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Technology Transfer

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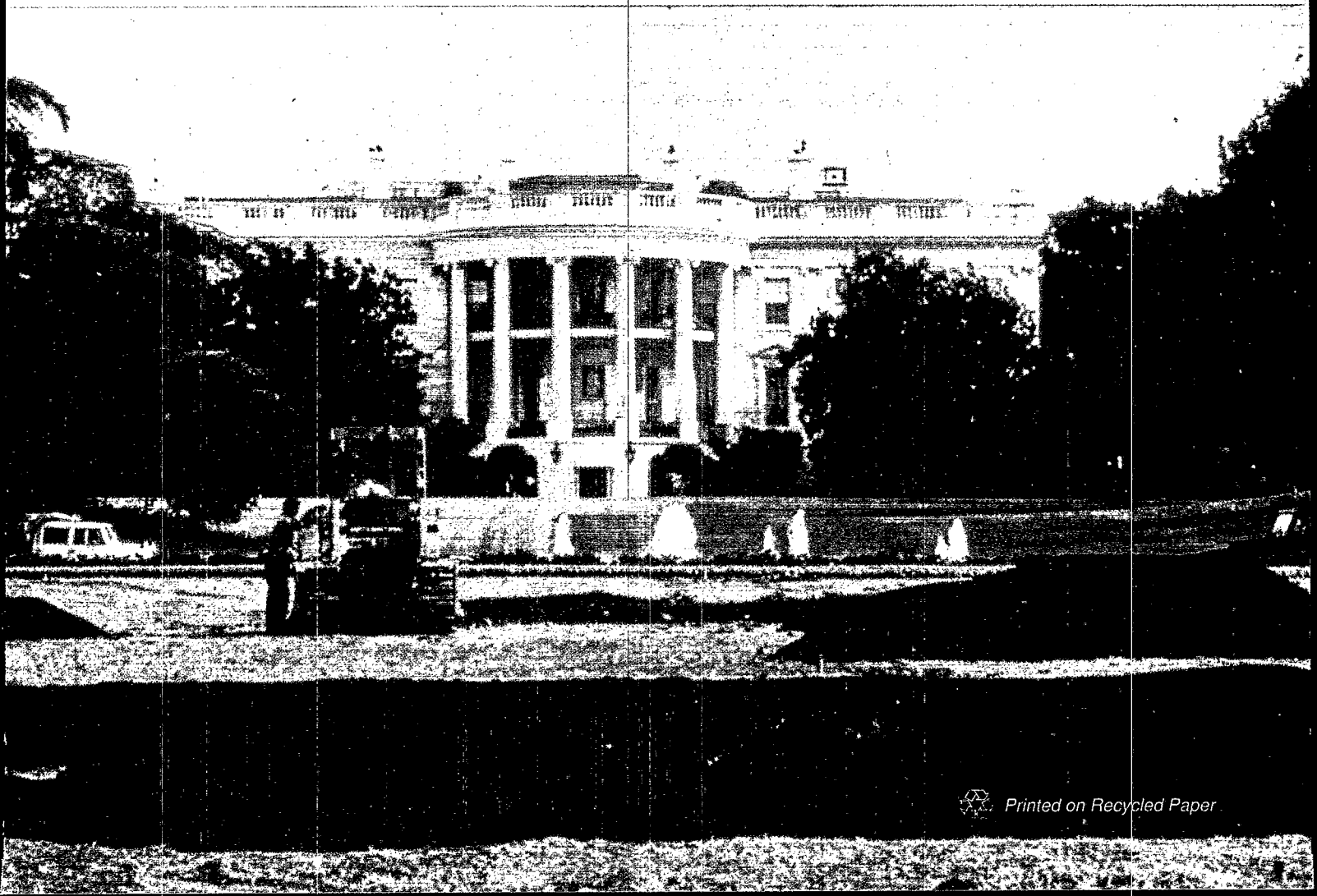
Environmental Regulations and Technology

Control of Pathogens in Municipal Wastewater Sludge



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Environmental Regulations and Technology

Control of Pathogens in Municipal Wastewater Sludge For Land Application Under 40 CFR Part 257

This guidance was prepared by
Pathogen Equivalency Committee
U.S. Environmental Protection Agency
Cincinnati OH 45268

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This document was produced by the U.S. Environmental Protection Agency's Pathogen Equivalency Committee, consisting of Robert Bastian, Joseph Farrell, Larry Fradkin, Walter Jakubowski, James E. Smith, Jr., and Albert Venosa. Jan Connery and Lynn Knight of Eastern Research Group, Inc., in Arlington, Massachusetts, prepared the document under the committee's direction and from information and data supplied by the committee. The document was reviewed by several Regional and State Sludge Coordinators, and by Alfred Dufour (EPA Environmental Monitoring Systems Laboratory), Vincent Olivieri (Johns Hopkins University), Charles Sorber (University of Pittsburgh), and Cris Morrison (EPA Office of Water Enforcement and Permits). The contributions of all these individuals are gratefully acknowledged.

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COVER PHOTOGRAPH: Application of Liquid Sludge to Forest Land in Washington

Contents

Abbreviations and Acronyms

°C	degrees Centigrade
CFR	Code of Federal Regulations
cm	centimeters
D&M	distribution and marketing
EPA	U.S. Environmental Protection Agency
°F	degrees Fahrenheit
FR	*Federal Register*
g	gram(s)
gpm	gallons per minute
kg	kilogram(s)
l	liter
log	logarithm
m^3	cubic meter(s)
mg	milligram(s)
ml	milliliter(s)
MPN	most probable number
no.	number
NP/LSA	no primary/long sludge age
OWEP	EPA Office of Water Enforcement and Permits
OWRS	EPA Office of Water Regulations and Standards
PEC	EPA Pathogen Equivalency Committee
PFRP	process to further reduce pathogens
PFU	plaque-forming unit
psig	pounds per square inch gauge
PSRP	process to significantly reduce pathogens
RSC	EPA Regional Sludge Coordinator
SOUR	specific oxygen uptake rate
spp.	species
SSC	State Sludge Coordinator
TSS	total suspended solids
VS	volatile solids

1. Introduction

Municipal wastewater sludge – a by-product of wastewater treatment (Figure 1-1) – is used as a soil conditioner and partial fertilizer in the United States and many other countries. It is applied to agricultural land (pastures and cropland), disturbed areas (mined lands, construction sites, etc.), plant nurseries, forests, recreational areas (parks, golf courses, etc.), cemeteries, highway and airport runway medians, and home gardens (see photos, pp. 3-4). Certain wastewater treatment plants own or have access to land dedicated solely to repeated sludge applications. The U.S. Environmental Protection Agency (EPA), the primary Federal agency responsible for sludge management, encourages the beneficial use of sludge wherever environmentally feasible (Figure 1-2). Some estimates suggest that as much as 40% of the municipal sludge generated in the United States is currently applied to land (EPA, 1984b).

Wastewater sludge has beneficial plant nutrients and soil conditioning properties; however, it may also contain bacteria, viruses, protozoa, parasites, and other microorganisms that can cause disease. All land application of sludge creates a potential for human exposure to these organisms through direct and indirect contact. To protect human health from these organisms and from the chemical contaminants that some sludges contain, many countries now regulate land application of sludge.

In 1976, Congress passed the Resource Conservation and Recovery Act (RCRA), which required the EPA to regulate the application of solid waste to land. Under RCRA, wastewater sludge was defined as a solid waste to be regulated under the Act. In addition, Section 405 of the Clean Water Act (CWA) was amended in 1977 to require EPA to issue regulations for controlling all sewage sludge use and disposal practices. Under the joint authority of RCRA and CWA, EPA promulgated regulations governing the application of wastewater sludge to land under 40 CFR Part 257 in September 1979. These regulations were designed to protect public health by mandating treatment of sludge to reduce its disease-bearing potential, and by controlling land use following sludge application.

This document describes the Federal requirements promulgated in 1979 for reducing pathogens in wastewater sludge and provides guidance in determining whether individual sludge treatment systems provide the level of pathogen and vector control mandated for particular land application settings. It is intended for:

- Owners and operators of municipal wastewater treatment works.
- Developers or marketers of sludge treatment processes.
- Groups that distribute and market sludge products.
- Individuals involved in applying sludge to land.
- Regional, state, and local government officials responsible for implementing and enforcing the land application regulations. These include the Regional and State Sludge Coordinators and permit writers.
- Consultants to these groups.
- Anyone interested in understanding the Federal pathogen and vector control requirements placed on land application practices.

Chapter 2 of this document discusses why pathogen control is necessary, and Chapter 3 summarizes the pertinent Federal regulations. These regulations list specific sludge treatment technologies that provide acceptable levels of pathogen reduction as specified under 40 CFR Part 257. Chapters 4 and 5 describe these listed sludge treatment systems. Sludge from other treatment technologies can be applied to land if the alternative treatment provides a level of pathogen control equivalent to that provided by the listed technologies. A special EPA committee – the Pathogen Equivalency Committee – was established to review alternative sludge treatment technologies and to provide technical guidance on whether they are equivalent. Chapter 6 of this document describes how the Committee evaluates equivalency and what information is needed for an equivalency evaluation. It lists processes that the Committee has determined to be equivalent. This chapter is particularly useful for developers and operators of sludge treatment systems and for those involved in the permitting process at the regional and state level.

Many municipal wastewater sludges also contain heavy metals and other toxic organic chemicals that may pose public health and environmental concerns if applied to land in excessive amounts. In addition to controlling pathogens, the Federal regulations under 40 CFR Part 257 limit the loading rates of some chemicals of concern when the sludge is applied to land. This document focuses on pathogen control and does not discuss the requirements for controlling chemicals. Information concerning sludge chemical limitations under 40 CFR Part 257 can be found in EPA (1984b), state regulatory programs, EPA (1983), and EPA (1989a).

The EPA is currently revising its technical regulations for all municipal sludge use and disposal practices, including land application and distribution and marketing (D&M) of sludge products. The new regulations covering land application and D&M were proposed on February 6, 1989 (EPA, 1989b) and are currently scheduled for final promulgation by October 1991. Land application will continue to be governed by the 40 CFR Part 257 regulations, as described in this document, until the final 503 regulations are promulgated. The pathogen control provisions of the proposed new regulations incorporate

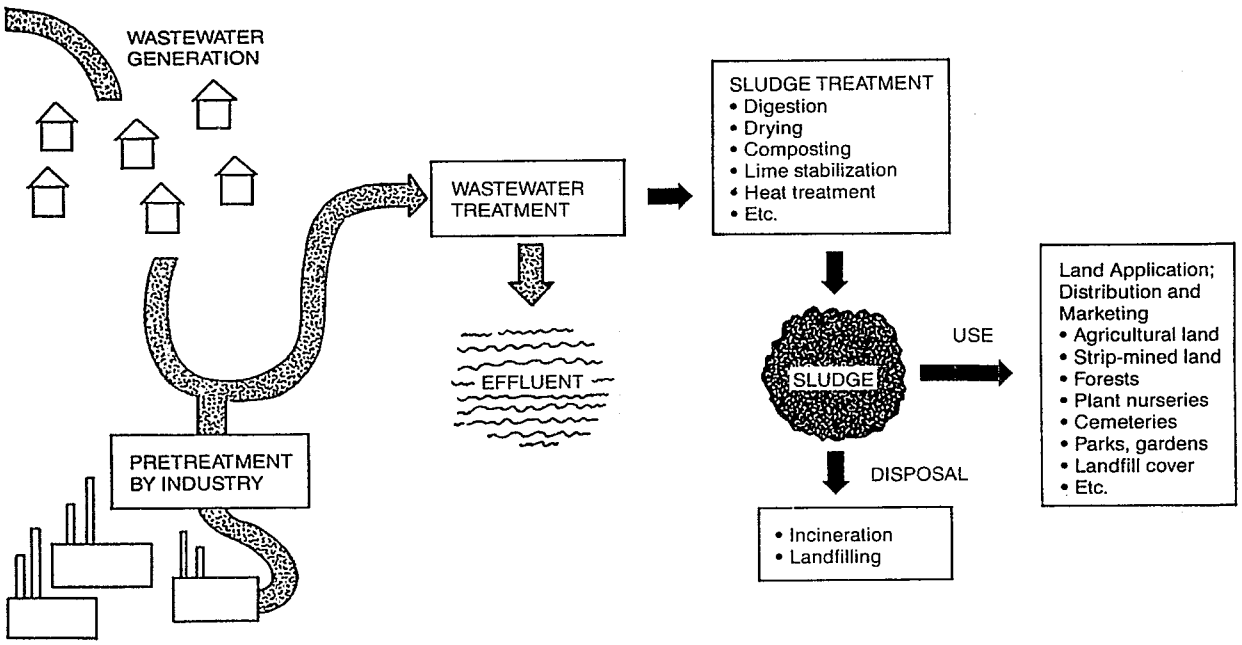


Figure 1-1. Generation, treatment, use, and disposal of municipal wastewater sludge.

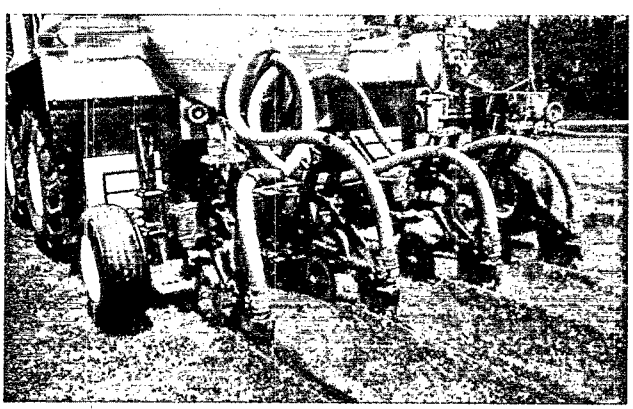
much of the knowledge and experience that has been gained in implementing 40 CFR Part 257. Thus there are many similarities between the pathogen control provisions of the proposed regulations and the guidance provided in Chapter 6 of this document. It is likely that the information provided in this document will be of value in implementing the final 503 regulations. Chapter 7 discusses the relationship between the proposed 503 regulations and the guidance in this document.

The U.S. Environmental Protection Agency (EPA) will actively promote those municipal sludge management practices that provide for the beneficial use of sludge while maintaining or improving environmental quality and protecting public health. To implement this policy, EPA will continue to issue regulations that protect public health and other environmental values. The Agency will require states to establish and maintain programs to ensure that local governments utilize sludge management techniques that are consistent with Federal and state regulations and guidelines. Local communities will remain responsible for choosing among alternative programs; for planning, constructing, and operating facilities to meet their needs; and for ensuring the continuing availability of adequate and acceptable disposal or use capacity.

Figure 1-2. EPA policy on sludge management. Source: EPA, 1984a.

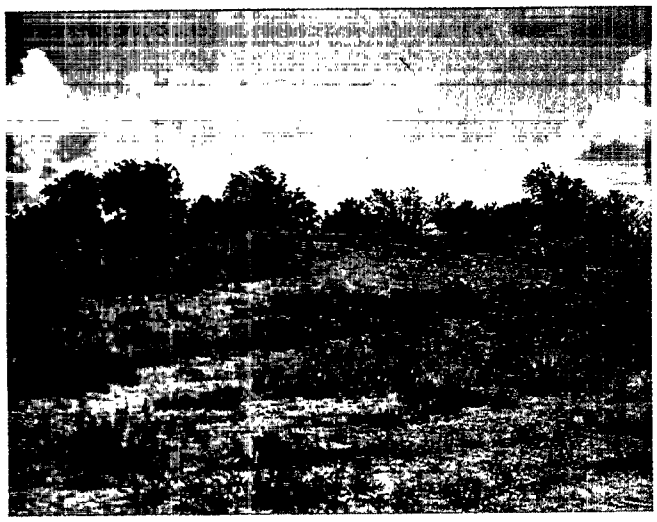
Highway median strip in Illinois after land application of dried sludge. (Photo credit: Metropolitan Water Reclamation District of Greater Chicago)

Flower beds amended with sludge compost in Tulsa, Oklahoma. (Photo credit: City of Tulsa, Oklahoma)



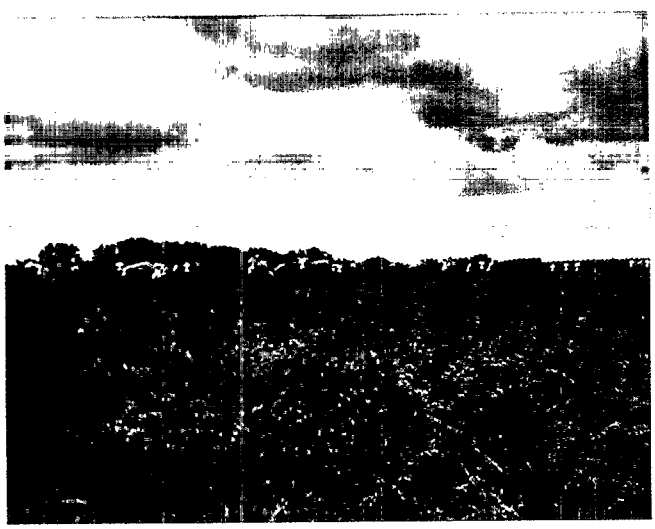
Injection of liquid sludge into sod.

Oat field showing sludge-treated (right) and untreated (left) areas. (Photo credit: City of Tulsa, Oklahoma)

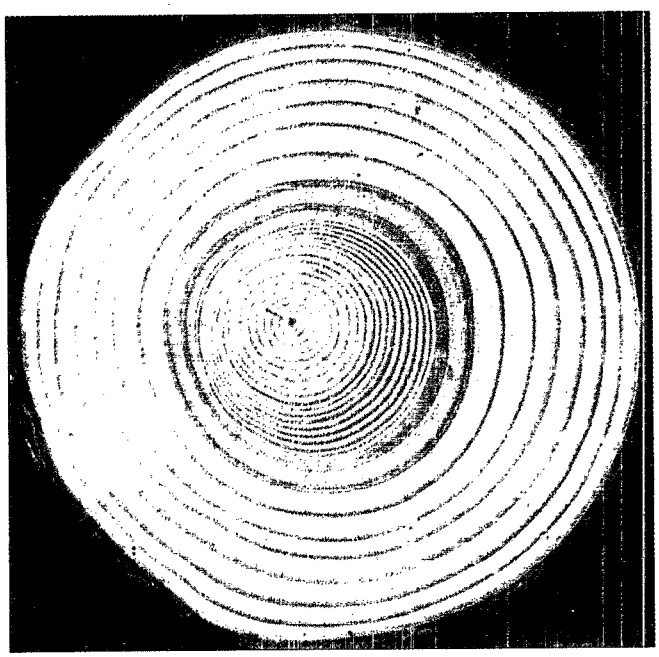


Mine spoil land before sludge treatment. Note sparse, weedy growth incapable of supporting grazing cattle. (Photo credit: City of Tulsa, Oklahoma)

Corn grown on sludge-treated soil (right) and untreated soil (left).



Mine spoil land after sludge treatment. Note lush vegetative cover on reclaimed soil which will support grazing. (Photo credit: City of Tulsa, Oklahoma)



Cross-section of a Douglas fir tree showing how sludge application increases tree growth. Note increased size of outer rings indicating more rapid growth after sludge application. (Photo credit: Metro Silvigrow)

2. Pathogen Reduction

Pathogens of Concern

Municipal wastewater generally contains four major types of human pathogenic (disease-causing) organisms: bacteria, viruses, protozoa, and helminths (parasitic worms) (EPA, 1985). The actual species and density of pathogens present in wastewater from a particular municipality (and the sludge produced when treating the wastewater) depend on the health status of the local community and may vary substantially at different times. The level of pathogens present in wastewater sludge also depends on the reductions achieved by the wastewater and sludge treatment processes.

The pathogens in wastewater are primarily associated with insoluble solids. Primary wastewater treatment processes concentrate these solids into sludge, so untreated or raw primary sludges have higher densities of pathogens than the incoming wastewater. Biological wastewater treatment processes such as lagoons, trickling filters, and activated sludge treatment may substantially reduce the number of pathogens in the wastewater (EPA, 1989c). Nevertheless, the resulting biological sludges may still contain sufficient levels of pathogens to pose a public health concern. Table 2-1 lists some principal pathogens of concern that may be present in wastewater and/or sludge (also see photos, pp. 9-10). These organisms and other pathogens can cause infection or disease if humans and animals are exposed to infectious doses. Infectious doses vary for each pathogen and each host.

Routes of Exposure

When sludge is applied to land, humans and animals can be exposed to sludge pathogens by coming into direct contact with the sludge, or indirectly by consuming drinking water or food that has been contaminated by sludge pathogens. Insects, rodents, and even farm workers can contribute to these exposure routes by transporting sludge and sludge pathogens away from the land application site. Potential routes of exposure include:

Direct Contact

- Inadvertent contact with sludge while applying it to land.
- Walking through an application area – such as a forest, reclamation area, or farmland – shortly after the sludge application.
- Handling soil and raw produce from home gardens where sludge has been applied.
- Inhaling microbes that become airborne (via aerosols, dust, etc.) during and/or after sludge spreading.
- Contact with dust raised by strong winds or by plowing or cultivating the soil.

Indirect Contact

- Consumption of pathogen-contaminated crops grown on sludge-amended soil or of other food products that have been contaminated by contact with these crops.
- Consumption of pathogen-contaminated milk or other food products from animals grazing in pastures or fed crops grown on sludge-amended fields.
- Ingestion of untreated drinking water or recreational waters contaminated by runoff from nearby land application sites or by organisms from sludge migrating into groundwater aquifers.
- Consumption of inadequately or uncooked pathogen-contaminated fish from water contaminated by runoff from a nearby sludge application site.
- Contact with sludge or pathogens that have been transported away from the land application site by rodents, insects, or other vectors.

The potential for exposure diminishes over time as environmental conditions such as heat, sunlight, desiccation, and other microorganisms destroy pathogens that may be present in land-applied sludge. Table 2-2 summarizes the survival rates of four types of pathogenic organisms on soil and plants. Because protozoan cysts are rapidly killed by environmental factors, the public health threat from protozoa in land-applied sludge is minimal. Bacteria, viruses, and helminths (particularly helminth eggs which are the hardiest part of the helminth life cycle) are of much greater concern. Some bacteria are unique among sludge pathogens in their ability to regrow. Even very small populations of certain bacteria can rapidly proliferate under the right conditions. Viruses, helminths, and protozoa cannot regrow outside their specific host organism(s). Once reduced by treatment, their populations stay reduced.

Approaches to Pathogen Reduction

The pathogens in sludge can be reduced to below detectable levels by adequately treating sludge prior to land application. Chapters 4 and 5 of this document describe treatment processes that have been shown to be effective in controlling pathogens and in controlling the attractiveness of sludge to disease vectors (insects and rodents). These processes use a variety of approaches to reduce pathogens and alter the sludge so that it becomes a less effective medium for microbial growth and vector attraction (Table 2-3). They vary significantly in their effectiveness. For example, some processes may completely destroy bacteria and viruses but have little or no effect on helminth eggs. The effectiveness of a particular process can also vary depending on the conditions under which it is operated. For example, the length of time and the temperature to which sludge is

Table 2-1. Principal Pathogens of Concern in Municipal Wastewater and Sludge

Organism	Disease/Symptoms
Bacteria	
Salmonella spp.	Salmonellosis (food poisoning), typhoid fever
Shigella spp.	Bacillary dysentery
Yersinia spp.	Acute gastroenteritis (including diarrhea, abdominal pain)
Vibrio cholerae	Cholera
Campylobacter jejuni	Gastroenteritis
Escherichia coli (pathogenic strains)	Gastroenteritis
Viruses	
Poliovirus	Poliomyelitis
Coxsackievirus	Meningitis, pneumonia, hepatitis, fever, common colds, etc.
Echovirus	Meningitis, paralysis, encephalitis, fever, common colds, diarrhea, etc.
Hepatitis A virus	Infectious hepatitis
Rotavirus	Acute gastroenteritis with severe diarrhea
Norwalk agents	Epidemic gastroenteritis with severe diarrhea
Reovirus	Respiratory infections, gastroenteritis
Protozoa	
Cryptosporidium	Gastroenteritis
Entamoeba histolytica	Acute enteritis
Giardia lamblia	Giardiasis (including diarrhea, abdominal cramps, weight loss)
Balantidium coli	Diarrhea and dysentery
Toxoplasma gondii	Toxoplasmosis
Helminth Worms	
Ascaris lumbricoides	Digestive and nutritional disturbances, abdominal pain, vomiting, restlessness
Ascaris suum	May produce symptoms such as coughing, chest pain, and fever
Trichuris trichiura	Abdominal pain, diarrhea, anemia, weight loss
Toxocara canis	Fever, abdominal discomfort, muscle aches, neurological symptoms
Taenia saginata	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances
Taenia solium	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances
Necator americanus	Hookworm disease
Hymenolepis nana	Taeniasis

Source: EPA (1985) and EPA (1989c).

Table 2-2. Survival Times of Pathogens in Soil and on Plant Surfaces[a]

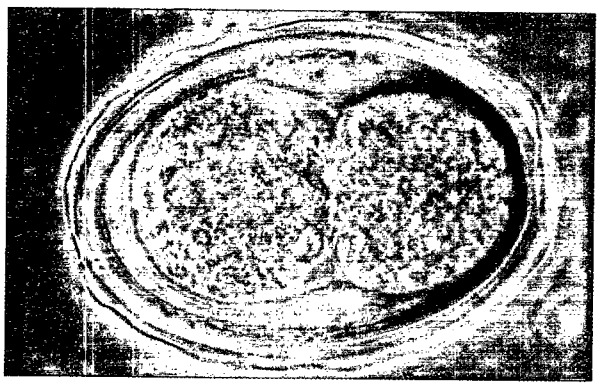
Pathogen	Soil		Plants	
	Absolute Maximum[a]	Common Maximum	Absolute Maximum[b]	Common Maximum
Bacteria	1 year	2 months	6 months	1 month
Viruses	6 months	3 months	2 months	1 month
Protozoan cysts[c]	10 days	2 days	5 days	2 days
Helminth ova	7 years	2 years	5 months	1 month

Source: EPA, 1985.

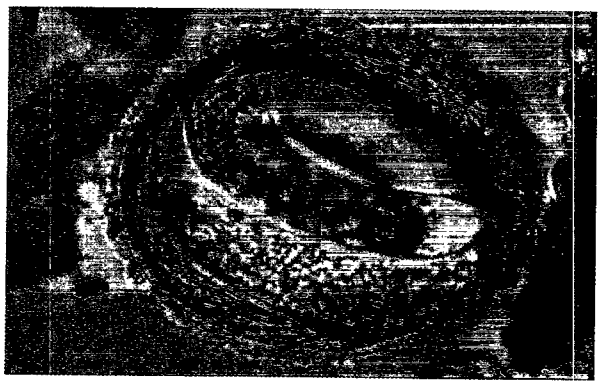
[a] For survival rates, see Sorber and Moore (1986).

[b] Greater survival time is possible under unusual conditions such as consistently low temperatures or highly sheltered conditions (e.g., helminth ova below the soil in fallow fields).

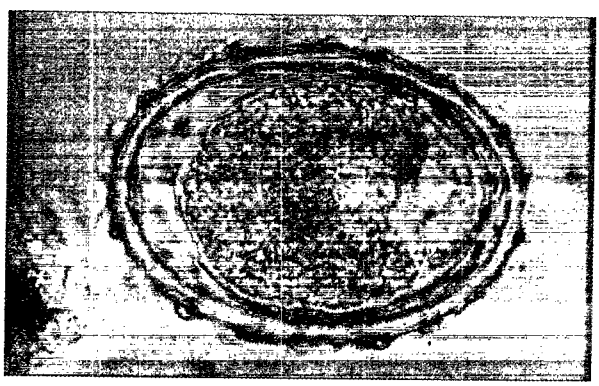
[c] Little, if any, data are available on the survival times of *Giardia* cysts and *Cryptosporidium* oocysts.



