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Biosolids Technology Fact Sheet
In-Vessel Composting of Biosolids

DESCRIPTION

Biosolids are primarily organic materials produced during wastewater treatment which may be put to beneficial use. Composting is the biological degradation of organic materials under controlled aerobic conditions. The process is used to stabilize wastewater solids prior to their use as a soil amendment or mulch in landscaping, horticulture, and agriculture. Figure 1 shows an example of a finished product of compost. Stabilization of wastewater solids prior to their use serves to destroy pathogens (disease causing organisms), minimize odors, and reduce vector attraction potential.

The Environmental Protection Agency's (EPA's) 40 CFR Part 503, *Standards for the Use and Disposal of Sewage Sludge*, (the Part 503 Rule) defines two types of biosolids with respect to pathogen reduction: Class A and Class B. The difference is defined by the degree of pathogen reduction on the solids. When federal performance standards are met, composting insures full destruction of pathogens to *non-detectable levels* in the wastewater solids (i.e., to Class A standards.) The Part 503 Rule requires the composting process to maintain a temperature of at least 55 degrees Celsius for a minimum of three days to effectively destroy pathogens and qualify as Class A.

Source: U.S. EPA, 1986.

FIGURE 1 FINISHED COMPOST PRODUCT

In addition to performance standards for the composting process, the Part 503 Rule established maximum concentrations for nine metals which cannot be exceeded in biosolids products, including compost. These are known as ceiling concentrations. The federal maximum allowable metals concentrations are provided in Table 1. The Part 503 Rule also established more stringent pollutant concentrations. Biosolids products which do not exceed pollutant concentrations, meet Class A pathogen reduction requirements, and are processed to reduce vector attraction potential are often referred to as *Exception Quality* products. Products meeting these requirements may be freely distributed for a variety of uses.

There are three general methods of composting biosolids: windrow, aerated static pile, and in-vessel. Each method uses the same scientific principals but varies in procedures and equipment needs. This Fact Sheet addresses in-vessel composting.

In-vessel composting occurs within a contained vessel, enabling the operator to maintain closer control over the process in comparison with other composting methods. A typical flow diagram for in-vessel composting is shown in Figure 2.

There are several types of in-vessel composting reactors: vertical plug-flow, horizontal plug-flow, and agitated bin. The primary difference involves

TABLE 1 MAXIMUM METAL CONCENTRATIONS

Metal	Ceiling Concentration (mg/kg)	Pollutant Concentrations (mg/kg)
Arsenic	75	41
Cadmium	85	39
Copper	4,300	1,500
Lead	840	300
Mercury	57	17
Molybdenum	75	NL
Nickel	420	420
Selenium	100	100
Zinc	7,500	2,800

NL = No established limit

Source: U.S. EPA, 1993 and 1994.

