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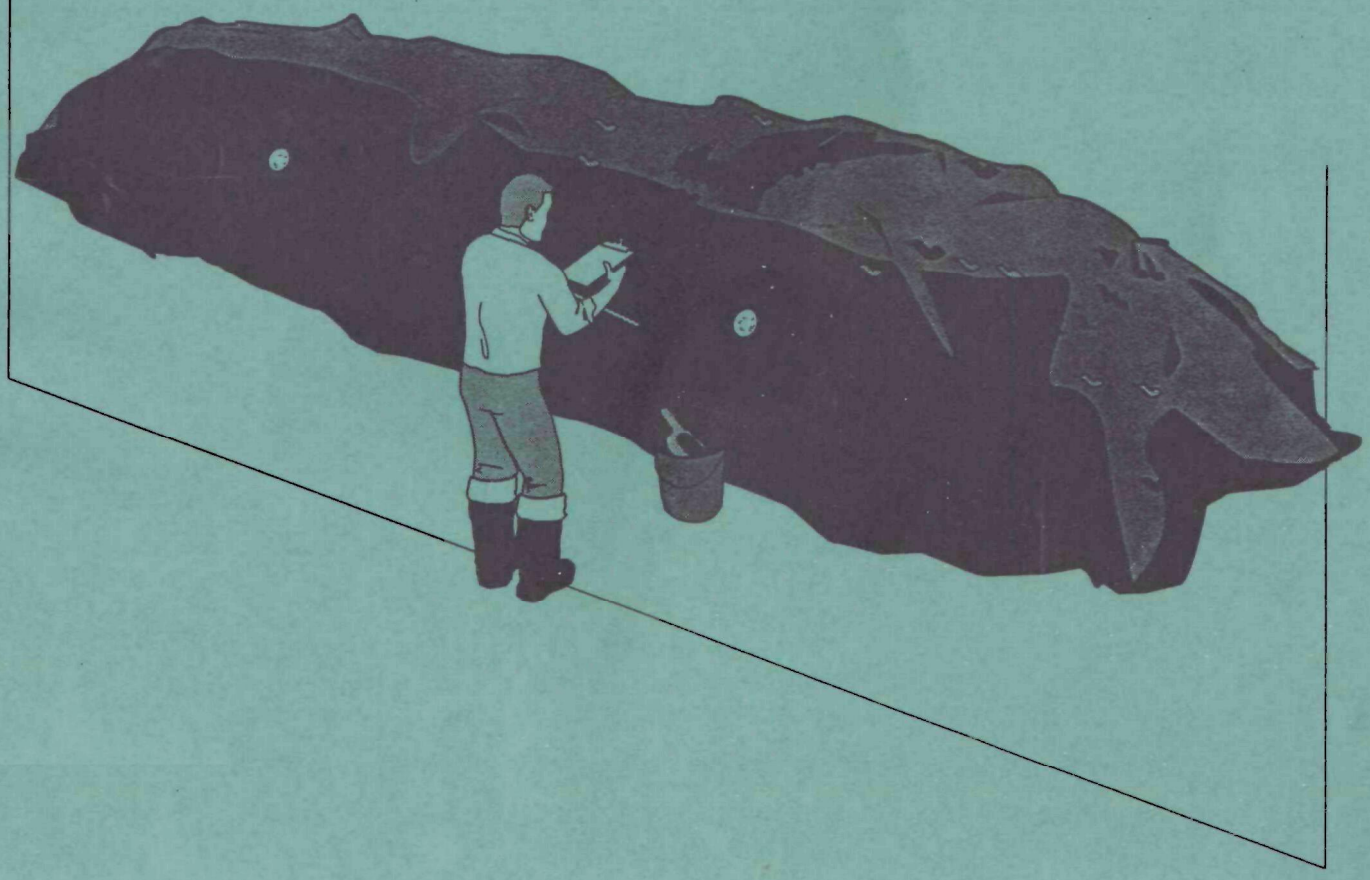
Guidance for NPDES
Compliance Inspectors

Evaluating Sludge Treatment Processes



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GUIDANCE FOR NPDES COMPLIANCE INSPECTORS: INSPECTION OF SLUDGE TREATMENT UNIT PROCESSES

November 1991

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The objective of the authors was to compile information into one reference for inspectors charged with the responsibility of evaluating sludge treatment processes. The authors drew information from many references, as indicated in the bibliography. In particular, the authors would like to acknowledge five EPA documents from which a great deal of information was excerpted in whole or in part:

- NPDES Compliance Inspection Manual
- Process Design Manual for Sludge Treatment and Disposal
- Operations Manual, Sludge Handling and Conditioning
- Field Manual for Performance Evaluation and Troubleshooting at Municipal Wastewater Treatment Facilities
- Inspectors Guide for Evaluation of Municipal Wastewater Treatment Plant

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INSPECTION OF SLUDGE TREATMENT UNIT PROCESSES

1. INTRODUCTION

This is a companion document to the guidance on evaluating compliance with sludge requirements during NPDES inspections. This document was compiled to serve as a reference providing detailed information about sludge treatment processes to NPDES inspectors. While it is not a design manual or an operation and maintenance manual, it does include a description of each process configuration and its major components. It summarizes process control considerations. This manual also contains a checklists to facilitate an evaluation of the performance of each unit process. This document covers sludge treatment processes commonly used throughout the United States. Because additional technologies are being developed or introduced from other countries, this manual will be updated periodically.

In inspecting sludge processing treatment trains, it is important that the inspector be cognizant of certain fundamentals:

- Sludge processing is an integral part of any biological wastewater treatment system. Sludge is the primary by-product of successful treatment, and efficient removal of sludge from biological treatment systems is essential to the successful operation of these systems.
  - Successful sludge processing, like successful wastewater treatment, requires the proper integration of a number of unit processes in order to effect desired change in sludge volumes and characteristics. Because of this, the inspector must go beyond the evaluation of individual unit processes and use these evaluations of the individual unit processes as the basis for an overall evaluation of the solids handling train.
- Sludge processing arguably poses the greatest challenges in wastewater treatment from the standpoints of design, operation and maintenance. As a result, shortcomings in sludge processing systems are very common. These shortcomings not only prevent compliance with 40 CFR Part 257, but they also frequently contribute to the treatment plant's noncompliance with its NPDES permit limitations.

In order to adequately assess both individual unit processes and the sludge processing train as a whole, it is necessary for the inspector to first fully understand all of the functions performed by sludge processing. The inspector must then combine this understanding with knowledge of the mechanics of inspecting and evaluating each of the individual unit processes. To assist the reader in achieving these goals the remainder of this manual is broken into separate chapters, each addressing a different sludge treatment process.

The remainder of this chapter discusses solids processing as a whole and describes the basic functions carried out by each of the general categories of unit processes. The following chapters provide an overview of the various technologies used to accomplish each basic function. Each chapter is organized to first describe the technology/unit process, and then, provide guidance to the inspector on how to go about evaluating the design, operation, and maintenance of each technology/unit process.

1.1 BACKGROUND ON SLUDGE TREATMENT

As noted previously, sludge generation is a byproduct of primary, secondary, and advanced wastewater treatment processes. In evaluating a particular wastewater treatment plant's sludge processing train, it is important to ascertain the characteristics of the sludge(s) being processed. In general, three types of raw sludge are likely to be generated by POTWs.

- Primary Sludge—This sludge consists of material removed from the raw wastewater by sedimentation. As such, raw primary sludge typically displays the following characteristics:

  - Total solids (percent of wastewater): 2 to 8
  - Volatile solids (percent of TS): 60 to 80
  - Grease content (percent of TS): 6 to 30

  Raw primary sludge is typically grey in color and has an offensive odor. It typically contains heavy solids, fecal matter, food particles, and vegetative matter.

- Secondary Sludge—This sludge consists primarily of excess microorganisms from the biological populations responsible for effecting secondary treatment. In the case of activated sludge systems, waste activated sludge (WAS) is removed from the system by the operators in order to maintain a relatively constant population size. In fixed film systems, such as trickling filters and rotating biological contractors, the sludge produced is the result of the continual sloughing of organisms from the biological "film." Typical characteristics of raw waste activated sludges are as follows:

  - Total solids (percent of wastewater): $\leq$1 percent

  - Volatile solids (percent of TS): 75 to 80 percent

  Biological sludges are brown in color, exhibit a visible floc structure, and have an inoffensive odor when fresh. Settling and compaction characteristics of waste activated sludges are poor compared to primary sludge. This is due primarily to the presence of "bound water" within the bacterial cells present in biological sludges.

- Other—Other sludges which may be encountered by the inspector may include:

  - Chemically precipitated sludges—These sludges may result from chemically assisted primary or secondary sedimentation, or from advanced wastewater treatment processes. The

characteristics of these sludges are dependent on both the unit process into which the chemical(s) are introduced and the chemical(s) used.

- Combined sludges—most commonly combined sludge consists of primary and thickened secondary sludge.

The primary goals of sludge processing are to:

1. Facilitate the removal from the treatment system the amounts of sludge necessary to allow proper, efficient treatment of wastewater.

2. Allow disposal or reuse of the sludge in an efficient, environmentally sound manner that protects both human health and impacts on the natural environment.

In order to achieve these goals, sludge processing trains typically incorporate unit processes which fall into several basic functional categories; these categories are described briefly below.

- Thickening—Carried out to increase the concentration of solids in the sludge. This is done primarily to improve the efficiency with which further processing (e.g., stabilization, dewatering) is carried out.

- Stabilization—Carried out to minimize the tendency of the sludge to putrefy following disposal in the environment, to reduce the level of pathogens in the raw sludge, and (in the case of anaerobic digestion) to produce methane gas that can be used as a fuel source.

- Conditioning—Generally practiced to improve the dewatering characteristics of the sludge.

- Dewatering—Involves the removal of a significant fraction of the liquid in the sludge. This is done to minimize the volume of sludge to be disposed, reduce the tendency for the sludge to attract disease vectors following disposal, and to meet landfill minimum moisture content limitations.

- Disinfection—Carried out to reduce the pathogen content of the sludge. Many stabilization processes also provide some degree of disinfection.

Sludge stabilization and disinfection can be completely separate processes, but frequently these functions are performed in a single process.

Figure 1 provides an overview of the various unit processes which can be used to carry out the functions described above.

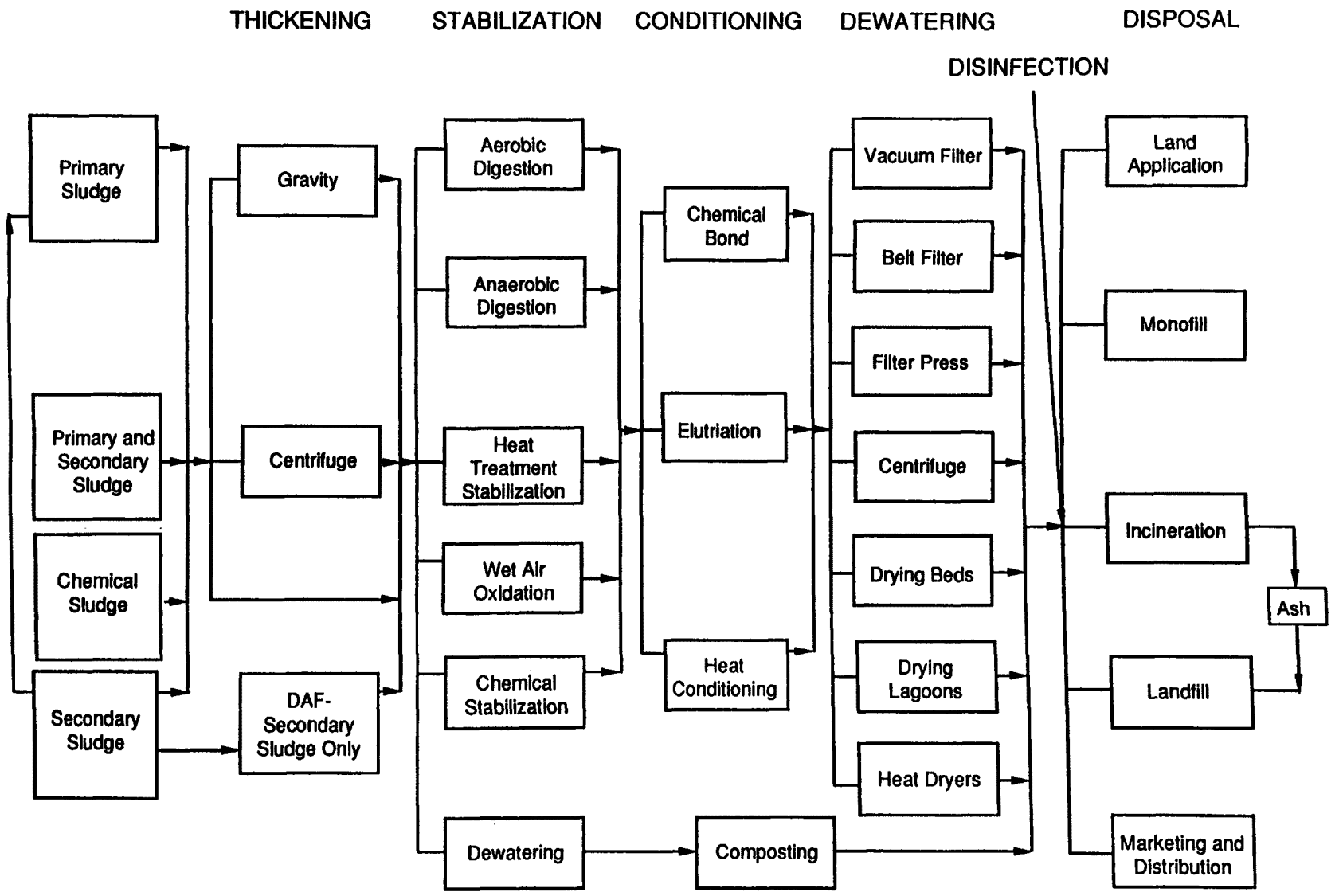

FIGURE 1. SLUDGE MANAGEMENT ALTERNATIVES

1.2 UNIT PROCESS EVALUATION

This remainder of this document provides information and guidance intended to assist the inspector in evaluating specific sludge unit processes. Processes covered are grouped according to the basic functions described in the previous section; these processes and the corresponding page designation are as follows:

Function	Page
• Thickening	
Gravity Thickening	2-1
Dissolved Air Flotation Thickening	3-1
Centrifugation	4-1
• Stabilization	
Aerobic Digestion	5-1
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Each unit process subsection provides information on the following:

- Process Configuration and Components
- Process Control Considerations
- Process Performance Evaluation

2. GRAVITY THICKENING

Gravity thickening is the most commonly used sludge concentration process in the United States. Gravity thickness are similar to sedimentation basins used in primary and secondary treatment and serve to gently agitate the sludge to aid in its concentration by promoting the release of trapped waster and gases. Thickening in a concentration technique in which relatively thin sludges such as waste activated sludges are increased in solids content in order to reduce the total sludge volume, which, in turn, allows a reduction in the size of subsequent treatment units. A tremendous reduction in volume can be achieved through a modest increase in solids content. To aid in this process, chemicals may be used to enhance the gravity thickening of waste activated sludges.