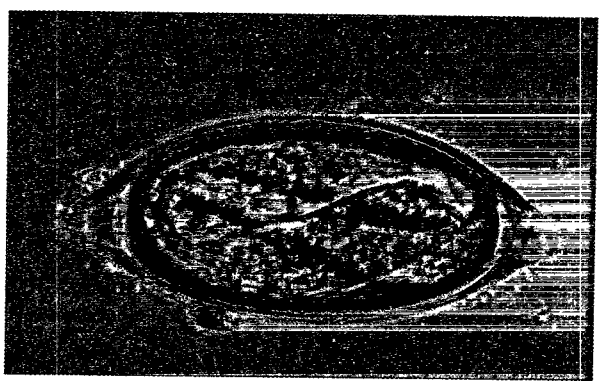
Ascaris lumbricoides **(or var. *suum*) eggs, 65 µm, from anaerobically digested sludge. Two-cell stage.**



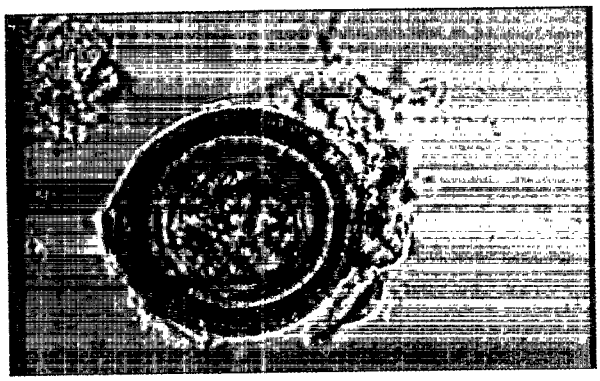
Toxocara **sp. egg, 90 µm, from raw sewage.**



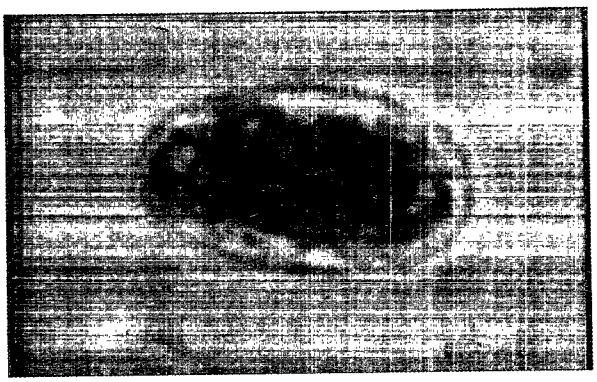
Ascaris lumbricoides **(or var. *suum*) eggs, 65 µm, from anaerobically digested sludge.**



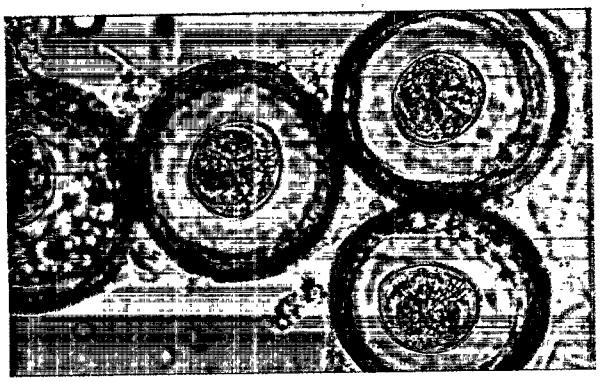
Trichuris **sp. egg, 80 µm, from anaerobically digested sludge.**



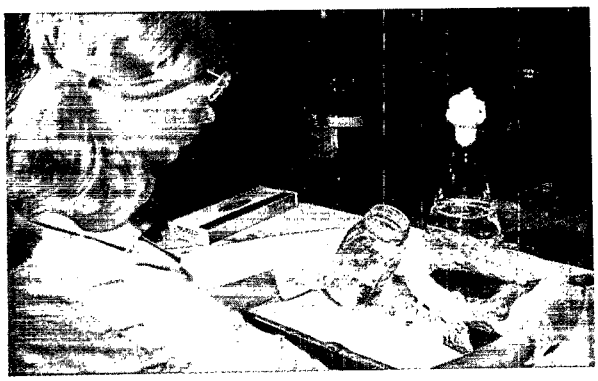
Taenia sp. ovum



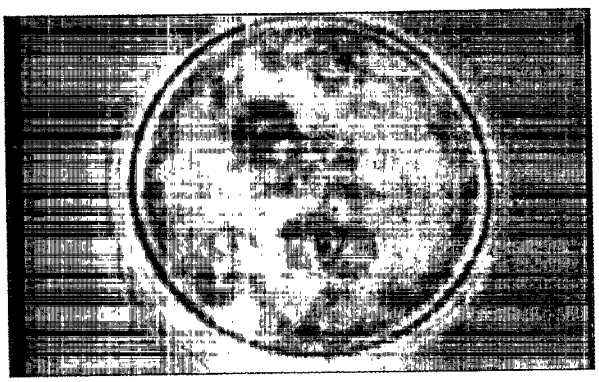
Giardia lamblia cyst, 10 µm, from raw sewage.



Hymenolepsis (tapeworm) ova.



Preparing compost for pathogen analysis. (Photo credit: U.S. Department of Agriculture, Beltsville, Maryland)



Entamoeba coli cyst, 15 µm, from anaerobically digested sludge.

heated is critical to the effectiveness of heat-based treatment processes.

The 40 CFR Part 257 sludge regulations protect human health by requiring sludge to be treated prior to land application. The regulations specify the treatment processes and operating conditions that will ensure adequate pathogen and vector attraction reduction. The sludge regulations also protect human health by controlling exposure to land-applied sludge until sufficient time has elapsed for environmental factors to reduce pathogens to a reasonable level for the intended land use.

Measuring Pathogen Reduction

Microbiological analysis of sludge is often an important means of determining the effectiveness of a sludge treatment process in reducing pathogens (see photo above). Methods have not yet been developed to detect all pathogens that may occur in sludge, and it would be impractical to run all the tests that do exist. Instead, only a

Table 2-3. General Approaches to Controlling Pathogens in Wastewater Sludge

Approach	Effectiveness	Process Examples[a]
Kill pathogens with high temperatures (temperatures may be generated by chemical, biological, or physical processes).	Depends on time and temperature. Sufficient temperatures maintained for sufficiently long time periods can destroy bacteria, viruses, protozoan cysts, and helminth ova. Helminth ova are the most resistant to high temperatures.	• Composting (uses biological processes to generate heat). • Heat drying and heat treatment (use physical processes to generate heat, e.g., hot gases, heat exchangers). • Pasteurization (physical heat, e.g., hot gases, heat exchangers). • Aerobic digestion (biological heat).[b] • Anaerobic digestion (biological heat).[b]
Kill pathogens with radiation.	Depends on dose. Sufficient doses can destroy bacteria, viruses, protozoan cysts, and helminth ova. Viruses are most resistant to radiation.	• Gamma and high-energy electron beam radiation.
Kill pathogens using chemical disinfectants.	Substantially reduces bacteria, viruses, and vector attraction. Probably reduces protozoan cysts. Does not effectively reduce helminth ova unless combined with heat.	• Superchlorination. • Lime stabilization.
Inhibit pathogen growth by reducing the sludge's volatile organic content (the microbial food source).	Reduces viruses and bacteria. Reduces vector attraction as long as the sludge remains dry. Probably effective in destroying protozoan cysts. Does not effectively reduce helminth ova unless combined with other processes such as high temperature.	• Aerobic digestion. • Anaerobic digestion. • Composting.[b]
Inhibit pathogen growth by removing moisture from the sludge.	Reduces viruses and bacteria. Reduces vector attraction as long as the sludge remains dry. Probably effective in destroying protozoan cysts. Does not effectively reduce helminth ova unless combined with other processes such as high temperature.	• Air drying.

[a] See Chapters 4 and 5 for a description of these processes. Many processes use more than one approach to reduce pathogens.
[b] Effectiveness depends on design and operating conditions.

few representative pathogens and nonpathogenic indicator organisms are generally included in the analysis.

For routine testing of municipal wastewater sludge, fecal coliform and fecal streptococci bacteria are commonly used as indicators of the potential presence of pathogens in wastewater sludges. These bacteria are abundant in human feces and therefore are always present in untreated sewage sludges. They are easily and inexpensively measured. Although fecal coliforms and fecal streptococci themselves are usually not harmful to humans, their presence indicates the presence of fecal waste which may contain pathogens.

When more specific information is needed on the levels of pathogens in sludge, it is generally considered acceptable to test for one representative of each of the three more common types of organisms of concern – bacteria, viruses, and helminth ova. Deciding which organism to test for depends on several factors: the effectiveness of the treatment process, the hardiness of the organism relative to other organisms of that type, the likelihood that it was present in the raw sludge, the availability and reliability of the testing procedures, and cost.

Testing requirements should be based on a knowledge of how the operating conditions of the sludge treatment process affect pathogen survival. For example, heating sludge to particular temperatures (e.g., 45° to 50°C [113° to 122°F]) for a sufficient period of time will destroy all viruses and bacteria, but may not adequately reduce helminth ova. In this case, fecal indicator tests could be used to confirm the level of reduction of bacteria and viruses; however, helminth ova would have to be tested for directly.

The processes described in Chapters 4 and 5 of this document are assumed to consistently provide an adequate level of pathogen control for particular land application settings. No testing is necessary for sludges produced by these processes if they are properly operated.

3. Current Federal Regulations

The current Federal regulations governing land application of municipal wastewater sludge were created under the joint authority of the Resource Conservation and Recovery Act (RCRA) and the Clean Water Act (CWA). They are contained in 40 CFR Part 257 - *Criteria for Classification of Solid Waste Disposal Facilities and Practices* (see also 44 *Federal Register* 53460, September 13, 1979; and 44 FR 54708, September 21, 1979). (Land application of sludge is considered a form of solid waste disposal and is subject to these Criteria.) These regulations protect public health by requiring sludge management practices that eliminate or minimize human contact with sludge contaminants. The 40 CFR 257 regulations concerning pathogen control are described below. They apply to all municipal sludge destined for land application, including sludge products that are distributed and marketed.

Sludge Treatment

Part 257.3-6 (*Disease*) of the Criteria requires that wastewater sludge be treated before it is applied to land to reduce pathogen levels and to reduce the attractiveness of sludge to disease vectors (rodents, flies, mosquitoes, etc., that could transmit disease to humans). Appendix II of Part 257 lists specific treatment processes and operating conditions that must be followed to ensure appropriate pathogen and vector attraction reduction. These processes are divided into two categories based on the level of pathogen control they can achieve: "Processes to Significantly Reduce Pathogens" (PSRPs), which reduce pathogens to a level comparable to that achieved by a well-run anaerobic digester, and "Processes to Further Reduce Pathogens" (PFRPs), which reduce pathogens to below detectable levels. The listings of PSRPs and PFRPs found in Appendix II of Part 257 are reproduced in Tables 3-1 and 3-2. Chapters 4 and 5 of this document describe these processes. Sludge treated by any of these processes can be applied to land, as long as the management practices detailed in Part 257.3-6 of the regulation are followed (Figure 3-1).

Requirements for Sites with PSRP-treated Sludges

Since PSRPs reduce but do not eliminate pathogens, PSRP-treated sludge still has a potential to transmit disease. To protect public health, the regulations minimize the potential for direct and indirect exposure to sludge by controlling public access, the growing of human food crops, and grazing by dairy or meat-producing livestock at sites where PSRP-treated sludges have been applied. Specifically, public access to the site must be restricted for at least 12 months following application of the PSRP-treated sludge, and grazing by animals whose products are consumed by humans must be prevented for at least 1 month following application. The 1-month waiting period is based on the typical survival rate of viruses and bacteria on vegetation. Crops for direct human consumption (i.e., crops such as fruits and vegetables that will not be processed to minimize the presence of pathogens prior to distribution to the consumer) can be grown on the land only if the edible portion of the crop will not come in contact with the sludge, or if the growing of these crops is delayed by at least 18 months from the time of sludge application. The 18-month waiting period is based on the anticipated survival of the hardiest pathogens, helminth eggs.

Requirements for Sites with PFRP-treated Sludges

PFRPs reduce pathogens to below detectable levels, therefore there are no pathogen-related restrictions to managing sites where PFRP-treated sludges have been applied. Treatment by a PFRP is important to protect human health (1) in situations where access to the land application site or food products from that site cannot be controlled, such as with home gardens, and (2) at sites where crops for direct human consumption will be grown within 18 months of application *and* there may be contact between the sludge and the edible portion of the crop.

Requirements for Application of Septic Tank Pumpings

The 40 CFR 257 regulations treat septic tank pumpings in a slightly different manner from sludge (Figure 3-2). Septic tank pumpings can be applied without any form of treatment if (1) public access to the site is restricted for at least 12 months; (2) grazing by animals whose products are consumed by humans is prevented for at least 1 month; and (3) crops for direct human consumption are not grown within 18 months of application. If crops for direct human consumption will be grown within 18 months of application, septic tank pumpings must be treated prior to application. PFRP treatment is required if the septic tank pumpings might contact the edible portion of the crop. If no such contact will occur, PSRP-treated pumpings can be applied if public access to the site is restricted for at least 12 months and grazing by animals whose products are consumed by humans is prevented for at least 1 month following application. The requirements for septic tank pumpings are more relaxed because the pumpings have generally been stored for long periods of time (which reduces pathogen levels) and land applications of septic tank pumpings are most often small-scale operations in rural settings.

Protecting Surface Waters

Humans may be exposed to sludge pathogens in drinking water or recreational waters if land application practices result in the contamination of surface waters. (If sludge application is properly managed, this route of exposure is unlikely.) To protect surface waters, Subpart 257.3-3

Table 3-1. Regulatory Definition of Processes to Significantly Reduce Pathogens (PSRPs)[a,b]

Aerobic Digestion: The process is conducted by agitating sludge with air or oxygen to maintain aerobic conditions at residence times ranging from 60 days at 15°C to 40 days at 20°C, with a volatile solids reduction of at least 38%.
Air Drying: Liquid sludge is allowed to drain and/or dry on underdrained sand beds, or on paved or unpaved basins in which the sludge depth is a maximum of 9 inches. A minimum of 3 months is needed, for 2 months of which temperatures average on a daily basis above 0°C.
Anaerobic Digestion: The process is conducted in the absence of air at residence times ranging from 60 days at 20°C to 15 days at 35°C to 55°C, with a volatile solids reduction of at least 38%.
Composting: Using the within-vessel, static aerated pile, or windrow composting methods, the solid waste is maintained at minimum operating conditions of 40°C for 5 days. For 4 hours during this period the temperature exceeds 55°C.
Lime Stabilization: Sufficient lime is added to produce a pH of 12 after 2 hours of contact.
Other Methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

Source: 40 CFR 257, Appendix II.
[a]15°C = 59°F, 20°C = 68°F, 0°C = 32°F, 35°C = 95°F, 55°C = 131°F, 40°C = 104°F.
[b]9 inches = 23 centimeters.

Table 3-2. Regulatory Definition of Processes to Further Reduce Pathogens (PFRPs)[a]

Composting: Using the within-vessel composting method, the solid waste is maintained at operating conditions of 55°C or greater for 3 days. Using the static aerated pile composting method, the solid waste is maintained at operating conditions of 55°C or greater for 3 days. Using the windrow composting method, the solid waste attains a temperature of 55°C or greater for at least 15 days during the composting period. Also, during the high temperature period, there will be a minimum of five turnings of the windrow.
Heat Drying: Dewatered sludge cake is dried by direct or indirect contact with hot gases, and moisture content is reduced to 10% or lower. Sludge particles reach temperatures well in excess of 80°C, or the wet bulb temperature of the gas stream in contact with the sludge at the point where it leaves the dryer is in excess of 80°C.
Heat Treatment: Liquid sludge is heated to temperatures of 180°C for 30 minutes.
Thermophilic Aerobic Digestion: Liquid sludge is agitated with air or oxygen to maintain aerobic conditions at residence times of 10 days at 55°C to 60°C, with a volatile solids reduction of at least 38%.
Other Methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods. Any of the processes listed below, if added to a PSRP, further reduce pathogens.
Beta Ray Irradiation: Sludge is irradiated with beta rays from an accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20°C).
Gamma Ray Irradiation: Sludge is irradiated with gamma rays from certain isotopes, such as ^{60}Cobalt and ^{137}Cesium, at dosages of at least 1.0 megarad at room temperature (ca. 20°C).
Pasteurization: Sludge is maintained for at least 30 minutes at a minimum temperature of 70°C.
Other Methods: Other methods or operating conditions may be acceptable if pathogens are reduced to an extent equivalent to the reduction achieved by any of the above add-on methods.

Source: 40 CFR 257, Appendix II.
[a]55°C = 131°F, 80°C = 176°F, 180°C = 356°F, 60°C = 143°F, 70°C = 158°F.

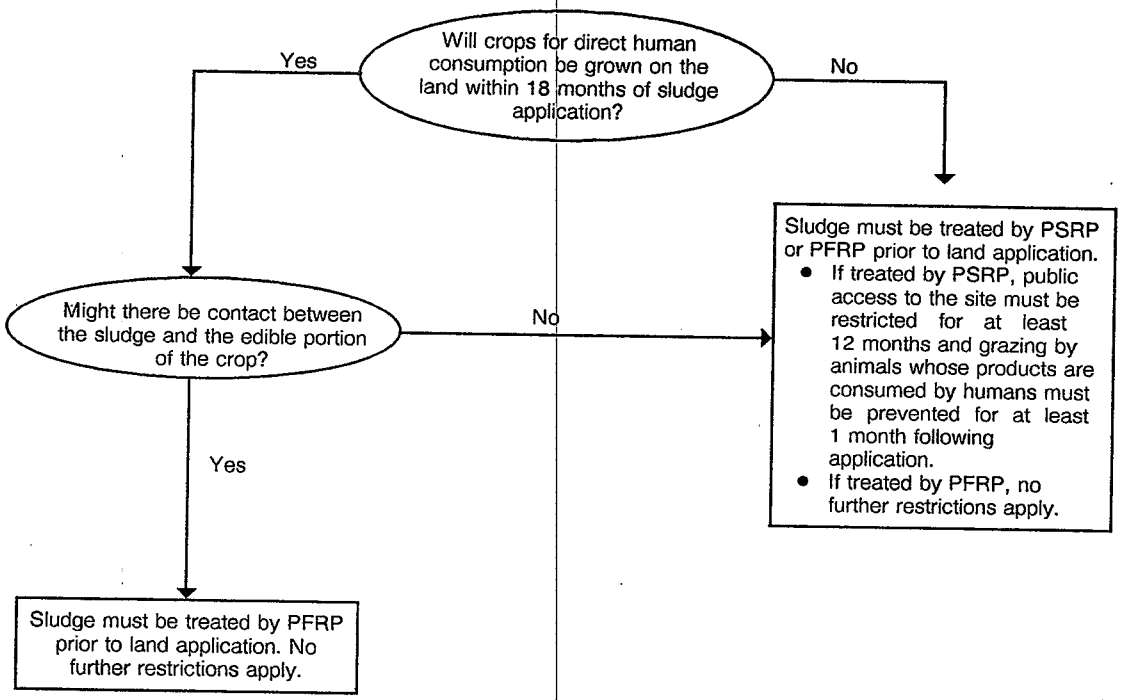


Figure 3-1. Federal requirements for management of municipal wastewater sludge applied to land.

(*Surface Water*) of the Criteria prohibits discharges (e.g., runoff) from solid waste disposal facilities (including land application sites) that would violate Sections 402, 404, and 208 of the Clean Water Act. Sections 402 and 404 do not concern land application sites. (Section 402 establishes the National Pollutant Discharge Elimination System to regulate point sources, and Section 404 controls the discharge of dredged and fill material.) Until the passage of the Water Act Amendments in 1987, Section 208 of the Clean Water Act was the primary mechanism for controlling nonpoint source pollution such as runoff. Under this section, state and local officials have established comprehensive plans for water quality control in areas with substantial water quality problems. Land application is prohibited if seepage or runoff from the site would violate these plans.

Section 319 of the 1987 Water Act Amendments instituted new requirements for control of nonpoint source pollution. Under this section, each state is required to submit to EPA a report identifying state waters that are not expected to meet water quality standards because of nonpoint source pollution. Each state must also submit to EPA and implement a management program for controlling nonpoint pollution. A sludge land application site could be affected by this program if it is identified as contributing to nonpoint source pollution of state waters.

Finally, Subpart 257.3-1 (*Floodplains*) of the Clean Water Act prohibits the application of sludge to land in floodplains where there is the potential of washout that may pose a hazard to human health, wildlife, or land or water resources.

Protecting Ground Waters

Another potential route of human exposure to pathogens is by drinking water from contaminated groundwater aquifers. The Criteria protect groundwater resources by requiring that land application sites may not "contaminate an underground drinking water source beyond the solid waste boundary or beyond an alternative boundary" (Subpart 257.3-4 [*Ground Water*]). In the case of sludge application, "boundary" means the outermost perimeter of the area where sludge has been applied. An alternative boundary may be established by a state with an EPA-approved solid waste management plan only if it does not result in contamination of ground water that may be needed or used for human consumption. The hydrogeologic characteristics of the site and surrounding land must be considered when setting an alternative boundary. If sludge application is properly managed, the potential for groundwater contamination is minimal.

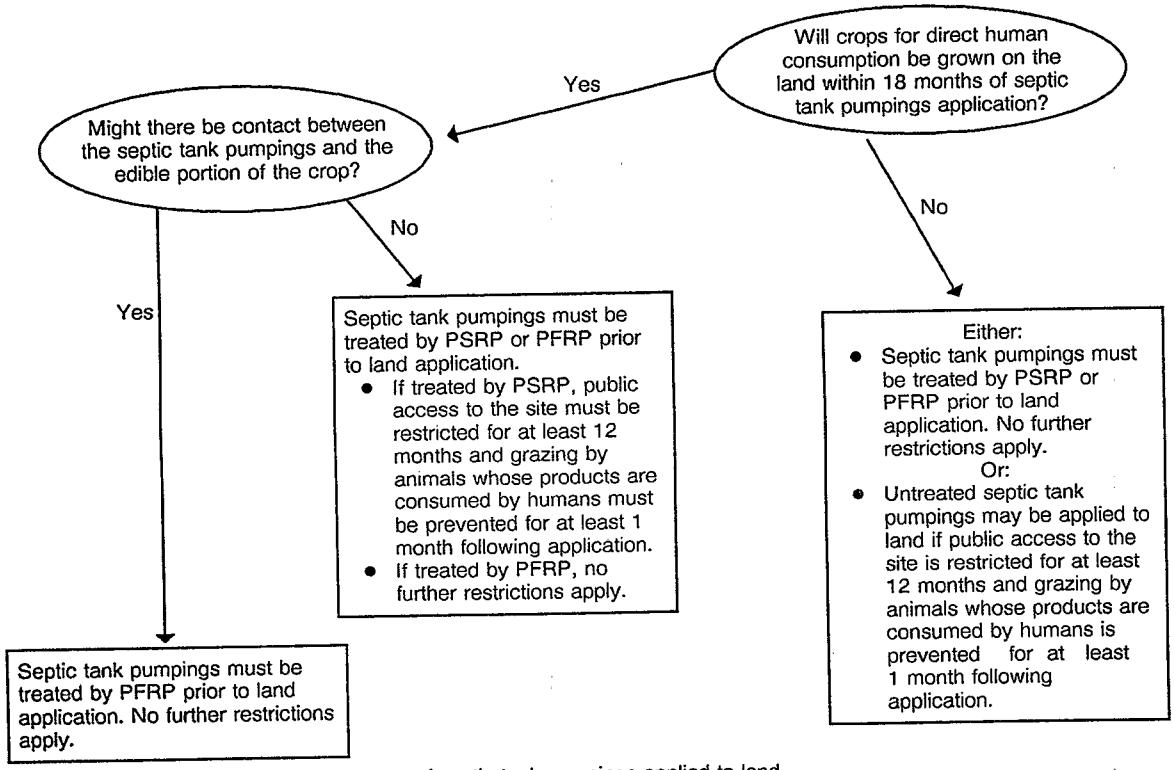


Figure 3-2. Federal requirements for management of septic tank pumpings applied to land.

4. Processes to Significantly Reduce Pathogens

Processes to Significantly Reduce Pathogens (PSRPs) are broadly defined as sludge treatment technologies that reduce both pathogen levels and the attractiveness of sludge to disease vectors. These processes effectively reduce (but do not eliminate) pathogenic viruses and bacteria; however, they are less effective in reducing helminth eggs. This level of pathogen reduction is the minimum requirement if sludge is to be applied to land. It is acceptable only if the risk of human exposure is minimized by restricting public access to the application site, restricting grazing, and delaying the cultivation of human food crops whose edible parts may contact the sludge (see Chapter 3). Processes identified in the Federal regulations (40 CFR 257, Appendix II) as PSRPs are aerobic digestion, anaerobic digestion, lime stabilization, air drying, and composting (Table 3-1).

Aerobic Digestion

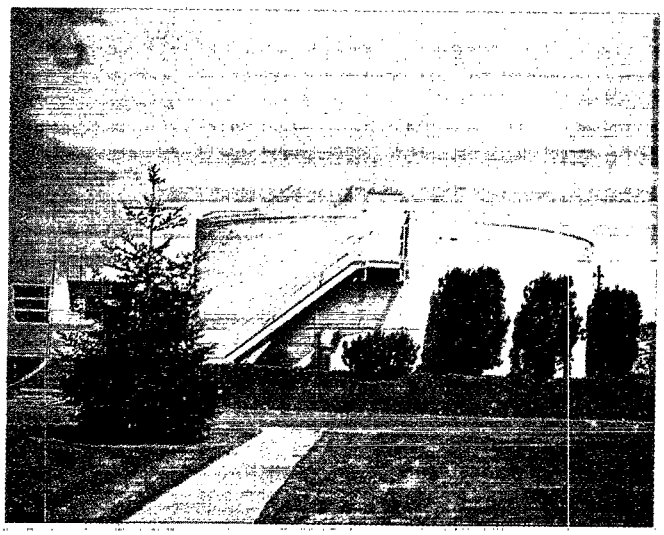
In aerobic digestion, sludge is biochemically oxidized in an open or enclosed aerobic tank (see photo, this page, and Figure 4-1). To supply the sludge with adequate oxygen, either the contents of the reactor are agitated by means of a mixer that introduces air into the sludge, or air is forcibly injected. The aerobic bacteria decompose much of the volatile organic matter in the sludge, converting it primarily to water, nitrate nitrogen, and carbon dioxide.

Aerobic digestion systems operate in either a batch or continuous mode. In the batch mode, the tank is filled with untreated sludge and aeration is maintained for 2 or 3 weeks. Then aeration is discontinued, the stabilized solids are allowed to settle, and the settled solids and clarified liquid are separated. The process is begun again with a small amount of stabilized sludge from the previous batch, to supply the necessary microbial population, and a new batch of untreated sludge. In the continuous mode, untreated sludge is fed into the digester once a day or more frequently while thickened, stabilized solids and clarified liquids are removed.

The regulation defines aerobic digestion as a process **"conducted by agitating sludge with air or oxygen to maintain aerobic conditions at residence times ranging from 60 days at 15°C (59°F) to 40 days at 20°C (68°F), with a volatile solids reduction of at least 38%."** The regulation does not differentiate between semi-batch or continuous operation so either method is acceptable.