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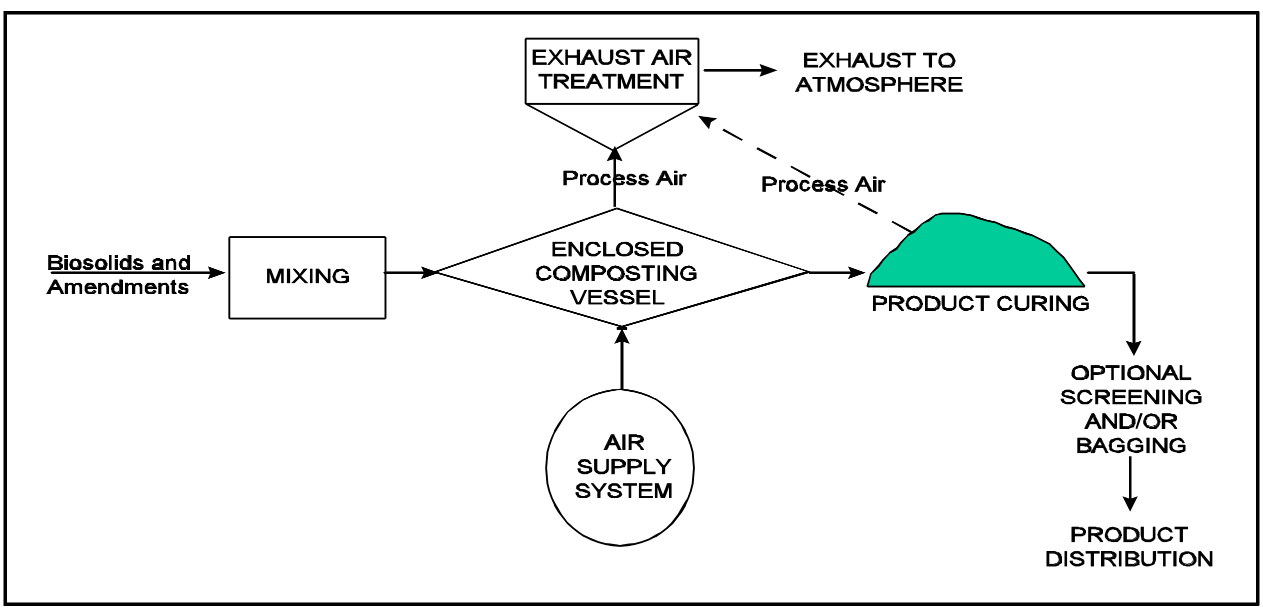
the aeration systems and loading/unloading provisions. The first two systems operate as plug-flow, which means that biosolids and bulking agent are loaded on a periodic basis (typically daily or weekly) while "finished" compost is discharged from the opposite end of the system on roughly the same schedule. The vessel is only completely emptied for maintenance.

In vertical plug-flow systems, the biosolids and bulking agent mixture is introduced into the top of the reactor vessel and compost is discharged out the bottom by a horizontally rotating screw auger. Air is introduced in these systems either from the bottom and travels up through the composting mass where it is collected for treatment or through lances hanging from the top of the reactor.

In horizontal plug-flow systems, the compost and bulking agent mixture is loaded into one end of the reactor. A steel ram pushes the mixture through the reactor. Air is introduced and exhausted through slots in the floor of the reactor. Compost is discharged from the end of the reactor opposite the ram.

The agitated bed reactors are typically open topped. The biosolids and bulking agent mixture is loaded from above. The composting mass is periodically agitated using a mechanical device and air is introduced through the floor of the reactors. Agitated bed reactors can be operated as either plug flow or batch operations. In batch operations, the vessel is loaded with biosolids and bulking agent, processing takes place, and the vessel is emptied.

As with other composting methods, the resulting product is generally cured for at least 30 days after



Source: Modified from U.S. EPA, 1989.

FIGURE 2 FLOW DIAGRAM OF A TYPICAL IN-VESSEL COMPOSTING FACILITY

Composting Basics

During composting, microorganisms break down organic matter in wastewater solids into carbon dioxide, water, heat, and compost. To ensure optimal conditions for microbial growth, carbon and nitrogen must be present in the proper balance in the mixture being composted. The ideal carbon-to-nitrogen ratio ranges from 25 to 35 parts carbon for each one part of nitrogen by weight. A lower ratio can result in ammonia odors. A higher ratio will not create optimal conditions for microbial growth causing degradation to occur at a slower rate and temperatures to remain below levels required for pathogen destruction. Wastewater solids are primarily a source of nitrogen and must be mixed with a higher carbon-containing material such as wood chips, saw dust, newspaper or hulls. In addition to supplying carbon to the composting process, the bulking agent serves to increase the porosity of the mixture. Porosity is important to ensure that adequate oxygen reaches the composting mass. Oxygen can be supplied to the composting mass through active means such as blowers and piping or through passive means such as turning to allow more air into the mass. The proper amount of air along with biosolids and bulking agent is important. Haug (1980) provides the basis for calculating the appropriate amounts of these materials.

active composting and before use. A properly operated facility produces a stable compost which can be easily handled and safely stored. Compost enhances soil properties, such as water holding capacity, nutrient availability, and texture. In *Compost Engineering*, R.T. Haug (1980) discusses several ways to determine the degree of stability achieved during composting including:

- Oxygen uptake rate.
- Low degree of reheating in curing piles.
- Organic content of the compost.
- Presence of nitrates and the absence of ammonia and starch in the compost.