During the gravity thickening process, solids settle by gravity to the bottom of the thickener forming a sludge blanket with a partially clarified liquid or supernatant above. The supernatant flows over the effluent weirs and is returned to the treatment plant headworks. Thickening takes place as the sludge particles compact at the bottom of the tank. As the drive unit turns the sludge collection mechanism the blanket is gently stirred, which helps compact the sludge solids and release water from the mass. Sludge solids are scraped toward a center well and withdrawn.

The efficiency of a gravity thickener is influenced by the following sludge characteristics:

- Type of sludge
- Age of sludge
- Sludge temperature
- Solids concentration.

Both the type and age of sludge to be thickened can have pronounced effects on the overall performance of gravity thickeners. Fresh primary sludge usually can be concentrated to the highest degree. If the primary sludge is septic or allowed to go anaerobic, hydrogen sulfide (H_2S), methane (CH_4), and carbon dioxide (CO_2) gases may be produced (gasification). If gas is produced, it will attach to sludge particles and carry these solids to the surface. The net effects of gas production due to anaerobic conditions will be reduced thickener efficiency and solids concentration, and increased sludge volumes.

Biological secondary sludges are not as well suited for gravity thickening as primary sludge. Secondary sludges contain large quantities of microorganisms. These biological solids are composed of approximately 85 to 90 percent water by weight within the cell mass. The "bound" water contained within the cell wall makes the sludge less dense than primary sludge solids. Therefore, gravity thickening of only biological secondary sludge is rarely, if ever, practiced. More commonly, biological secondary sludge is combined with primary sludge prior to gravity thickening.

The fact that biological solids contain large volumes of cell water and are often smaller or finer in size than primary sludge solids makes them harder to separate by gravity concentration. The age of the biological secondary sludge also plays an important role in the efficiency of the gravity thickening process. Generally, as the age of the biological secondary sludge increases, nitrate levels in the sludge will also increase. If this sludge is retained under anoxic conditions (as is likely in gravity thickeners), denitrification will occur and result in rising solids and excessive solid concentrations in the thickener overflow. If the "old" sludge is kept in an aerobic condition, it will thicken more readily than a younger sludge. One method of ensuring that a gravity thickener remains aerobic is through the addition of "dilution" water. This is a clear, relatively high dissolved oxygen (DO) water (typically plant effluent) that acts to provide needed oxygen to the thickener.

One other problem associated with activated sludge is "sludge bulking." A predominance of filamentous organisms in the sludge results in a bulking sludge which settles and compacts poorly. This in turn results in lower solids concentrations and the increased likelihood of solids loss from the gravity thickener. Low pH, low DO, and/or low nutrients may cause growth of filamentous organisms in the aeration tanks.

Another sludge characteristic which affects the degree of thickening is the temperature of the sludge. As the temperature of the sludge (primary and biological secondary) increases, the rate of biological activity is increased and the sludge tends to gasify and rise at a faster rate. During warm weather operation the settled sludge has to be removed at a faster rate from the thickener than during cold weather operation. When the sludge temperature is lower during the winter, biological activity and gas production proceed at a lower rate.

2.1 PROCESS CONFIGURATION AND COMPONENTS

Gravity thickeners are typically circular and resemble circular clarifiers. The main components of gravity thickeners, as shown in Figure 2 are:

- Inlet and distribution assembly
- Sludge rake to move the sludge to a sludge hopper
- Vertical steel members or "pickets" mounted on the sludge rake
- Effluent or overflow weir
- Scum removal equipment.

The inlet or distribution assembly usually consists of a circular steel skirt or baffle which originates above the water surface and extends downward approximately 2 to 3 ft. below the water surface. The sludge to be thickened enters the assembly, and flows downward under the steel skirt and through the tank where the solids settle to the bottom. The inlet assembly provides for an even distribution of sludge throughout the tank and reduces the possibility of short-circuiting to the effluent end of the thickener.

The sludge rake provides for movement of the settled (thickening) sludge. As the rake slowly rotates, the settled solids are moved to the center of the tank where they are deposited in a sludge hopper. The tank bottom is usually sloped towards the center to facilitate the movement of sludge to the collection point. Typically, sludge pumps used to remove the thickened sludge from the collection point include centrifugal recessed-impeller type pumps or positive displacement type pumps.

The vertical steel members (pickets) that are usually mounted on the sludge rake assembly provide for gentle stirring or flocculation of the settled sludge as the rake rotates. This gentle stirring action serves two purposes. Trapped gases in the sludge are released to prevent rising of the solids. Also, stirring prevents the accumulation of a large volume of solids floating on the thickener surface that must be removed as scum, and which will create nuisance and odor problems.

The effluent or thickener overflow flows over a continuous weir located on the periphery of the thickener. This weir usually includes an effluent baffle to retain floating debris and a scum scraper and collection system to remove these floatables.

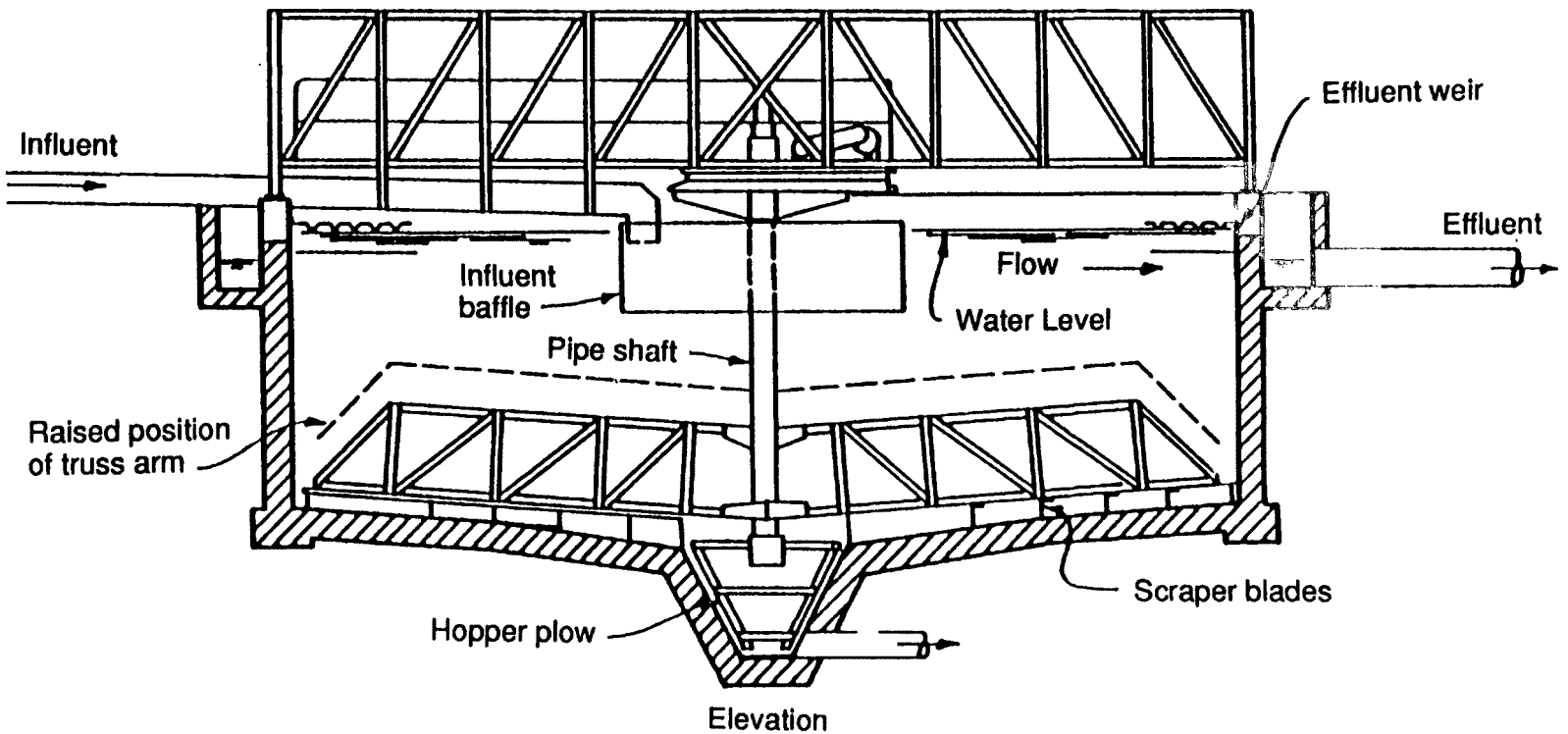


FIGURE 2. GRAVITY THICKENER

2.2 PROCESS CONTROL CONSIDERATIONS

Typically, the flow through the thickener is continuous and should be controlled to be as constant as possible. Monitoring of the influent, effluent, concentrated sludge streams, and sludge blanket depth should be done at least once per shift, and should include collection of samples for later laboratory analysis. Table 1 lists typical gravity thickener loadings and performance parameters.

Under normal operating conditions, water at the surface should be relatively clear and free from solids and gas bubbles. The sludge blanket depth is usually kept around 5 to 8 ft. The speed of the sludge collectors should be fast enough to allow the settled solids to move towards the sludge collection pump. The bottom sludge collectors should not be operated at speeds that will disrupt the settled solids and cause them to float to the surface. Sludge withdrawal rates should be sufficient to maintain a constant blanket level. Solids content in sludge withdrawn can frequently be increased by using intermittent withdrawal. This helps prevent "ratholing" or "piping".

Process controls which can affect the performance of a gravity thickener include:

- Solids and hydraulic loadings
- Solids and hydraulic detention times
- Sludge blanket depths.

2.2.1 Solids and Hydraulic Loadings

The hydraulic loading or overflow rate is the total number of gallons applied per square foot of thickener surface area per day (gpd/ft^2). The solids loading is the total number of pounds of solids applied per square foot of thickener surface area per day (lbs/day/ft^2). To achieve the optimum solids loading rate with the solids concentrations typically fed to gravity thickeners, a low hydraulic loading would be necessary. However, this low hydraulic loading causes excessive detention times, which results in septic conditions. Dilution water, provides a means to increase the hydraulic loading to the optimum hydraulic loading rate without increasing solids loading rates. As mentioned above, dilution water is also used to add oxygen to the sludge that is fed to gravity thickeners.

The solids and hydraulic loadings are affected by the efficiency of the clarifiers and the sludge wasting rates. Increased sludge wasting rates will increase the hydraulic load on the thickener. Increased efficiency of primary and secondary clarifiers will increase the solids load on the thickener.

TABLE 1. GRAVITY THICKENER TYPICAL LOADINGS AND PERFORMANCE

Sludge type	Influent Solids Concentration, (percent)	Typical Solids Loading Rate, ($lb/ft^2/day$)	Thickened Sludge Concentration, (percent)
Raw primary	2.0-5.0+	20 to 30	8.0 to 10
Raw primary + $FeCl_3$	2.0+	6	4.0
Raw primary + low lime	5.0	20	7.0
Raw primary + high lime	7.5	25	12.0
Raw primary + WAS*	2.0	6 to 10	4.0 to 9.0
Raw primary + (WAS + $FeCl_3$)	1.5	6	3.0
(Raw primary + $FeCl_3$) + WAS	1.8	6	3.6
Digested primary	8.0	25	12.0
Digested primary + WAS	4.0	15	8.0
Digested primary + (WAS + $FeCl_3$)	4.0	15	6.0
WAS	1.0	5 to 6	2.0 to 3.0
Trickling filter	1.0	8 to 10	7.0 to 10.0
Primary + trickling filter	2.0	12 to 20	5.0 to 9.0

*WAS = Waste activated sludge

2.2.2 Solids and Hydraulic Detention Times

The solids detention time is based on the amount of solids applied, the depth and concentration of the sludge blanket, and the quantity of solids removed from the bottom of the thickener. The hydraulic detention time is dependent upon the hydraulic loading. An excessive hydraulic detention time can allow septic conditions to develop and produce odors. Short detention times can cause a washout of solids and adversely affect the operation of the wastewater treatment processes. The solids detention time can be controlled by controlling the depth of the sludge blanket.