These operational requirements are based on a calculation of residence time. The appropriate method for calculating residence time depends on the type of operation of the digestion process.

- **Continuous-mode, No Supernatant Removal.** For continuous-mode digesters where no supernatant is removed, nominal residence times may be calculated by dividing liquid volume in the digester by the average daily flow *in or out* of the digester.
- **Continuous-mode, Supernatant Removal.** In systems where supernatant is removed from the digester and recycled, the volume of sludge product can be much less than the input volume of sludge. For these systems, the flow rate of the sludge product *out of* the digester is used to calculate residence time.
- **Continuous-mode Feeding, Batch Removal of Product.** For some aerobic digesters, the digester is initially filled above the diffusers with treated effluent and sludge is wasted daily into the digester. Periodically, aeration is stopped to allow for settling and removal of supernatant. As supernatant is removed, the solids content in the digester gradually increases. The process is complete when either settling and supernatant removal is inadequate to provide space for the daily sludge wasting requirement or sufficient time for digestion has been provided. The batch of digested sludge then is removed and the process begins again. If the mass of sludge solids introduced daily has been constant, nominal residence time is one-half the total time from initial change to final withdrawal of the digested sludge.
- **Batch-mode.** In the batch mode, the residence time is the actual time of the batch.
- **Other.** Frequently digesters are operated in unique ways that do not fall into the above categories.



Digester in Vancouver, Washington.

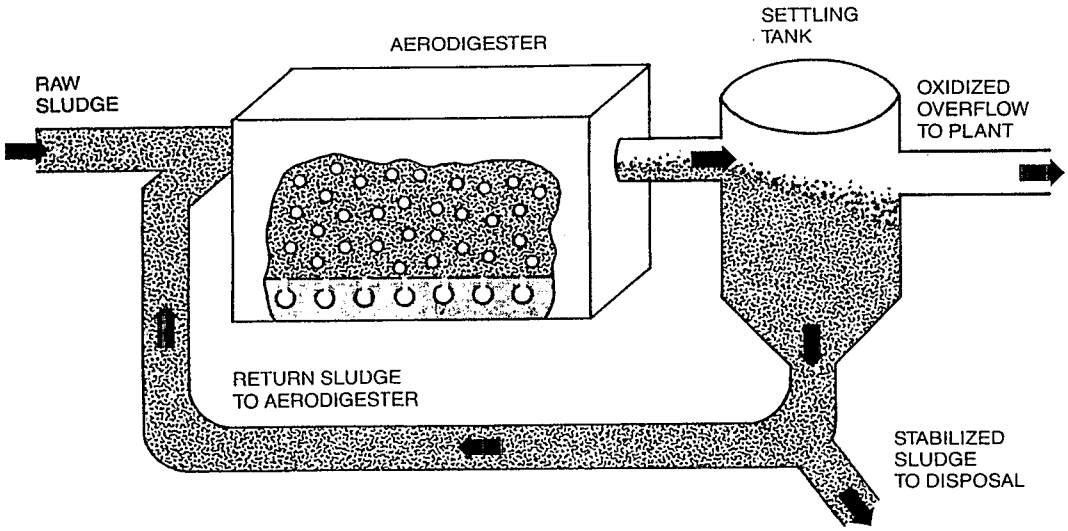


Figure 4-1. Aerobic digestion.

Appendix A provides information that should be helpful in developing a calculation procedure for these cases.

Aerobic digestion carried out according to the conditions specified in the regulation typically reduces viral and bacterial pathogens by 90% (i.e, by a factor of ten, or 1 log to the base 10). Helminth ova are reduced to varying degrees depending on the hardiness of the individual species. Aerobic digestion typically reduces the volatile solids content (the microbial food source) of the sludge by 40 to 50% depending on the conditions maintained in the system.

Anaerobic Digestion

Anaerobic digestion is a biological process similar to aerobic digestion; however, the bacteria it uses to decompose the organic matter thrive under conditions devoid of oxygen. Anaerobic digestion takes place in an enclosed reactor (Figure 4-2) that may or may not be heated. The volatile solids are degraded by anaerobic bacteria and converted primarily to methane and carbon dioxide. Since the biological activity consumes most of the elements needed for further bacterial growth, the volatile solids in the sludge are stabilized.

Most anaerobic digestion systems are classified as either standard-rate or high-rate systems. Standard-rate systems take place in a simple storage tank. Mixing, which accelerates the biological process, is not provided beyond the natural mixing that occurs from sludge gases rising to the surface. Sometimes heat is supplied to increase biological activity.

High-rate systems provide mixing by mechanical means and are heated, with temperatures being carefully controlled. In addition, high-rate systems may use pre-thickened sludge that is introduced into the tank at a uniform rate in order to maintain constant conditions in the reactor. Conditions in the high-rate system foster more efficient sludge digestion.

The regulations define anaerobic digestion as a process that is **"conducted in the absence of air at residence times ranging from 60 days at 20°C (68°F) to 15 days at 35° to 55°C (95° to 131°F), with a volatile solids reduction of at least 38%."** (See previous section on *Aerobic Digestion* for calculation of residence times.) Under heated conditions at mesophilic (32° to 38°C [90° to 100°F]) or thermophilic (48° to 55°C [118° to 131°F]) temperatures, at least 15 days of digestion are required, assuming the digester is well mixed. Thermophilic digestion proceeds at a faster rate than mesophilic digestion, but is more susceptible to upsets, particularly due to temperature fluctuations. A residence time of 15 days is required to compensate for potential instability in the process.

Anaerobic digestion conducted under the conditions outlined above typically reduces viral and bacterial pathogens by approximately 90% (i.e., 10-fold) or more. Helminth ova are not substantially reduced under mesophilic conditions, and may not be completely reduced at thermophilic conditions less than 53°C (127°F). (At the time the regulation was written, there was substantial doubt that anaerobic digesters could be operated reliably at temperatures above 49°C [120°F] [Garber, 1982], so anaerobic digestion was not included in the list of PFRPs.) Anaerobic digestion reduces volatile solids by 35 to 60% depending on the nature of the sludge and the operating conditions of the digestion system. If conditions specified by the regulation are maintained, the process typically reduces volatile solids by at least 38%.

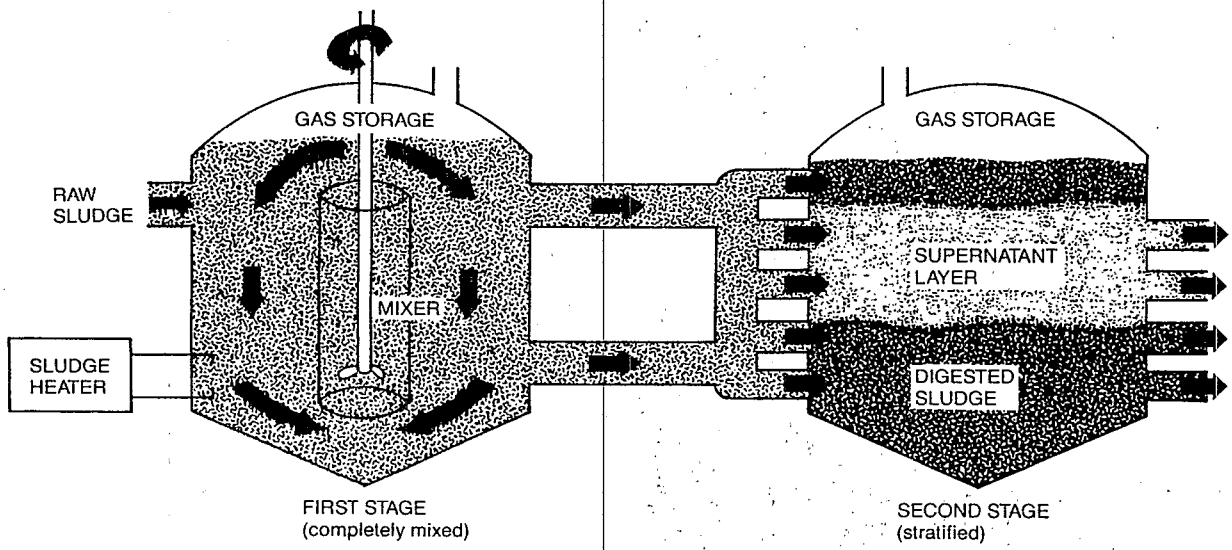


Figure 4-2. Two-stage anaerobic digestion.

Lime Stabilization

Lime stabilization is a simple process in which lime is added to sludge in sufficient quantities to produce a pH of 12 after 2 hours of contact. Lime may be introduced to liquid sludge in a mixing tank. Alternatively, lime may be mixed with dewatered sludge provided mixing is intimate and the cake is moist enough to allow aqueous contact between sludge and lime.

The effectiveness of lime stabilization in controlling pathogens depends on maintaining the pH at levels that destroy microorganisms and inhibit growth should contamination occur after treatment. Lime stabilization does not reduce volatile solids. Therefore, if the pH drops below 11, regrowth of pathogenic bacteria can resume.

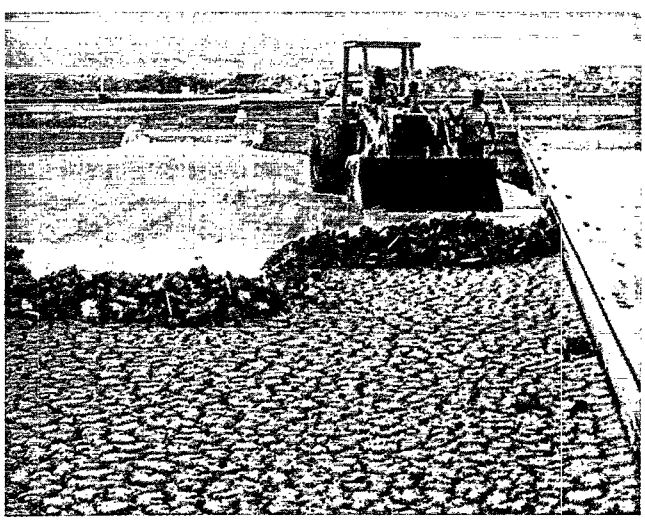
Lime stabilization reduces pathogenic bacteria and viruses by well over 90 percent (i.e., 10-fold). Some helminth ova will be destroyed, but certain species are not substantially affected by this process.

Air Drying

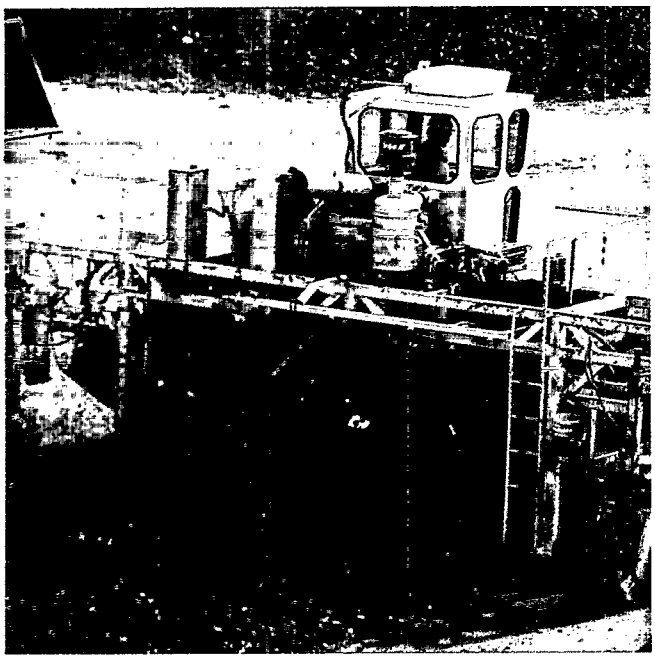
The air drying process is simply a system that allows the sludge to dry naturally in the open air (see photo, this page). Wet sludge is generally applied to sand beds, paved or unpaved basins to a depth of approximately 23 cm (9 inches). (Sludge depths in basins often exceed 23 cm.) The sludge is left to drain and dry by evaporation. While sand beds have an underlying drainage system, basins frequently involve some type of mechanical mixing or turning. The effectiveness of the drying process depends very much on the local climate.

For air drying to be considered a PSRP, **the regulations require at least 3 months of air drying on under-drained sand beds or paved or unpaved basins with sludge piled to a maximum depth of 23 cm. (After drying, the sludge layer will be much thinner.) For at least 2 of the 3 months (60 of the 90 days, which do not have to be consecutive), the temperature must average above 0°C (32°F) on a daily basis.** During the 2 months that temperatures are above 0°C (32°F), the sludge beds must be exposed (i.e., not covered with snow). The sludge should be at least partially digested before air drying.

Air drying, under the conditions specified above, will reduce the density of pathogenic bacteria and viruses by



Sludge drying operation. (Photo credit: East Bay Municipal Utility District)



Compost mixing equipment turns over a windrow of compost for solar drying prior to screening. (Photo credit: East Bay Municipal Utility District)

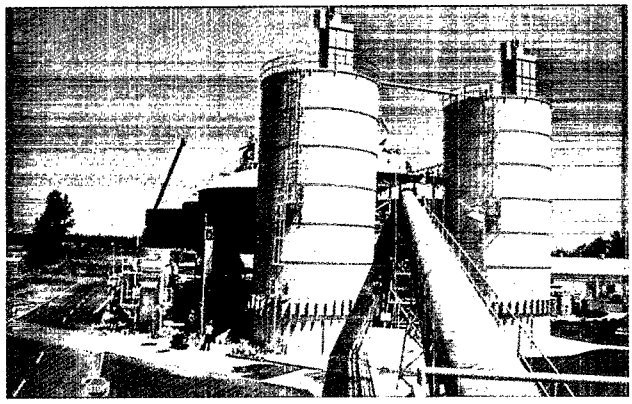
approximately 90% (10-fold). Helminth ova are reduced, but some species remain substantially unaffected.

Composting

There are several different methods of composting sewage sludge. Three of the most common methods are windrow, static aerated pile, and within-vessel composting. Composting may be a PSRP or a PFRP depending on the time and temperature variables of the operation. This section discusses the process conditions necessary for PSRPs. Those relevant to PFRPs are discussed in Chapter 5.

Sludge composting involves the aerobic decomposition of organic constituents at elevated temperatures (ideally under thermophilic conditions) (see photo, bottom of p. 18). The end result of composting is a highly stable, humus-like material. Although there are several composting techniques, the basic process is similar. Bulking agents such as wood chips, bark, sawdust, straw, rice hulls, or even finished compost are added to the sludge to absorb moisture, increase porosity, and add a source of carbon. This mixture is stored in windrows, large aerated piles or reactor vessels for a period of time sufficient to allow substantial decomposition of organic matter (generally 3 to 4 weeks). The biological activity in the mixture creates temperatures ranging from 55° to 65°C (131° to 149°F). Pathogen destruction depends on time and temperature variables. Bulking agents may or may not be screened from the completed compost and recycled (see photo, p. 19).

The windrow composting process involves stacking the mixture to be composted in long windrows. The piles are



Taulman Weiss in-vessel composting facility in Portland, Oregon.

frequently aerated by mechanical turning and mixing (e.g., using a front-end loader) to keep an adequate supply of oxygen available to the microorganisms (see photo, top left, p. 18). The active windrows are typically placed in the open air except in areas with heavy rainfall.

The aerated static pile method uses a forced-air supply instead of mechanical aeration (see Figure 4-3). The sludge/bulking agent mixture is placed on top of either (1) a fixed underlying forced aeration system, or (2) a system involving perforated piping laid on the compost pad surface and covered with a bed of bulking agent. These systems are used to blow air into or withdraw it from the pile. The entire pile is covered with a layer of cured compost for insulation and containment of noxious odors.

Compost operator measures compost pile temperatures as part of process monitoring. (Photo credit: East Bay Municipal Utility District, Oakland, California)

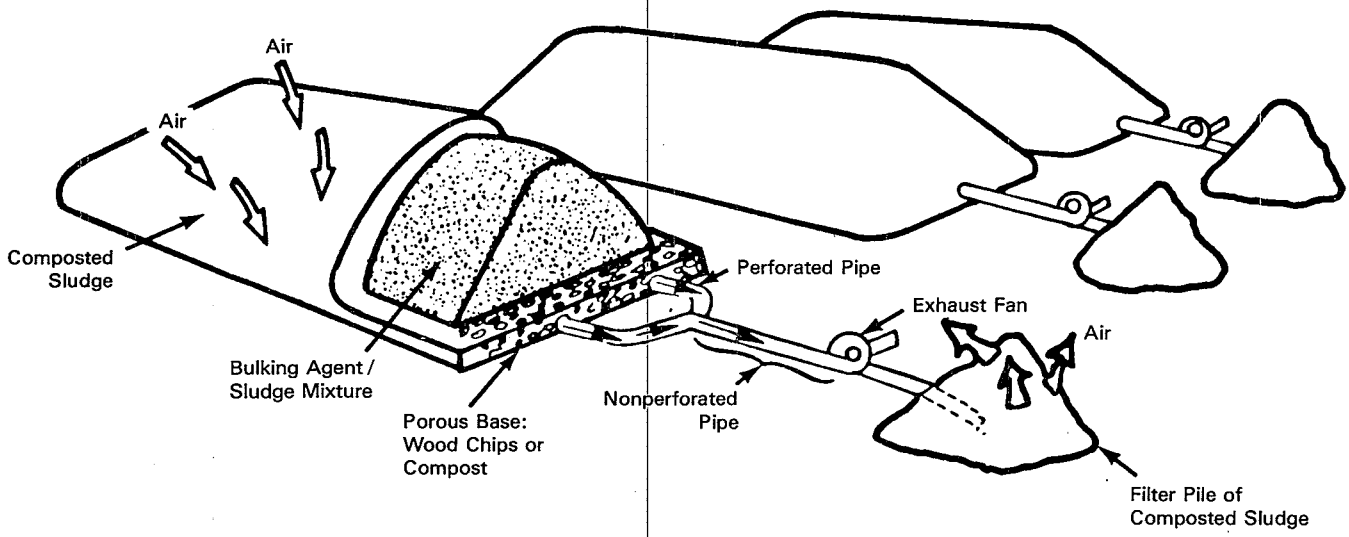


Figure 4-3. Aerated static pile composting.

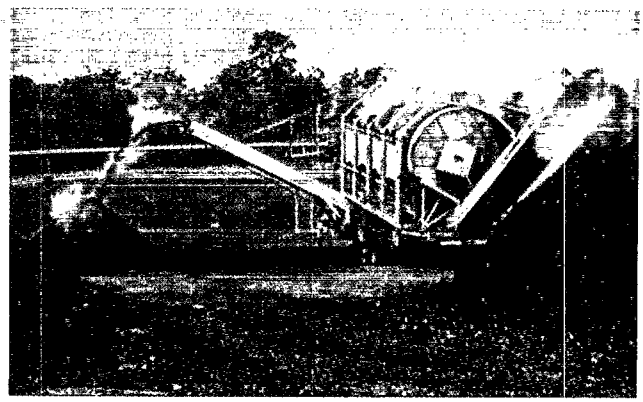
Within-vessel composting systems vary greatly in terms of design; however, the basis for each technique is similar. The process takes place in a reactor vessel where operating conditions can be carefully controlled (see photo, top right, p. 18). The compost mixture is actively aerated and may or may not be actively mixed within the container by mechanical means, depending on the type of in-vessel composting system involved.

The regulatory requirements for composting to be classified as a PSRP are as follows: **"Using the within-vessel, static aerated pile, or windrow composting methods, the solid waste is maintained at minimum operating conditions of 40°C (104°F) for 5 days. For 4 hours during this period the temperature exceeds 55°C (131°F)."**

Composting under the conditions outlined above will reduce pathogenic viruses and bacteria at least 90% (ten-fold). Helminth ova populations are diminished but not necessarily eliminated. However, composting as defined above does not satisfactorily reduce vector attraction. Five days of composting is not adequate to fully stabilize the sludge. Fortunately, composting facilities generally compost actively for longer periods of time (14 to 21 days for within-vessel; 21 days or more for static aerated pile; and 30 days or more for windrow) and frequently allow the compost to "mature" in storage piles for at least several weeks. The PSRP definition of composting will likely be changed in the new regulation.

Other Methods

The regulation states that other methods or operating conditions may be acceptable as PSRPs if they reduce pathogens and vector attraction of the waste to an extent equivalent to the reduction achieved by any of the listed PSRPs operated under the conditions specified (Table 3-1).



Composted sludge is screened to remove the bulking agent prior to land application.

EPA has established a Pathogen Equivalency Committee to provide guidance on whether other methods or operating conditions are equivalent. To obtain guidance on whether a proposed process is equivalent to PSRPs, data demonstrating the required reductions in pathogens and vector attraction should be submitted to EPA's Pathogen Equivalency Committee for review. The specifics of the review process are discussed in Chapter 6. Processes that have been found by the Committee to be equivalent to PSRP are described in Table 6-1.

5. Processes to Further Reduce Pathogens

Processes to Further Reduce Pathogens (PFRPs) effectively reduce bacteria, viruses, and helminth ova in sludge to below detectable levels. The risk of infection from PFRP sludge products is therefore minimal. This level of sludge treatment is required when the land application process (and thus the potential for human exposure) cannot be adequately controlled. PFRPs listed in the regulation are composting, heat drying, heat treatment, and thermophilic aerobic digestion (Table 3-2). If added to a PSRP, the following processes are considered to be a PFRP: high-energy irradiation, gamma ray irradiation, and pasteurization.

Composting

As described in Chapter 4, composting reduces sludge, which has generally been mixed with a bulking agent, to a humus-like material through biological degradation. There are three commonly used methods of composting: windrow, aerated static pile, and within-vessel.

To be considered a PFRP, the composting operation must meet certain operating conditions. These regulatory conditions are specific to the method of composting practiced. **For windrow composting, the sludge must attain a temperature of 55°C (131°F) or greater for at least 15 days during the composting period. In addition, during the high-temperature period, the windrow must be turned at least five times. If the static aerated pile or the within-vessel method is used, the sludge must be maintained at operating temperatures of 55°C (131°F) or greater for 3 days.**

In general, within-vessel composting attains the required conditions in approximately 10 days. The static-pile and windrow processes generally require about 3 weeks. If the conditions specified by the regulation are met, all pathogenic viruses, bacteria, and parasites will be reduced to below detectable levels. However, composting under these conditions may not adequately reduce vector attraction. Longer composting periods may be necessary to fully stabilize the sludge (see *Composting*, in Chapter 4). The PFRP definition of composting will likely be modified in the new regulations.

Heat Drying

Heat drying is used to reduce both pathogens and the water content of sludge. The regulation defines heat drying as a process in which **"dewatered sludge cake is dried by direct or indirect contact with hot gases, and moisture content is reduced to 10% or lower. Sludge particles reach temperatures well in excess of 80°C (176°F), or the wet bulb temperature of the gas stream in contact with the sludge at the point where it leaves the dryer is in excess of 80°C (176°F)."** Properly conducted heat drying will reduce pathogenic viruses, bacteria, and helminth ova to below detectable levels.

Four processes are commonly used for heat drying of municipal sludge: flash dryers, spray dryers, rotary dryers, and the Carver-Greenfield process (EPA, 1979). Flash dryers were the most common heat drying process installed at wastewater treatment plants, but current practice favors rotary dryers.

Flash Dryers

Flash dryers pulverize sludge in the presence of hot gases. The process is based on exposing fine sludge particles to turbulent hot gases long enough to attain at least a 90% solids content. A schematic of a cage mill flash drying process is provided in Figure 5-1. In this system, wet sludge and recycled dried sludge are combined to create a free-flowing mixture. This mixture and hot gases are then fed into a cage mill; drawn through a duct where the particles lose most of their moisture; and finally drawn through a cyclone, where the sludge particles are separated from the gases.

Spray Dryers

A spray dryer uses centrifugal force to atomize liquid sludge into a spray that is directed into a drying chamber. The drying chamber contains hot gases that rapidly dry the sludge mist. Some spray drying systems use a nozzle to atomize sludge.

Rotary Dryers

Rotary dryers function as horizontal cylindrical kilns. The drum rotates and may have plows or louvers that mechanically mix the sludge as the drum turns. There are many different rotary kiln designs, utilizing either direct heating or indirect heating systems. Direct heating designs maintain contact between the sludge and the hot gases. Indirect heating separates the two with steel shells.

Carver-Greenfield Process

The Carver-Greenfield process is a patented multiple-effect evaporative oil-immersion process in which dewatered sludge is mixed with a light oil. This mixture is pumped through a series of evaporators which selectively remove the water in sludge, which has a lower boiling point than the oil carrier. The oil maintains the mixture in a liquid state, even when virtually all the water has been removed. The product of this process, an oil and dry sludge mixture, is put through a centrifuge to separate the dry sludge solids from the oil. The recovered oil can be reused in the process.

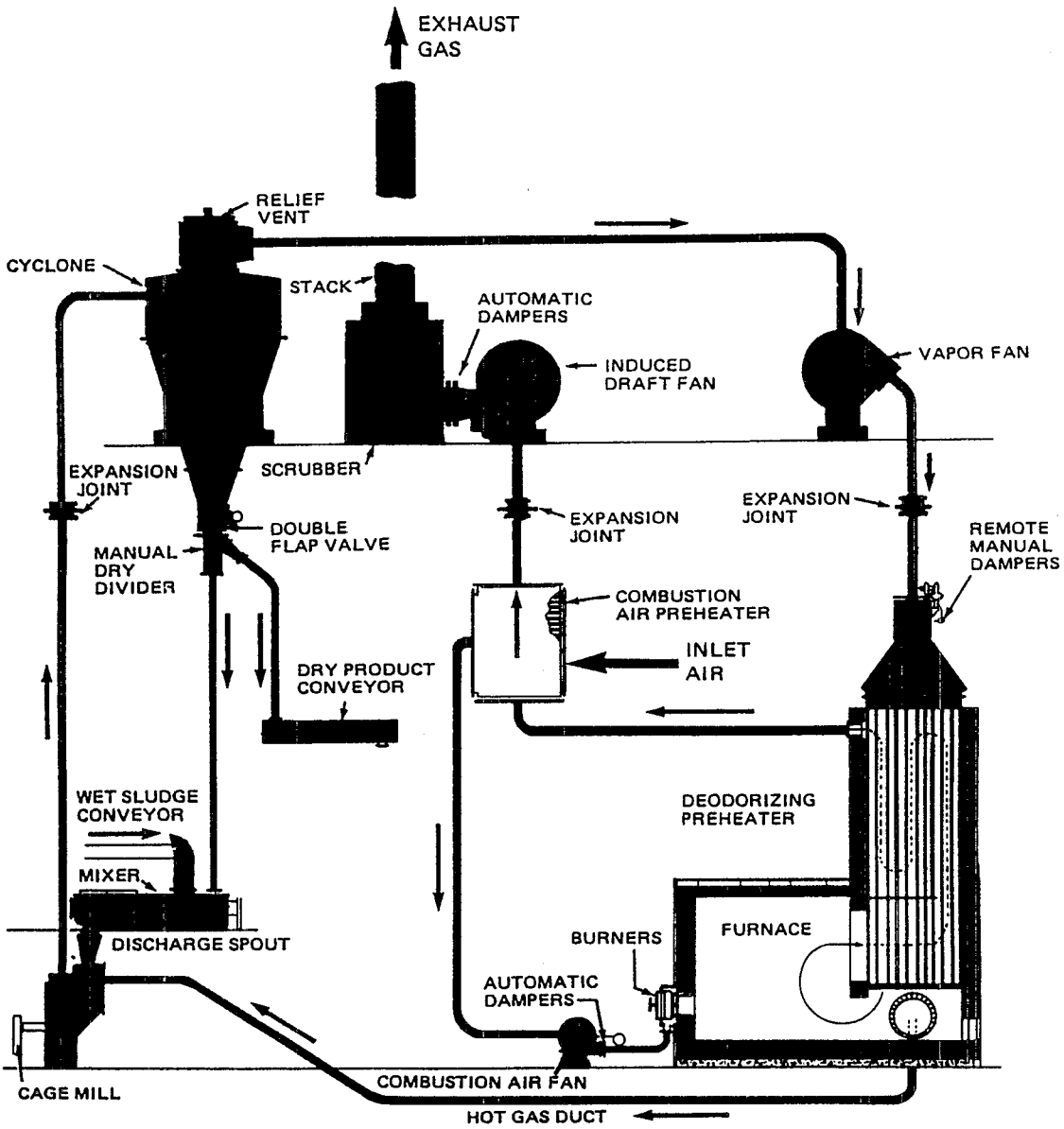


Figure 5-1. Flash dryer system (Courtesy of C.E. Raymond). Source: EPA, 1979.

