RESEARCH & DEVELOPMENT OF COMPOSTING TOILETS THE ROTA-LOO TECHNOLOGY.

Buzz Burrows- General Manager, Environment Equipment Pty Ltd.

Introduction

Over the last 50 years science and technology has advanced at a staggering rate in many of the so-called hard sciences. But it has only been in relatively recent years that multidisciplinary approaches to global and environmental problems have taken place. It has been through these pursuits that advances have occurred in ecological and environment sciences.

‘Composting’ is one of the most fundamental natural processes and is as basic and important as life and death itself. Composting has developed from a once simple activity to become more than an Art to the agricultural or horticultural enthusiast and is now a science in itself. Testament to this is the increasing number of publications and University courses on the subject. As we increasingly understand the internal and external processes involved in composting we also begin to realise the benefits of ecologically processing organic matter compared to most of our current practices. The biological processing of human waste will have profound effects on the way we manage our natural and built environments and habitats both now and in the future and it is the reason I am here to speak with you today.

Understanding the composting process has given us the tools and criteria by which to design and construct the most appropriate sanitation systems for any given geographical or climatic conditions. Understanding the relationships between the many variable in the composting process has allowed us to minimise risk and maximise efficiency when dealing with human waste management.

As research and development in this science increases our knowledge so will our systems evolve and become more efficient. We at Environment Equipment Pty Ltd are about to commence a significant demonstration and research project in conjunction with CSIRO and a Victorian Water Authority. This project will focus on alternative methods of dealing with the wastewater and sanitation for domestic residence in an urban setting. CSIRO is just one, among a growing number of research institution from around the world, looking for more appropriate ways of dealing with human waste as it has become increasingly apparent that reticulated sewerage systems are less economically viable in the medium to long term.

For today’s presentation we would like to highlight the importance of the Rangers and other Managers of National Parks for becoming familiar with the science of composting. This will allow for those people ultimately responsible for the park’s infrastructure to better analyse and evaluate the different technologies available for human waste disposal and ascertain for themselves which systems will work. Two of the most objective reference available for such understanding are:

1 the “Centre for Environment” at Cornell University,

2. “The Humanure Handbook” by Joe Jenkins available through Environment Equipment

The process of composting relies on the interplay of many different variables which when combined in the right quantities allows for the rapid and odourless degradation of organic materials. The science of composting is the understanding of how each of the many variables in the composting process interacts with the next and how the different balances of each ingredient will influence the behaviour or characteristics of the others. Whilst the composting process is as old as the hills or more correctly as old as the dirt, our understanding of the process is relatively new and expanding all the time. To understand the basics of composting we will look at several of the key factors involved.

1. The phases of composting.

2. Composting Physics

a) Temperature Curve
b) Mechanisms of Heat Loss
c) Aeration
d) Moisture

3.Compost Chemistry
a) C/N Ratio
b) Oxygen
4. Odour Management
a) Factors leading to Anaerobic Conditions
(i) excess moisture
(ii) inadequate porosity
(iii) a rapid degrading substrate
(iv) excessive pile size

From the information presented we will then take a closer look at the Rota-Loo composting system and see how many of its features and variations in design are ideally suited for managing human waste in remote cold climate areas.

1.The Phases of Composting.

In the process of composting microorganisms break down organic matter and produce carbon dioxide, water heat and humus, the relatively stable end product. Under optimal conditions, composting proceeds through three phases: 1) the mesophilic, or moderate temperature phase, which lasts for a couple of days, 2) thermophilic, or high temperature phase, which can last for a few days to a couple of months, and finally, 3) a several-month cooling and maturation phase. Different communities of microorganisms predominate during the various composting phases. Initial decomposition is carried out by mesophilic organisms, which rapidly break down the soluble, readily degradable compounds. The heat they produce causes the compost temperature to rapidly rise.

As the temperature rises above about 40°C, the mesophilic microorganisms become less competitive and are replaced by others that are thermophilic, or heat loving. At temperatures of 55°C and above, many microorganisms that are human or plant pathogens are destroyed. Temperatures over about 65°C will kill many of the composting microbes and the process becomes one of desiccation where the organic material dries out and doesn’t reduce in volume.

During the thermophilic phase, high temperatures accelerate the breakdown of proteins, fats, and complex carbohydrates like cellulose and hemicellulose, the major structural molecules in plants. As the supply of these high-energy compounds becomes exhausted, the compost temperature gradually decreases and mesophilic microorganisms once again take over the final phase of “curing” or maturation of the remaining organic matter.