Because this process results in a usable material, an important and often overlooked part of any composting facility is product storage and marketing. Unlike disposal-oriented technologies, end users and markets for the product are seasonal with peak demand in the spring and fall. Therefore, provisions for storage of the final product until it is sold are necessary. In addition, product marketing efforts are essential to insure that end users understand the material, recognize its value, and are familiar with proper application techniques.

APPLICABILITY

The physical characteristics of most biosolids allow for their successful composting. However, many characteristics will impact design decisions. These characteristics are discussed in the Design Criteria section.

In-vessel technology is more suitable than other composting technologies in suburban and urban settings because the system allows for containment and treatment of air to remove odors before release. The requirement for a relatively small amount of land also increases its applicability in these settings over other types of composting. However, a market for use of the resulting product will generally be more readily available in suburban and rural areas rather than urban settings.

ADVANTAGES AND DISADVANTAGES

Advantages

Composting offers advantages and disadvantages that must be considered before selecting this option for managing biosolids. First, composting produces a reusable product as long as the feed materials are suitable. Use of the product returns valuable nutrients to the soil and enhances conditions for vegetative growth. Compost can be handled more easily than some other biosolids products such as digested biosolids. It is very friable and has the consistency of a peat soil. In addition, compost, unlike other Class A products, is not subject to end use restrictions. However, composting somewhat increases the amount of material to be managed through addition of bulking agent to improve aeration in the composting mass. Typically, one cubic yard of cake will produce three cubic yards of compost. Some bulking agents can be screened out and reused to minimize this disadvantage. This "disadvantage" may also be an advantage because the product can be sold.

In comparison with other types of composting, the in-vessel technology offers the following conveniences:

- C The composting process can be more closely controlled.
- C The effects of weather are diminished.
- C Less bulking agent may be required.
- C The quality of the resulting product is more consistent.
- C Less manpower is required to operate the system and staff is less exposed to the composting material.
- C Process air can be more easily collected for treatment to reduce odor emissions.
- C Less land area is required.
- C Public acceptance of the facility may be better.

Disadvantages

There are also disadvantages associated with in-vessel composting which must be considered before selecting this technology for wastewater solids management. In-vessel composting is generally more costly than other composting methods, particularly with respect to capital expenditures. In addition, because it is more mechanized, more equipment maintenance is necessary. A significant drawback of composting that must be addressed during facility design is the potential for fires. The large amount of carbonaceous material stored and used at composting facilities creates the potential for fires in storage areas as well as in the active composting mass. Sufficient aeration and moisture are necessary to avoid fires.

Environmental Impacts

Several aspects of an in-vessel composting facility can result in environmental impacts if the facility is mismanaged. Proper design and operation can reduce environmental impacts. Storage, distribution, and use of the resulting product can also result in environmental impacts if not performed properly.

In-vessel composting facilities can impact air, water, and soil. The primary impact to the air is nuisance odors if process air is not properly treated before emission to the atmosphere. Most in-vessel composting facilities treat process air with either a biofilter or chemical scrubbing system prior to release to the atmosphere. Odors can result from several possible constituents in the air exiting a composting vessel. Much work has been done in the last several years to characterize and control odors from composting operations. Bioaerosols (organisms or biological agents in air that affect human health) are also a concern in compost emissions. The most widely studied bioaerosol is *Aspergillus fumigatus,* a fungal spore. Endotoxins (non-living components of cell walls of gram-negative bacteria) and organic dust (such as pollens) are also bioaerosols. These contaminants are primarily of concern to workers at the composting facilities and are generally not present in quantities that would cause reactions in most humans. Health effects to compost facility workers have not been readily apparent in studies conducted to identify such effects (Epstein *et al*., 1998.)

Impacts to surface water bodies resulting from in-vessel composting are unlikely. The enclosed nature of the technology greatly diminishes the potential for impacts to surface water due to high nitrogen concentrations in runoff. Buildings should be designed with floor drains to sewers or holding tanks. Any unenclosed portions of an in-vessel composting operation, such as materials receiving and mixing, product curing, and product storage should be designed with leachate/runoff containment and provisions for disposal or treatment to avoid runoff potential.