Heat Treatment

Heat treatment processes are used both to stabilize and condition sludge. The processes involve heating sludge under pressure for a short period of time. The sludge becomes sterilized and bacterial slime layers are solubilized, making it easier to dewater the remaining solids. **The regulation requires that heat treatment processes heat liquid sludge to 180°C (356°F) for 30 minutes.** If operated according to these requirements, the process effectively destroys pathogenic viruses, bacteria, and helminth ova. Sludge must be properly stored after processing because organic matter has not been reduced and, therefore, regrowth of pathogenic bacteria can occur if treated sludge is reinoculated with such organisms.

Two processes have been used for heat treatment: the Porteous and the Zimpro process. In the Porteous process the sludge is preheated and then injected into a reactor vessel. Steam is also injected into the vessel under pressure. The sludge is retained in the vessel for approximately 30 minutes after which it is discharged to a decant tank. The resulting sludge can generally be concentrated and dewatered to high solids concentrations. Further dewatering may be desirable to facilitate sludge handling.

The Zimpro process is similar to the Porteous process. However, air is injected into the sludge before it enters the reactor and the vessel is then heated by steam to reach the required temperature. Temperatures and pressures are approximately the same for the two processes.

Thermophilic Aerobic Digestion

Thermophilic aerobic digestion is a refinement of the conventional aerobic digestion processes discussed in Chapter 4. In this process, feed sludge is generally pre-thickened and an efficient aerator is used. In some modifications, oxygen is used instead of air. Because there is less sludge volume and less air to carry away heat, the heat released from biological oxidation warms the sludge in the digester to as high as 60°C (140°F).

Because of the increased temperatures, this process achieves higher rates of organic solids destruction than conventional aerobic digestion which operates at ambient air temperature. The biodegradable volatile solids content of the sludge can be reduced up to 70% in a relatively short period of time. The digested sludge is effectively pasteurized due to the high temperatures. Pathogenic viruses, bacteria, and parasites are reduced to below detectable limits if temperatures exceed 55°C (131°F).

This process can either be accomplished using auxiliary heating of the digestion tanks or through special designs that allow the energy naturally released by the microbial digestion process to heat the sludge. The regulation defines thermophilic aerobic digestion as a process where **"liquid sludge is agitated with air or oxygen to maintain aerobic conditions at residence times of 10 days at 55° to 60°C (131° to 140°F), with a volatile solids reduction of at least 38%."** The thermophilic process requires significantly lower residence times than conventional aerobic processes designed to qualify as a PSRP, which must operate 40 to 60 days at 20° to 15°C (68° to 59°F) respectively. Residence time is normally determined by dividing the volume of sludge in the vessel by the volumetric flow rate.

Processes that Are PFRPs When Combined with a PSRP

EPA has determined that certain combinations of processes, if carried out in series, will attain the pathogen reduction of a PFRP. The current regulation specifies three processes that, if combined with a PSRP, would be considered a PFRP: high-energy irradiation, gamma ray irradiation, and pasteurization. These three processes do not reduce vector attraction. The addition of a PSRP is necessary to ensure this reduction.

Electron and Gamma Ray Radiation

Radiation can be used to disinfect municipal wastewater sludge. Radiation destroys certain organisms by altering the colloidal nature of the cell contents (protoplasm). Gamma rays and high-energy electrons are the two potential energy sources for use in sludge disinfection. Gamma rays are high-energy photons produced by certain radioactive elements. High-energy electrons are electrons accelerated in velocity by electrical potentials in the vicinity of 1 million volts.[1] Both types of radiation destroy pathogens that they penetrate if the doses are adequate.

The regulatory requirements for irradiation systems are as follows:

- **High-energy electron irradiation – Sludge is irradiated with energized electrons from an accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20°C [68°F]).**
- **Gamma ray irradiation – Sludge is irradiated with gamma rays from certain isotopes, such as 60 Cobalt and 137 Cesium, at dosages of at least 1.0 megarad at room temperature (ca. 20°C [68°F]).**

The effectiveness of radiation in reducing pathogens depends on the radiation dose, which is measured in rads. A dose of 1 megarad or more will reduce pathogenic viruses, bacteria, and helminths to below detectable levels. Lower doses may successfully reduce bacteria and helminth ova but not viruses. Sludge must be properly stored after processing because organic matter has not been reduced and, therefore, regrowth of pathogenic bacteria can occur if sludge is reinoculated.

Although the two types of radiation function similarly to inactivate pathogens, there are important differences. Gamma rays can penetrate substantial thicknesses of sludge and can therefore be introduced to sludge by either piping liquid sludge into a vessel that surrounds the radiation source (Figure 5-2) or by carrying composted or dried sludge by hopper conveyor to the radiation source. High-energy electrons have limited penetration ability and

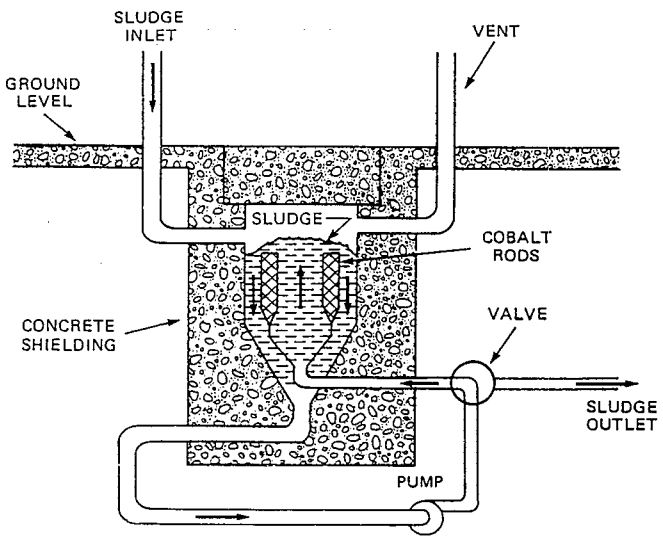


Figure 5-2 Schematic representation of cobalt-60 (gamma ray) irradiation facility at Geiselbullach, West Germany. Source: EPA, 1979.

[1]Certain radioactive elements also produce high-energy electrons, called beta rays. This term is generally reserved for electrons generated by naturally occurring radioactive decay.

therefore are introduced by passing a thin layer of sludge under the radiation source (Figure 5-3).

Pasteurization

Pasteurization involves heating sludge to above a predetermined temperature for a minimum time period. **The regulation requires sludge to be heated to at least 70°C (158°F) for a minimum of 30 minutes.** Proper pasteurization destroys bacteria, viruses, and helminth ova.

Sludge can be heated by heat exchangers or by steam injection. Although sludge pasteurization is uncommon in the United States, it is widely used in Europe. The steam injection method is preferred because it is more effective at maintaining even temperatures throughout the sludge batch being processed. Sludge is pasteurized in batches to prevent recontamination that might occur in a continuous process. Sludge must be properly stored after processing because the organic matter has not been stabilized and, therefore, odors and regrowth of pathogenic bacteria can occur if sludge is reinoculated.

In Europe, serious problems with regrowth of *Salmonella* species have occurred, so pasteurization is rarely used now as a terminal treatment process. Pre-pasteurization followed by mesophilic digestion has successfully replaced the use of pasteurization after digestion in many European communities.

Other Methods

The regulation states that other treatment methods or other operating conditions may be acceptable if they reduce pathogens and vector attraction to an extent equivalent to that achieved by the listed PFRPs. "Other methods" may be a modification of a listed PSRP or PFRP, a new process, or a combination of processes. As noted previously, EPA's Pathogen Equivalency Committee provides guidance on the equivalency of other methods or operating conditions. To obtain this guidance, data demonstrating the required reductions in pathogens and vector attraction should be submitted to EPA's Pathogen Equivalency Committee for review. The specifics of the review process are discussed in Chapter 6. Processes that have been found by the Committee to be equivalent to PFRPs are described in Table 6-1.

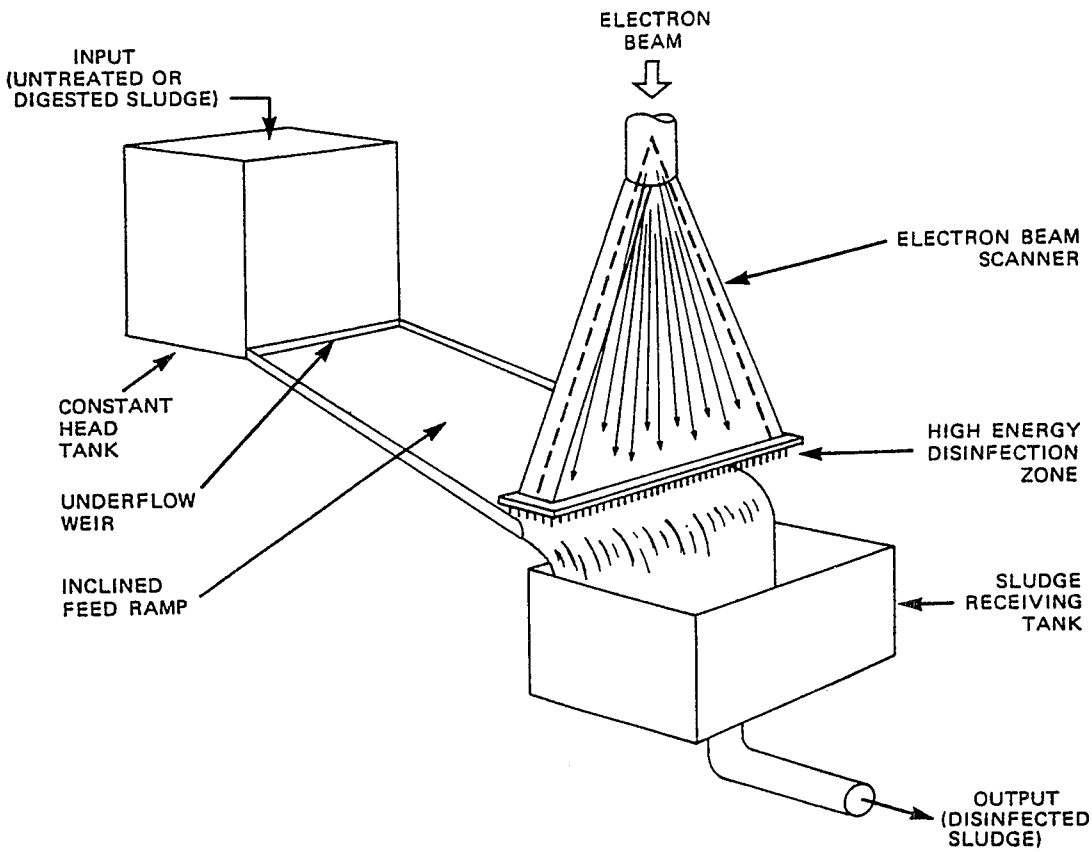


Figure 5-3 Electron beam scanner and sludge spreader. Source: EPA, 1979.

6. Determining Equivalency of Sludge Treatment Processes to PSRPs and PFRPs

Pathogen and Vector Attraction Reductions that Must Be Achieved by PSRPs and PFRPs

The Federal regulations governing land application of municipal sludge require sludge to be treated by either a Process to Significantly Reduce Pathogens (PSRP) or a Process to Further Reduce Pathogens (PFRP) prior to land application. The regulations list acceptable processes in each of these categories. They also define operating conditions for these processes that must be followed to ensure that pathogens and vector attraction are adequately reduced before the sludge is applied to land (see Tables 3-1 and 3-2 and Chapters 4 and 5 of this document).

The operating conditions for the listed PSRPs were selected to ensure the processes would consistently reduce the density of pathogenic viruses and bacteria in mixed sludge from a conventional plant by 1 log (base 10) (Whittington and Johnson, 1985). This is the reduction achieved by anaerobic digestion under the operating conditions described in the regulation, which was used as the standard to define adequate reduction by PSRPs.

The operating conditions for the listed PFRPs were selected to ensure that pathogens (as represented by *Salmonella* spp., total enteroviruses, and helminth ova) would be reduced to below the detection limits of the methods in use in 1979 when the regulations were promulgated (Whittington and Johnson, 1985). These detection limits were 3 MPN (most probable number)/100 ml sludge at 5% solids for *Salmonella* spp., 1 plaque-forming unit (PFU)/100 ml sludge at 5% solids for total enteroviruses, and 1 viable ovum/100 ml sludge at 5% solids for *Ascaris* spp.

In addition, both PSRPs and PFRPs must reduce vector attraction to the same extent as the reduction achieved by good anaerobic digestion.

The regulations recognize that other sludge treatment processes or operating conditions may be able to reduce pathogens and vector attraction to an extent equivalent to or greater than the listed PSRPs and PFRPs. They state that alternative methods "may be acceptable" if equivalent reductions can be demonstrated.

In 1985, EPA created a Pathogen Equivalency Committee (PEC) to review requests for guidance on PSRP and PFRP equivalency on a case-by-case basis (Whittington and Johnson, 1985). This chapter explains the review process and describes how to apply for PEC guidance.

How Does the Pathogen Equivalency Committee Function?

The PEC consists of approximately six members with expertise in microbiology, wastewater engineering, statistics, and sludge regulations. It includes representatives from EPA's Office of Research and Development and Office of Water. The committee reviews and makes recommendations to EPA management on applications for PSRP or PFRP equivalency. Its members also provide guidance to applicants on the data necessary to determine equivalency. The committee does not recommend process changes or appropriate uses of sludge products.

Each application is considered on a case-by-case basis. Applicants submit information on process operating parameters and/or the sludge product. The committee evaluates this information in light of the current state of knowledge concerning sludge treatment and pathogen reduction.

The applicant is notified in writing by the State Sludge Coordinator about the Committee's decision regarding the application. The committee recommends one of five decisions about the process or process sequence:

- It is equivalent to PFRPs.
- It is not equivalent to PFRPs.
- It is equivalent to PSRPs.
- It is not equivalent to PSRPs.
- Additional data or other information are needed.

Most processes have been found equivalent on a site-specific basis only. That is, the equivalency applies only to that particular operation run at that location under the conditions specified. For site-specific PSRP or PFRP determinations, equivalency cannot be assumed for the same process performed at a different location, or for any modification of the process.

The PEC has considered applications for national equivalency status. To show national equivalency, the applicant must demonstrate that the process will produce the desired reductions in pathogens and vector attraction under the variety of conditions that may be encountered at different locations in the country. Processes affected by local climatic conditions or that use materials whose properties may vary significantly from one part of the country to another are unlikely to be found equivalent on a national basis.

The committee has also evaluated stockpiled sludge. For example, a municipality may have a pile of sludge created from a past treatment operation that is no longer in use. If the municipality can demonstrate that pathogens and vector attraction have been reduced to PSRP or PFRP levels throughout the pile, then the sludge may be applied to land under the same conditions as sludge produced by a PSRP or PFRP. A finding of equivalency would pertain only to that pile of sludge.

If the members of the PEC determine, based on the information submitted, that a process is equivalent to PSRPs or PFRPs, they specify the operating parameters and any other conditions critical to adequate disinfection and reduction of vector attraction. These conditions are communicated to the applicant in the equivalency determination letter. The process then is considered equivalent to PSRPs or PFRPs only when operated under the specified conditions.

If the Committee determines that a process is not equivalent, the committee will provide an explanation for this finding. If additional data are needed, the committee will describe what those data are and work with the applicant, if necessary, to ensure that the appropriate data are gathered in an acceptable manner. The committee then will review the revised application when the additional data are submitted.

The PEC's equivalency determination is reviewed and approved by the EPA Office of Water Regulations and Standards before being sent to the applicant. **The PEC's determinations are not formal binding Agency decisions.** Rather, they constitute technical guidance and are advisory.

In its first 2 years of operation, the PEC received 13 requests for equivalency determination. Most of these processes were determined to be equivalent to PSRPs or PFRPs (see Table 6-1).

Who Should Apply for Guidance on Equivalency?

All municipal wastewater sludge or sludge-derived products applied to land must be treated by a PSRP or a PFRP. No demonstration of equivalency is necessary for processes listed in the 40 CFR Part 257 regulations that consistently meet the specified operating conditions (see Tables 3-1 and 3-2). **Processes that deviate in any way from the specified operating conditions or novel processes or process combinations not described in the regulations must reduce pathogens and vector attraction to an extent equivalent to a PSRP or PFRP; if you own or operate such a process, you may wish to obtain guidance on whether your process is equivalent to either PSRPs or PFRPs before the sludge product is applied to land.**

How Long Does the Review Process Take?

Generally, the review process takes 1 to 2 months from the PEC's receipt of application to recommendation *if* the application is complete. Additional time must be allowed for state and regional review of the application. If the application is incomplete the process will take longer or the applicant may have to reapply at a later date.

How Do I Apply for Equivalency?

Figure 6-1 shows a flow chart for the equivalency guidance application process. If you have questions about how to apply, you should contact the Regional Sludge Coordinator (RSC) in the EPA Water Management Division of your EPA regional office, or the State Sludge Coordinator (SSC) in your state's environmental agency that regulates land application of sludge. (Appendices B and C provide phone numbers and addresses for the RSCs and SSCs.) The RSC or SSC will either answer your questions or direct you to the PEC. The RSCs and SSCs may also have additional information on equivalency (in the form of memos and other guidance issued by the PEC subsequent to the publication of this document) that may be useful in preparing your application.

There is no application form to fill out. You should prepare an application according to the instructions and outline provided on p. 35 (*How Do I Prepare an Application for Equivalency*?) and submit two copies to the Regional Sludge Coordinator at your EPA regional office (see Appendix B) and one copy to your State Sludge Coordinator (see Appendix C). The RSC will forward a copy to the PEC, together with any comments on the process from the RSC, SSC, or other state or regional staff who are familiar with the process. The RSC and the SSC may participate with the PEC in the equivalency evaluation if they are familiar with your process (e.g., through site visits, research activities, etc.).

If you have questions about how to obtain the necessary microbiological data, you may submit a work plan describing your proposed approach to sampling and analysis of the sludge product. The PEC or a designated representative will review your plan and indicate whether the approach would be expected to yield acceptable and complete data.

The PEC forwards a copy of the application to the EPA Office of Water Enforcement and Permits and the EPA Office of Water Regulations and Standards (OWRS). The PEC also forwards copies of any correspondence with you (e.g., requests for additional data) to the RSC and the SSC. If the PEC requests additional data, you should submit that data directly to the PEC. The PEC will forward it, as appropriate, to the RSC, SSC, and OWRS.

The PEC documents its recommendation concerning each application and includes any supporting information. A copy of the final recommendation is forwarded to OWRS for approval. OWRS forwards the PEC's conclusions to the RSC, who forwards a copy to the SSC. The SSC forwards a copy to the applicant. Figure 6-2 shows the channels of communication for the equivalency guidance process.

Confidential Business Information

If you wish to assert a business confidentiality claim covering part or all of the information submitted to the PEC, you should follow the procedures spelled out in 40 CFR Part 2 - Subpart B (*Confidential Business Information*).

You can assert a business confidentiality claim covering the information by placing on (or attaching to) the information, *at the time it is submitted to EPA*, a cover sheet, stamped or typed legend, or other form of notice indicating the claim of confidentiality. Suitable notice would include language such as "trade secret," "proprietary," or "company confidential." If documents for which confidentiality is asserted are submitted with other nonconfidential documents they should be clearly identified and may be submitted separately to facilitate

Table 6-1. Processes Determined to Be Equivalent to PSRP or PFRP

Operator	Process Description	Status
Town of Telluride, Colorado	Combination oxidation ditch, aerated storage, and drying process. Sludge is treated in an oxidation ditch for at least 26 days and then stored in an aerated holding tank for up to a week. Following dewatering to 18% solids, the sludge is dried on a paved surface to a depth of 2 feet. The sludge is turned over during drying. After drying to 30% solids, the sludge is stockpiled prior to land application. Together, the drying and stockpiling steps take approximately 1 year. To ensure that PSRP requirements are met, the stockpiling period must include one full summer season.	PSRP
Comprehensive Materials Management, Inc., Houston, Texas	Use of cement kiln dust (instead of lime) to treat sludge by raising sludge pH to at least 12 after 2 hours of contact. Dewatered sludge is mixed with cement kiln dust in an enclosed system and then hauled off for land application.	PSRP
N-Viro Energy Systems Ltd., Toledo, Ohio	Use of cement kiln dust and lime kiln dust (instead of lime) to treat sludge by raising the pH. Sufficient lime or kiln dust is added to sludge to produce a pH of 12 for at least 12 hours of contact.	National PSRP
Public Works Department, Everett, Washington	Anaerobic digestion of lagooned sludge. Suspended solids had accumulated in a 30-acre aerated lagoon that had been used to aerate wastewater. The lengthy detention time in the lagoon (up to 15 years) resulted in a level of treatment exceeding that provided by conventional anaerobic digestion. The percentage of fresh or relatively unstabilized sludge was very small compared to the rest of the accumulation (probably much less than 1% of the whole).	PSRP
Haikey Creek Wastewater Treatment Plant, Tulsa, Oklahoma	Oxidation ditch treatment plus storage. Sludge is processed in aeration basins followed by storage in aerated sludge holding tanks. The total sludge aeration time is greater than the aerobic digestion operating conditions specified in the Federal regulations of 40 days at 20°C (68°F) to 60 days at 15°C (59°F). The oxidation ditch sludge is then stored in batches for at least 45 days in an unaerated condition or 30 days under aerated conditions.	PSRP
Ned K. Burleson & Associates, Inc., Fort Worth, Texas	Aerobic digestion for 20 days at 30°C (86°F) or 15 days at 35°C (95°F).	PSRP
Scarborough Sanitary District, Scarborough, Maine	Static pile aerated "composting" operation that uses fly ash from a paper company as a bulking agent. The process creates pile temperatures of 60° to 70°C (140° to 158°F) within 24 hours and maintains these temperatures for up to 14 days. The material is stockpiled after 7 to 14 days of "composting" and then marketed.	PFRP
Mount Holly Sewage Authority, Mount Holly, New Jersey	Zimpro 50-gpm low-pressure wet air oxidation process. The process involves heating raw primary sludge to 177° to 204°C (350° to 400°F) in a reaction vessel under pressures of 250 to 400 psig for 15 to 30 minutes. Small volumes of air are introduced into the process to oxidize the organic solids.	PFRP
N-Viro Energy Systems Ltd., Toledo, Ohio	Advanced alkaline stabilization with subsequent accelerated drying. • Alternative 1: Fine alkaline materials (cement kiln dust, lime kiln dust, quicklime fines, pulverized lime, or hydrated lime) are uniformly mixed by mechanical or aeration mixing into liquid or dewatered sludge to raise the pH to greater than 12 for 7 days. If the resulting sludge is liquid, it is dewatered. The stabilized sludge cake is then air dried (while pH remains above 12 for at least 7 days) for at least 30 days *and* until the cake is at least 65% solids. A solids concentration of at least 60% is achieved before the pH drops below 12. The mean temperature of the air surrounding the pile is above 5°C (41°F) for the first 7 days. • Alternative 2: Fine alkaline materials (cement kiln dust, lime kiln dust, quicklime fines, pulverized lime, or hydrated lime) are uniformly mixed by mechanical or aeration mixing into liquid or dewatered sludge to raise the pH to greater than 12 for at least 72 hours. If the resulting sludge is liquid, it is dewatered. The sludge cake is then heated, while the pH exceeds 12, using exothermic reactions or other thermal processes to achieve temperatures of at least 52°C (126°F) throughout the sludge for at least 12 hours. The stabilized sludge is then air dried (while pH remains above 12 for at least 3 days) to at least 50% solids.	National PFRP
Miami-Dade Water and Sewer Authority, Miami, Florida	Anaerobic digestion followed by solar drying. Sludge is processed by anaerobic digestion in two well-mixed digesters operating in series in a temperature range of 35° to 37°C (95° to 99°F). Total residence time is 30 days. The sludge is then centrifuged to produce a cake of between 15 to 25% solids. The sludge cake is dried for 30 days on a paved bed at a depth of no more than 46 cm (18 inches). Within 8 days of the start of drying, the sludge is turned over at least once every other day until the sludge reaches a solids content of greater than 70%. The PFRP approval was conditional on the microbiological quality of the product (see *Examples of Approvals* at the end of Chapter 6).	Conditional PFRP

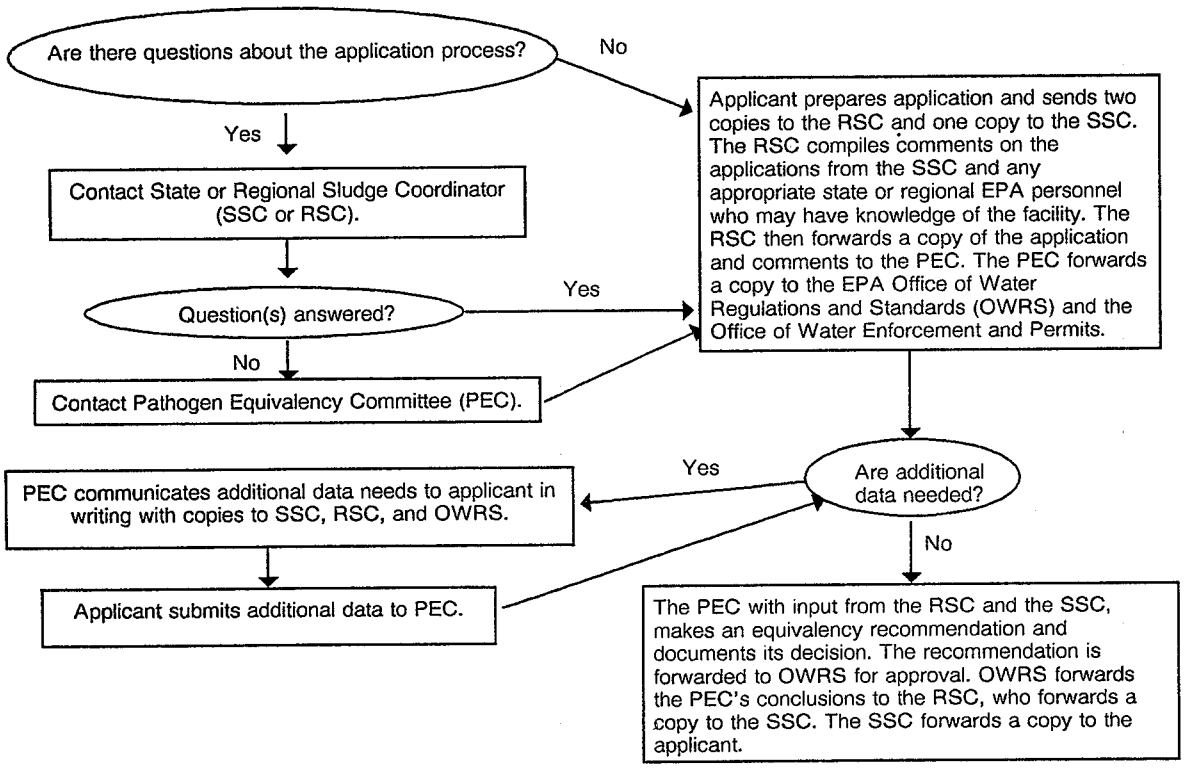


Figure 6-1. PSRP and PFRP equivalency application and determination process.