2. Compost Physics.

The rat eat which composting occurs depends on the physical as well as the chemical factors. Temperature is a key parameter determining the success of composting operations. Physical characteristics of the component ingredients, including moisture content and particle size, affect the rate at which composting occurs. Other physical considerations include the size and shape of the system, which affect the type and rate of aeration and the tendency of the compost to retain or dissipate the heat that is generated.

a) Temperature curve

Compost heat is produced as a by-product of the microbial breakdown of organic material. The heat production depends on the size of the pile, its moisture content, aeration and C/N ratio. Additionally, ambient (indoor or outdoor) temperature affects compost temperatures. David Delporto of Sustainable Strategies in Connecticut USA has identified a principle factor he calls Q10, which states that for every 10°C that can be introduced to the composting environment the rate of composting can be doubled. The composting process only starts at around 4-5°C below this all bacteria are dormant.

Decomposition occurs most rapidly during the thermophilic stage of the composting (40-60°C), which lasts for several weeks or months depending on the size of the system and the composition of the ingredients. This stage also is important for destroying thermosensitive pathogens and fly larvae. The U.S. EPA has regulations in place which specifies that to achieve a significant reduction of pathogens during composting, the compost should be maintained at minimum operating conditions of 40°C for five days, with temperatures exceeding 55°C for at least four hours of this period. In terms of public health and safety this is an important issue, it must be noted however that the same results can also be achieved at slightly lower temperatures for longer periods of time as long as no fresh material is being added to the compost. This point alone identifies the importance of using the batch system for composting human waste. Joe Jenkins, in his thoroughly researched book “The Humanure Handbook” recognises that batch composting piles ensure that all parts of the pile are subjected to the high internal temperatures, thereby ensuring total pathogen destruction.

After the thermophilic phase the temperature begins to drop and can’t be restored. At this point the decomposition is taken over by the mesophilic microbes through a long process of curing or maturation. Although the decomposition rate is slower, chemical reactions continue to occur that makes the remaining organic matter more stable and suitable as humus, for use with plants.

b) Mechanisms of Heat Loss

The internal pile temperature at any point during composting depends on how much heat is being produced by microorganisms, balanced by how much is being lost through conduction, convection and radiation. Through conduction energy is being transferred from atom to atom by direct contact; at the edges of a compost pile, conduction causes heat loss to the surrounding air molecules.

Convection refers to transfer of heat by movement of a liquid such as air or water. When compost gets hot, warm air rises within the system, and the resulting convective currents cause a steady but slow movement of heated air upwards through the compost and our the top. In addition to this natural convection, some composting systems use ‘forced convection’ driven by blowers or fans. This forced air increases the rate of both conductive and convective heat losses. Much of the energy transfer is in the form of latent heat (the energy required to evaporate water).
The third mechanism for heat loss, radiation, refers to electromagnetic waves. The warmth generated in a compost pile radiates out into cooler air. The smaller the bioreactor or compost pile, the greater the surface area-to-volume ratio, and therefore the larger the degree of heat loss to conduction and radiation. Insulation is therefore important to reduce theses losses in small compost bioreactors.

Moisture content affects temperature change in compost; since water has a higher specific heat than most other materials, drier compost mixtures tend to heat up and cool off more quickly than wetter mixtures, providing adequate moisture levels for microbial growth are maintained. The water acts as a kind of thermal flywheel, damping out the changes in temperatures as microbial activity ebbs and flows.

c) Aeration

Oxygen is essential for the metabolism and respiration of aerobic microorganisms, and for oxidizing the various organic molecules in the waste material. At the beginning of the microbial oxidative activity, the O2 concentration in the pore space is about 15-20% (similar to the normal composition of air), the O2 concentration varies from 0.5-5%. As the biological activity progresses, the O2 concentration falls below about 5%, regions of the anaerobic conditions develop. Providing the anaerobic activity is kept to a minimum, the compost pile acts as a bio-filter to trap and degrade the odourous compounds produced as a by-product of anaerobic decomposition. However, should the anaerobic activity increase above a certain threshold, undesirable odours may result.