The use of biosolids compost as a soil conditioner results in the following:

- C Increases water holding capacity.
- C Increases aeration and drainage for clay soils.

- Provides organic nitrogen, phosphorus, and potassium.
- Provides essential plant micronutrients.
- Can reduce the need for pesticides.

Other environmental benefits of producing and using compost include the recycling of a valuable resource, reduction of dependence on chemical fertilizers, and offsetting the use of natural resources such as trees or peat moss as mulch material.

DESIGN CRITERIA

The following biosolids characteristics must be considered in designing an in-vessel composting system:

- Moisture content.
- Volatile solids content.
- Carbon content.
- Nitrogen content.
- Bulk density.

These factors are discussed in detail in *Composting Engineering* (Haug, 1980.)

The following bulking agent characteristics must also be considered:

- Size.
- Cost/availability.
- Recoverability.
- Carbon availability.
- Preprocessing requirements.
- Porosity.
- Moisture content.

Metals content of the biosolids will affect the usability of the final product and must be considered during design to ensure a market for the final product.

An odor control system is an inherent part of in-vessel design. The cost of an odor control system can account for up to 50 percent of both capital and operation and maintenance costs. Composting facilities usually use either wet scrubbers or biofilters for odor control. The level of odor control required is a function of the quality and quantity of air to be treated, the results of air dispersion modeling, and proximity to occupied dwellings.

The most important design feature of a composting system is the ability to maintain uniform aerobic conditions during composting. The air distribution system may be controlled by cycle timers and/or temperature feedback control. The design must avoid compaction of the composting mass to maintain sufficient pore space for aeration. In addition, provisions for routine monitoring of temperatures must be included.

Equipment should be designed to provide maintenance staff with safe access. Equipment and instrumentation should be able to be removed or repaired without having to relocate composting material.

Systems that minimize worker exposure to hot exhaust process gases are preferable because workers can maintain the system and control odors with greater ease, including minimizing the volume of process air that must be treated.

Many in-vessel systems include a water spray system to add moisture to the composting mass, to control temperatures, and for fire protection.

Detention times, which vary with system configuration, will affect many design considerations, including equipment sizing. Horizontal agitated bed systems are designed for 21 days of aerated composting followed by curing. Other in-vessel systems use 10 to 21 days of active composting. Some state regulations dictate detention times for composting systems. In general, about 21 days is a good minimum time for adequate stabilization. Provisions to monitor the degree of stabilization allow operators to determine when the biosolids are adequately processed and ready for removal to curing piles.

Features of the site on which the in-vessel composting facility is to be located must be considered during design, including size, relative position to residential areas, availability of wastewater treatment, drainage, and access. Examples of optimum locations for in-vessel composting include a large tract of land in an industrial area or a site near a municipal solid waste landfill. One needs to determine the meteorology of a potential site so that odors can be adequately treated, diluted and dispersed.

PERFORMANCE

According to a survey conducted by *BioCycle, Journal of Composting and Recycling*, in January 1999, there were 54 in-vessel composting facilities processing wastewater residuals across the United States (Goldstein and Gray, 1999) and 11 more facilities were in various stages of design or construction. Since that survey, at least two facilities (Portland, Oregon and Camden County, New Jersey) have closed. The vendor systems used at the facilities listed in this survey include:

- Davis Composting and Residuals Management (formerly Taulman Composting Systems.)
- Bedminster Bioconversion (co-composting with municipal solid waste.)
- US Filter/International Process Systems.
- Longwood Manufacturing.
- American Biotech Systems.
- Purac.
- Gicon Tunnels.
- Resource Optimization Technology (ROT Box.)
- Compost System Company Paygro.
- Green Mountain Technologies.
- Waste Solutions.
- Royer.
- Fairfield.
- Conporec.
- Compost System Company Dynatherm.
- Dano.

In addition to these, there are several aerated static pile systems contained within a building that are categorized as in-vessel systems.