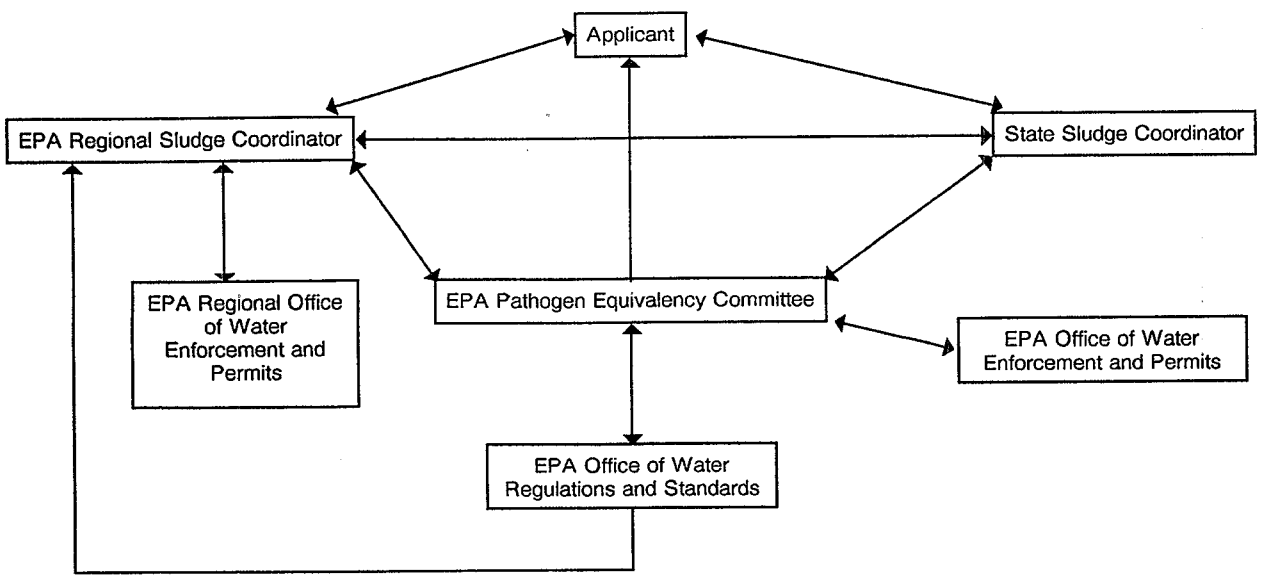


Figure 6-2. Channels of communication for equivalency guidance.

identification and handling by EPA. If you desire confidential treatment only until a certain date or until the occurrence of a certain event, the notice should state this. **If a business has been notified of the requirement of 40 CFR Section 2.208 to assert a claim of confidentiality and no claim of confidentiality accompanies the information when it is received by EPA, the information may be made available to the public by EPA without further notice to the business.**

How Is Equivalency Defined?

The PEC's criteria for equivalency are based on the same rationale used in developing the 40 CFR 257 regulations. As explained at the beginning of this chapter, the operating conditions for the listed PSRPs and PFRPs were specified to ensure that these processes would consistently achieve certain levels of pathogen and vector attraction reduction. To be "equivalent," other (i.e., nonlisted) technologies must achieve these same levels of reduction, as described below. EPA (1989c) discusses the scientific data and rationale used to develop some of these equivalency criteria.

PSRP Equivalency

To be equivalent to PSRPs, a process must (1) consistently reduce the density of pathogenic viruses and bacteria (measured as the number/gram total suspended solids sludge [no./g TSS] at 5% solids) in mixed sludge from a conventional plant by equal to or greater than 1 log (base 10), and (2) reduce vector attractiveness to the same degree as properly conducted anaerobic digestion.

The reduction in pathogenic viruses and bacteria can be demonstrated in different ways, depending on whether the process is conventional or nonconventional. The requirements are modified slightly for sludges produced by no primary/long sludge age (NP/LSA) wastewater treatment processes, because of the consistently lower pathogen densities in these sludges. The various criteria for demonstrating PSRP equivalency are described below and summarized in Figure 6-3.

Conventional Processes

Data indicate that, for conventional biological and chemical treatment processes (e.g., digestion, lime treatment, chlorine treatment), a reduction of 1 log (base 10) in pathogenic virus and bacteria density correlates with a reduction of 1 to 2 logs (base 10) in the density of indicator organisms (Farrell et al., 1985; Farrah et al., 1986). On this basis, a 2-log (base 10) reduction in fecal indicator density is accepted as satisfying the requirement to reduce pathogen density by 1 log (base 10) for these types of processes (EPA, 1989c). Specifically, you must demonstrate a 2-log (base 10) reduction (measured in no./g total suspended solids) in either (1) fecal coliforms and fecal streptococci, *or* (2) fecal coliforms and enterococci. In the past, this has been the standard reduction required to demonstrate equivalency to PSRPs for conventional processes.

Recently, however, a substantial amount of data have been generated to indicate that sludge produced by conventional wastewater treatment and anaerobic digestion at 35°C (95°F) for more than 15 days contains fecal coliforms and fecal streptococci at average log (base 10) densities (no./g TSS) of less than 6.0 (Farrell, 1988). Thus, for processes or combinations of processes that do not depart radically from conventional treatment (gravity thickening, anaerobic or aerobic biological treatment, dewatering, air drying, and storage of liquid or sludge cake), or for any process where there is a demonstrated correlation between pathogenic bacteria and virus reduction and indicator organism reduction, the PEC accepts an average log (base 10) density (no./g TSS) of fecal coliforms and fecal streptococci of less than 6.0 in the treated sludge as indicating adequate viral and bacterial pathogen reduction. (The average log density is the log of the geometric mean of the samples taken. Calculations of average log density should be based on data from approximately nine sludge samples to account for the natural variability and the variability of the microbiological tests.)

Nonconventional Processes

For nonconventional sludge treatment processes, such as radiation, for which no data are available or data indicate an inappropriate correlation between pathogen reduction and indicator organism reduction, indicator organism data are not acceptable. Instead, you must demonstrate that your process is capable of causing at least a 1-log (base 10) reduction in the density of the least susceptible organism (i.e., total enteroviruses or *Salmonella* spp.).

Processes Treating Sludges Generated by No Primary/Long Sludge Age (NP/LSA) Wastewater Treatment

The original PSRP criterion of a 1-log (base 10) reduction in pathogenic viruses and bacteria was based on reductions achieved by processes treating mixed sludge produced by conventional wastewater treatment. Recent data indicate that sludges produced by no primary/long sludge age wastewater treatment processes,[1] such as extended aeration and oxidation ditch treatment, have pathogen densities that are approximately 0.3 log (base 10) lower than sludges produced by conventional primary and waste-activated wastewater treatment processes (Farrell et al., 1989). Therefore, if NP/LSA sludges are treated by processes that provide an additional 0.7 log (base 10) reduction in the density of pathogenic bacteria and viruses, they will have achieved a pathogen reduction equivalent to that achieved in a conventional sludge treated by a PSRP. Thus, to be considered equivalent to PSRPs, processes that are treating NP/LSA sludges need only demonstrate a 0.7-log (base 10) reduction in the density of either pathogenic bacteria or viruses (i.e., total enteroviruses or *Salmonella* spp.), whichever is the least susceptible organism. If the sludge treatment process is a conventional process, then indicator organism data can be used to demonstrate pathogen reduction. For NP/LSA sludges, a conventional process must achieve a 1.4-log reduction in the density of either (1) fecal coliforms and fecal streptococci, *or* (2) fecal coliforms and enterococci.

[1] No primary/long sludge age treatment processes are processes where wastewater directly enters a secondary treatment system and sludge circulates through the system (i.e., "ages") for 20 or more days.

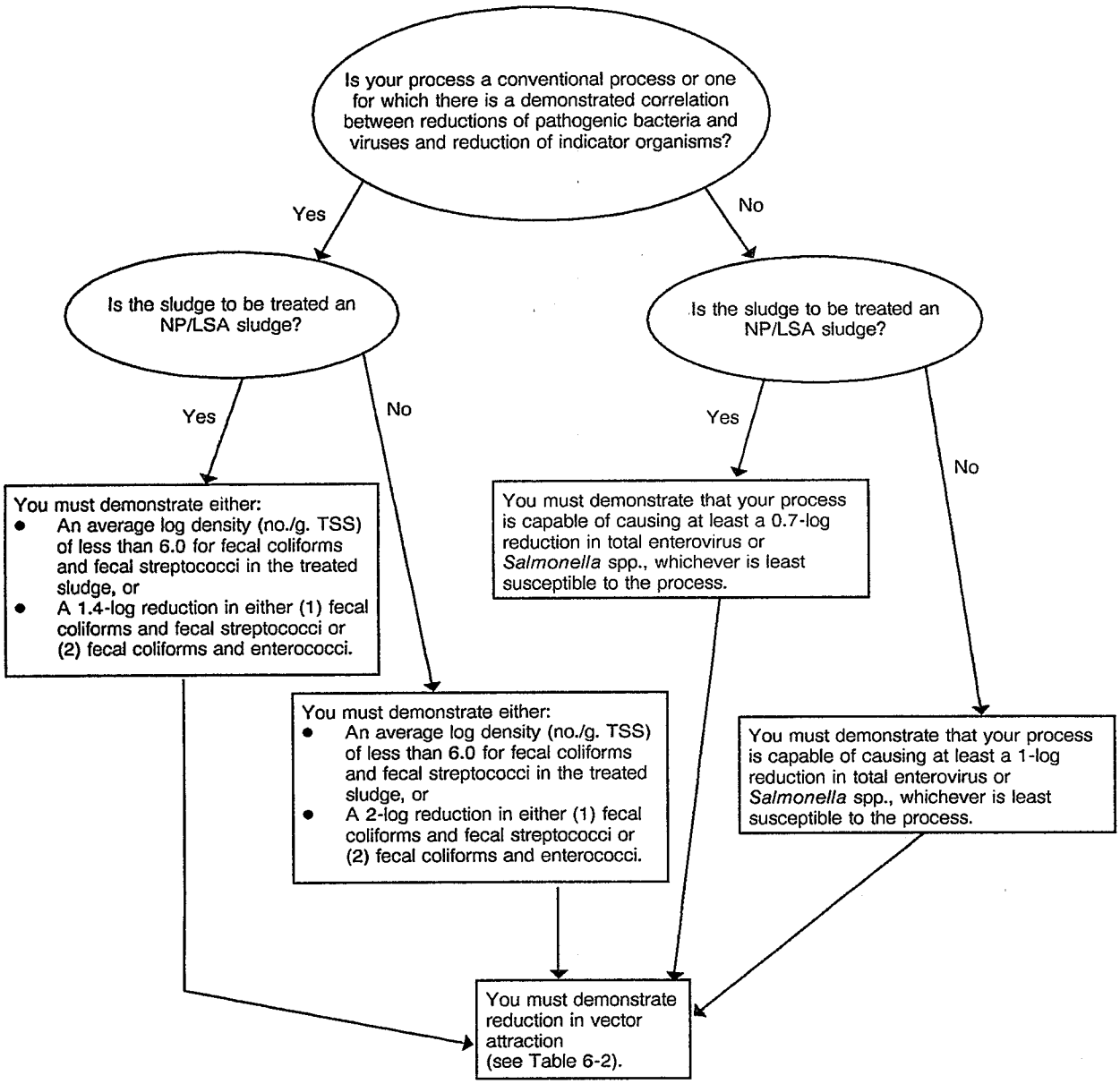


Figure 6-3. Requirements for demonstrating equivalency to PSRP.

NP/LSA plants generally use treatment processes that do not depart radically from conventional treatment. In such cases, these plants can also use an average log density of less than 6.0 for fecal coliforms and fecal streptococci in the treated sludge to demonstrate adequate viral and bacterial pathogen reduction. This option is discussed in *Conventional Processes* above. Since this approach involves half the sampling and analytical effort of the indicator organism reduction approach, it is expected that most NP/LSA plants will choose the log density option.

Reduction of Vector Attractiveness

To demonstrate that your process is equivalent to PSRPs, you must also show that it reduces vector attractiveness to the same degree as properly conducted anaerobic digestion. This requirement can be satisfied in several ways depending on the type of sludge.[2] Table 6-2 summarizes the equivalency criteria for vector

[2] Sludge with demonstrated reduced vector attraction may later attract vectors if it is improperly handled (e.g., exposed to precipitation or applied to land at high rates). Applying the sludge to land at agronomic rates will maintain the reduction in vector attraction. Heat-dried undigested sludges should not be applied during or shortly after precipitation.

Table 6-2. Reduction in Vector Attractiveness: Criteria for Demonstrating Equivalency

Type of Sludge	Criteria
All types	Reduction of volatile solids content of the sludge by at least 38% during treatment. See Appendix D for guidance on calculating this parameter.
Sludges from aerobic processes (aerobic digestion or extended aeration)	Treated sludge has an oxygen intake of less than 1 mg oxygen/hour/g TSS as demonstrated by the Specific Oxygen Uptake Rate (SOUR) test at 20°C (68°F).
Anaerobic sludges	Volatile solids reduction in treated sludge after 40 days *additional* batch mesophilic digestion is less than 15%.
Sludges that contain no raw primary sludge	Total suspended solids content of treated sludge is 75% or greater and remains at this level until the point of land application.
High pH sludges	Treated sludge maintains a pH of 11.5 or greater up to the time of land application.
Stockpiled sludge	Lack of odor throughout the sludge pile.

Table 6-3. Recommended Analytical Methods to Demonstrate PSRP or PFRP Equivalency

Organism or Parameter of Interest	Method/Reference
Microbial Populations	
Indicator Organisms:	
Fecal coliform	Standard Methods, Methods 908 and 909 (APHA, 1985).
Fecal streptococcus	Standard Methods, Method 910A (APHA, 1985) *or* Slanetz and Bartley, 1957.
Enterococci	Levin et al., 1975.
Salmonella spp.	Standard Methods, Method 912C.1 (APHA, 1985) *or* Kenner and Clark, 1974.
Total enteroviruses	EPA, 1984c *or* Goyal et al., 1984.
Helminth ova (including *Ascaris* spp., *Toxocara* spp., *Trichuris trichiura*)	Fox et al., 1981 *or* Yanko, 1987 *or* Tulane University, 1981.
Vector Attraction Potential	
Specific Oxygen Uptake Rate (SOUR)	Standard Methods, Method 213A. (APHA, 1985)
Sludge Characteristics	
Total solids	Standard Methods, Method 209A (APHA, 1985).
Total suspended solids	Standard Methods, Method 209C (APHA, 1985).
Volatile solids	Standard Methods, Method 209D (APHA, 1985).
Volatile suspended solids	Standard Methods, Method 209D (APHA, 1985).

attractiveness. For all sludges, the requirement can be met by demonstrating that the volatile solids content of the sludge was reduced during treatment by at least 38%. Appendix D provides guidance on how to calculate this reduction. For sludges with a high proportion of aerobic bacteria (i.e., produced by aerobic processes such as aerobic digestion or extended aeration),the requirement can be met by performing the SOUR (Specific Oxygen Uptake Rate) test (see Table 6-3) to show that the sludge has an oxygen uptake of less than 1 mg oxygen/hour/g total suspended solids (subsequent guidance may change these numbers). The SOUR test is not appropriate for limed or anaerobically digested sludges. Sludges from anaerobic processes (including lagooned sludge that has not been chemically treated) are considered to have adequately reduced vector attraction if the volatile solids reduction from 40 days *additional* batch mesophilic digestion is less than 15%. Sludges that contain no raw primary sludge are considered to have adequately reduced vector attractiveness if their total suspended

solids content is 75% or greater *and* remains at this level until the point of land application (such sludges may spontaneously combust unless dried to 95% solids or greater so caution in storage is suggested). Sludges that maintain a pH of 11.5 up to the time of land application are also considered to have adequately reduced vector attraction. For stockpiled sludge, a finding of no odors throughout the pile is accepted as evidence of adequately reduced vector attraction.

PFRP Equivalency

Figure 6-4 summarizes the requirements for PFRP equivalency. To be equivalent to PFRPs, a process must reduce microorganisms to below the following limits:

- *Salmonella* spp. - 3 MPN/100 ml sludge at 5% solids (100 ml sludge at 5% solids equals approximately 5 g dry solids).[3,4,5]
- Total enteroviruses - 1 plaque-forming unit (PFU)/100 ml sludge at 5% solids.[3,4,5]
- Helminth ova - 1 viable ovum/100 ml sludge at 5% solids.[5] For treatment processes, you must demonstrate this reduction for *Ascaris* spp. only.[3] If you are applying for PFRP status for stockpiled sludge, you must demonstrate that *Ascaris* spp., *Toxocara* spp., and Trichuris *trichiura* have been reduced to no more than 1 viable egg per 100 ml sludge at 5% solids. (These additional requirements for stockpiled sludge are necessary because it is impossible to know whether the untreated sludge contained helminths. A negative finding for one helminth species alone does not necessarily indicate helminth reduction. It may simply mean that species was not present initially. Negative findings in three species provides greater reassurance of destruction.)

In addition, as part of PFRP equivalency, you must demonstrate that your process reduces vector attractiveness to the same degree as properly conducted anaerobic digestion (see above).

How Do I Demonstrate Equivalency?

Equivalency must be demonstrated either directly, by measuring microbe levels and vector attraction in sludge as described above, or indirectly by relating process parameters to reduction of pathogens and vector attraction.[6] Three basic approaches can be taken to demonstrate equivalency, as described below and summarized in Figure 6-5.

Note: Conventional design methods do not ensure that your process will meet the pathogen and vector attraction reduction requirements. Likewise, a reduction in volatile solids does not necessarily correlate with adequate pathogen destruction.

Comparison to Operating Conditions for Existing PSRPs or PFRPs

If your process is similar to a PSRP or PFRP described in the regulations (see Tables 3-1 and 3-2), you may be able to demonstrate equivalency by providing performance data showing that your process consistently meets or exceeds the conditions specified in the regulations.

For example, a process that consistently produces a pH of 12 or greater for 2 hours of contact (the conditions required in the regulations for lime stabilization) but uses a substance other than lime to raise pH would qualify as a PSRP. In such cases, microbiological data would not be necessary.

Use of Literature Data to Demonstrate Adequacy of Operating Conditions

If scientific data from the literature establish a reliable relationship between operating conditions (time, temperature, pH, etc.) and pathogen reduction, well-maintained operating records verifying that the necessary

[3]To demonstrate adequate pathogen destruction, the untreated sludge must contain 1,000 MPN *Salmonella* spp./g total suspended solids (TSS); 1,000 PFU total enteroviruses/g TSS; and 100 viable *Ascaris* spp. ova/g TSS *prior to treatment*. If your untreated sludge does not naturally contain these densities, you must spike it to achieve these levels (see *Spiking* later in this chapter).
However, if you can demonstrate that one organism is more susceptible than others, it may be sufficient to test only for the least susceptible organism. For example, viruses are much less sensitive to radiation than bacteria and helminth ova. For radiation-based processes, it is sufficient to demonstrate that the process reduces viruses to the required level. If you think your process might qualify for this reduction in testing, provide the PEC with the data necessary to substantiate your claim.

[4] For processes for which data in the literature indicate a correlation between indicator organism reduction and reduction of pathogenic viruses and bacteria (for example, thermal processes using temperatures of sufficient degree and duration to anticipate pathogen destruction, e.g., 3 days at 53°C [127°F], 30 minutes at 70°C [158°F]), it may be possible to substitute indicator organism data for total enterovirus and *Salmonella* spp. data. If you think your process might qualify for such a substitution, consult with the PEC prior to performing microbiological testing, and provide the committee with the data necessary to substantiate your claim. Processes that qualify for this substitution must demonstrate the capability to reduce either fecal coliforms and fecal streptococci or fecal coliforms and enterococci to densities below 100/g total suspended solids.

[5]For sludges with a different solids percentage, the volume or weight equivalent of 5 grams dry solids must be calculated to determine the appropriate units of sludge for demonstrating PFRP pathogen reduction. This is done by dividing 5 grams by the density of the sludge. For example, for a 1% sludge, the density (on a volume basis) is approximately 1 g/100 ml. For this sludge, the volume equivalent of 5 g is:

$$\frac{5 \text{ g dry solids}}{1 \text{ g/100 ml}} = 500 \text{ ml.}$$

Thus, to meet PFRP requirements, a 1% sludge must contain less than 3 MPN *Salmonella* spp., 1 PFU total enteroviruses, and 1 viable helminth ovum per 500 ml sludge. For an 18% sludge, the density (on a weight basis) is 0.18 g dry solids/1 g total sludge cake. The weight equivalent of 5 g dry solids is:

$$\frac{5 \text{ g dry solids}}{0.18 \text{ g dry solids/1 g sludge cake}} = 28 \text{ grams sludge cake.}$$

[6]Certain conventional and commonly used wastewater treatment and sludge treatment processes, such as oxidation ditch and extended aeration wastewater treatment systems and aerobic sludge digesters with traditional detention times (20 to 30 days) may not qualify as equivalent to PSRPs or PFRPs without some modification. However, it is possible that they may meet new regulatory requirements that will eventually be promulgated under the Part 503 Sewage Sludge Regulation. (Proposed Part 503 regulations were published for public comment in the *Federal Register* on February 6, 1989 [EPA, 1989b]. They contain a special Class C sludge category for sludges generated in systems such as but not limited to oxidation ditch and extended aeration wastewater treatment systems. See Chapter 7.) To avoid the expense of permanent process modifications that may not be necessary once the new regulations are promulgated in final form, operators of these technologies may wish to make less expensive temporary modifications, such as combining the process with lime treatment or providing additional aerobic digestion through aerated storage, in order to qualify as a PSRP or PFRP.

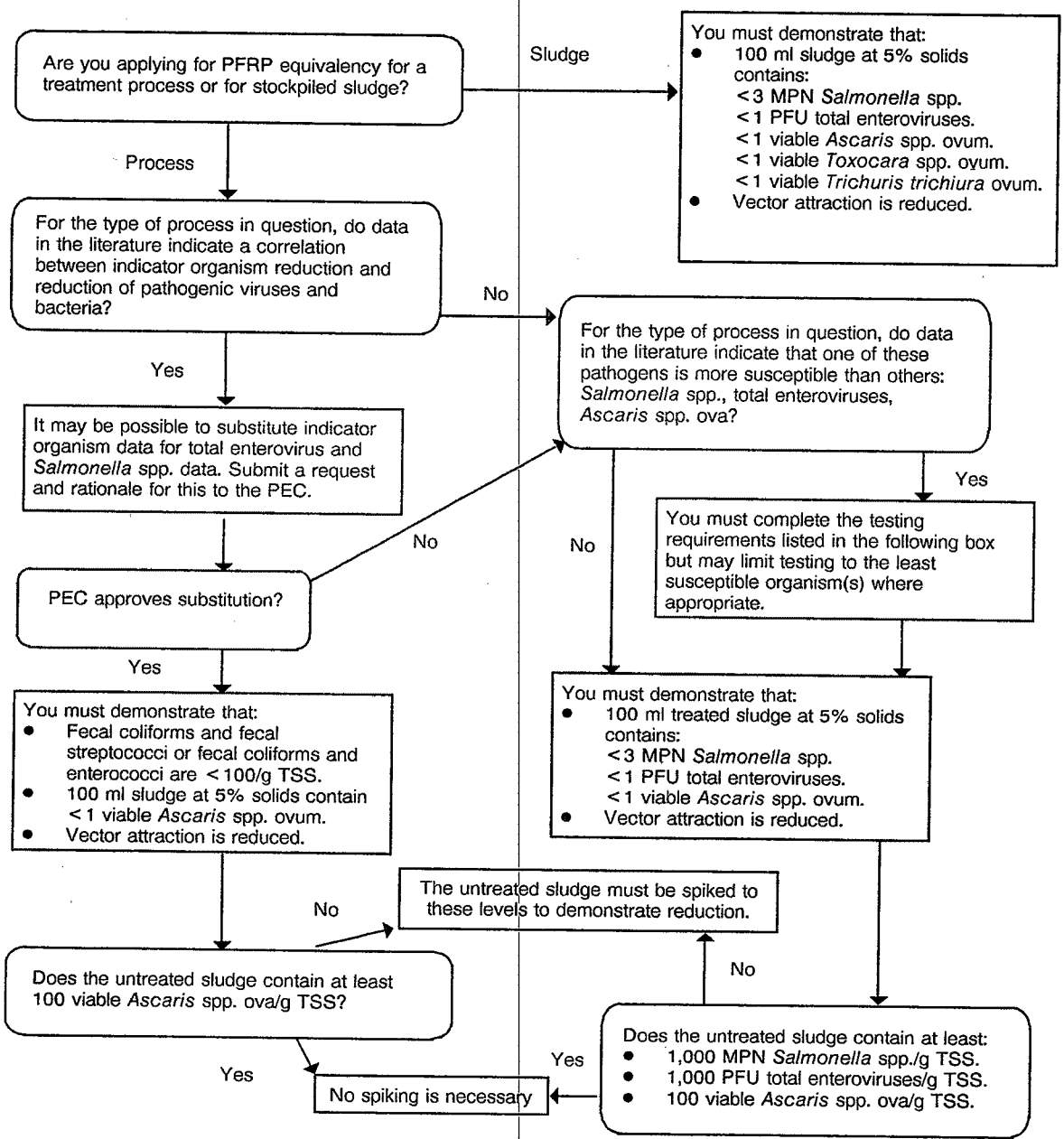


Figure 6-4. Requirements for demonstrating equivalency to PFRP.

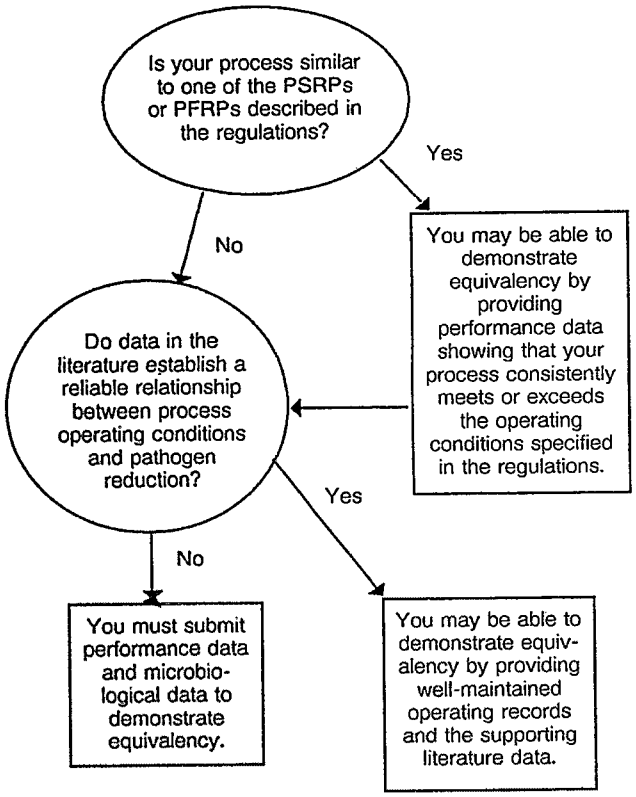


Figure 6-5. Approaches to demonstrating equivalency.

operating conditions were satisfied may be acceptable as a substitute for actual microbiological sampling and analysis. In such cases, you must include adequate supporting operational and literature data.