2.2.3 Sludge Blanket Depths

The sludge blanket depth influences the solids detention time and degree of thickening. If the blanket is maintained at too high a level and the solids detention time is excessive, gasification may develop with subsequent rising sludge and deterioration of effluent quality. A certain amount of blanket depth is desirable to obtain the maximum possible sludge concentration. The objective is to maintain as much depth as possible to get the highest concentration of solids without the process going septic. Operations should maintain 4-6 foot free settling zone above the sludge blanket.

2.3 PROCESS PERFORMANCE EVALUATION

When evaluating the performance of a gravity thickener the inspector should compare the actual operating conditions to recommended conditions. An inspection checklist is included in Appendix A. The inspection checklist is designed to assist the inspector in gathering the information and making the calculations required to make the comparison.

The specific areas of concern regarding gravity thickeners are:

- Surface and overflow quality
- Sludge blanket depth and thickened sludge concentrations.

The overflow should be relatively clear and the liquid surface should be free of gas bubbles. The effluent weirs should be level and free of debris. The sludge blanket depth should be deep enough to obtain a good sludge concentration but not so deep that it produces gasification.

3. DISSOLVED AIR FLOTATION THICKENING

Sludge thickening by dissolved air flotation (DAF) is a process well-suited for biological wastewater treatment sludges. In this process, solids separation/concentration is achieved by making the solids float and form a concentrated layer of sludge. DAF is especially effective on activated sludge, which is difficult to thicken by gravity because of its low specific gravity.

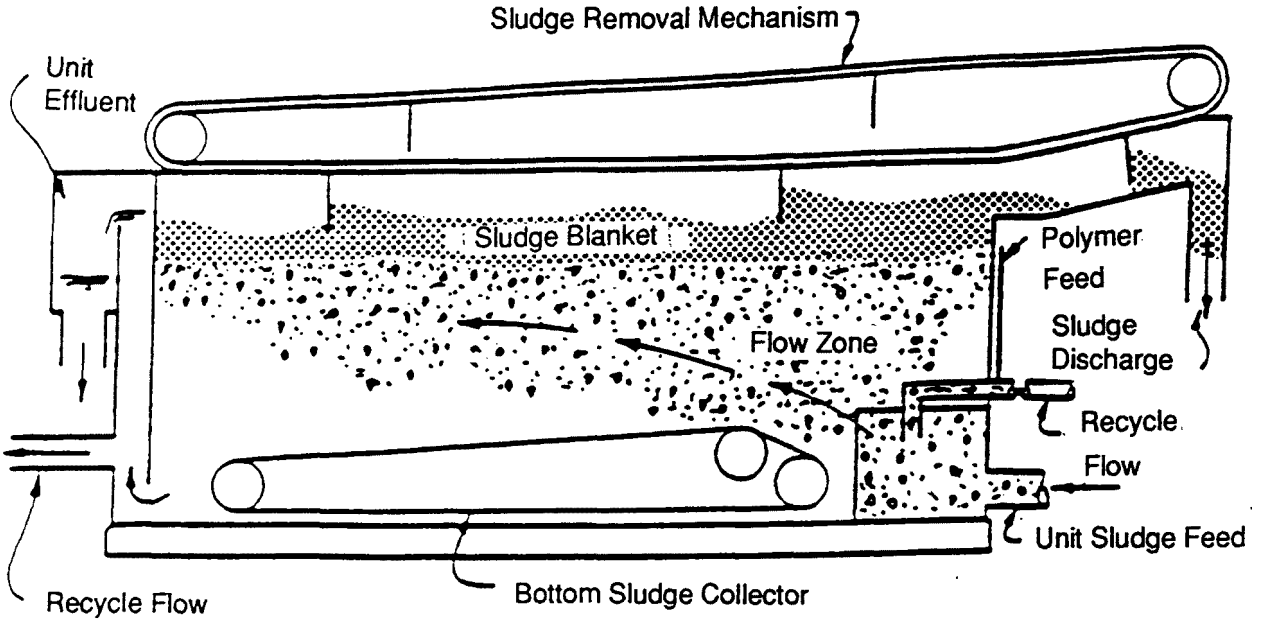
Typically, a pressurized recycle stream is saturated with air. This supersaturated stream is mixed with the sludge to be thickened at atmospheric pressure. The thousands of minute air bubbles released at atmospheric pressure from the recycle stream adhere to, or are trapped by, the biological flocs. The resulting matrix of air and solids has a bulk specific gravity of less than 1.0. This low specific gravity results in the floc rising to the surface of the thickener, where it can be removed from the liquid phase. A sludge layer 8 to 24 in. thick forms on the surface of the tank and can be removed by a skimming mechanism for further processing. Flotation aids such as polymers can be used to increase performance.

3.1 PROCESS CONFIGURATION AND COMPONENTS

Figure 3 shows a typical air flotation system. Part of the effluent from the flotation unit is pumped to a retention tank at 60 to 70 psig. Air is fed into the pump discharge line at a controlled rate and mixed by the reaeration pump. The flow through the recycle system is controlled by a valve. Effluent recycle ratios can range from 30 to 150 percent of the influent flow. The recycle flow and sludge feed are mixed in a chamber at the entrance to the unit. If flotation aids are used, they usually are fed into this mixing chamber. The sludge particles are floated to the surface and the clarified effluent or subnatant flows over a weir. The thickened sludge is removed by a skimmer. Bottom sludge collectors are used to remove any settled sludge or grit.

The dissolved air system employs either a compressed air supply or an aspirator-type air injection assembly to obtain a pressurized air-water solution. The key components of DAF thickener units are:

- Air compressor
- Pressurized retention tank
- Recycle pump



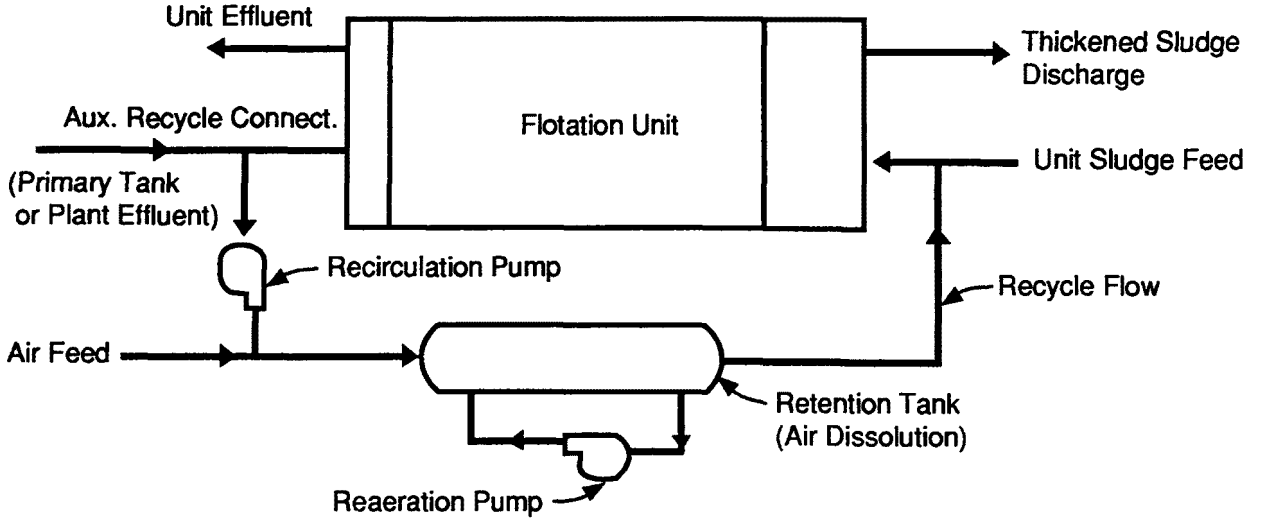


FIGURE 3. DISSOLVED AIR FLOTATION THICKENER

- Pressure release valve
- Inlet or distribution assembly
- Sludge scrapers
- Effluent baffle.

The sludge to be thickened may be introduced at the bottom of the unit, through a distribution box, and blended with a pressurized recycle stream. Alternatively, the entire influent stream is injected with air and pressurized. Compressed air is either introduced into the retention tank directly or at some point upstream of the retention tank. The pressurized and air-saturated liquid then flows to the distribution or inlet assembly and is released at atmospheric pressure through a pressure-release valve. The decrease in pressure causes the air to come out of solution in the form of thousands of minute air bubbles. These bubbles make contact with the sludge solids in the distribution box and attach to the solids, causing the solids to rise to the surface. An effluent baffle is provided to keep floated solids from going into the effluent. This baffle extends approximately 2 to 3 in. above the water surface and 12 to 18 in. below the surface. Clarified effluent flows under the baffle and leaves the unit through an effluent weir.

3.2 PROCESS CONTROL CONSIDERATIONS

Typically, the flow through the thickener is continuous and should be set to be as constant as possible. Monitoring of the influent, effluent, and float sludge streams should be done at least once per shift, and composite samples should be taken for later laboratory analysis. In addition, a jar "float" test should be performed frequently to provide a visual indicator of the influent stream's tendency to form a float layer, and of any inclination to leave fine solids in the subnatant. This test is usually performed by drawing a sample of the pressurized influent flow into a glass cylinder, and observing the formation of the float layer and clear subnatant.

Under normal operating conditions, the effluent stream should be relatively free of solids (less than 100 mg/l suspended solids) and should resemble secondary effluent. The float solids will have a consistency resembling that of cottage cheese. The depth of the float solids should extend approximately 6 to 18 in. below the surface. The surface farthest from the float solids collection should be scraped clean of floating solids with each pass of the sludge collection scrapers. If the sludge blanket is allowed to build up (become too thick) and drop too far below the surface, thickened (floated) solids will be carried under the effluent baffle and contaminate the subnatant.

Proper control of a DAF thickener is based on:

- Retention tank pressure
- Recycle ratio
- Feed solids concentration
- Detention period
- Air-to-solids ratio
- Type and quality of sludge
- Solids and hydraulic loading rates
- Use of chemical aids.

Air pressure used in flotation is important because it determines the size of the air bubbles formed and can affect the solids concentration and the subnatant (separated water) quality. Increases in pressure or air flow typically produce greater float solids concentrations and a lower effluent suspended solids concentration. There is an upper limit, however, because too much air breaks up the floc structure.

Recycle ratio and feed solids concentration are related. Additional recycle of clarified effluent does two things:

- It allows more air to be dissolved because there is more liquid.
- It dilutes the feed sludge.

Dilution reduces the effect of particle interference on the rate of separation. Concentration of sludge increases as the sludge blanket detention time increases.

The air-to-solids ratio is also important because it affects the sludge rise rate. The air-to-solids ratio is the ratio of air feed to dry sludge solids feed, by weight. The air-to-solids ratio needed depends mostly on sludge characteristics such as the sludge volume index (SVI). The most common air-to solids ratio used for an activated sludge thickener is 0.02.

The quality of the activated sludge, as well as the solids concentration, will affect the performance of the thickener. If the SVI of the activated sludge exceeds 200, the concentration of the float solids will generally decrease.

If either the solids or hydraulic loading becomes excessive, effluent quality declines and thickened sludge concentrations are reduced. Typical maximum hydraulic loading or overflow rate is 0.80 gpm/ft^2 at solids concentrations of 5,000 mg/l.

Chemical flotation aids (polymers) improve thickening and solids capture. The dosage must be determined for each specific sludge, but dosages of 5 to 15 lbs/ton of sludge solids are common.

3.3 PROCESS PERFORMANCE EVALUATION

When evaluating the performance of a DAF thickener compare the actual operating conditions to recommended operating conditions. Typical operating conditions for DAF thickeners are presented in Table 2. An inspection checklist is included in Appendix A. The inspection checklist is designed to assist the inspector in gathering the information and making the calculations required to make the comparison.

The inspector should visually inspect the effluent quality and float sludge characteristics. The effluent from the DAF units should be relatively clear. Well-operated units should produce effluents equivalent in appearance to secondary clarifier effluent. If an unusually high amount of suspended solids are exiting the unit in the effluent, the following parameters should be evaluated:

- Hydraulic and solids loading rates—Excessive loadings will cause solids to washout.
- Air to solids ratio—A low ratio will indicate an inadequate air application rate, and a high ratio will indicate an excessive air application rate. An excessive rate will sheer the sludge floc and prevent flotation.