Maintaining aerobic conditions can be accomplished by various methods including forced air flow, the inclusion of aeration pipe, increasing the porosity of the compost mixture or by adding the Rota-Loo organic (non bacterial) bio stimulant. This specially designed product is an aqueous extract of seaweed, which has been formulated to stimulate the aerobic bacteria and enzymes and not allow them to degrade into an anaerobic phase. This product not only eliminates odour but it also increases the rate of microbial action and therefore decomposition.

d) Moisture

A moisture content of 50-60 % is generally considered optimum for composting. Microbially induced decomposition occurs most rapidly in the thin liquid films found on the surface of the organic particles. Whereas too little (<30 %) inhibits bacterial activity, too much moisture (>65%) results in slow decomposition, odour production in anaerobic pockets, and nutrient leaching. All organic materials have different moisture levels. Often the same materials that are high in nitrogen are very wet, and those that are high in carbon are dry. Combining different materials can help develop an optimal composting mix.

3. Compost Chemistry

a) C/N Ratio

Of the many elements required for microbial decomposition, carbon and nitrogen are the most important. Carbon provides both an energy source and the basic building block making up about 50% of the mass of microbial cells. Nitrogen is a crucial component of the proteins, nucleic acids, amino acids, enzymes and co-enzymes necessary for cell growth and function.

The ideal C/N ration of composting is generally considered around 30:1, or 30 parts carbon for each part nitrogen by weight. At lower ratios, nitrogen will be supplied in excess and will be lost as ammonia gas, causing undesirable odours. Higher ratios mean that there is not sufficient nitrogen for optimal growth of the microbial populations, so the compost will remain relatively cool and degradation will proceed at a slow rate.

As composting proceeds, the C/N ratio gradually decreases from 30:1 to 10-15:1 for the finished product. This occurs because each time that organic compounds are consumed by microorganisms, two-thirds of the carbon is given off as carbon dioxide. The remaining third is incorporated along with nitrogen into microbial cells, then later released for further use once those cells die.

One of the most crucial elements in composting toilet systems is that the majority of nitrogen is in liquid form. This raises two issues. Firstly, too much urine in the system can cause anaerobic and therefore odorous conditions, and secondly, to balance the carbon to nitrogen ratio consistent with efficient decomposition, a great deal of carbonaceous bulking material may need to be added. Faecal material is also fairly high in nitrogen and can be balanced out with carbonaceous material such as toiler paper. Ideally what needs to be done is to take the majority of the urine out of the equation. Two ancillary products in the Rota-Loo range help achieve this.

1. The Waterless Urinal,

2. The Separating Pedestal.

The type of toiler paper used in a composting toiler system can also effect the rate of decomposition. Newspaper, for example, is slower to breakdown because it is made up of cellulose fibres sheathed in lignin, a highly resistant compound found in wood. Some course toilet papers are manufactured from recycled cardboard and have been through the recycling process a few times. Excessive recycling breaks down the fibre lengths making them difficult to re-bond naturally, when this happens, “size” an inorganic plastic bonding agent is normally added which encapsulates the fibres and makes them inaccessible for composting.

b) Oxygen

Another essential ingredient for successful composting is oxygen. As microorganisms oxidize for energy, oxygen is used up and carbon dioxide is produced. Without sufficient oxygen, the process will become anaerobic and produce undesirable odours, including the rotten egg smell of hydrogen sulfide gas.

Even though the atmosphere is 2.1% oxygen, aerobic microbes can survive at concentrations as low as 5%. Oxygen concentrations greater than 10% are considered optimal for maintaining aerobic composting. The pile size of a composting toilet system can therefore be an issue. If the pile size is too large and not regularly maintained with bulky materials oxygen will on average only be able to penetrate to a depth of 30cm. Pile sizes should therefore be kept to a minimum of 60cm in diameter.

4. Odour Management

Odour is possibly the most common problem associated with composting toilet systems and failure to adequately address the issue has lead to some installations being closed down. This never has to be the case, for the most part odour can be controlled as long as the basic understanding of the process involved in their creation are understood. In 99% of cases odour problems are the result of low oxygen or anaerobic conditions. Anaerobic odours include a wide range of compounds, most notoriously reduce sulphur compounds (eg. Hydrogen sulphide, dimethyl sulphide and dimethyl disulphide), volatile fatty acids, aromatic compounds and amines. Ammonia is the most common odour that can be formed aerobically as well as anaerobically, and thus has its own management options.