Process-specific Performance Data and Microbiologic Data

In all other cases, both performance data and microbiological data will be necessary to demonstrate process equivalency. Specifically, you will need to provide the following information:

- A description of the various parameters (e.g., sludge characteristics, process operating parameters, climatic factors, etc.) that influence (1) the microbiological characteristics of your sludge product and (2) the attractiveness of the product to vectors (see *Process Description*, p. 35, for more detail on relevant parameters).

- Sampling and analytical data to demonstrate that the process has reduced pathogens and vector attraction to the required levels (see previous section for a description of levels).

- A discussion of the reliability of your treatment process in consistently operating within the parameters necessary to achieve the appropriate reductions.

Stockpiled Sludge

Stockpiled sludge from a past process can be found equivalent to PSRP or PFRP. If you are applying for PFRP equivalency, you must either (1) provide microbiological data to demonstrate that pathogens are reduced to the PFRP limits *throughout* the stockpiled sludge (see *PFRP Equivalency* in previous section), or (2) demonstrate that the treatment process (including, if relevant, the storage time) that produced the sludge was sufficient to reduce pathogens to the required PFRP levels (for example, it may be sufficient to submit indicator organism and parasite data for a sludge pile produced by a thermal process, since data indicate a correlation between indicator organism reduction and reduction of viruses and pathogenic bacteria when heat is used as the method for disinfection).

If you are applying for PSRP equivalency, you must provide microbiological data to demonstrate that the average log density (no./g TSS) of fecal coliforms and fecal streptococci is less than 6.0 *throughout* the stockpiled sludge *and* provide data to show that the treatment process either did not depart radically from conventional treatment or was a process for which there is a demonstrated correlation between pathogenic bacteria and virus reduction and indicator organism reduction.

Reduction of vector attraction must also be demonstrated for both PSRP and PFRP equivalency. There is a qualitative correlation between the odor of stockpiled sludge and its attractiveness to vectors. A finding of no odors throughout the pile is acceptable as demonstrating that vector attraction has been adequately reduced in stockpiled sludge.

Sampling and Analytical Methods

You should use accepted, state-of-the-art techniques for sampling and analyzing sludge. Important points to consider when conducting microbiological sampling include:

- The choice of sampling device should be appropriate for the physical characteristics of the sludge (viscosity and solids content).
- Effort must be made to minimize the possibility of sample contamination.
- The samples should be representative of the random and cyclic variation in sludge characteristics that occur during treatment. Representative samples can be obtained by compiling composite samples over volume (composites over time are generally *not* appropriate for microbiological sampling); by ensuring that each grab sample, or aliquot of a composite sample, is as representative as possible of the total stream flow passing the sampling point; by establishing an appropriate frequency of sampling that accounts for variation; and by taking an appropriate number of samples to account for variation.
- A minimum of nine measurements on input sludge and nine measurements on output sludge are needed to determine log reductions in the densities of viruses, pathogenic bacteria, and indicator organisms. For

absolute densities of indicator organisms in the output sludge (no. organisms/g TSS), a minimum of nine measurements are needed. If the process variability is high, more measurements should be taken. Standard deviation of the mean should be less than or equal to 0.3 $\log_{10}$ of the organism density (no./g TSS).

- A pair of input and output samples can be drawn simultaneously. However, to ensure that measurements are independent, samples should *not* be taken on successive days. At least 3 days should separate each successive pair of input and output samples.
- The sample should be taken at the point where process conditions are likely to be least favorable for microbe destruction. For example, if the process is a thermal process, the sample should be taken at the point where the temperature is lowest. If the process depends on high pH, the sample should be taken from the point where pH is lowest.
- If ambient conditions affect sludge microbial characteristics, sludge should be sampled after treatment under the least favorable conditions. (This guidance would apply, for example, to aerobic digestion, which has a low operating temperature in the winter, and thus would be expected to be least effective at reducing microorganism densities during this season.)
- Sampling, packaging, and shipping procedures should not alter the sludge character or quality.
- Proper quality assurance procedures appropriate for collecting samples for microbiological analysis should be defined and adhered to.

The draft *POTW Sludge Sampling and Analysis Guidance Document* (EPA, 1988a) provides guidance on sampling and quality control procedures. (The document *Sampling Procedures and Protocols for the National Sewage Sludge Survey* [EPA, 1988b] also provides information on sludge sampling; however, its relevancy to microbiological sampling is limited since it focuses on sampling sludge for toxic chemicals.)

Table 6-3 lists some recommended procedures for analysis of municipal wastewater sludge.

Data Quality

The quality of the data you provide will be an important factor in EPA's equivalency determination. You can help ensure the quality of your data by using accepted, state-of-the-art sampling and analytical techniques such as those described above; obtaining samples that are representative of the expected variation in sludge quality; developing and following quality assurance procedures for sampling; and using an independent, experienced laboratory to perform the analysis.

Since processes differ widely in their nature, effects, and processing sequences, the experimental plan to demonstrate that your process meets the requirements for PSRP or PFRP equivalency must be tailored to the process. Field verification and documentation by independent or third-party investigators is desirable. EPA will evaluate the study design, the accuracy of the data, and the adequacy of the results for supporting the conclusions drawn.

Can Pilot-scale Data Be Submitted?

Operation on a full-scale is desirable. However, if a pilot-scale operation truly simulates full-scale operation, testing on this reduced scale is possible. In such cases, you should indicate that the data were provided from a pilot-scale operation, and you should discuss why and to what extent you think that this simulates full-scale operation. For example, include any data available from existing full-scale operations.

It is critical that the conditions of the pilot-scale operation be at least as severe as those of full-scale operation. The arrangement of process steps, degree of mixing, nature of the flow, vessel sizing, proportion of chemicals used, etc. are all part of the requirement. Any substantial degree of departure in process parameters that might reduce the severity of the procedure will invalidate any approvals given and will require a retest at the new condition.

How Do I Prepare an Application for Equivalency?

The following outline and instructions are provided as a guideline for preparing applications for equivalency.[7] Be sure to include all the information discussed below that may be relevant to demonstrating equivalency for your particular process. Inadequate information may substantially delay the review process.

Summary Fact Sheet

As part of the application, you *must* submit a brief fact sheet that summarizes key information about your process. Refer to Appendix E for guidance on what to include in the fact sheet. Provide any additional facts you feel are important if they are not included on the sample fact sheet in Appendix E.

Introduction

Provide the full name of the facility and the treatment process. Indicate whether you are applying for:

- Equivalency for a process or for stockpiled sludge.
- PSRP or PFRP equivalency.
- Site-specific or national equivalency.

Process Description

Describe the type of sludge used in the process. Describe other materials used in the process. Provide specifications for these materials as appropriate. Provide definitions for any terms used. Break the process down into key steps. Graphically display these steps in a quantified flow diagram of the wastewater and sludge treatment processes. Provide details of the wastewater treatment

[7] Your Regional and State Sludge Coordinators may have additional guidance on preparing an application in the form of memos and other guidance from the Pathogen Equivalency Committee issued subsequent to publication of this document. It is advisable to contact them to obtain the latest information before preparing your application.

process. Define precisely which steps constitute the beginning and end of sludge treatment.[8] The earliest point at which treatment can be defined as beginning is the point at which the sludge is collected from the wastewater treatment process. For sludges with a high potential for regrowth, such as heat-treated sludges, the end of treatment should be as close as possible to the point at which the treated sludge leaves the site for distribution or land application. Provide sufficient information for a mass balance calculation (i.e., actual or relative volumetric flows and solids concentration in and out of all streams, additive rates for bulking agents or other additives). Provide a description of process parameters for each step of the process, giving typical ranges and mean values where appropriate. The specific process parameters that should be discussed will depend on the type of process and should include any of the following that affect pathogen reduction or process reliability:

Sludge Characteristics

Moisture/solids content of sludge before and after treatment
Total suspended solids of sludge before and after treatment
Volatile solids content of sludge before and after treatment
Volatile suspended solids of sludge before and after treatment
Chemical characteristics (as they affect pathogen survival/destruction)
Type(s) of sludge (unstabilized vs. stabilized, primary vs. secondary, etc.)
Wastewater treatment plant performance data (as it affects sludge type, sludge age, etc.)
Sludge quantity
Sludge age
Sludge detention time

Process Characteristics

Sludge feed process (e.g., batch vs. continuous)
Organic loading rate (e.g., kg VS/m^3/day)
Operating temperature(s) (including maximum, minimum, and mean temperatures)
Operating pressure(s) if greater than ambient
Type of chemical additives and the loading rate
pH
Mixing
Aerobic vs. anaerobic
Duration/frequency of aeration
Dissolved oxygen level maintained
Residence/detention time
Depth of sludge
Mixing procedures
Duration and type of storage (e.g., aerated vs. nonaerated)

Climate

Ambient seasonal temperature range
Precipitation
Humidity

Describe how the process parameters are monitored. Describe the process uniformity and reliability. Provide actual monitoring data whenever appropriate.

If you are applying for equivalency of stockpiled sludge, describe how the sludge was produced, how long and under what conditions it has been stored, the pile volume, and the relevant sludge characteristics.

Product Description

Describe the type and use of product. Describe the product monitoring program for pathogens if you have one. How and when are samples taken? What is analyzed for? What are the results? How long has this program been in operation?

Sampling Technique(s)

The PEC will be evaluating the representativeness of the samples and the adequacy of the sampling and analytical techniques. For both PSRP and PFRP equivalency, samples must be taken before and after the process. The sampling points should correspond to the beginning and end of the treatment process as defined previously under *Process Description*. Samples should be representative of the sludge product in terms of location of collection within the sludge pile or batch. The samples taken should include samples from treatment under the least favorable operating conditions that are likely to occur, e.g., wintertime. Describe:

- Where the samples were collected from within the sludge mass. (If samples were taken from a pile, include a schematic of the pile and indicate where the subsamples were taken.)
- Date and time the samples were collected. Discuss how this timing relates to important process parameters (e.g., turning over, beginning of drying, etc.).
- Sampling method used.
- How any composite samples were compiled.
- Total suspended solids (TSS), volatile solids (VS), and volatile suspended solids (in mg/l) of each sample.
- Ambient temperature at time of sampling.
- Temperature of sample at time of sampling.
- Sample handling, preservation, packaging, and transportation procedures.
- The amount of time that elapsed between sampling and analysis.

Spiking

If you want to demonstrate equivalency to PFRPs and the untreated sludge contains low levels of *Salmonella* spp., total enteroviruses, or *Ascaris* spp. ova, you will have to spike the untreated sludge with the pathogen(s) just prior to treatment to ensure sufficient levels to demonstrate pathogen destruction (see footnote 1, p. 29). Spiking will generally be necessary for enteroviruses and *Ascaris* eggs, since these are normally found in low densities in sludge. Eggs for this purpose should be eggs obtained from fecal discharges of humans or pigs (not milked from "gravid" worms) since these eggs will have developed maximum hardiness. The added eggs should be thoroughly blended into the sludge. This is best accomplished before the sludge is dewatered. However, if the sludge is being chemically conditioned for dewatering

[8]When defining which steps constitute your "treatment process," bear in mind that all steps included as part of a process equivalent to PSRPs or PFRPs must be continually operated according to the specifications and conditions that are critical to pathogen destruction and reduction of vector attraction. Thus, the operational and monitoring burden may be greater for a multi-step process.

and this conditioning is severe (e.g., lime conditioning) and has not been defined as part of the sludge treatment process, the blending may have to be done afterwards.

Analytical Methods

Identify the analytical techniques used and the laboratory(s) performing the analysis.

Analytical Results

Summarize the analytical results, preferably in tabular form. Provide a discussion of the results and a summary of major conclusions. Where appropriate, present the results graphically. Provide copies of original data in an Appendix.

Quality Assurance

Describe how you have assured the quality of the analytical data. Subjects appropriate to address are: Why your sample(s) are representative; your quality assurance program; the qualifications of your laboratory or the contract laboratory used; and the rationale for selecting your sampling and analysis technique (if it was not one recommended in this document).

Reduction of Vector Attraction

Describe the ability of your process to reduce the attractiveness of the sludge to vectors (see Table 6-2 for a description of ways to demonstrate reduction of vector attraction). If you used the criterion of volatile solids reduction to demonstrate reduction of vector attraction, you must describe how the VS reduction was calculated. Appendix D provides guidance on calculating VS reduction.

Rationale for Why Process Should Be Determined PSRP or PFRP Equivalent

Describe why you think your process qualifies for PSRP or PFRP equivalency. Provide complete references for any data that you cite. You may wish to describe or review particular aspects of the process that contribute to pathogen reduction and/or vector attraction, and why you are confident that the process will operate consistently. If you are applying for national approval, discuss why you expect that process effectiveness will be independent of the location of operation.

Appendices

If you have provided sampling and analytical data, attach a copy of the complete laboratory report(s) as an appendix. Attach any important supporting literature references as appendices.

Examples of Approvals

Table 6-1 lists processes that have been found by the PEC to be equivalent to PSRPs or PFRPs. Three of these processes are discussed below.

Raising Sludge pH Using an Alternative Chemical

A Texas-based company requested approval of a treatment process as a PSRP. The process was similar to lime stabilization except that cement kiln dust was used instead of lime to raise sludge pH. The data provided by the applicant showed that the process reliably raised sludge pH to greater than 12 for at least 2 hours, so the PEC found that the process was equivalent to PSRPs.

Use of a Chemical to Generate Heat for "Composting"

The Scarborough Sanitary District in Maine requested approval of their sludge treatment process as a PFRP. The process was described as composting using fly ash as a bulking agent. The applicant provided time and temperature data demonstrating that the piles reached temperatures of 60° to 70°C (140° to 158°F) within 24 hours and maintained them for up to 14 days. The process exceeded the PFRP requirements for static aerated pile composting. However, the PEC found that the process might not in fact be a composting process since it worked by adding an inorganic agent (fly ash) that produced high temperatures. The regulatory requirements for composting were based on the generation of heat by the biological processes that occur when an *organic* bulking agent is used. Thus, a determination of equivalency was necessary.

The applicant provided information on the location of the samples from the compost pile, so that the PEC could determine that sufficient temperatures were maintained throughout the pile to provide adequate pathogen destruction. The applicant demonstrated that the product would not attract vectors because it was dry and would not putrefy. The PEC found that the process was equivalent to PFRPs because it met the regulatory PFRP operating conditions for composting.

Combined Anaerobic Digestion and Solar Drying

The Miami-Dade Water and Sewer Authority requested PFRP approval for a combination process involving anaerobic digestion followed by solar drying. In this process, sludge is anaerobically digested for 30 days at temperatures of 35° to 37°C (95° to 99°F). After centrifugation, the sludge is dried for 30 days on a paved bed at a depth of no more than 46 cm (18 inches). The drying process is a batch process.

Microbiological analysis of the sludge showed that the drying process caused reductions in bacteria, viruses, and helminth ova that met or exceeded PFRP criteria. However, the process depends on natural conditions (sunlight, ambient temperature, and precipitation) that cannot be controlled. The PEC was therefore unable to approve the process as a PFRP on the basis of a technology description alone, since the operator could not guarantee that the process would always meet the necessary operating conditions. Instead, the PEC required monitoring of each batch of treated sludge.

Because this treatment process involved biological treatment, desiccation, and elevated temperatures, there was likely to be some correlation between indicator organism densities and reduction of pathogenic bacteria and viruses. The PEC therefore approved the substitution of fecal indicator densities for expensive and technologically complex viral and bacterial pathogen tests; however, specific tests for helminth ova were required. The PEC specified the number, frequency, and location of samples required for monitoring. The PEC also specified operational procedures that the process must follow to

maximize pathogen destruction. When operational requirements are followed *and* the product meets the monitoring requirements, the process is considered a PFRP. If either requirement is not met, the process is not a PFRP and the resulting sludge cannot be utilized as such.

7. Relationship Between the Proposed 503 Sludge Land Application Regulations and the PEC's Criteria for Equivalency

Introduction

Subpart F of the proposed Part 503 "Standards for Disposal of Sewage Sludge" (EPA, 1989b), published on February 6, 1989, describes the requirements for land application of sludge to replace the 257 regulations. The proposed 503 land application regulations are performance-based; they specify reductions and densities of pathogens that must be achieved in sludges before they are applied to land. The proposed 503 rule defines three classes of sludge: Class A, Class B, and Class C. There is a close correspondence between the proposed Class A standards and the PFRP equivalency criteria, Class B standards and the PSRP equivalency criteria, and Class C standards and the PSRP equivalency criteria for sludges produced by no primary/long sludge age (NP/LSA) treatment. Like 257, the proposed 503 regulations also specify some restrictions concerning access to and use of land where sludge has been applied, depending on sludge quality.

In part, EPA chose to propose performance-based standards rather than continue with the technology-based standards of 257 (PSRPs and PFRPs, see Chapter 3) because of the potential confusion concerning the question of equivalency. As discussed in this document, treatment technologies that are not explicitly listed under 257 as a PSRP or PFRP must reduce pathogens and vector attraction to an extent equivalent to a listed technology before the treated sludge can be applied to land. EPA felt it would be more expedient to replace the requirement of equivalency with an explicit statement of the performance requirements that sludge treatment technologies must meet. EPA developed these new proposed pathogen performance requirements based on the knowledge and experience that has been gained from implementation of the 257 regulations. Therefore, one important source for the new proposed pathogen requirements was the equivalency criteria developed by the Pathogen Equivalency Committee. Thus, there are many similarities between the proposed 503 requirements and the pathogen equivalency criteria discussed in Chapter 6.

The 503 standards described here are *proposed* standards. They will be reviewed and revised before final promulgation, currently scheduled for October 1991. Thus the final 503 standards will almost certainly differ from those described here. The extent of the differences will depend on the extent of the comments received and the revisions made.

Class A Standards

The proposed requirements for Class A sludges are similar to the criteria used by the PEC to define equivalency to PFRPs. The proposed Class A standards state that "to achieve Class A reduction, the pathogenic bacteria, viruses, protozoa, and helminth ova in the sewage sludge must be reduced to below detectable limits." Alternatively, "when the temperature of sewage sludge is raised (53°C for 5 days or 55°C for 3 days or 70°C for one-half hour) and the density of fecal coliforms and fecal streptococci (enterococci) per gram of volatile suspended solids (VSS) are each equal to or less than 100, the Class A pathogen reduction requirement are achieved." Class A sludges must also meet vector attraction reduction requirements as described below.

The proposed 503 Class A requirement to reduce pathogens to below detectable limits corresponds to the general guidance for PFRP equivalency-- that Processes to Further Reduce Pathogens must reduce pathogens to below detectable limits (Whittington and Johnson, 1985). The alternative option proposed in 503 of demonstrating an indicator organism density of equal to or less than 100 organisms/g VSS applies only to certain processes meeting the specified time and temperature requirements. This is very similar to the option of demonstrating PFRP equivalency by showing an indicator organism density of less than 100/g TSS (Figure 6-4). This option applies only to processes where there is a correlation between indicator organism reduction and reduction of pathogenic viruses and bacteria; these processes include primarily time- and temperature-controlled processes.

As with PFRP sludges, there are no access and use restrictions for Class A sludges.

Class B Standards

To achieve the proposed Class B pathogen reductions, treatment works must demonstrate either "that the treatment processes reduce the average density of pathogenic bacteria and of viruses per unit mass of volatile suspended solids in the sludge two orders of magnitude lower than those densities in the incoming wastewater or demonstrate that the densities of each of the fecal indicator organisms is 6 $\log_{10}$ or less." Class B sludges must also have reduced vector attraction as discussed below.

These proposed requirements resemble the equivalency criteria for PSRPs (Figure 6-3). The 503 requirement to demonstrate a two-order-of-magnitude (i.e., 2-log) reduction in the density of pathogenic bacteria and viruses corresponds to the PSRP equivalency requirement to demonstrate a 1-log reduction in the density of total enterovirus or *Salmonella* species (whichever is least susceptible to the process). The 1-log difference in these two requirements is because the 503 reduction is demonstrated by comparing the incoming wastewater to the treated sludge, whereas the PSRP equivalency reduction is demonstrated by comparing sludge before and after treatment. Thus, the 2-log requirement includes

reductions in pathogenic bacteria and viruses that occur during wastewater treatment.

The 503 option of demonstrating a density of 6 $\log_{10}$ (i.e., 10^6) or less in each of the fecal indicator organisms corresponds to the PSRP equivalency criteria to demonstrate an average log density of less than 6.0 for fecal coliforms and fecal streptococci in the treated sludge.

The proposed 503 requirement does not include an option corresponding to the PSRP equivalency option of demonstrating a 2-log reduction in indicator organisms. This is because the proposed 503 option to demonstrate an indicator organism density of 10^6 or less requires only half the testing necessary to demonstrate a 2-log reduction, and therefore supercedes the reduction option.

Class B sludges have use and access restrictions similar to those of PSRP sludges. These are compared in Table 7-1.

Class C Standards

The proposed Class C requirements under 503 are based on the performance of treatment works that have aerobic processes with long detention times and no primary settling processes (e.g., NP/LSA plants). The Class C pathogen reduction requirements are less stringent than the Class B requirements; consequently, the Class C use and access restrictions are more stringent than those of Class B.

The proposed 503 regulations state that "Class C pathogen reduction is achieved when processes reduce the density of bacteria and animal viruses per unit of volatile suspended solids in the sludge 1.5 orders of magnitude lower than those densities in incoming wastewater....Treatment works may also demonstrate that the density of fecal coliforms in sewage sludge does not exceed 6.3 $\log_{10}$ or less per gram of volatile suspended solids and the density of fecal streptococci (enterococci) in the sewage sludge does not exceed 6.7 $\log_{10}$ or less per gram of volatile suspended solids prior to disposal." Vector attraction must also be reduced in Class C sludges, as discussed below.

The proposed Class C requirement to show a reduction in the density of bacteria and animal viruses resembles the equivalency criteria developed by the PEC for NP/LSA processes (Figure 6-3). However, the 1.5-order-of-magnitude reduction that must be achieved under the proposed 503 regulations is higher than the reduction of 0.7 log in total enterovirus or *Salmonella* (whichever is least susceptible to the process) that must be demonstrated to meet the PSRP equivalency criteria for NP/LSA processes. This is because the 503 reduction is measured as the difference between the incoming wastewater and the treated sludge, whereas the equivalency reduction is the difference between untreated and treated sludge. Thus, the 503 requirement includes the additional pathogen reductions that can be achieved by wastewater treatment.

The proposed 503 option of demonstrating absolute densities of 6.3 $\log_{10}$ (i.e., $10^{6.3}$) or less fecal coliforms and 6.7 $\log_{10}$ (i.e., $10^{6.7}$) or less fecal streptococci in the sludge prior to disposal is similar to the PSRP equivalency option for NP/LSA sludges of demonstrating an average density of less than $10^{6.0}$ for fecal coliforms and fecal streptococci in the treated sludge from conventional processes.

Collectively, the use and access restrictions for Class C sludges are slightly more stringent than those for Class B sludges. The food crop restrictions are the same for Class B and Class C. However, both the harvesting of feed crops and the grazing of animals on land where Class C sludge has been applied are restricted for 60 days - 30 days longer than for Class B. The 12-month restriction on access to land where Class C sludge has been applied pertains to both the public *and* to agricultural workers, except personnel applying the sludge, for 12 months. These more stringent use and access requirements for Class C sludges are necessary to compensate for the reduced pathogen reduction requirements.

Reduction of Vector Attraction

All three classes of sludge must demonstrate reduction of vector attraction. Under the proposed 503 regulations, a sludge is considered to have adequately reduced vector attraction if it meets any of these six criteria:

- The volatile solids of the processed sludge are 38% lower than the volatile solids in the influent.
- A less than 15% reduction in volatile solids occurs in 40 days of additional batch digestion at mesophilic temperatures (30° to 38°C).
- The specific oxygen uptake rate of the sludge is reduced to 1 mg oxygen/hour/gram of sewage sludge solids or less. (This applies only to sewage sludge treated in aerobic processes.)
- Alkali is added to raise the pH of the sludge to 12 or above and, without the further addition of alkali, the pH remains at 12 or above for 2 hours and then at 11.5 or above for an additional 22 hours.
- The sludge is dried to a 75% solids content prior to mixing with other materials.
- The sludge is injected below the soil surface (unless the sewage sludge is intended for distribution and marketing).

These proposed requirements are very similar to the criteria established by the PEC for reduction of vector attractiveness (see Table 6-2). Some are identical. The major difference is the option, under the proposed 503 regulations, of injecting sludge below the soil surface. This is not an option under the PEC's current criteria for equivalency.

Table 7-1. Comparison of Use and Access Restrictions for PSRP Sludges and Class B Sludges

PSRP Sludges	Class B Sludges (Proposed Restrictions)
Public Access: Must be restricted for at least 12 months following sludge application.	**Public Access:** Must be restricted for 12 consecutive months following land application.
Grazing: Animals whose products are consumed by humans must not graze on the land for at least 1 month following application.	**Grazing:** Animals must not graze on agricultural land for 30 days after application of sewage sludge.
Food Crops: If the edible portion of crops for direct human consumption may come in contact with the sludge, growing of the crops must be delayed for 18 months from the time of application.	**Food Crops:** Food crops with harvested parts above the ground touching the sludge-soil mixture cannot be grown for 18 months after application of the sewage sludge. Food crops with harvested parts below the ground cannot be grown for 5 years unless it is shown that there are no viable helminth ova in the soil (in which case the waiting time shall then be 18 months).
	Feed Crops: May not be harvested for 30 days after application of sewage sludge.

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Appendix A
Determination of Residence Time for Anaerobic and Aerobic Digestion

Introduction

The PSRP and PFRP specifications in 40 CFR 257 for anaerobic and aerobic digestion not only specify temperatures but also require minimum residence times of the sludge in the digesters. The residence time is the time that the sludge particles are retained in the digestion vessel under the conditions of the digestion. The calculation of residence time is ordinarily simple but it can become complicated under certain circumstances. This presentation describes how to make this calculation for most of the commonly encountered modes for operating digesters.

Approach

The discussion has to be divided into two parts: residence time for batch operation and for plug flow and residence time for fully mixed digesters. For batch operation, residence time is obvious--it is the duration of the reaction. For plug flow, the liquid-solid mixture that makes up sludge passes through the reactor with no back or forward mixing. The time it takes to pass through the reactor is the residence time. It is normally calculated by the following equation:

$$\theta_p = V/q \quad (1)$$

where

- θ = plug flow solids residence
- V = volume of the liquid in the reactor
- q = volume of the liquid leaving the reactor

Normally volume of liquid leaving equals volume entering. Conceivably, volume leaving could be smaller (e.g., because of evaporation losses) and residence time would be longer than expected if θ_p were based on inlet flow. Ordinarily, either inlet or outlet flow rate can be used.

For a fully mixed reactor, the individual particles of the sludge are retained for different time periods--some particles escape very soon after entry whereas others circulate in the reactor for long periods before escaping. The average times in the reactor is given by the relationship:

$$\theta_n = \frac{\Sigma(\delta s \times \theta)}{\Sigma(\delta s)} \quad (2)$$

where

- δs in an increment of sludge solids that leave the reactor
- θ is time period this increment has been in the reactor
- θ_n = nominal average solids residence time

When the flow rates of sludge into and out of the completely mixed vessel are constant, it can be demonstrated that this equation reduces to

$$\theta_n = \frac{VC_v}{qC_q} \quad (3)$$

where

- q = flow rate leaving
- C_v = concentration of solids in the reactor
- C_q = concentration of solids in exiting stream

It is important to appreciate that q is the flow rate leaving the reactor. Some operators periodically shut down reactor agitation, allow a supernatant layer to form, decant the supernatant, and resume operation. Under these conditions, flow rate entering is higher than flow rate of sludge leaving.