TABLE 2. FLOTATION THICKENER OPERATION AND PERFORMANCE

Operating Parameter	Range	Typical
Solids loading, lbs dry solids/hr/ft^2 of surface		
With chemicals	2 to 5	2
Without chemicals	1 to 2	1
Influent solids concentration, mg/l	5,000 to 10,000 min.	5,000 min.
Air-to-solids ratio	0.02 to 0.04	0.03
Blanket thickness, in.	8 to 24	—
Retention tank pressure, psig	60 to 70	—
Recycle ratio, % of influent flow	30 to 150	
Expected Performance		
Float solids concentration, %		3 to 7
Solids removal, %		
With flotation aid		95
Without flotation aid		50 to 80

4. CENTRIFUGATION

Centrifugation concentrates sludge solids by increasing the gravitational force. As sludge is rotated in the centrifuge, solids, which are heavier than water, are sedimented. Centrifuges may be used as thickening devices for activated sludge or as dewatering devices for digested or conditioned sludges. Waste activated and digested sludges, which have a specific gravity similar to water due to their high content of biological cell-bound water, are not amenable to some types of thickening/dewatering processes. Centrifugation achieves particle separation by enhancing the difference in specific gravity between the sludge solids and water.

4.1 PROCESS CONFIGURATION AND COMPONENTS

Three types of centrifuges (solid bowl, basket, disc) are typically used to thicken or dewater wastewater sludges. The following section discusses the basic operation of each type of centrifuge.

The continuous-feed, solid-bowl, decanter centrifuge (or solid-bowl centrifuge) is the most widely used type of centrifuge for dewatering sewage sludge (Figure 4), because it operates in a continuous flow-through mode and because it has a low cost/capacity ratio. The solid bowl centrifuge consists of a rotating bowl having a cylindrical-conical shape and a screw conveyor. Sludge enters the rotating bowl through a stationary feed pipe that extends into the hollow shaft of the rotating screw conveyor, and is distributed through ports into the rotating bowl. The gravitational force causes the solids to settle out on the inner surface of the rotating bowl. The screw conveyor moves the sludge solids across the bowl, up the inclined beach (conical section of bowl) and to the outlet ports. The lighter liquid, or centrate, pools above the sludge layer and flows towards the centrate outlet ports located at the large end of the machine. The pool depth is maintained by baffles located before the centrate outlet ports.

The basket centrifuge is also referred to as the imperforate-bowl, knife-discharge type, and is a batch dewatering unit that rotates around the vertical axis (Figure 5). Sludge is fed into the unit at the bottom center of the bowl through a stationary feed pipe. Sludge solids form a cake on the inside of the rotating bowl while centrate flows over the top lip of the bowl. The duration of the feed time is

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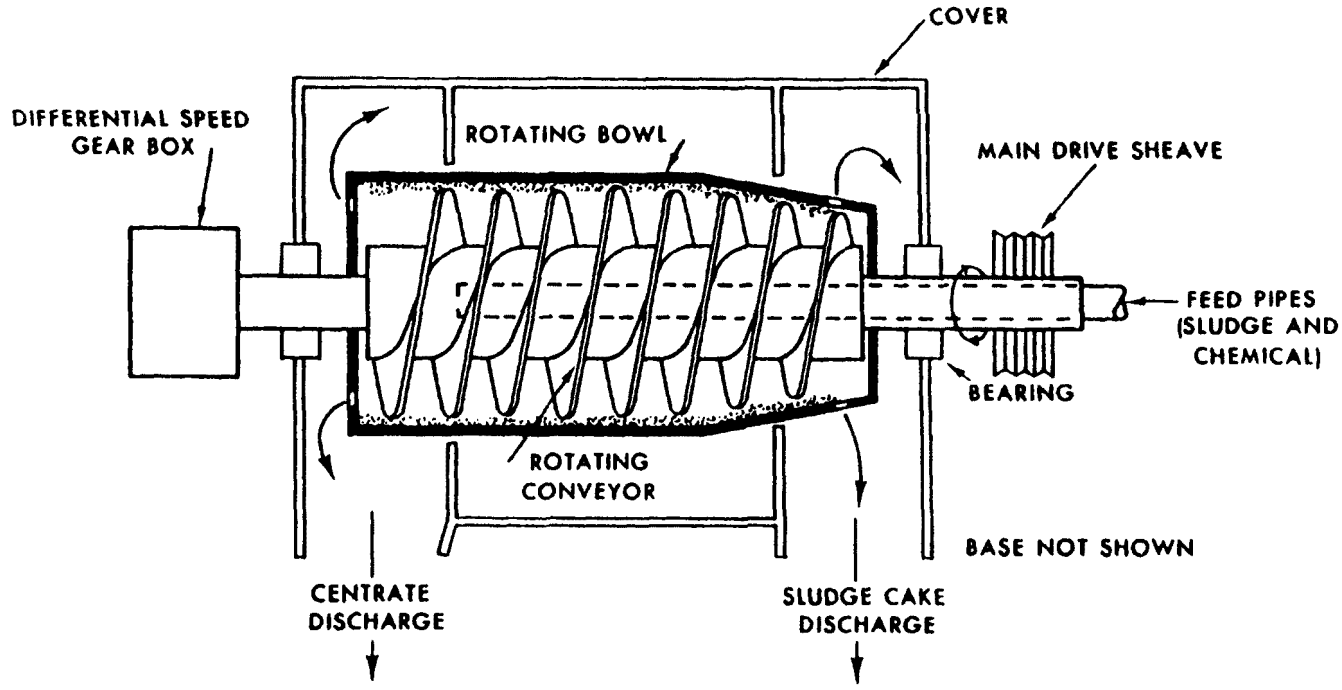


FIGURE 4. CONTINUOUS COUNTERCURRENT SOLID BOWL CONVEYER DISCHARGE CENTRIFUGE

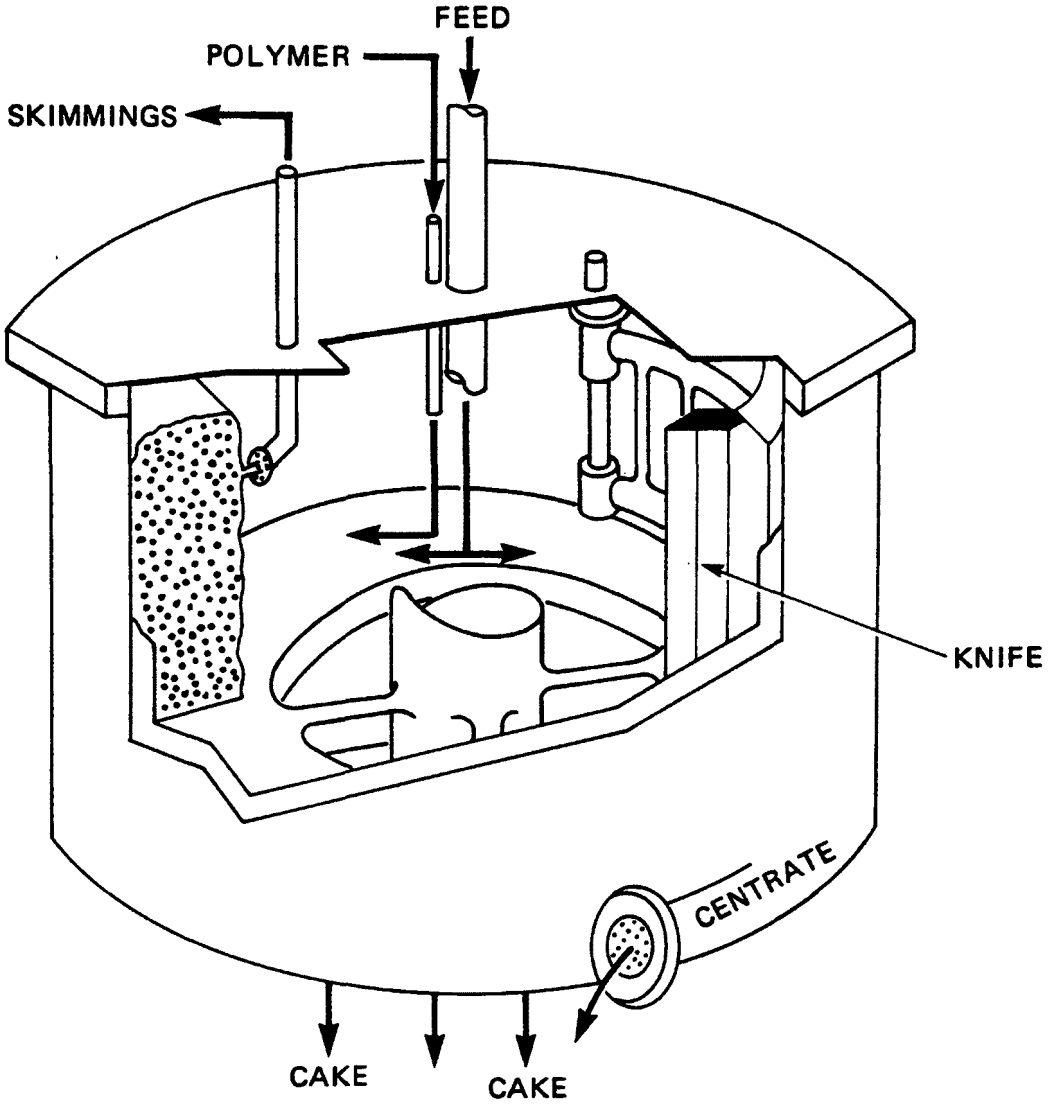


FIGURE 5. GENERAL SCHEMATIC OF IMPERFORATE BASKET CENTRIFUGE

controlled by either a preset timer or a centrate monitor. The centrate monitor shuts the feed pump off when a certain level of suspended solids appears in the centrate. Deterioration in the centrate indicates that the centrifuge bowl is filled with solids, and separation can no longer take place.

Once the feed is stopped the bowl begins to decelerate. When the bowl has decelerated to a certain point a plow is activated and scrapes the solids from the bowl wall. The solids drop out the bottom into a hopper, the plow retracts, and the bowl accelerates, starting a new cycle.

Figure 6 features a cut-away view of a disc nozzle centrifuge. The feed normally enters through the top (bottom feed is also possible) and passes down through a feedwell in the center of the rotor. An impeller within the rotor accelerates and distributes the feed slurry, filling the rotor interior. The heavier solids settle outward toward the circumference of the rotor under increasingly greater centrifugal force. The liquid and the lighter solids flow inward through the cone-shaped disc stack. These lighter particles are settled out on the discs, and migrate out to the nozzle region. The clarified liquid passes on through the disc stack into the overflow chamber and is then discharged through the effluent line.

The centrifugal action causes the solids to concentrate as they settle outward. At the outer rim of the rotor bowl, the high energy imparted to the fluid forces the concentrated material through the rotor nozzles. One part of this concentrated sludge is drawn off as the thickened product and another is recycled back to the base of the rotor and pumped back into the concentrating chamber; there, it is subjected to additional centrifugal force and is further concentrated before it is once again discharged through the nozzles. This recirculation is advantageous because it increases the overall underflow by flushing action; allows the use of larger nozzles, thus decreasing the potential for nozzle plugging; and helps achieve a stable separation equilibrium that lends itself to precise adjustment and control.

Nozzle wear can be a major problem with this process. Grit in the sludge greatly accelerates nozzle deterioration. Grit removal prior to centrifuging is very important.

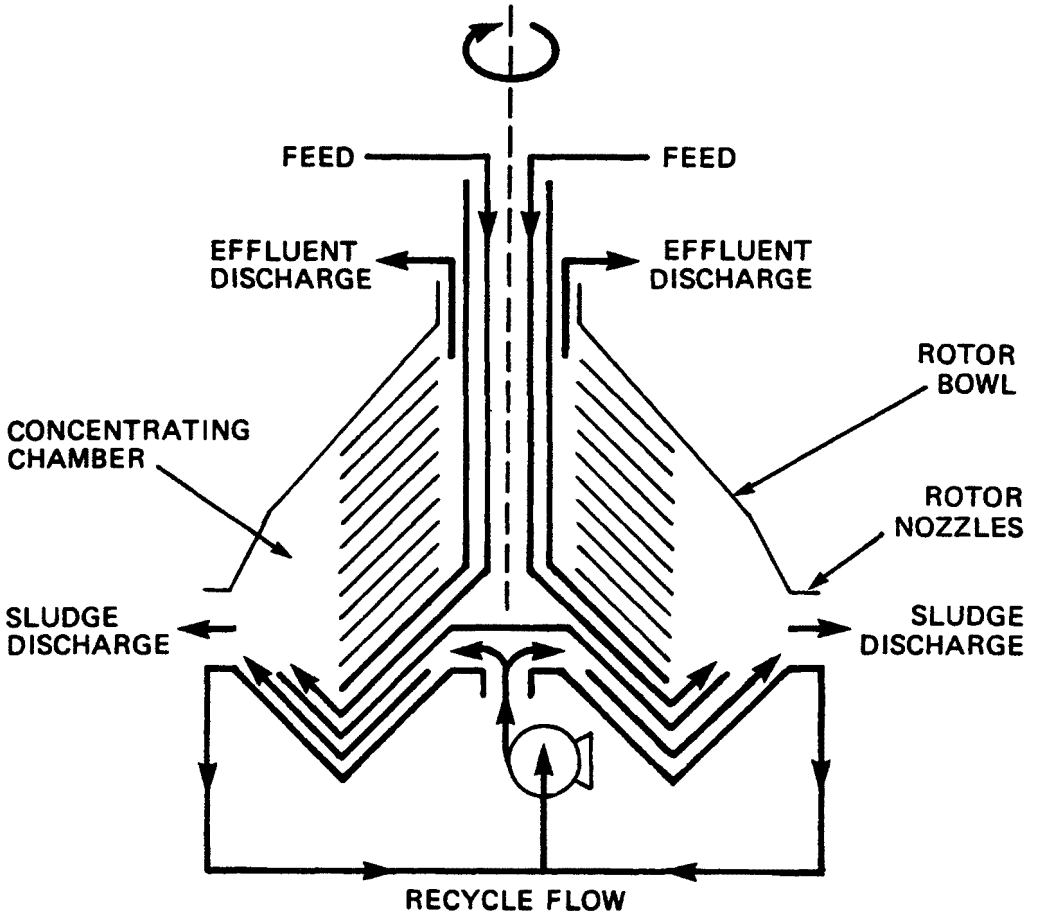


FIGURE 6. SCHEMATIC OF A DISC NOZZLE CENTRIFUGE

4.2 PROCESS CONTROL CONSIDERATIONS

There are several variables that determine the performance of solid bowl centrifuges. Bowl speed is one of the most important, since centrifugal force speeds up the separation process. At any given pool depth, an increase in bowl speed provides more gravitational force, providing greater clarification and faster sedimentation.