Significant release of anaerobic odours from a composting system is usually a symptom that some important management factor has been neglected or misunderstood.
The most common factors, which result in anaerobic odours, are:

1. Excess moisture.
2. Inadequate porosity,
3. A rapidly degrading substrate,
4. Excessive pile size.

All of these factors make it more difficult for oxygen to penetrate throughout a pile before it is depleted, or allow airflow to short-circuit around large zones which become anaerobic. Because oxygen diffuses so much slower in water than in air, excess moisture reduces oxygen penetration. This reduction occurs in two ways. Firstly, because moist compost hydrophilic(it loves water), water is strongly held to the surfaces of particles, so as water content increases the thickness of the aqueous film surrounding each particle increases. The second, closely related effect, is a matrix effect due to capillarity-water fills the smallest pores first, and thus creates water filled zones between particles, which slow oxygen diffusion and result in anaerobic clumps.

The particle size distribution, bulk density and porosity of compound mixture are the second group factors that can lead to anaerobic conditions. These physical characteristics of the compost mixture can interact with high moisture levels to reduce oxygen transport. Small particle sizes educe the number of large pores and increase the likelihood that oxygen will need to diffuse a long way through small pores. The shape, size and structure of particles will affect how they settle, with tight packing arrangements increasing the bulk density and reducing the air filled porosity. In effect this explains why some composting installations, especially in areas with a high usage, that porous bulking material may be required.

The oxygen content at any location in a composting pile reflects balance between oxygen supply and oxygen consumption. Rapidly degrading substrates such as food scraps and human manure consume oxygen much more rapidly than leaves or digested sewerage sludge. Oxygen consumption is a function of substrate characteristics (C/N ratio, bioavailability, moisture, particle size) and environmental conditions (temperature, moisture, oxygen concentration and pH). To provide for the increased oxygen demand of a rapidly degrading substrate, oxygen supply must also be increased. In forced aeration systems this can often be accomplished by increasing the fan blower size. With passive systems, any restrictions on oxygen transport such as inadequate porosity or excess moisture must be reduced. A final alternative, which is commonly practiced with food scraps and humanure, is to reduce the pile size.

Composting toilets come in many shapes and sizes, in all these systems the correct and appropriate pile size will have to balance the heat generated by microbial decomposition and system design with the heat lost through conduction, convection and radiation. Passively aerated systems, which depend on diffusion and natural convection for oxygen transport, usually have large open surface area to encourage air movement, with corresponding convective heat losses. This large surface area also results in conductive and radiant heat loss. Because heat loss on these systems is largely a function of exposed surface area (as well as ambient temperatures) and microbial heat generation largely a function of volume (assuming the environmental conditions are near optimum) for any material and configuration there will be an ideal surface to volume ratio. Larger piles with a smaller surface to volume ratio, will tend to overheat, while small piles will be too cool. The ideal pile height for a composting toilet with rapidly degrading substrates will be close to 1 metre.

Key Points

The points just covered will help any manager of composting toilet systems to better understand the dynamic process that is talking place inside their system. This basic understanding will also be extremely helpful when evaluating the many different types of composting toilet systems available on the market, to determine which one is going to meet and full-fill all of the requirements for an efficient composting toilet system.

In a nutshell, one has to remember that to achieve an efficient system that there are basically three main things that they are to look for in a systems design. How does the system deal with;

1. Minimal liquid retention and drainage,
2. Oxygen flow,
3. Heat (Internal & External temperatures)

Rota-Loo Design

The Australian designed Rota-Loo composting toilet system has evolved over the many years since its start in 1974 and it has evolved in response to a growing and better understanding of the requirements for efficient and effective composting. The Rota-Loo design has been finely tuned to meet the requirements for composting and minimum maintenance.

The internal turntable houses a number of removable composting bins. Each bin has a series of drain holes and air holes located in its base and around the outer surface are of the pile. Inside each bin is a filter material made from a non-woven, inorganic geo-textile material. This material has a flow rate of around 300lts/sqm, which means that all liquids can easily drain through whilst allowing oxygen to penetrate the pile from the base. The filter material also has a porosity of 170 microns, which means that no solids greater than 0.175mm will escape the bin, therefore ensuring that all solids remain in the bin. Once the liquid has drained from the bin it is stored in the base of the outer container. The complete separation of liquids from solids also ensures the pile remains aerobic and reduces the possibility of odours. The bin design allows for the most appropriate and manageable amounts of waste material to be stored, which can be quickly and easily composted by allowing oxygen to penetrate to the centre of the pile and which can easily be moved. Once the initial bin has been filled, the turntable is simply rotated to allow a new bin to take the waste as the first remains inside the system without any fresh material being added just composting away. Once all the bins have been filled and the first bin has returned to the front position, it can then be removed so that its humus contents can be emptied into a small hole in the dirt, the bin replaces and the cycle started again.