Note that in Equation 3, VC_v is the mass of solids in the system and qC_q is the mass of solids leaving. Ordinarily, $C_v = C_q$ and these terms could be canceled. They are left in the equation because it shows us the essential form of the residence time equation:

$$\theta = \frac{\text{mass of solids in the digester}}{\text{mass flow rate of solids leaving}} \quad (4)$$

Using this form we can calculate residence time for the important operating mode in which sludge leaving the digester is thickened and returned to the digester.

In many aerobic digestion installations, digested sludge is thickened with part returned to increase residence time and part removed as product. The calculation follows Equation 4 and is identical with the SRT (solids retention time) calculation used in activated sludge process calculations. We focus on the solids in the digester and the solids that ultimately leave the system. Applying Equation 4 for residence time then gives Equation 5:

$$\theta_n = \frac{VC_v}{pC_p} \quad (5)$$

where

- p = flow rate of processed sludge leaving the system
- C_p = solids concentration in the processed sludge

The subscript p indicates the final product leaving the system, not the underflow from the thickener. This approach ignores any additional residence time in the thickener since this time is relatively short and not at proper digestion conditions.

Sample Calculations

In the following paragraphs, these equations and principles presented above are used to demonstrate the

calculation of residence time for several commonly used digester operating modes:

Case 1

- Complete-mix reactors
- Constant feed and withdrawal at least once a day
- No substantial increase or decrease in volume in the reactor (V)
- One or more feed streams and a single product stream (q)

Case 1 fits the situation that the regulators had in mind when the regulation was written. The residence time desired is the nominal residence time. Use Equation 3 as shown below:

$$\theta_n = \frac{VC_v}{qC_q} = \frac{V}{q}$$

The concentration terms in Equation 4 cancel out because $C_v = C_q$

Case 2a

- Complete-mix reactor
- Vessel contains a "heel" of liquid sludge V_h at the beginning of the digestion step
- Sludge is introduced in daily batches of volume v_i and solids concentration C_i
- When final volume V_f is reached, sludge is discharged until volume V_h remains and the process starts again

Some aerobic digesters are run in this fashion. This problem is a special case of a batch reaction. We know exactly how long each day's feeding remains in the reactor. We must calculate an average residence time as shown in Equation 2:

$$\theta_n = \frac{\Sigma v_i C_i \times \text{time that batch i remains in the reactor}}{\Sigma v_i C_i}$$

The following problem illustrates the calculation:

Let V_h = 30 m³ (volume of "heel")
V_d = 130 m³ (total digester volume)
v_i = each day 10 m³ is fed to the reactor
C_i = 12 kg/m³
V_f is reached in 10 days. Sludge is discharged at the end of Day 10.

$$\text{Then } \theta_n = \frac{(10 \cdot 12 \cdot 10 + 10 \cdot 12 \cdot 9 + \cdots + 10 \cdot 12 \cdot 1)}{10 \cdot 12 + 10 \cdot 12 + \cdots + 10 \cdot 12)}$$

$$\theta_n = \frac{10 \cdot 12 \cdot 55}{10 \cdot 12 \cdot 10} = 5.5 \text{ days}$$

Notice that the volume of the digester or of the "heel" did not enter the calculation.

Case 2b

Case 2 b is the same as Case 2a except:

- The solids content of the feed varies substantially from day to day.
- Decantate is periodically removed so more sludge can be added to the digester.

The following problem illustrates the calculation:

Let V_h = 30 m³, V_d = 130 m³

Day	v_i (m³)	Solids Content (kg/m³)	Decantate (m³)
1	10	10	0
2	10	15	0
3	10	20	0
4	10	15	0
5	10	15	0
6	10	10	0
7	10	20	0
8	10	25	0
9	10	15	10
10	10	10	0
11	10	15	10
12	10	20	0

$$\theta_n = \frac{(10 \cdot 10 \cdot 12 + 10 \cdot 15 \cdot 11 + 10 \cdot 20 \cdot 10 + \cdots + 10 \cdot 10 \cdot 3 + 10 \cdot 15 \cdot 2 + 10 \cdot 20 \cdot 1)}{(10 \cdot 10 + 10 \cdot 15 + 10 \cdot 20 + \cdots + 10 \cdot 10 + 10 \cdot 15 + 10 \cdot 20)}$$

θ_n = 11,950/1,900 = 6.29 d

The volume of "heel" and sludge feedings equaled 150 m³, exceeding the volume of the digester. This was made possible by decanting 20 m³.

Case 3

Same as Case 2 except that after digester is filled it is run in batch mode with no addition or withdrawals for several days.

A conservative θ_n can be calculated by simply adding the number of extra days of running to the θ_n calculated for Case 2. The same applies to any other cases followed by batch mode operation.

Case 4

- Complete-mix reactor
- Constant feed and withdrawal at least once a day
- No substantial increase or decrease in volume in the reactor
- One or more feed streams, one decantate stream returned to the plant, one product stream. The decantate is removed from the digester so the sludge in the digester is higher in solids than the feed.

This mode of operation is frequently used in both anaerobic and aerobic digestion in small plants.

Equation 3 is used to calculate the residence time:

Let $V = 100\ m^3$

$q_f = 10\ m^3/d$ (feed stream)
$C_f = 40\ kg\ solids/m^3$
$q = 5\ m^3/d$ (exiting sludge stream)
$C_v = 60\ kg\ solids/m^3$

$$\theta = \frac{100 \times 60}{5 \times 60} = 20\ d$$

Case 5

- Complete-mix reactor
- Constant feed and withdrawal at least once a day
- Volume in digester reasonably constant
- One or more feed streams, one product stream that is thickened, some sludge is recycled and some is drawn off as product

This mode of operation is sometimes used in aerobic digesters. Equation 5 is used to calculate residence time.

Let $V = 100\ m^3$
Feed flow rate $= 10\ m^3/d$
Feed solids content $= 10\ kg/m^3$
Flow rate from the digester $= 12\ m^3/d$
Solids content of sludge from the digester $= 13.3\ kg/m^3$
Flow rate of sludge from the thickener $= 4\ m^3/d$
Solids content of sludge from the thickener $= 40\ kg/m^3$
Flow rate of sludge returned to the digester $= 2\ m^3/d$
Flow rate of product sludge $= 2\ m^3/d$

$$\theta_n = \frac{100 \times 13.3}{2 \times 40} = 16.6\ d$$

The denominator is the product of the flow rate leaving the system ($2\ m^3/d$) and the concentration of sludge leaving the thickener ($40\ kg/m^3$). Notice that flow rate of sludge leaving the digester did not enter into the calculation.

Comments on Plug Flow and Batch Operation

The above calculations of solids residence time for pathogen reduction are conservative for plug flow and batch operation. In fully mixed reactors, the sludge that exits is contaminated with pathogens in sludge that has only been in the reactor for a short time. As residence time increases, the effect of this contamination decreases. For plug flow or batch operation, this contamination does not occur. It is not yet possible to properly credit these modes of operation for this advantage. If sufficient kinetic pathogen decay data are eventually collected, it will be possible to calculate directly pathogen reductions from the kinetic rate equations for the operating mode utilized.

Appendix B
EPA Regional Sludge Coordinators[1] and Map of EPA Regions

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[1] This list was compiled in May 1989. Some names may have changed since that time.

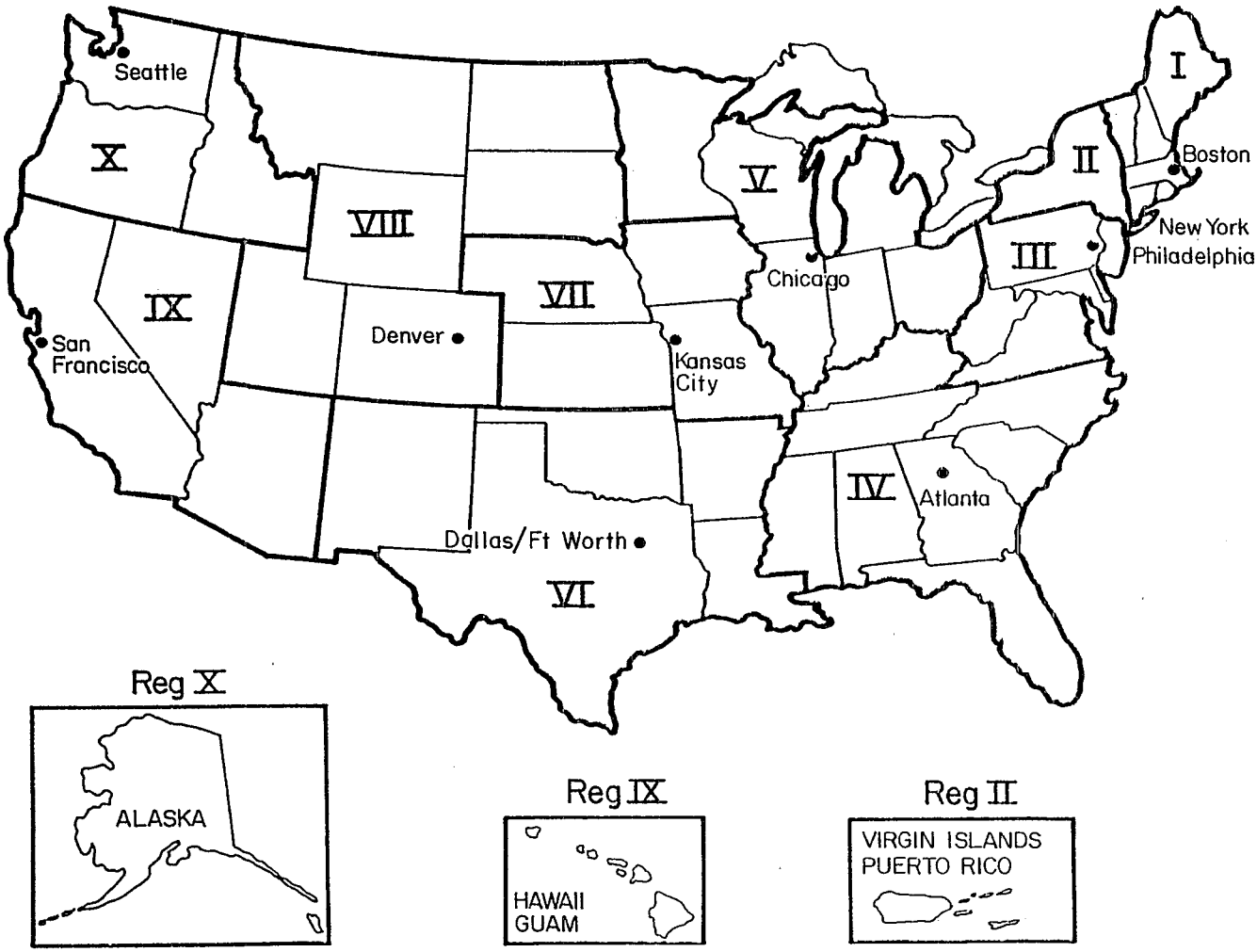

Figure B-1. EPA regions.

Appendix C
State Sludge Coordinators

Region 1

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Region 2

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Appendix D
Determination of Volatile Solids Reduction in Digestion
By J. B. Farrell

Introduction

When sewage sludge is utilized on land, Federal regulations require that it be treated by a "process to significantly reduce pathogens" (PSRP) or a "process to further reduce pathogens" (PFRP). A requirement of both of these steps is a reduction in "vector attraction" of the sludge. If the PSRP or PFRP is anaerobic or aerobic digestion, the requirement for vector attraction reduction is achieved if volatile solids are reduced by 38 percent. As Fischer[1] has noted, the Federal regulation[2] does not specify a method for calculating volatile solids reduction. Fischer observed that the United Kingdom has a similar requirement for volatile solids reduction for digestion (40 percent), but also failed to prescribe a method for calculating volatile solids reduction. Fischer has provided a comprehensive discussion of the ways that volatile solids reduction may be calculated and their limitations. He presents the following equations for determining volatile solids reduction:

1. Full mass balance equation
2. Approximate mass balance equation
3. "Constant ash" equation
4. Van Kleeck equation

The full mass balance equation is the least restricted but requires more information than is currently collected at a wastewater treatment plant. The approximate mass balance equation assumes steady state conditions. The "constant ash" equation requires the assumption of steady state conditions as well as the assumption that ash input rate equals ash output rate. The Van Kleeck equation, which is the equation generally suggested in publications originating in the United States[3] is equivalent to the "constant ash" equation. Fischer calculates volatile solids reduction using a number of examples of considerable complexity and illustrates that the different methods frequently yield different results. He closes with the recommendation, obviously directed to rulemakers, that "if it is necessary to specify a particular value for FVSR (fractional volatile solids reduction) then the specification should indicate the method of calculation of FVSR."

Fischer's paper is extremely thorough and is highly recommended for someone trying to develop a deep understanding of potential complexities in calculating volatile solids reduction. However, it was not written as a guidance document for field staff faced with the need to calculate volatile solids reduction in their own plant. The nomenclature is precise but so detailed that it makes comprehension difficult. In addition, two important troublesome situations that complicate the calculation of volatile solids reduction--grit deposition in digesters and decantate removal--are not explicitly discussed. Consequently, this presentation has been prepared to present guidance that describes the major pitfalls likely to be encountered in calculating volatile solids reduction and assists the practitioner of digestion to the best route to take for his situation.

The recommendation of this presentation is not the same as Fischer's. He suggests that the authorities should have provided a calculation method when they required specific volatile solids reductions. From a review of Fischer's results and this presentation, it will be clear that sometimes very simple calculations will give correct results and in other cases the simple methods will yield results seriously in error. Selecting one method and requiring that it be followed is excessively restrictive. The best solution is to require that the calculation be done correctly and then provide adequate guidance. This presentation attempts, belatedly, to provide that adequate guidance.

It is important to note that the calculations of volatile solids reduction will only be as accurate as the measurement of volatile solids content in the sludge streams. The principal cause of error is poor sampling. Samples should be representative, covering the entire charging and withdrawal periods. Averages should cover extended periods of time during which changes in process conditions are minimal. For some plants it is expected that periodic checks of volatile solids reduction will produce results so erratic that no confidence can be placed in them. In this case, adequacy of stabilization can be verified by the method suggested in the text--periodically batch digest the product for 40 days. If VS reduction is less than 15%, the product is sufficiently stable.

The Equations for FVSR

The equations for fractional volatile solids reduction (FVSR) that will be discussed below are the same as developed by Fischer[1], except for omission of his "constant ash" equation. This equation gives identical results to the Van Kleeck equation so it is not shown. Fischer's nomenclature has been avoided or replaced with simpler terms. The material balance approaches are called "methods" rather than "equations." The material balances are drawn to fit the circumstances. There is no need to formalize the method with a rigid set of equations.

In the derivations and calculations that follow, both VS (total volatile solids content of the sludge or decantate on dry solids basis) and FVSR are expressed throughout as fractions to avoid the frequent confusion that occurs when these terms are expressed as percentages. "Decantate" is used in place of the more commonly used "supernatant" to avoid the use of "s" in subscripts. Similarly, "bottoms" is used in place of "sludge" to avoid use of "s" in subscripts.

The "Full Mass Balance" Method

The "full mass balance" method must be used when steady conditions do not prevail over the time period chosen for the calculation. The chosen time period must be substantial, at least twice the nominal residence time in the digester (nominal residence time = average volume of sludge in the digester ÷ average volumetric flow rate. Note: when there is supernatant withdrawal, volume of sludge withdrawn should be used to calculate average volumetric flow rate). The reason for the long time period is to reduce the influence of short-term fluctuations in feed or product flow rates or compositions. If input compositions have been relatively constant for a long period of time, then the time period can be shortened.

An example where the full mass balance method would be needed is an aerobic digester operated as follows:

1) Started with the digester 1/4 full (time zero).
2) Raw sludge is fed to the digester daily until digester is full.
3) Supernatant is periodically decanted and raw sludge is charged into the digester until not enough settling occurs to accommodate daily feeding. (Hopefully this will not occur until enough days have passed for adequate digestion.)
4) Draw down the digester to about 1/4 full (final time), discharging the sludge to sand beds.

The full mass balance is written as follows:

> Sum of total volatile solids inputs in feed streams during the entire digestion period = sum of volatile solids outputs in withdrawals of decantate and bottoms + loss of volatile solids + accumulation of volatile solids in the digester. (1)

Loss of volatile solids is calculated from Equation 1. FVSR is calculated by Equation 2:

$$\text{FVSR} = \frac{\text{loss in volatile solids}}{\text{sum of volatile solids inputs}} \quad (2)$$

The accumulation of volatile solids in the digester is the final volume in the digester after the drawdown times final volatile solids concentration less the initial volume at time zero times the initial volatile solids concentration.

To properly determine FVSR by the full mass balance method requires determination of all feed and withdrawal volumes, initial and final volumes in the digester, and determination of volatile solids concentrations on all streams. In some cases, which will be discussed later, simplifications are possible.

The "Approximate Mass Balance" Method

If volumetric inputs and outputs are relatively constant on a daily basis, and there is no substantial accumulation of volatile solids in the digester over the time period of the test, an approximate mass balance (AMB) may be used. The basic relationship is stated simply:

> volatile solids input rate = volatile solids output rate + loss of volatile solids. (3)

The FVSR is given by Equation 2.

No Decantate, No Grit Accumulation

Calculation of FVSR is illustrated for Problem 1 in Table D-1 which represents a simple situation with no decantate removal and no grit accumulation. An approximate mass balance is applied to the digester operated under constant flow conditions. Since no decantate is removed volumetric flow rate of sludge leaving the digester equals flow rate of sludge entering.

Applying Equations 3 and 2,

$$FY_f = BY_b + \text{loss} \quad (4)$$

$$\text{Loss} = 100\,(50\text{-}30) = 2000 \quad (5)$$

$$\text{FVSR} = \frac{\text{Loss}}{FY_f} \quad (6)$$

$$\text{FVSR} = \frac{2000}{(100)\,(50)} = 0.40 \quad (7)$$

Nomenclature is given in Table D-1. Note that the calculation did not require use of the fixed solids concentrations.

The calculation is so simple that one wonders why it is so seldom used. One possible reason is that the input and output volatile solids concentrations (Y_f and Y_b) may show greater coefficients of variation (standard deviation ÷ arithmetic average) than the fraction volatile solids (VS, fraction of the sludge solids that is volatile--note the difference between VS and Y).

Grit Deposition

Grit deposition can be a serious problem in both aerobic and anaerobic digestion. The biological processes that occur in digestion dissolve or destroy the substances suspending the grit and it tends to settle. If agitation is inadequate to keep the grit particles in suspension they will accumulate in the digester. The approximate mass balance can be used to estimate accumulation of fixed solids.

For Problem 1, the balance yields the following:

$$FX_f = BX_b + \text{loss} \quad (8)$$

$$(100)(17) = (100)(17) + \text{Fixed Solids Loss} \quad (9)$$

$$\text{Fixed Solids Loss} = 0 \quad (10)$$

The material balance compares fixed solids in output with input. If some fixed solids are missing, this loss term will be a positive number. Since we know that digestion does not consume fixed solids, we assume that the fixed solids are accumulating in the digester. As Equation 10 shows, the fixed solids loss equals zero. Note that for this case where input and output sludge flow rates are equal, the fixed solids concentrations are equal when there is no grit accumulation.

The calculation of fixed solids is repeated for Problem 2. Conditions in Problem 2 have been selected to show grit accumulation. Parameters are the same as in Problem 1 except for the fixed solids concentration (X_b) and parameters related to it. Fixed solids concentration in the

Table D-1. Quantitative Information for Example Problems[1,2,3]

Parameter	Symbol	Units	Problem Statement Number 1	2	3	4
Nominal residence time	θ	d	20	20	20	20
Time period for averages	-	d	60	60	60	60
Feed Sludge						
Volumetric flow rate	F	m^3/d	100	100	100	100
Volatile solids concentration	Y_f	kg/m^3	50	50	50	50
Fixed solids concentration	X_f	kg/m^3	17	17	17	17
Fraction volatile solids	VS_f	kg/kg	0.746	0.746	0.746	0.746
Mass flow rate of solids	M_f	kg/d	6700	6700	6700	6700
Digested Sludge (Bottoms)						
Volumetric flow rate	B	m^3/d	100	100		49.57
Volatile solids concentration	Y_b	kg/m^3	30	30	41.42	41.42
Fixed solids concentration	X_b	kg/m^3	17	15	23.50	23.50
Fraction volatile solids	VS_b	kg/kg	0.638	0.667	0.638	0.638
Mass flow rate of solids	M_b	kg/d	4700	4500		
Decantate						
Volumetric flow rate	D	m^3/d	0	0		50.43
Volatile solids concentration	Y_d	kg/m^3	-	-	12.76	12.76
Fixed solids concentration	X_d	kg/m^3	-	-	7.24	7.24
Fraction volatile solids	VS_d	kg/kg	-	-	0.638	0.638
Mass flow rate of solids	M_d	kg/d	-	-		

1. Conditions are steady state; all daily flows are constant. Volatile solids are not accumulating in the digester, although grit may be settling out in the digester.
2. Numerical values are given at 3 or 4 significant figures. This is unrealistic considering the expected accuracy in measuring solids concentrations and sludge volumes. The purpose of extra significant figures is to allow more understandable comparisons to be made of the different calculation methods.
3. All volatile solids concentrations are based on the total solids, not merely on the suspended solids.

digested sludge is lower than in Problem 1. Consequently, VS is higher and mass flow rate of solids leaving is lower than in Problem 1. A mass balance on fixed solids (input rate = output rate + rate of loss of fixed solids) is presented in Equations 11-13.

$$FX_f = BX_b + \text{Fixed Solids Loss} \quad (11)$$

$$\text{Fixed Solids Loss} = FX_f - BX_b \quad (12)$$

$$\text{Fixed Solids Loss} = (100)(17) - (100)(15) = 200 \text{ kg/d} \quad (13)$$

The material balance, which only looks at inputs and outputs, informs us that 200 kg/d of fixed solids have not appeared in the outputs as expected. We know that fixed solids are not destroyed and conclude that they are accumulating in the bottom of the digester. The calculation of FVSR for Problem 2 is exactly the same as for Problem 1 (see Equations 4-7) and yields the same result. The accumulation of solids does not change the result.

Decantate Withdrawal, No Grit Accumulation

In Problem 3, supernatant is withdrawn daily. Volatile and fixed solids concentrations are known for all streams but the volumetric flow rates are not known for decantate and bottoms. It is impossible to calculate FVSR without knowing the relative volumes of these streams. However they are easily determined by taking a total volume

balance and a fixed solids balance, provided it can be assumed that loss of fixed solids, i.e., accumulation in the digester is zero.

Selecting a basis for F of 100 m^3/d,

$$\text{Volume balance: } 100 = B + D \tag{14}$$

$$\text{Fixed solids balance: } 100\,X_f = BX_b + DX_d \tag{15}$$

Since the three Xs are known, B and D can be found.

Substituting 100-D for B and the values for the Xs from Problem 3 and solving for D and B,

$$(100)(17) = (100 - D)(23.50) + (D)(7.24) \tag{16}$$

$$D = 40.0\ m^3/d, B = 60.0\ m^3/d \tag{17}$$

The FVSR can now be calculated by drawing a volatile solids balance:

$$FY_f = BY_b + DY_d + \text{loss} \tag{18}$$

$$FVSR = \frac{\text{loss}}{FY_f} = \frac{FY_f - BY_b - DY_d}{FY_f} \tag{19}$$

$$FVSR = \frac{(100)(50) - (60)(41.42) - (40)(12.76)}{(100)(50)} = 0.40 \tag{20}$$

Unless information is available on actual volumes of decantate and sludge, there is no way to determine whether grit is accumulating in the digester. If it is accumulating, the calculated FVSR will be in error.

When we make the calculation shown in Equations 18-20, we assume that the volatile solids that are missing from the output streams are consumed by biological reactions that convert them to carbon dioxide and methane. We assume accumulation is negligible. Volatile solids are less likely to accumulate than fixed solids but it can happen. In poorly mixed digesters, the scum layer that collects at the surface is an accumulation of volatile solids. FVSR calculated by Equations 18-20 will be overestimated if volatile solids accumulation rate is substantial.

Decantate Withdrawal and Grit Accumulation

In Problem 4, there is suspected grit accumulation. The quantity of B and D can no longer be calculated by Equations 14 and 15 because Equation 15 is no longer correct. The values of B and D must be measured. All parameters in Problem 4 are the same as Problem 3 except measured values for B and D are introduced into Problem 4. Values of B and D calculated assuming no grit accumulation (Problem 3 – see previous section), and measured quantities are compared below:

	Calculated	*Measured*
B	60	49.57
D	40	50.43

The differences in the values of B and D are not large but they make a substantial change in the numerical value of FVSR. The FVSR for Problem 4 is calculated below:

$$FVSR = \frac{(100)(50) - (49.57)(41.42) - (50.43)(12.76)}{(100)(50)} = 0.461 \tag{21}$$

If it had been assumed that there was no grit accumulation, FVSR would equal 0.40 (see Problem 3). It is possible to determine the amount of grit accumulation that has caused this change. A material balance on fixed solids is drawn:

$$FX_f = BX_b + DX_d + \text{Fixed Solids Loss} \tag{22}$$

The fractional fixed solids loss due to grit accumulation is found by rearranging this equation:

$$\frac{\text{Fixed Solids Loss}}{FX_f} = \frac{FX_f - BX_6 - DX_d}{FX_f} \tag{23}$$

Substituting in the parameter values for Problem 4,

$$\frac{\text{Fixed Solids Loss}}{FX_f} = \frac{(100)(17) - (49.57)(23.50) - (50.43)(7.24)}{(100)(17)} = 0.100 \tag{24}$$

If this fixed solids loss of 10 percent had not been accounted for, the calculated FVSR would have been 13 percent lower than the correct value of 0.461. Note that if grit accumulation occurs and it is ignored, calculated FVSR will be lower than the actual value.

The Van Kleeck Equation

Van Kleeck first presented his equation without derivation in a footnote for a review paper on sludge treatment processing in 1945[4]. The equation is easily derived from total solids and volatile solids mass balances around the digestion system. Consider a digester operated under steady state conditions with decantate and bottom sludge removal. A total solids mass balance and a volatile solids mass balance are:

$$M_f = M_b + M_d + (\text{loss of total solids}) \tag{25}$$

$$M_f \cdot VS_f = M_b \cdot VS_b + M_d \cdot VS_d + (\text{loss of volatile solids}) \tag{26}$$

where

M_f, M_b, and M_d are the mass of solids in the feed, bottoms and decantate streams.

The masses must be mass of *solids* rather than total mass of liquid and solid because VS is an unusual type of concentration unit--it is "mass of volatile solids per unit mass of *total solids*."

It is now assumed that fixed solids are not destroyed and there is no grit deposition in the digester. The losses in Equations 25 and 26 then comprise only volatile solids so the losses are equal. It is also assumed that the VS of the decantate and of the bottoms are the same. This means that the bottoms may have a much higher solids content than the decantate but the proportion of volatile solids to fixed solids is the same for both streams. Assuming then that VS_b equals VS_d and making this substitution in the defining equation for FVSR (Equation 2),

$$FVSR = \frac{\text{Loss of vol. solids}}{M_f \times VS_f} = 1 - \frac{(M_b + M_d)\,VS_b}{M_f \times VS_f} \tag{27}$$

From Equation 25, recalling that we have assumed that loss of total solids equals loss of volatile solids,

$$M_b + M_d = M_f - \text{loss of vol. solids} \quad (28)$$

Substituting for $M_b + M_d$ into Equation 27,

$$FVSR = 1 - \frac{(M_f - \text{loss of vol. solids}) \cdot VS_b}{M_f \cdot VS_f} \quad (29)$$

Simplifying further,

$$FVSR = 1 - \frac{(1 - FVSR) \cdot VS_b}{VS_f} \quad (30)$$

Solving for FVSR,

$$FVSR = \frac{VS_f - VS_b}{VS_f - VS_f \times VS_b} \quad (31)$$

This is the form of the Van Kleeck equation found in WPCF's Manual of Practice No. 16[3]. Van Kleeck[4] presented the equation in the following equivalent form:

$$FVSR = 1 - \frac{VS_b \times (1 - VS_f)}{VS_f \times (1 - VS_b)} \quad (32)$$

The Van Kleeck equation is applied below to Problems 1-4 in Table 1 and compared to the approximate mass balance equation results:

	1	*2*	*3*	*4*
Approximate Mass Balance (AMB)	0.40	0.40	0.40	0.461
Van Kleeck (VK)	0.40	0.318	0.40	0.40

Problem 1: No decantate and no grit accumulation. Both methods give correct answers.

