix. For example, producers of highly putrescible food wastes may need to collaborate with producers of garden, paper or wood wastes to obtain a suitable C:N ratio, structural component and water content. Commercial and industrial businesses are, however, able to control their waste separation to a greater extent than is generally possible for domestic waste. Commercial waste streams are therefore more amenable to treatment by composting within the existing waste handling infrastructure (source separation of domestic wastes can be achieved with community and consumer involvement).

Product marketing

While collection, handling and processing of waste are often within the purview of local government, disposal of compost is governed to a greater extent by the market. The most sought after outcome of composting is a reduction in organic waste destined to landfill, but as we have discussed, closing the loop and returning organic matter to land is the sustainable solution. Product marketing is the key to this closure, which should also generate beneficial economics for the whole composting process and community.

Compost has uses in horticulture, agriculture, domestic gardening, land restoration, roadwork restoration and landscaping and erosion control. It is beyond the scope of this document to fully explore marketing issues, but they are highlighted here as there is a need to consider this aspect in any composting based waste solution.

Summary

Removal of organic waste from landfill is a pressing need. Composting is a technically and economically viable treatment option for much of this waste, with added benefits for soil health if the product is used suitably. Compost quality depends on feedstock cleanliness, and the ability to obtain uncontaminated organic waste is often an impediment.