The sludge feed rate is also very important. Lower sludge feed rates result in increased solids separation. If the sludge feed is increased, the residence period decreases, and the solids recovery will decrease. The sludge feed rate can be controlled to optimize the performance of a centrifuge.

Differential speed between bowl and conveyor (sludge feed) is provided by the backdrive assembly. This speed between bowl and conveyor is important as it determines the Solids Retention Time (SRT). A longer residence time allows the solids the opportunity to become more concentrated.

The use of polymers has allowed more materials to be dewatered by centrifuges. The degree of solids recovery (percent solids of sludge cake) can vary over wide ranges, depending on the sludge and the amount of polymer used.

4.3 PROCESS PERFORMANCE EVALUATION

An inspection checklist is included in Appendix A. The inspection checklist is designed to assist the inspector in gathering the information and in evaluating the performance of the centrifuge.

The centrifuge process is a mechanized process and as such more attention must be paid to the maintenance of the units. The equipment should be greased and oiled as specified by the equipment manufacturer. Any major overhaul of the equipment should be conducted by qualified personnel. Routine inspection and repair of the centrifuge should include an evaluation of:

- Shear pins
- Main bearings
- Seals
- Conveyor bushings
- Thrust bearing seal
- Feed and discharge ports.

During the operation of a centrifuge the operators should routinely check the oil reservoir (if present) level, and cooling water and oil temperatures; and check for vibration, noises, and leaks.

The centrifuge sludge cake and centrate should be checked daily. The centrate should be relatively clear and free of solids. The sludge cake should be in the range of 10 to 30 percent solids. The systems solids recovery should be in the range of 60 to 95 percent.

When evaluating a centrifuge operation, the inspector should evaluate the general operating condition of the unit. He/she should pay special attention to any leaks, worn parts, vibrations, or noises—which are all signs of inadequate maintenance. The maintenance records should be reviewed to ensure that worn parts are being inspected and replaced appropriately.

5. AEROBIC DIGESTION

The function of aerobic digestion is to stabilize waste primary sludge, waste biological sludge, or a combination of these by long-term aeration. This process results in reduction of volatile solids and pathogens. A stable sludge with a low oxygen demand, good settling characteristics, and no offensive odor is produced.

During aerobic digestion, organic substrate is oxidized to carbon dioxide, water, and ammonia. As the digestion proceeds, ammonia is oxidized to nitrate nitrogen. The oxidation of ammonia can create a pH drop if the alkalinity is insufficient to buffer the solution. The following reaction may be used to describe the overall aerobic digestion process for the oxidation of both carbonaceous and nitrogenous substances:

$$C_5H_7NO_2 + 7O_2 \text{-----}> 5CO_2 + 3H_2O + NO_3^- + H^+$$

Recently, the addition of pure oxygen to the aeration system has been used in aerobic digester design. In conventional digesters, concentrations of influent sludge volatile suspended solids (VSS) must be no more than 3 percent for retention times of 15 to 20 days. Above this percentage, oxygen from atmospheric air cannot be dissolved into the digesting sludge fast enough to keep the biological reaction going. However, pure oxygen can dissolve in sludge nearly five times as fast as can oxygen from the air. As a result, pure oxygen aeration allows a more concentrated sludge feed. By feeding a more concentrated sludge, either the SRT can be longer or the total pounds of sludge digested per day can be increased. Pure oxygen digesters usually are closed so that oxygen is not lost to the atmosphere.

5.1 PROCESS CONFIGURATION AND COMPONENTS

Aerobic digesters are typically a single-stage process that can be operated in a batch, semibatch, or continuous mode. Batch and semibatch operations are by far the most common. In the batch mode the digester tank is filled with raw sludge and aerated for 2 to 3 weeks. The aeration is then stopped and the stabilized solids are allowed to settle. The clarified liquid is decanted and the settled solids are removed.

The semibatch mode of operation is similar to the batch mode, with the following exceptions:

- Raw sludge is added every couple of days.
- The clarified liquid is periodically decanted.
- Solids are generally held in the digester for long periods of time before they are removed for further treatment or disposal.

In the continuous mode of operation, solids are pumped directly from the clarifiers into the aerobic digester. The digestion basin operates at a fixed level, with the overflow going to a solids-liquid separator. Thickened and stabilized solids are either recycled back to the digestion tank or removed for further processing.

Aerobic digesters are designed to provide an oxygen rich, well-mixed environment for the digestion of organic matter and reduction of pathogenic organisms. Aeration and mixing are usually accomplished simultaneously by either diffused air aerators or mechanical mixers. Diffused air aerators should be capable of supplying 20 to 35 ft^3 per minute (cfm) of air per 1,000 ft^3 of digester volume. Mechanical aerators should supply 0.5 to 4.0 horsepower per 1,000 ft^3 of digester volume. Typically, the tanks are uncovered and installed above ground. However, tanks may be covered and the walls insulated to minimize heat loss and to prevent freezing.

5.2 PROCESS CONTROL CONSIDERATIONS

40 CFR Part 257 specifies minimum residence times and temperatures that the sludge must remain in the digester. These time and temperature requirements are set to ensure that the proper amount of pathogen and volatile solids reduction occurs for the facility's ultimate disposal option. If the sludge is to be land applied and the requirements for a PSRP are to be met (see 40 CFR Part 257), the residence time requirements range from 60 days at 15°C to 40 days at 20°C. If properly operated, an aerobic digester is capable of achieving a volatile solids reduction of 40 to 50 percent and a pathogen reduction of 90 percent.

Proper control of an aerobic digester is based on:

- Solids retention time (SRT)
- Temperature
- Volatile solids loading
- Air supply requirements.

5.2.1 Solids Retention Time

In general, as the SRT is increased, the efficiency of the aerobic digestion process is also increased. The solids retention time is limited by the digester volume and sludge loading rates. In order to maximize the SRT, the sludge should be thickened as much as possible prior to digestion.

5.2.2 Temperature

The efficiency and rate of aerobic digestion is directly related to the temperature. As the temperature of the system decreases, the rate of biological activity also decreases. A decrease in biological activity will result in a decreased rate of destruction of the biomass, and the potential for unstabilized sludge to exit the digester. Desirable aerobic digestion temperatures are approximately 65° to 80°F. In colder climates, provisions may have to be made to heat the digester (or conserve self-generated heat by using a cover and/or a more efficient aerator) to maintain temperatures in the desirable range. Actual temperatures in aerobic digesters depend on the temperature and volume of sludge fed to the digester and the temperature of the air coming from the blowers to the digester.

5.2.3 Volatile Solids Loading

Volatile solids loading is an estimate of the quantity of organic matter applied to the digester. The optimum volatile solids loading for aerobic digestion depends on the treatment plant and is generally determined by pilot and/or full-scale experimentation. In general, volatile suspended solids loadings for effective aerobic stabilization vary from 0.07 lb VSS/day/ft^3 to 0.20 lb VSS/day/ft^3, depending on the temperature and type of sludge. Operation outside of the recommended range can result in decreased treatment efficiency.

5.2.4 Air Supply Requirement

The air requirements of an aerobic digester are governed by a need to keep the digester solids in suspension (well mixed) and to maintain a dissolved oxygen (DO) concentration of 1 to 2 mg/l. The quantity of air required will vary depending on the sludge type, temperature, and concentration; and on the activity of biomass within the digester. Obviously, as the concentration and/or activity increases, more air is required to satisfy the oxygen requirements of the biomass and to keep solids in suspension. The residual DO is a measure of the quantity of oxygen supplied beyond that used by the biomass. The residual DO within the digester should always be greater than 1.0 mg/l. If the digester DO falls below 1.0 mg/l, aerobic processes will be negatively impacted.

5.3 PROCESS PERFORMANCE EVALUATION

When evaluating the performance of an aerobic digester the inspector should compare the actual operating conditions to recommended operating conditions. Typical operating conditions for aerobic digesters are presented in Table 3. An inspection checklist, included in Appendix A, is designed to assist the inspector in gathering the information and making the calculations required to make the comparison.

5.3.1 Design Evaluation

In evaluating the design adequacy of an aerobic digestion system, the inspector should consider the following:

- Air supply system—The existing system should be capable of providing sufficient oxygen and mixing.
- Digester volume—The digester should be large enough to provide a sufficient solids retention time, provide for storage of sludge, and handle all solids generated by the wastewater treatment systems.

TABLE 3. OPERATING AND DESIGN CONDITIONS FOR AEROBIC SLUDGE DIGESTION

Solids retention time (days)	
Activated sludge only	15 to 20 days
Activated sludge + primary	20 to 25 days
Volatile suspended solids loading (lb VSS/ft^3/day)	0.024 to 0.14
Diffused air requirements (cfm/1,000 ft^3)	
Activated sludge only	20 to 35
Primary and activated sludge	>60
Mechanical mixer requirements (hp/1,000 ft^3)	1.0 to 1.25
Minimum dissolved oxygen (mg/l)	1.0 to 2.0
Temperature (liquid) (°F)	>59
Reactor pH (s.u.)	>6.5
Volatile suspended solids reduction (%)	35 to 50

5.3.2 Operation and Maintenance Evaluation

When evaluating the aerobic digester operation, the following parameters should be considered:

- Dissolved oxygen levels—To ensure adequate solids reduction, the digester dissolved oxygen level of the sludge in the digester should be maintained at between 1.0 and 2.0 mg/l. If the DO falls below 1.0 mg/l, filamentous organisms will begin to form and inhibit digestion. If the DO is maintained above 2.0 mg/l, energy is being wasted.

- Digester temperature—Temperature has a significant influence on biological activity. The minimum temperature of the digester should be 59°F.

- Digester pH—The pH should be above 6.5. The extended digestion times of aerobic digestion are conducive to nitrification. Nitrification will lower the pH, which in turn could inhibit the carbonaceous digestion process.

- Feed sludge—The undigested sludge should be monitored for total solids (TS), total volatile solids (TVS), pH, and flow rate. These parameters are useful in determining digester loading rates and volatile solids reduction levels.

- Digested sludge—The digested sludge should be monitored for TS, TVS, pH, and flow rate to determine the volatile solids reduction levels and solids retention times.

- Supernatant—The supernatant should be monitored for flow rate, biochemical oxygen demand (BOD), total suspended solids (TSS), and pH to measure digestion efficiency and to determine the loading on the wet-end treatment processes.

6. ANAEROBIC DIGESTION

Anaerobic digestion is the biological degradation of complex organic substances in the absence of free oxygen. During these reactions, energy is released and much of the volatile organic matter is converted to methane, carbon dioxide, and water. Since little carbon and energy remain available to sustain further biological activity, the remaining solids are rendered stable.

Anaerobic digestion involves several successive fermentations carried out by a mixed culture of microorganisms. This web of interactions compromises two general degradation phases: acid formation and methane production. Figure 7 shows, in simplified form, the reactions involved in anaerobic digestion.

In the first phase of digestion, microorganisms including facultative bacteria convert complex organic substrates to short-chain organic acids. These volatile organic acids tend to reduce the pH, although alkaline buffering materials are also produced. Organic matter is converted into a form suitable for breakdown by the second group of bacteria. In the second phase, strictly anaerobic bacteria (called methanogens), convert the volatile acids to methane (CH_4), carbon dioxide (CO_2), and other trace gases.

When an anaerobic digester is working properly, the two phases of degradation are in dynamic equilibrium; that is, the volatile organic acids are converted to methane at the same rate that they are formed from the more complex organic molecules. As a result, volatile acid levels are low in a working digester. However, methane formers are inherently slow-growing, with doubling times measured in days. In addition, methanogenic bacteria can be adversely affected by even small fluctuations in pH, substrate concentrations, and temperature. In contrast, the acid formers can function over a wide range of environmental conditions and have doubling times normally measured in hours. As a result, when an anaerobic digester is stressed by shock loads, temperature fluctuations, or an inhibitory material, methane bacterial activity begins to lag behind that of the acid formers. When this happens, organic acids cannot be converted to methane as rapidly as they form. Once the balance is upset, intermediate organic acids accumulate and the pH drops resulting in further inhibition of the methanogens and process use.