The above list is not intended to be a comprehensive list of vendors who offer in-vessel composting facilities. There are also many facilities in operation which use non-patented systems and components.

The number of operating in-vessel composting facilities for biosolids in the United States has steadily increased in the last two decades but has leveled off in recent years. In spite of early operational difficulties and challenges, many early facilities have been upgraded and are successfully operating today.

OPERATION AND MAINTENANCE

In-vessel composting systems can be relatively complex but the skills required for successful operation are common to wastewater treatment plant personnel. Typical labor requirements include heavy equipment operators, maintenance personnel, and instrumentation/computer operators. A clear understanding of biological systems is necessary. Additional staff or consultants are needed to manage end use and to market the compost.

In-vessel composting facilities can require significant maintenance. Many early composting facilities constructed in the United States experienced a variety of operating problems. Odor complaints from neighboring residents have caused facilities to operate at reduced capacity or to shut down for extended periods of time for system modification. For example, a horizontal plug-flow system in Hickory, North Carolina, was shut down for more than a year while an odor issue was addressed. The system reopened after the addition of air pollution control equipment. The lack of available spare parts has also caused extensive periods of downtime at some facilities. Design configurations have caused some facilities, primarily vertically oriented plug-flow systems, to experience month-long periods of inoperation while routine maintenance was performed. Difficulties in emptying the vessels have been cited as a reason for significant maintenance requirements (O'Brien, 1986.) A system in Lancaster, Pennsylvania, was shut down when state regulators determined it did not meet temperature requirements for Class A pathogen reduction.

There are three basic compost market strategies. The first is the use of compost areas used by the public sector, such as parks, ball fields, landfill cover, and urban reclamation projects. Second, direct marketing to users maximizes revenue and improves the public image of the producer. This strategy could include distribution centers run by the compost facility where customers, such as homeowners, greenhouses, landscapers, and nurseries, can come to pick up the compost. The third strategy is to use a compost broker. This may result in lower revenue but removes the administrative burden of compost marketing. About 25 percent of composters employ a broker. It should be noted that revenue from compost sales will not cover production costs but should offset market development costs. Sale prices range from $5 to $60 per ton.

COSTS

Costs associated with in-vessel composting systems vary considerably from facility to facility. Site specific factors and the many configurations and equipment choices make it difficult to provide general costs for this technology. Annual operation and maintenance costs as low as $61 and as high as $534 per dry ton of biosolids composted were cited in a 1989 survey (Alpert *et. al.*, 1989.) A more recent assessment estimated costs for composting between $100 and $280 per dry ton of biosolids processed. In-vessel systems generally represent the high end of such cost ranges (O'Dette, 1996.)

The following items must be considered when estimate costs for a specific in-vessel composting facility:

- Land acquisition.
- Equipment procurement, including the composting vessel, loading equipment, conveyors, air supply equipment, temperature monitoring equipment, and odor control equipment.
- Operation and maintenance labor.
- Additives, such as bulking agents, to be used in the specific vessel selected.
- Energy (electricity and fuel for equipment).
- Water and wastewater treatment.
- Equipment maintenance and upkeep.
- Product distribution expenses and marketing revenues.
- Regulatory compliance expenses such as permitting, product analysis, process monitoring, record keeping and reporting.
- Preprocessing equipment for bulking agent.

REFERENCES

Other Related Fact Sheets

Odor Management in Biosolids Management
EPA 832-F-00-067
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Centrifugal Dewatering/Thickening
EPA 832-F-00-053
September 2000

Belt Filter Press
EPA 832-F-00-057
September 2000

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm.

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ADDITIONAL INFORMATION

City of Davenport
Scott Plett
P.O. Box 2707
Davenport, Iowa 52808

E&A Environmental Consultants
Eliot Epstein
95 Washington Street; Suite 218
Canton, Massachusetts 02071

NC Division of Pollution Prevention
Craig Coker
1639 Mail Service Center
Raleigh, North Carolina 27699-1639

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For more information contact:

Municipal Technology Branch
U.S. EPA
Mail Code 4204
1200 Pennsylvania Ave, N.W.
Washington, D.C. 20460

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