One of the most important aspects of the Rota-Loo system is that it has its own heat source. The Soltran™ building is an integral part of the Rota-Loo concept and enables the system to become one of the most efficient in the world, especially in cold climates. The Soltran™ design incorporates a 10mm twin-wall polycarbonate glazing placed at a 60° angle facing north at the rear of the building. The area under the glazing is insulated and almost airtight except for a few bleeder holes allowing new air into the void. The air inside the Soltran™ is heated by the sun and drawn into the Rota-Loo via the air inlet and through the system by a fan. Whilst the fan is used to vent the internal system it can also cause heat loss from the pile. The heat being generated by the Soltran™ can overcome the heat loss from the pile and in fact increase the available heat well above the ambient. The increased heat within the local environment will again assist in a more rapid degradation of the organics as well as providing a high internal temperature for the pathogen kill. As mentioned earlier, pathogen kill is an extremely important public health and safety issue and the most natural way of killing pathogens is through a factor of heat and time.

An experimental Soltran building has been in operation for several years on the Routburne Walking Track in the South Island of New Zealand at an altitude of 6000 feet. A Rota-Loo toilet was used for several years at Greenpeaces' Mawson base in Antarctica with an outside temperature of around -35°C until the base was disbanded and the unit moved to its new home in the South Pacific.

Inducing and retaining heat in to a composting toiler system is the key to a successfully operating high altitude or cold climate system. The Mobile Rota-Loo shown here is a unique system incorporating passive solar design the functionality of the standard Rota-Loo composting toilet and mobility. The material used in construction of the Mobil is a polystyrene, insulated, 50mm colourbond sandwich panel. This is the same material which is used in coolroom construction. Its thermal properties are excellent for retaining generated heat and allowing the composting process to continue even under extreme conditions. The versatility of the Mobile allows for its superstructure to be easily changed. The trailer section can be replaced with skids and lifting lugs, making the unit ideal as a remote location toilet facility which can double as an emergency shelter. The compact building can be air lifted into place or several put on the back of a truck and dropped with a Hyab crane.

Urine and Excess Liquid

Probably the most difficult management issue for any composting toilet system is how to deal with excess liquid and urine. Not only is it the cause of most anaerobic odour problems it is sometimes difficult to get rid of.

The safest way of dealing with urine is to evaporate it off. To do this effectively requires a fair amount of energy. This can be generated quite easily with an Excess Liquid Tank and a Soltran™ Module (Overhead-Rota-Loo & Soltran cutaway). The stored liquid in the base of the Rota-Loo is drained into an Excess Liquid Tank (ELT) placed in the base of the Soltran™. The ELT has its own dedicated venting system to allow for maximum airflow over the greatest surface area in the hottest conditions. A stainless steel sheet is placed horizontally in the middle of the ELT. The unit is sealed with a clear sheet of 3mm-polycarbonate glazing on the top. A dedicated fan in the vent pulls the warm air from the apex of the Soltran, across the liquid, which falls onto the superheated stainless steel sheet and quickly evaporates it.

In larger facilities or where high number of people are expected or in very cold climates with little possibility of generating heat naturally, other strategies are available such as LPG evaporators. (Overhead-LPG Evaporator) These systems are expensive, around $10,000.00 per unit but are only able to convert large amount of urine into urea salt crystals in only a few hours and at fairly economical rates compared to alternative means of removal.

The Last Words

Now that you have a better working knowledge of the composting process and how the Rota-Loo toilet system is designed to meet the necessary requirements, there leaves me to mention one last strategy that is filtering though the research institutions.

"SEPARATE AT SOURCE". This means that where possible separate the urine from the faecal material before they go into the pile. This can be achieved by using waterless urinals and separating pedestals. As mentioned earlier, this will eliminate the possibility of anaerobic conditions, increase the decomposition rate by balancing the C/N ratio and help solve many maintenance issues, some of which I haven't raised as yet such as fly or insect control.