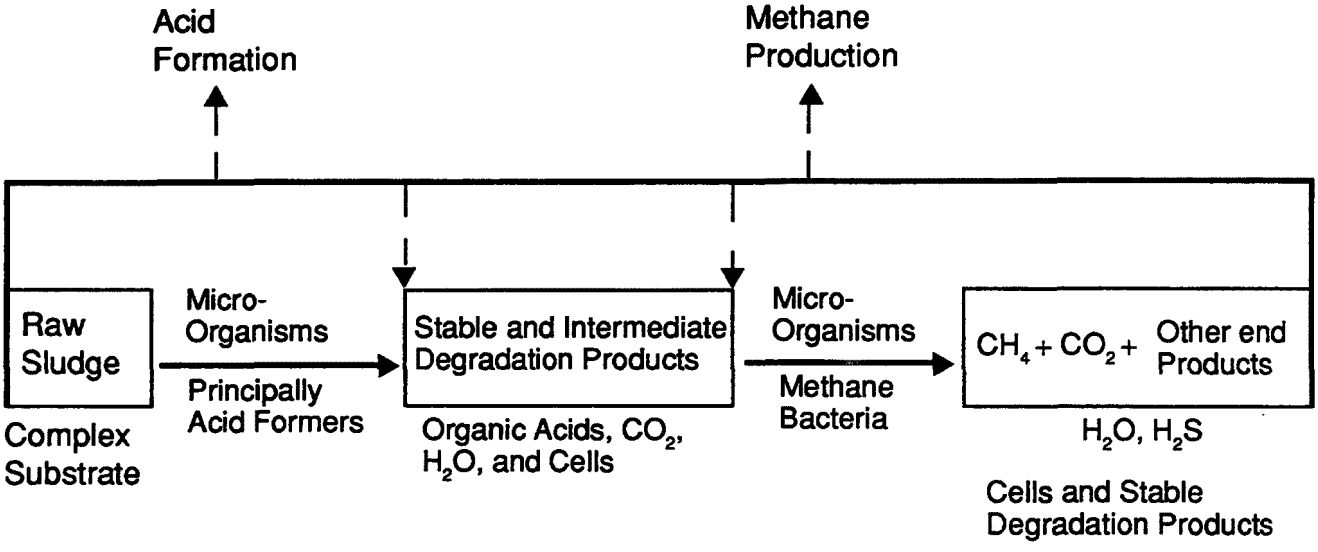


FIGURE 7. SUMMARY OF THE ANAEROBIC DIGESTION PROCESS

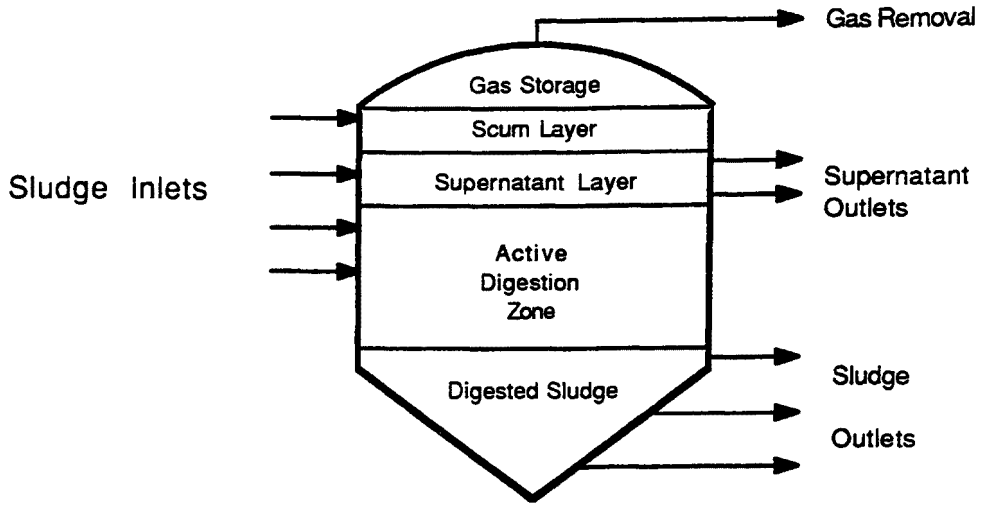
Anaerobic digesters may be "low-rate" or "high-rate." The primary difference between the two is the rate at which the degradation of organic matter occurs. The low-rate system is not mixed and the degradation process is generally slower than the high-rate. The high-rate system is well-mixed and receives a higher solids loading rate. This forces the degradation of organic matter to occur much faster. Consequently, the high-rate digester is more susceptible to an upset that the low-rate and requires more intensive process controls.

The process has been successful when fed primary sludge, combinations of the primary sludge and secondary sludge, and (to a lesser extent) thickened secondary sludge. Anaerobic digestion converts about 50 percent of the organic solids to liquid and gas, greatly reducing the amount of sludge to be disposed. About two-thirds of the gas produced in the process is methane, with a heat value of 600 BTU/standard cubic foot (scf). About 15 scf of gas is formed per pound of volatile solids (VS) destroyed. Anaerobic digester gas has been used extensively in wastewater treatment plants for many years to heat digesters and buildings, and as fuel for engines that drive pumps, air blowers, and electrical generators. In a few areas, it has been used as a Grade 6 heating oil to heat municipal office buildings.

6.1 PROCESS CONFIGURATION AND COMPONENTS

The configuration of an anaerobic digester is typically either a single-stage process or a two-stage process (Figure 8). In the low rate, single-stage process, three separate layers form as decomposition occurs. A scum layer is formed at the top of the digester, and below it are supernatant and sludge layers. The sludge zone has an actively decomposing upper layer and a relatively stabilized bottom layer. The stabilized sludge settles at the base of the digester and the supernatant is usually returned to the plant influent. In a single-stage, high rate process the digester is heated and mixed, and supernatant is not withdrawn. In the two-stage process sludge stabilizes in the first stage, while the second stage provides settling and thickening. The digester is heated to between 85° and 95°F, and usually provides 10 to 20 days detention of sludge. More recently, packed bed anaerobic digesters have been used. These innovative configurations may offer advantages in certain circumstances over the more traditional designs. These configurations are not widely demonstrated to date in municipal plants.

Single-Stage Anaerobic Digester



Two Stage Anaerobic Digester

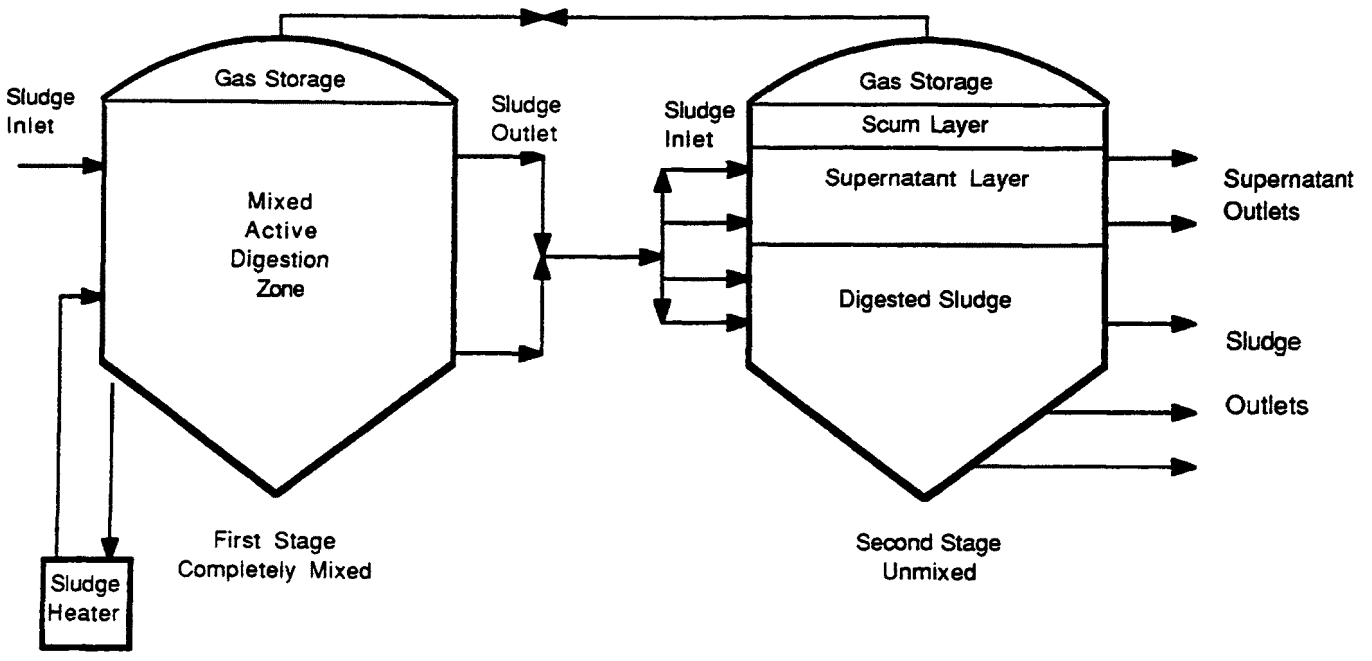


FIGURE 8. CONFIGURATION OF ANAEROBIC DIGESTERS

Anaerobic digesters are designed to provide an oxygen free, warm, and well-mixed environment for the digestion of organic matter and reduction of pathogenic organisms. This environment is effected through three major systems in a digester:

- Covers
- Heaters
- Mixers.

6.1.1 Covers

Digesters have either fixed or floating covers, as shown in Figure 9. Fixed covers are made of concrete or steel and may be flat, conical, or dome shaped. It is difficult to make concrete covers gas-tight because concrete tends to develop cracks. Sludge must be removed from fixed-cover units without letting air into the system, which could form an explosive mixture. For this reason, fixed-cover digesters have water-level controls to make the overflow equal to inflow. Floating covers may be either the type that rest directly on the liquid and have limited gas storage, or the gas-holder type that rests on a cushion of gas and is provided with side skirts. Floating covers are the safest digesters to operate since there is little chance of creating an explosive mixture under the cover. The gas-holder type is used to store gas as it is produced. The pressure developed inside the tank causes the cover to lift as much as 6 ft or more above the minimum height.

6.1.2 Heaters

Digesters can be heated by:

- Hot-water coils within the digester—Hot water coils inside the digester have been used widely in the past. The main disadvantage of using coils is that they corrode and cake with sludge, which results in reduced heat transfer efficiency.

- Recirculating sludge through an external heat exchanger—The external heat exchanger with recirculation of the sludge is the most often used method of heating. This method provides good scum control with no pipes inside the digester.

- Direct contact of hot gas with sludge—Direct flame heating has been used where gas is mixed into the sludge in small heating tanks.

- Steam injection—Steam injection has been used in only a few cases.

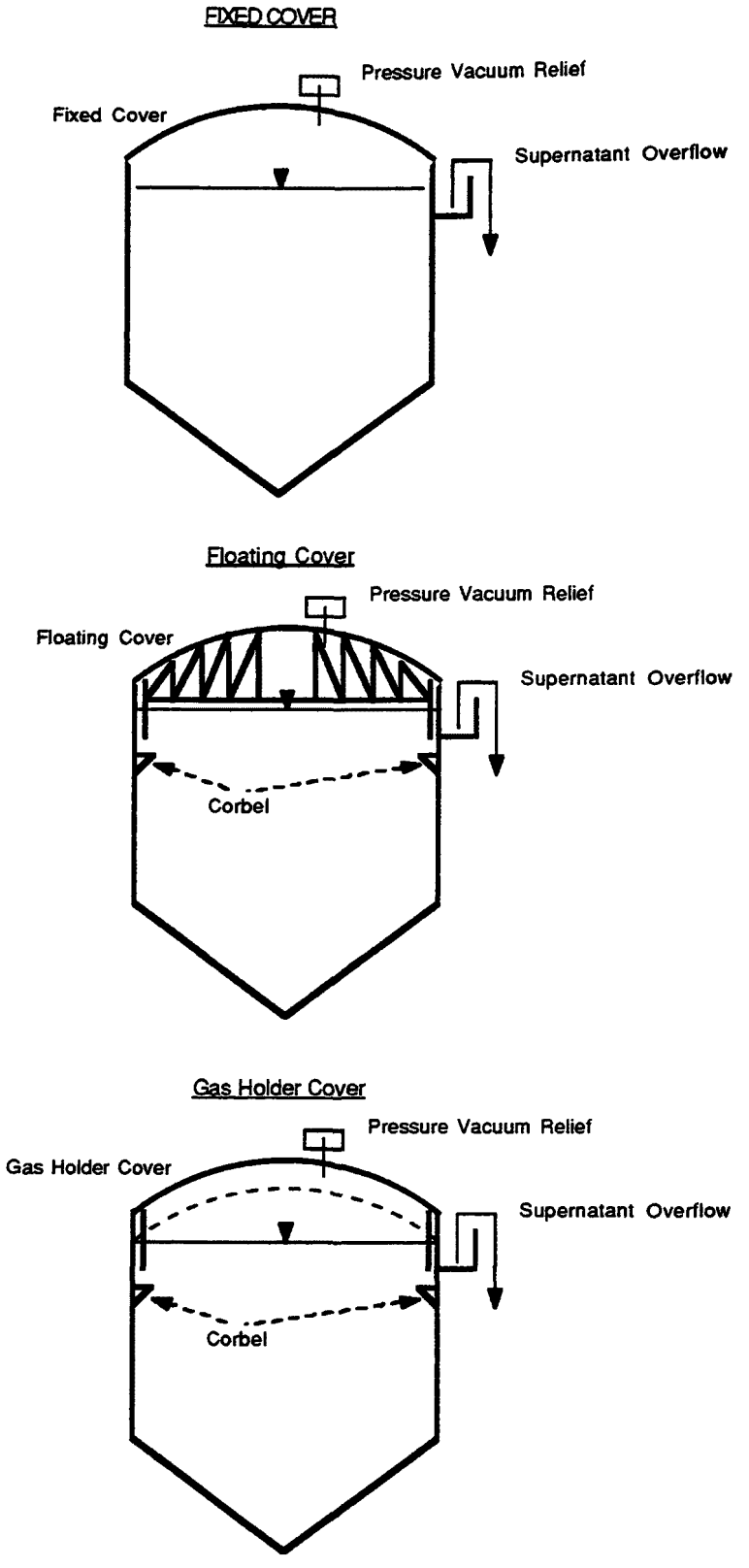


FIGURE 9. FIXED AND FLOATING DIGESTER COVERS

6.1.3 Mixers

Mixing can be provided by:

- Recirculating sludge through an exterior heat exchanger
- Mechanically mixing or pumping the sludge within the digester
- Releasing compressed digester gas through diffusers near the bottom of the digester, through several pipes discharging above the top of the cone.