Problem 2: No decantate but grit accumulation. VK is invalid and incorrect.

Problem 3: Decantate but no grit accumulation. AMB method is valid. VK method is valid *only* if $VS_b = VS_d$.

Problem 4: Decantate and grit accumulation. AMB method valid only if B and D are measured. VK method is invalid.

The Van Kleeck equation is seen to have serious shortcomings when applied to certain practical problems. The AMB method can be completely reliable whereas the Van Kleeck method is useless under some circumstances.

Review and Discussion of Calculation Methods and Results

Complete Mass Balance Method

The complete mass balance method allows calculation of volatile solids reduction of all approaches to digestion, even processes where final volumes in the digester does not equal initial volume and where daily flows are not steady. A serious drawback is the need for volatile solids concentration and volumes of all streams added to or withdrawn from the digester as well as initial and final volumes and concentrations in the digester. This can be a daunting task particularly for the small plants which are most likely to run their digesters in other than steady flow modes. For plants of this kind, an "equivalent" method that shows that the sludge has undergone the proper volatile solids reduction is likely to be a better choice than trying to demonstrate 38 percent volatile solids reduction. An aerobic sludge has received treatment equivalent to a 38 percent volatile solids reduction if specific oxygen uptake rate is below a specified maximum. Anaerobically digested sludge has received treatment equivalent to a 38 percent volatile solids reduction if volatile solids reduction after batch digestion of the product sludge for 40 days is less than a specified maximum[5].

Approximate Mass Balance (AMB) Method

The approximate mass balance method assumes that daily flows are steady and reasonably uniform in composition, and that digester volume and composition do not vary substantially from day to day. Results of calculations and an appreciation of underlying assumptions show that the method is accurate for all cases, including withdrawal of decantate and deposition of grit, provided that in addition to composition of all streams the quantity of decantate and bottoms (the digested sludge) are known. If the quantities of decantate and bottoms are not known, the accumulation of grit cannot be determined. If accumulation of grit is substantial and FVSR is calculated assuming it to be negligible, FVSR will be lower than the true value. The result is conservative and could be used to show that minimum volatile solids reductions are being achieved.

The Van Kleeck Equation

The Van Kleeck equation has underlying assumptions that should be made clear wherever the equation is presented. It is never valid when there is grit accumulation because it assumes the fixed solids input equals fixed solids output. Fortunately, it produces a conservative result in this case. Unlike the AMB method it does not provide a convenient way to check for accumulation of grit. It can be used when decantate is withdrawn provided VS_b equals VS_d. Just how big the difference between these VS values can be before an appreciable error in FVRS occurs is unknown, although it could be determined by making up a series of problems with increasing differences between the VS values, calculating FRVS using the AMB method and a Van Kleeck equation, and comparing results.

The shortcomings of the Van Kleeck equation are substantial and may eventually lead to a recommendation not to use it. However, it has one strong point. The VS of the various sludge and decantate streams are likely to show much lower coefficients of variation (standard deviation ÷ arithmetic average) than volatile solids and fixed solids concentration. Review of data are needed to determine how seriously the variation in concentrations affect the confidence interval of FVSR calculated by both methods. A hybrid approach may turn out to be advantageous. The AMB method could be used first to

determine if grit accumulation is occurring. If grit is not accumulating, the Van Kleeck equation could be used. If decantate is withdrawn, the Van Kleeck equation still cannot be used unless VS_b is nearly equal to VS_d.

Average Values

The concentrations and VS values used in the equations will all be averages. For the material balance methods, the averages should be weighted averages according to the mass of solids in the stream in question. The example below shows how to average the volatile solids concentration for four consecutive sludge additions.

Addition	*Volume*	*Volatile Solids Concentration*
1	10 m^3	50 kg/m^3
2	7 m^3	45 kg/m^3
3	15 m^3	40 kg/m^3
4	12 m^3	52 kg/m^3

$$Y\,av = \frac{10 \times 50 + 7 \times 45 + 15 \times 40 + 12 \times 52}{10 + 7 + 15 + 12} = 46.3\ kg/m^3 \qquad (33)$$

For the Van Kleeck equation, the averages of VS are required. Properly they should be weighted averages based on the weight of the solids in each component of the average although an average weighted by the volume of the component or an arithmetic average may be sufficiently accurate if variation in VS is small. The following example demonstrates the calculation of all three averages.

Addition	*Volume*	*Total Solids Concentration*	*VS*
1	12 m^3	72 kg/m^3	0.75
2	8 m^3	50 kg/m^3	0.82
3	13 m^3	60 kg/m^3	0.80
4	10 m^3	55 kg/m^3	0.77

Weighted by Mass

$$VS = \frac{12 \times 72 \times 0.75 + 8 \times 50 \times 0.82 + 13 \times 60 \times 0.80 + 10 \times 55 \times 0.77}{12 \times 72 + 8 \times 50 + 13 \times 60 + 10 \times 55} \qquad (34)$$

$$= 0.795$$

Weighted by Volume

$$VS\ av = \frac{12 \times 0.75 + 8 \times 0.82 + 13 \times 0.80 + 10 \times 0.77}{12 + 8 + 13 + 10} \qquad (35)$$

$$= 0.783$$

Arithmetic Average

$$VS\ av = \frac{0.75 + 0.82 + 0.80 + 0.77}{4} = 0.785 \qquad (36)$$

In this example the arithmetic average was nearly as close as the volume-weighted average to the mass-weighted average, which is the correct value.

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5. EPA. 1989. Technical Support Document: Pathogens. Office of Water Regulation and Standards, Washington, DC.

Appendix E
Examples of Process Summary Sheets

The process summary sheets in this Appendix are provided solely to illustrate the type of information and level of detail appropriate for process summary fact sheets submitted as part of an equivalency guidance application for PSRP or PFRP. The sample sheets in this Appendix are modified from a 1980 document.[1] Therefore, the actual information provided may be out of date.

[1] EPA. 1980. Innovative and alternative technology manual. EPA Pub. No. 430/9-78-009. EPA Municipal Environmental Research Laboratory, Cincinnati, Ohio.

Composting Sludge, Static Pile — Fact Sheet

Description – Wastewater sludge is converted to compost in approximately eight weeks in a four-step process:

Preparation – Sludge is mixed with a bulking material such as wood chips or leaves, in order to facilitate handling, to provide the necessary structure and porosity for aeration, and to lower the moisture content of the biomass to 60 percent or less. Following mixing, the aerated pile is constructed and positioned over porous pipe through which air is drawn. The pile is covered for insulation.

Digestion – The aerated pile undergoes decomposition by thermophilic organisms, whose activity generates a concomitant elevation in temperature to 60°C (140°F) or more. Aerobic composting conditions are maintained by drawing air through the pile at a predetermined rate. The effluent air stream is conducted into a small pile of screened, cured compost where odorous gases are effectively absorbed. After about 21 days the composting rates and temperatures decline, and the pile is taken down, the plastic pipe is discarded, and the compost is either dried or cured, depending upon weather conditions.

Drying and Screening – Drying to 40 to 45 percent moisture facilitates clean separation of compost from wood chips. The unscreened compost is spread out with a front end loader to a depth of 12 inches. Periodically a tractor-drawn harrow is employed to facilitate drying. Screening is performed with a rotary screen. The chips are recycled.

Curing – The compost is stored in piles for about 30 days to assure no offensive odors remain and to complete stabilization. The compost is then ready for utilization as a low grade fertilizer, a soil amendment, or for land reclamation.

Modifications – 1. Extended High Pile – pile height is extended to 18 ft using a crane (still experimental). Can result in savings of space and materials. 2. Aerated Extended Pile – each day's pile is constructed against the shoulder of the previous day's pile, forming a continuous or extended pile. Can result in savings of space and materials.

Technology Status – Successfully demonstrated at four locations and projected to be capable of serving large cities. Experiments are ongoing on various operating parameters.

Applications – Suitable for converting digested and undigested sludge cake to an end product of some economic value. Insulation of the pile and a controlled aeration rate enable better odor and quality control than the windrow process from which it evolved.

Limitations – The drying process is weather-dependent and requires at least two rainless days. The use of compost on land is limited by the extent to which sludge is contaminated by heavy metals and industrial chemicals. Industrial pretreatment of wastewater treatment plant influent should increase the availability of good quality sludges for composting.

Performance – Sludge is generally stabilized after 21 days at elevated temperatures. Maximum temperatures of between 60° to 80°C are produced during the first three to five days, during which time odors, pathogens and weed seeds are destroyed. Temperatures above 55°C (131°F) for sufficient periods can effectively destroy most human pathogens. The finished compost is humus-like material, free of malodors, and useful as a soil conditioner containing low levels of essential plant macronutrients such as nitrogen and phosphorus and often adequate levels of micronutrients such as copper and zinc.

Chemicals Required – None

Residuals Generated – Final product is compost.

Design Criteria (79) – Construction of the pile for a 10 dry ton/d (43 wet tons) operation: 1. A 6-in. layer of unscreened compost for base. 2. A 94-ft loop of 4-in. dia. perforated plastic pipe is placed on top (hole dia. 0.25 in.). 3. Pipe is covered with 6-in. layer of unscreened compost or wood chips. 4. Loop is connected to a 1/3 hp blower by 14 ft of solid pipe fitted with water trap to collect condensate. 5. Timer is set for cycle of 4 minutes on and 16 minutes off. 6. Blower is connected to conical scrubber pile (2 yd^3 wood chips covered with 10 yd^3 screened compost) by 16 ft of solid pipe. 7. Sludge (wet) – wood chip mixture in a volumetric ratio of 1:2.5 is placed on prepared base. 8. A 12-in. layer of screened compost is placed on top for insulation. Air Flow: 100 ft^3/h/ton of sludge; land area requirement for 10 dry tons processed daily: 3.5 acres, including runoff collection pond, bituminous surface for roads, mixing, composting, drying, storage, and administration area. Pile dimension: 53 ft × 12 ft × 8 ft high. Population equivalent, 100,000.

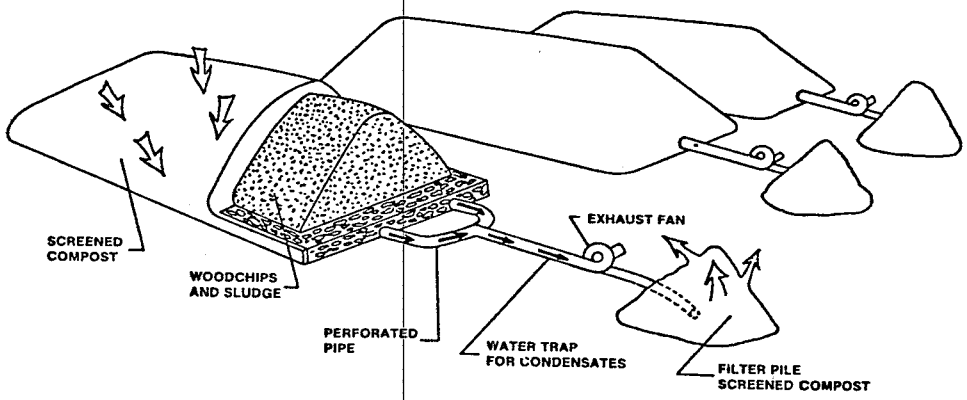
Process Reliability – High degree of process reliability through simplicity of operation. Thoroughness (percent stabilization) is a function of recycle scheme, porosity distribution in pile, and manifold design.

Toxics Management – Heavy metals entering the process remain in the final product. The degree of removal of organic toxic substances is not defined.

Composting Sludge, Static Pile

Fact Sheet

FLOW DIAGRAM



Composting Sludge, Windrow — Fact Sheet

Description – Composting is the microbial degradation of sludge and other putrescible organic solid material by aerobic metabolism in piles or windrows on a surfaced outdoor area. The piles are turned periodically to provide oxygen for the microorganisms to carry out the stabilization and to carry off the excess heat that is generated by the process. When masses of solids are assembled, and conditions of moisture, aeration and nutrition are favorable for microbial activity and growth, the temperature rises spontaneously. As a result of biological self-heating, composting masses easily reach 60°C (140°F) and commonly exceed 70°C (150°F). Peak composting temperatures approaching 90°C (194°F) have been recorded. Temperatures of 140° to 160°F serve to kill pathogens, insect larvae and weed seeds. Nuisances such as odors, insect breeding and vermin harborage are controlled through rapid destruction of putrescible materials. Sequential steps involved in composting are preparation, composting, curing and finishing.

Preparation – To be compostable, a waste must have at least a minimally porous structure and a moisture content of 45 to 65 percent. Therefore, sludge cake, which is usually about 20 percent solids, cannot be composted by itself but must be combined with a bulking agent, such as soil, sawdust, wood chips, refuse, or previously manufactured compost. Sludge and refuse make an ideal process combination. Refuse brings porosity to the mix, while sludge provides needed moisture and nitrogen, and both are converted synergistically to an end product amenable to resource recovery. The sludge is suitably prepared and placed in piles or windrows.

Composting – The composting period is characterized by rapid decomposition. Air is supplied by periodic turnings. The reaction is exothermic, and wastes reach temperatures of 140°F to 160°F or higher. Pathogen kill and the inactivation of insect larvae and weed seeds are possible at these temperatures. The period of digestion is normally about six weeks.

Curing – This is characterized by a slowing of the decomposition rate. The temperature drops back to ambient, and the process is brought to completion. The period takes about two more windrow weeks.

Finishing – If municipal solid waste fractions containing non-digestible debris have been included, or if the bulking agent such as wood chips is to be separated and recycled, some sort of screening or other removal procedure is necessary. The compost may be pulverized with a shredder, if desired.

Common Modifications – Composting by the static pile method is discussed in Fact Sheet 6.2.3. Composting within a vessel is an emerging technology.

Technology Status – Successfully demonstrated.

Applications – A sludge treatment method that successfully kills pathogens, larvae and weed seeds. Is suitable for converting undigested primary and/or secondary sludge to an end product amenable to resource recovery with a minimum capital investment and relatively small operating commitment.

Limitations – A small porous windrow may permit such rapid air movement that temperatures remain too low for effective composting. The outside of the pile may not reach temperatures sufficiently high for pathogen destruction. Pathogens may survive and regrow. Sale of product may be difficult.

Performance – Sludge is converted to a relatively stable organic residue, reduced in volume by 20 to 50 percent. The residue loses its original identity with respect to appearance, odor and structure. The end product is humified, has earthy characteristics; pathogens, weed seeds and insect larvae are destroyed.

Chemical Requirements – None

Residuals Generated – None

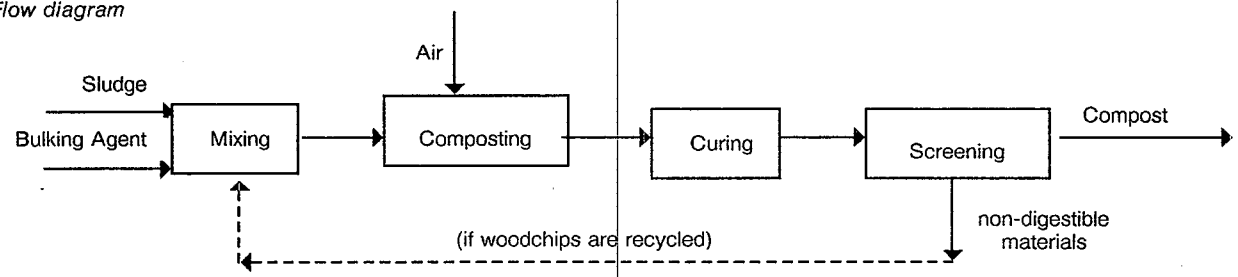
Design Criteria – Approximate land requirement: 1/3 acre/dry ton sludge daily production, which is roughly equivalent to a population of 10,000 with primary and secondary treatment. Windrows can be 4 to 8 ft high, 12 to 25 ft wide at the base, and variable length. Sludge cannot be composted by itself but must be combined with a bulking agent to provide the biomass with the necessary porosity and moisture content. Biomass criteria: moisture content, 45 to 65 percent; C/N ratio between 30 to 35:1; C/P, 75 to 150:1; air flow 10 to 30 ft^3 air/d/lb VS. Detention time, six weeks to 1 year.

Process Reliability – Highly reliable. Ambient temperatures and moderate rainfall do not affect the process.

Composting Sludge, Windrow

Fact Sheet

Flow diagram



Digestion, Aerobic — Fact Sheet

Description – Aerobic digestion is a method of sludge stabilization in an open tank that can be regarded as a modification of the activated sludge process. Microbiological activity beyond cell synthesis is stimulated by aeration, oxidizing both the biodegradable organic matter and some cellular material into CO_2, H_2O and NO_3. The oxidation of cellular matter is called endogenous respiration and is normally the predominant reaction occurring in aerobic digestion. Stabilization is not complete until there has been an extended period of primarily endogenous respiration (typically 15 to 20 days). Major objectives of aerobic digestion include odor reduction, reduction of biodegradable solids and improved sludge dewaterability. Aerobic bacteria stabilize the sludge more rapidly than anaerobic bacteria, although a less complete breakdown of cells is usually achieved. Oxygen can be supplied by surface aerators or by diffusers. Other equipment may include sludge recirculation pumps and piping, mixers and scum collection baffles. Aerobic digestors are designed similarly to rectangular aeration tanks and use conventional aeration systems, or employ circular tanks and use an eductor tube for deep tank aeration.

Common Modifications – Both one- and two-tank systems are used. Small plants often use a one-tank batch system with a complete mix cycle followed by settling and decanting (to help thicken the sludge). Larger plants may consider a separate sedimentation tank to allow continuous flow and facilitate decanting and thickening. Air may be replaced with oxygen (see Fact Sheet 6.4.3).

Technology Status – Primarily used in small plants and rural plants, especially where extended aeration or contact stabilization are practiced.

Applications – Suitable for waste primary sludge, waste biological sludges (activated sludge or trickling filter sludge) or a combination of any of these. Advantages of aerobic digestion over anaerobic digestion include simplicity of operation, lower capital cost, lower BOD concentrations in supernatant liquid, recovery of more of the fertilizer value of sludge, fewer effects from interfering substances (such as heavy metals), and no danger of methane explosions. The process also reduces grease content and reduces the level of pathogenic organisms, reduces the volume of the sludge and sometimes produces a more easily dewatered sludge (although it may have poor characteristics for vacuum filters). Volatile solids reduction is generally not as good as anaerobic digestion.

Limitations – High operating costs (primarily to supply oxygen) make the process less competitive at large plants. The required stabilization time is highly temperature sensitive, and aerobic stabilization may require excessive periods in cold areas or will require sludge heating, further increasing its cost. No useful by-products, such as methane, are produced. The process efficiency also varies according to sludge age, and sludge characteristics, and pilot work should be conducted prior to design. Improvement in dewaterability frequently does not occur.

Performance –

	Influent	*Effluent*	*Reduction*
Total solids	2 – 7%	3 – 12%	-
Volatile solids	50 – 80% of above		30 – 70% (typical 35 – 45%)
Pathogens			Up to 85%

Physical, Chemical, and Biological Aids – pH adjustment may be necessary. Depending on the buffering capacity of the system, the pH may drop below 6 at long detention times, and although this may not inhibit the process over long periods, alkaline additions may be made to raise the pH to neutral.

Residuals Generated – Supernatant Typical Quality: SS 100 to 12,000 mg/l, BOD_5 50 to 1,700 mg/l, soluble BOD_5 4 to 200 mg/l, COD 200 to 8,000 mg/l, Kjeldahl N 10 to 400 mg/l, Total P 20 to 250 mg/l, Soluble P 2 to 60 mg/l, pH 5.5 to 7.7. Digested sludge.

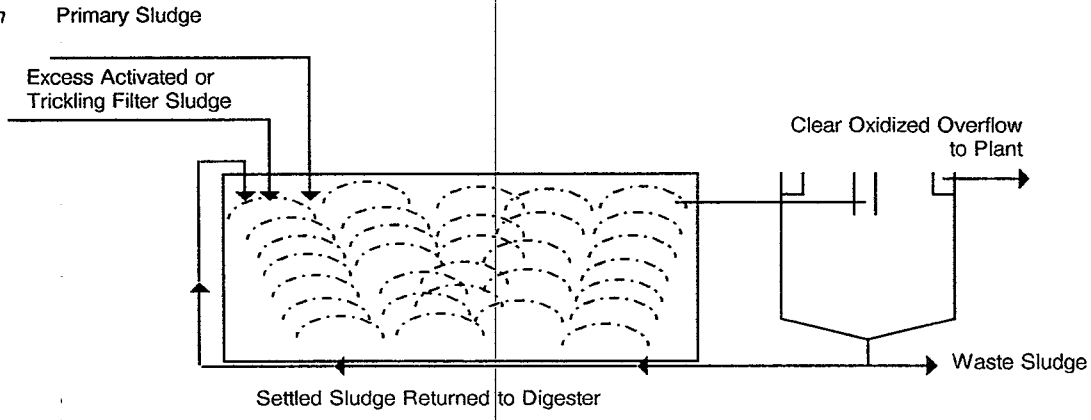
Design Criteria – Solids retention time (SRT) required for 40% VSS reduction: 18 to 20 days at 20°C for mixed sludges from AS or TF plant, 10 to 16 days for waste activated sludge only, 16 to 18 days average for activated sludge from plants without primary settling; volume allowance: 3 to 4 ft^3/capita: VSS loading: 0.02 to 0.4 lb/ft^3/d; air requirements, 20 to 60 ft^3/min/1000 ft^3; minimum DO: 1 to 2 mg/l; energy for mechanical mixing: 0.75 to 1.25 hp/1,000 ft^3; oxygen requirements: 2 lb/lb of cell tissue destroyed (includes nitrification demand), 1.6 to 1.9 lb/lb of BOD removed in primary sludge.

Reliability – Less sensitive to environmental factors than anaerobic digestion. Requires less laboratory control and daily maintenance. Relatively resistant to variations in loading, pH and metals interference. Lower temperatures require much longer detention times to achieve a fixed level of VSS reduction. However, performance loss does not necessarily cause an odorous product. Maintenance of the DO at 1 to 2 mg/l with adequate detention results in a sludge that is often easier to dewater (except on vacuum filters).

Digestion, Aerobic

Fact Sheet

Flow diagram



Digestion, Two-Stage Anaerobic — Fact Sheet

Description – A two vessel system of sludge stabilization, where the first tank is used for digestion and is equipped with one or more of the following: heater, sludge recirculation pumps, methane gas recirculation, mixers and scum breaking mechanisms. The second tank is used for storage and concentration of digested sludge and for formation of a supernatant. Anaerobic digestion results in the breakdown of the sludge into methane, carbon dioxide, unusable intermediate organics and a relatively small amount of cellular protoplasm. This process consists of two distinct simultaneous stages of conversion of organic material by acid forming bacteria and gasification of the organic acids by methane forming bacteria. The methane producing bacteria are very sensitive to conditions of their environment and require careful control of temperature, pH, excess concentrations of soluble salts, metal cations, oxidizing compounds and volatile acids. They also show an extreme substrate specificity. Can operate at various loading rates and is therefore not always clearly defined as either standard or high rate. Digester requires periodic cleanout (from 1 to 2 years) due to buildup of sand and gravel on digester bottom.

Technology Status – Widespread use (60 to 70 percent) for primary or primary and secondary sludge in plants having a capacity of 1 Mgal/d or more.

Applications – Suitable for primary sludge or combinations of primary sludge and limited amounts of secondary sludges. Digested sludge is reduced in volume and pathogenic organism content, is less odorous and easily dewatered, and is suitable for ultimate disposal. Advantages over single stage digestion include increased gas production, a clearer supernatant liquor, necessity for heating a smaller primary tank thus economizing in heat, and more complete digestion. Process also lends itself to modification changes, such as to high-rate digestion.

Limitations – Is relatively expensive, about twice the capital cost of single-stage digestion. It is the most sensitive operation in the POTW and is subject to upsets by interfering substances, e.g., excessive quantities of heavy metals, sulfides, chlorinated hydrocarbons. The addition of activated and advanced waste treatment sludges can cause high operating costs and poor plant efficiencies. The additional solids do not readily settle after digestion. Digester requires periodic cleanout due to buildup of sand and gravel on digester bottom.

Performance –

	Influent	*Effluent*	*Reduction*
Total solids	2 – 7%	2.5 – 12%	33 – 58%
Volatile solids			35 – 50%
Pathogens			85 – < 100%
Odor Reduction			–

Sidestream – Gas Production

Quantity – 8 to 12 ft^3/lb volatile solids added, or 12 to 18 ft^3/lb volatile solids destroyed or 0.6 to 1.25 ft^3/cap, or 11 to 12 ft^3/lb total solids digested.

Quality – 65 to 70% methane N_2, H_2, H_2S, NH_3, e.t al., – trace 25 to 30% CO_2 550 to 600 Btu/ft^3

Physical, Chemical, and Biological Aids – Heat; maintain pH with lime, also ammonia, soda ash, bicarbonate of soda, and lye are used; addition of powder activated carbon may improve stability of overstressed digesters; precipitate heavy metals with ferrous or ferric sulfate; control odors with hydrogen peroxide.

Residuals Generated – Supernatant – Quality: SS 200 to 15,000 mg/l, BOD_5 500 to 10,000 mg/l,, COD 1,000 to 30,000 mg/l, TKN 300 to 1,000 mg/l, Total P 50 to 1,000 mg/l, scum, sludge, gas.

Design Criteria – Solids retention time (SRT) required at various temperatures (22).

	Mesophilic Range				
Temperature, °F	50	67	75	85	95
SRT, days	55	40	30	25	20

Volume Criteria, (ft^3/capita): Primary sludge 1.3-3, Primary and Trickling Filter Sludges 2.6-5, Primary and Waste Activated Sludges 2.6-6. Tank Size (ft): diameter, 20-115; depth 25-45; bottom slope 1 vertical/4 horizontal. Solids Loading (lb vss/ft^3/d): 0.04-0.40. Volumetric Loading (ft^3/cap/d): 0.038-0.1. Wet Sludge Loading (lb/cap/d): 0.12-0.19. pH 6.7-7.6.

Overall Reliability – Successful operation subject to a variety of physical, chemical and biological phenomena, e.g., pH, alkalinity, temperature, concentrations of toxic substances of digester contents. Sludge digester biomass is relatively intolerant to changing environmental conditions. Under one set of conditions particular concentrations of a substance can cause upsets, while under another set of conditions higher concentrations of the same substance are harmless. Requires careful monitoring of pH, gas production, and volatile acids.

Miscellaneous Information – Digester gas can be used for on-site generation of electricity and/or for any in-plant purpose requiring fuel. Can also be used off-site in a natural gas supply system. Off-site use usually requires treatment to remove impurities such as hydrogen sulfide and moisture. Removal of CO_2 further increases the heat value of the gas. Utilization is more successful when a gas holder is provided.

Digestion, Two Stage Anaerobic

Fact Sheet

Flow diagram