6.2 PROCESS CONTROL CONSIDERATIONS

The anaerobic process is mostly controlled by the methane-forming bacteria. These bacteria grow slowly and have generation times which range from just less than 2 days to about 22 days. Methane formers are very sensitive to pH, sludge composition, and temperature. If the pH drops below 6.5, methane does not form and the organics in the sludge do not decrease. The methane bacteria are very active in the mesophilic range (between 80° and 110°F), and in the thermophilic range (between 113° and 149°F). Most of the anaerobic digesters in the United States operate within the mesophilic temperature range.

Proper control of anaerobic sludge digestion is based on:

- Food supply
- Detention time and temperature
- Mixing
- pH and alkalinity
- Gas production.

6.2.1 Food Supply

Microorganisms are most effective when food (raw sludge feed) is provided in small amounts at frequent intervals or on a continuous basis. If too much sludge is added rapidly to the primary digesters, the first (acid-forming) step may produce acid faster than the organisms needed for the second (gas-forming) step can break them down. This results in incomplete digestion, and causes bad odors.

The sludge fed to the digester should be as thick as possible without clogging pumps and piping. Thin sludge takes up too much digester space and adds excess water which must be heated.

6.2.2 Time and Temperature

Less detention time usually is needed for complete digestion as temperature increases. Most digesters are designed to operate in the 90°F to 95°F temperature range. If the temperature falls much below this range, more time is needed for digestion. Complete digestion usually occurs in about 15 days in a well mixed, properly heated digester. A temperature change of 2° or 3°F can be enough to disturb the balance between the acid and methane formers.

40 CFR Part 257 specifies minimum residence times and temperatures that sludge must remain in the digester if the sludge product is to meet PSRP requirements. These time and temperature requirements are set to ensure that the proper amount of pathogen and volatile solids reduction occurs to support the facility's ultimate disposal option. To meet these minimum requirements, sludge must be digested in the absence of air at residence times ranging from 60 days at 20°C to 15 days at 35°C to 55°C. There must also be a 38% volatile solids reduction. The regulations do not stipulate any PFRP requirements for anaerobically digested sludge.

6.2.3 Mixing

Raw sludge feed should be well-mixed with the contents of the primary digester. This helps to ensure that the organisms have adequate contact with their food supply, and that the contents of the digester are uniformly heated. The mixing system operation should be closely monitored.

6.2.4 pH and Alkalinity

Anaerobic digestion is relatively effective within the pH range of 6.5 to 7.5; however, the optimum range is 6.8 to 7.2. Outside these ranges, digestion efficiency drops rapidly. Bicarbonate alkalinity should be kept at a minimum level of 1,000 mg/l as calcium carbonate ($CaCO_3$) for good pH control. To determine the bicarbonate alkalinity, both the volatile acid concentration and the total alkalinity must be measured. The bicarbonate alkalinity is then calculated as shown:

$$\text{Bicarbonate Alkalinity} = (\text{Total Alkalinity}/0.8\ \text{Volatile Acids})$$

The 0.8 factor in the above equation is needed to convert the volatile acid units from mg/l as acetic acid to mg/l as $CaCO_3$, the equivalent alkalinity unit. The volatile acid to total alkalinity ratio should be kept below 0.5 for good digester operation.

If the digester volatile acid concentration increases, pH will decrease unless bicarbonate alkalinity is added. Two of the most popular forms of bicarbonate alkalinity are lime and sodium bicarbonate. Lime additions beyond a bicarbonate alkalinity of 500 to 1,000 mg/l will react with carbon dioxide, form a precipitate, and have little effect on digester pH. Sodium bicarbonate does not react with carbon dioxide, and although it is more expensive than lime, smaller amounts are needed because it does not precipitate out of solution.

Chemicals can be added to the digestion system at several points. It is best to feed the chemicals with metering pumps for good control. Chemicals can be added directly to the digester to make big changes in bicarbonate alkalinity. The EPA publication, Operations Manual—Anaerobic Digestion (EPA 430/9-76-001) contains detailed guidance on chemical addition.

6.2.5 Gas Production

Gas production is one of the most important measurable digestion parameters. Overall digester performance is reflected by the total volume, rate, and composition of gas produced. Generally, the gas production should be between 13-18 ft^3 of digester gas/lb volatile solids destroyed. Differences in average gas production at a plant usually mean a change in the degree of digestion or a change in the character of the sludge being fed. Gas from a properly operating digester contains about 65 to 69 percent methane and 30 to 35 percent carbon dioxide. If more than 35 percent of the gas is carbon dioxide, there is probably something wrong with the digestion process.

6.2.6 Supernatant Return

As shown in Figure 8, supernatant (the liquid above the sludge zone) is displaced as sludge is added to the digester. Table 4 presents typical digester supernatant quality data. Inadequate digestion can result in poor quality supernatant, which can lower overall plant performance when the supernatant is recycled. Usually, supernatant is returned to the head of the plant; however, this recycle stream may greatly increase the BOD, COD, TSS, and ammonia nitrogen loading on the plant. The supernatant should be pretreated or returned to plant units where it will have the least effect. Additionally, it is best to return the supernatant when the raw wastewater flow is at its daily low.

TABLE 4. SUPERNATANT CHARACTERISTICS FROM ANAEROBIC DIGESTERS

	Trickling Filters* (mg/l)	Activated Sludge Plants* (mg/l)
Suspended solids	500 to 5,000	5,000 to 15,000
BOD_5	500 to 5,000	1,000 to 10,000
COD	2,000 to 10,000	3,000 to 30,000
Ammonia as NH_3	400 to 600	500 to 1,000
Total phosphorus as P	100 to 300	300 to 1,000

*Includes primary sludge.

6.3 PROCESS PERFORMANCE EVALUATION

In evaluating anaerobic digestion systems, the inspector is cautioned to bear in mind the following:

- In many plants, the anaerobic digestion system is the most complex unit process, from both a technology/hardware stand point and from an operations stand point.
- Anaerobic digestion is a form of biological treatment, and as such requires a coherent process control strategy. This strategy should incorporate target values, regular monitoring, trend tracking, etc.

When evaluating the performance of an anaerobic digester the inspector should compare the actual operating conditions to recommended operating conditions. Typical operating conditions for both low-rate and high-rate anaerobic digesters are presented in Table 5. An inspection checklist is included in Appendix A. The inspection checklist is designed to assist the inspector in gathering the information and making the calculations required to make the comparison.

TABLE 5. OPERATING AND DESIGN CONDITIONS FOR ANAEROBIC SLUDGE DIGESTION

Temperature	
Mesophylic	85°F to 95°F
Thermophylic	113°F to 149°F
pH	
Optimum	6.8 to 7.2
General Range	6.5 to 7.5
Gas Production	
Per pound VS added	6 to 8 ft^3
Per pound VS destroyed	16 to 18 ft^3
Gas Composition	
Methane	65 to 69%
Carbon dioxide	31 to 35%
Hydrogen sulfide	trace
Volatile Acids Concentration	
General Range	200 to 800 mg/l
Alkalinity Concentration	
Normal Operation	2000 to 3500 mg/l
Volatile Solids Loading	
Low-rate	0.02 to 0.05 lb VS/ft^3/day
High-rate	0.05 to 0.15 lb VS/ft^3/day
Digester Capacity Based on Design Population Equivalent (PE)	
Low-rate	4 to 6 ft^3/PE
High-rate	0.7 to 1.5 ft^3/PE
Solids Retention Time (SRT), days	
Low-rate	30 to 60
High-rate	10 to 20
Digested Solids Concentration (%)	
Low-rate	4 to 6
High-rate	4 to 6

6.3.1 Design Evaluation

In evaluating the design adequacy of an anaerobic digestion system, the inspector should consider the systems configuration and capacity. Keeping in mind whether the system is high or low-rate, the inspector should evaluate the following design elements:

- Volatile solids—Loading rate and nominal solids retention time should be calculated (per checklist).
- Cover design—Check to see that adequate guides are provided for floating covers, to prevent tipping.
- Gas storage—Check to see that adequate storage capacity (or a proper flare) is provided.
- Mixing
  - If gas mixing is used, check to see if adequate injection points are provided to mix the entire volume of the digester. Also check the condition of the injection system.
  - If recirculation is provided for mixing, check for piping configuration which might promote short-circuiting within the digester, and recirculation pump capacities and condition.
- Heating—Look for the use of in-tank coils; these are typically found in older systems and are usually caked with solids, lowering their efficiency. In systems using external heat exchangers, note the date of last cleaning. If pre- and post-heat exchanger temperatures are monitored, look for a downward trend in the post-heat exchanger temperature value (indicative of failing heat exchangers).
- Insulation—In colder climates, check to see if tankage is bermed and covers are appropriately insulated.

6.3.2 Operation and Maintenance Evaluation

Due to the complexity of the anaerobic digestion process, efficient operation requires that a comprehensive process control program be in place. The operator must monitor various parameters to maintain conditions conducive to the microorganisms involved in the digestion process. As previously noted, the digestion process relies on two major groups of microorganisms having significantly different growth rates and nutritional requirements. This complexity of requirements increases the difficulty of operation and makes the system more prone to upsets. An upset digester may lead to a deterioration in the plant effluent quality as a result of increased loadings on the wet-end treatment processes; these increased loadings result from poor quality supernatant and/or decreased solids processing capacities.

The inspector must therefore not only evaluate the operation of the digester, but must also consider what effect, if any, the digester operation is having on the wet-end operations and effluent quality.

When evaluating the digester operation, the following parameters should be considered:

- Digester temperature—Temperature has a significant influence on biological activity. The optimum digestion temperature ranges are given in Table 5 for mesophylic and thermophylic digestion; use these ranges.

- Digester pH—The pH should be in the range of 6.8 to 7.2 in order for complete digestion to occur. Since pH changes very slowly, it must be monitored in conjunction with other parameters for effective process control.

- Alkalinity—An effective digestion process exists at a total alkalinity of 2000 to 3500 mg/L.

- Volatile acids—Volatile acids are intermediate products of digestion which should be monitored in conjunction with pH and alkalinity. A typical volatile acids concentration ranges from 200 to 800 mg/l. A volatile acids/alkalinity ratio in excess of 0.8 is indicative of process failure. Generally, at ratios greater than 0.8, methane production is inhibited.

- Digester gas—Effective digestion should produce from 12 to 18 ft^3 of gas per pound of volatile solids destroyed. The composition of the gas is another indicator of digester efficiency. Generally, most smaller POTWs do not monitor the composition of the digester gas, so this information may not be readily available.

- Feed sludge—The undigested sludge should be monitored for Total Solids (TS), Total Volatile Solids (TVS), pH, and flow rate. These parameters are useful in determining digester loading rates and volatile solids reduction levels.

- Digested sludge—The digested sludge should be monitored for TS, TVS, pH, and flow rate to determine the volatile solids reduction levels and solids retention times.

- Supernatant—The supernatant should be monitored for flow rate, BOD, TSS, and pH to measure digestion efficiency and to determine the loading on the wet-end treatment processes.

7. HEAT TREATMENT

The heat treatment process involves heating wastewater sludge to temperatures of 350° to 400°F (177° to 240°C) in a reaction vessel under pressures of 250 to 400 psig (1,723 to 2,758 kN/m^2) for periods of 15 to 40 minutes. This significantly changes the sludge dewatering characteristics, primarily by breaking down the structure of microbial cells in waste activated sludges and releasing the water bound in the cell. The process effectively sterilizes the sludge by destroying pathogenic organisms. The heat-treated sludge retains the characteristics of a very dense, well-digested domestic sludge. The heat-treated sludge has excellent dewatering characteristics and does not normally require chemical conditioning to dewater well on mechanical equipment, yielding cake solid concentrations of 40 to 50 percent. The process is suitable for many types of sludges that cannot be stabilized biologically because of the presence of toxic materials and is relatively insensitive to changes in sludge composition. The heat treatment process generates odorous off-gases that must be collected and treated before release, and a liquor, or decant, with high concentrations of organics (creating a high chemical oxygen demand COD), ammonia nitrogen, and color.

Many heat treatment systems in use today are of the oxidation type. In this system high pressure air is introduced into the sludge feed upstream of the heat exchanger. Some oxygen is consumed in the process which generates heat, improves heat transfer rates, and reduces supplemental heat requirements. Another modification of this process involves using higher temperatures and pressures in the reaction vessel, and adding air under high pressures. These processes, known as low-pressure and high-pressure wet air oxidation, are described in the next chapter. The wet air oxidation process produces results nearly identical to the non-oxidation heat treatment process.

7.1 PROCESS CONFIGURATION AND COMPONENTS

Heat treatment systems are technically complex, even though the process itself is relatively straight forward. A typical non-oxidation heat treatment system is shown in Figure 10.

Thickened sludge is first passed through a grinder or grinder pump to reduce the maximum particle size. The resulting slurry is then pressurized and sent through one or more heat exchangers. From the heat exchangers, the preheated slurry enters the reaction vessel, where the conditioning reactions occur. Sufficient pressure is maintained to prevent boiling of the sludge. The treated slurry is subsequently cooled in the heat exchanger; gases are pulled off in a vapor-liquid separator and reduced to atmospheric

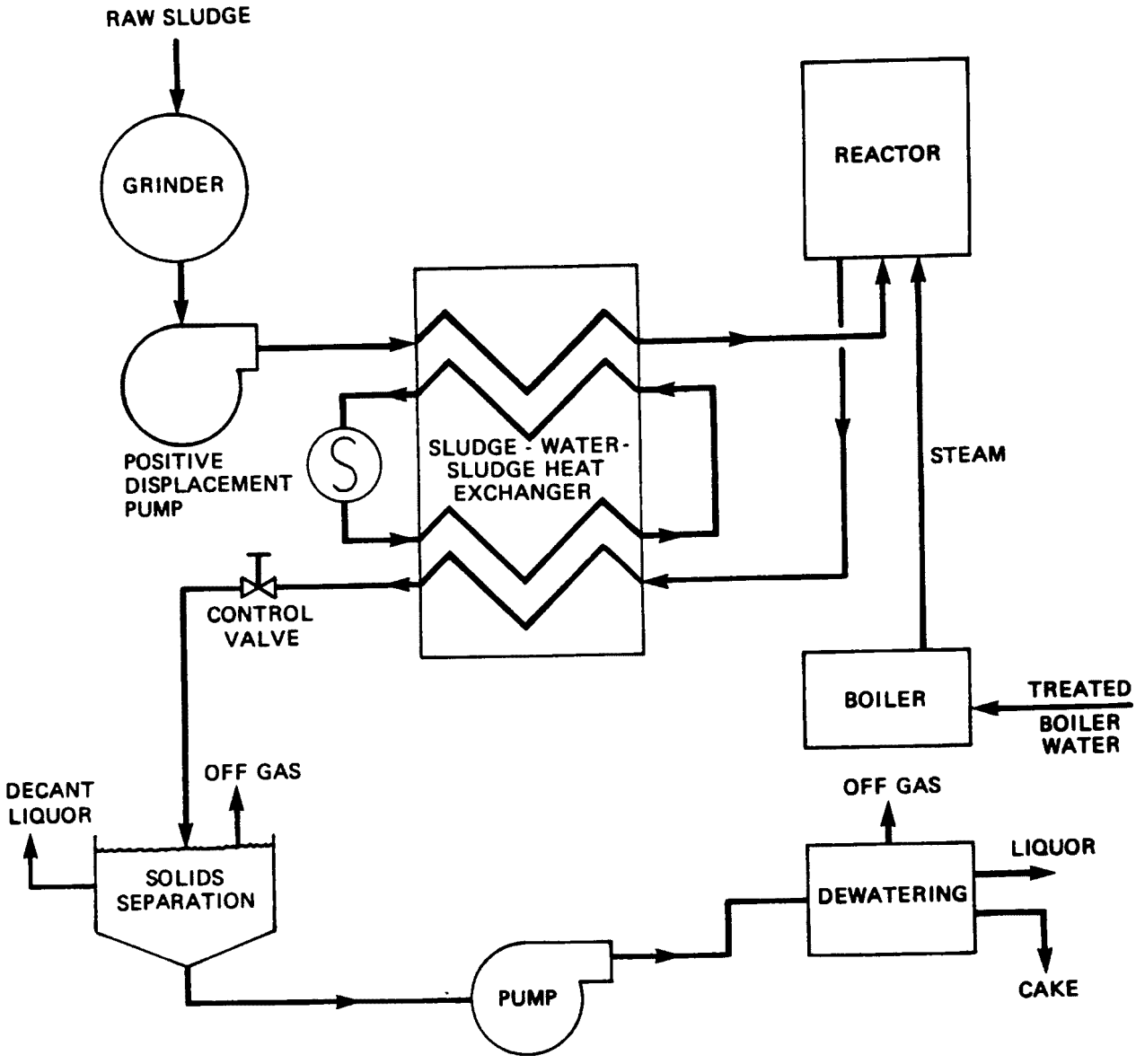


FIGURE 10. GENERAL THERMAL SLUDGE CONDITIONING FLOW SCHEME FOR A NON-OXIDATIVE SYSTEM

pressure through a pressure control valve. In many systems, the gases are processed to eliminate odors. Gas cleanup methods include wet scrubbing, activated carbon absorption, after burning with fossil fuel, and catalytic oxidation. With the last two methods, energy recovery is possible through the use of heat recovery boilers and gas-liquid heat exchangers. Slurry from the gas-liquid separator passes through a liquid-level control valve and is dewatered for final disposal. The liquid phase is recycled to the treatment plant or given separate treatment for reduction of the residual soluble organics.

Heat treatment system failures are associated with the high pressures involved, heat exchanger scaling and corrosion, and required supernatant liquid treatment.

The basic components of a heat treatment system are as follows:

- Grinders—These units are used to reduce sludge particle size. This reduction prevents problems with the handling of the sludge throughout the rest of the system and, more importantly, increases the ratio of surface area to mass for the sludge particles.

- Low-and-high pressure feed pumps—Together, these pumps achieve the pressures necessary to support wet air (flameless) oxidation. Low-pressure pumps are typically centrifugal types, while high-pressure pumps are typically positive displacement pumps.

- Heat exchangers—A series of heat exchangers are used to recover heat from the reactor effluent stream; this heat is used to preheat the incoming sludge. Heat exchangers may be sludge-to-sludge, or sludge-to-water-to-sludge types.

- Reactor—The reactor serves to provide the necessary residence time at the design temperature and pressure. Reactors are cylindrical in shape, and are constructed of either stainless steel or, in some cases, titanium.

- Boiler—The boiler provides the steam used as a source of supplemental heat.

- Separator—The separator is the pressurized vessel in which the treated sludge stream is split into two phases: the off-gases and the treated slurry.

7.2 PROCESS CONTROL CONSIDERATIONS

Proper control of a heat treatment system consists largely of maintaining temperature and pressure conditions at the system's design flow rate. The primary control parameters for heat treatment of sludge are:

- Temperature/pressure—These two intimately related parameters determine the degree of stabilization/conditioning that takes place. Temperature is typically held at 350° to 400°F, and pressure at 250 to 400 psig. Under these conditions, only a nominal degree of organics oxidation (typically less than 5 percent) will occur.

- Feed sludge percent solids—Typically 3 to 6 percent. Sludge with too low a percentage of solids will require excessive supplemental heat, while sludge much over 6 percent solids is difficult to pump at high pressure. Six percent solids is probably close to optimal for most systems.

- Volatile solids reduction (VSS)—This is the primary performance evaluation criteria. Reduction should be commensurate with the temperature and pressure of the system. (See Section 8.2. VSS reduction for heat treatment is typically less at given temperatures and pressures, than for wet air oxidation systems.)

- Decant—In a properly functioning system, the treated sludge should exhibit good settling characteristics, and decant solids should be relatively low (< 1,000 mg/l). The decant produced by heat treatment typically exhibits very high levels of organics, ammonia, and color, as follows:

Substances in Decant (Liquor)	Concentration Range, mg/l (except as shown)
COD	2,500 to 22,000
BOD	1,600 to 12,000
NH_3-N	30 to 700
Phosphorus	70 to 100
Color	2,000 to 8,000 units

The recycle liquor can be very difficult to treat, offensive-smelling, and can upset wastewater treatment processes. The high concentration of organics and ammonia indicates the potential impact that recycling the liquor can have on the wastewater treatment processes. It is important to recognize the significance of the recycle load in the management of the overall plant operation. Pretreatment of these recycles and/or their consideration in the design as secondary treatment are necessary.

7.3 PROCESS PERFORMANCE EVALUATION

In evaluating a heat treatment system, the inspector should bear in mind the following:

- In most plants in which it is installed, heat treatment will be the most complex, maintenance-intensive unit process.

- The strength of the decant liquor sidestream causes its handling to be a problem in most plants. The inspector should include an evaluation of the impact of this sidestream on plant operations.

When evaluating one of these systems, the inspector should obtain the manufacturer's O&M manual for the system being evaluated. An inspection checklist is provided in Appendix A. The checklist is structured to aid the inspector in gathering the information needed to properly evaluate a heat treatment system.

7.3.1 Design Evaluation

The inspector should consider the design capacity of each heat treatment system or "train" at the POTW. The inspector should evaluate design capacity in terms of gpm of sludge produced, detention time in the reactor, and the intended temperature and pressure of the operation.

In evaluating the systems configuration, the inspector should consider:

- The level of redundancy provided, both in terms of number of "trains" and in individual components. The level of "availability" expected by the manufacturer (75 percent is typically specified and is optimistic) can affect the required redundancy. If individual components are "available" and can be shipped quickly when needed then the number of units needed on-site as "back-up" can be reduced.
- The "serviceability" of both the individual units specified, and of the overall system layout.
- Provisions for acid washing and manual scale removal, acid washing is a necessity for most plants.
- Material of construction of the pumps, piping, heat exchangers and reactors.
- Decant handling—Adequate treatment should be provided to handle the decant, or the plant's wastewater treatment units (specifically biological treatment) should have been sized to accommodate the load imposed by this sidestream.
- Gas handling—There should be provisions to handle all off-gases. In addition, the decant tank, ash storage tanks, and dewatering facilities may require gas handling to control odor problems.

7.3.2 Operations and Maintenance Evaluation

The basic control parameters, discussed earlier, are:

- Temperature
- Pressure
- Sludge feed rate
- Percent solids of sludge feed.

In general, all of these parameters should be closely monitored, so as to detect deviations from design operating conditions. Given the complexity of these systems, and the differences that exist between the various systems in use, it is important that the manufacturer's recommended operating procedures form the basis for the plant operating strategy.

As most "operations" problems with heat treatment systems are in reality maintenance problems, it is important that a comprehensive preventative and reactive maintenance program be in place. Such a program should include:

- Routine inspections of all components
- Scheduled cleaning/descaling of the piping, heat exchangers, reactors, and decanting system
- Procedures for evaluating operations data on a daily basis to detect impending problems
- Annual indepth inspection, to include pressure testing, and checks for pipe erosion and component fatigue.

8. WET AIR OXIDATION

Sludge, like many other complex organics, may be oxidized at high temperatures, in the presence of water, in what can be described as flameless combustion. This process, known as "wet air oxidation," is related to heat treatment (see last section) but differs in that it 1) includes air injection, 2) typically occurs at higher temperatures and pressures, and 3) as a result, includes a significant level of oxidation of organic matter. Wet air oxidation parallels incineration in terms of the ash-like, largely inorganic residue produced.

In wet air oxidation, sludge and air are introduced into a reaction vessel at high temperatures (400° to 700°F) and pressures (500 to 1500 psi) and held under those conditions while oxidation proceeds. Because the oxidation of sludge is exothermic, under the proper conditions (high enough sludge concentration and internal heat system recovery) this process can proceed with no external heat supplied to the reactor.

The end products of this process are:

- (Largely) inorganic "ash"
- Off-gases
- Liquid phase.

Off-gases from this process include oxygen, nitrogen, carbon dioxide, water vapor, oxides of nitrogen, and sulfur. The liquid phase, which typically separates rapidly from the ash (generally in proportion to the degree of oxidation), is rich in a variety of complex, soluble organics.

Figure 11 is a composite representation of the results of wet oxidation for a typical sewage sludge. The figure shows volatile solids content or COD content in the solid phase, and the total sludge as a function of total oxidation in both phases. The vertical distance between the two curves is the solids or COD content in the liquid phase. Up to approximately 50 percent total oxidation, reduction in the volatile solids or COD in the liquid phase is minimal; above 50 percent, the volatile solids and COD of both phases are reduced to low values. At 80 percent total oxidation, about 5 percent of the original total volatile solids in the sludge is in the solid phase, and 15 percent is in the liquid phase.

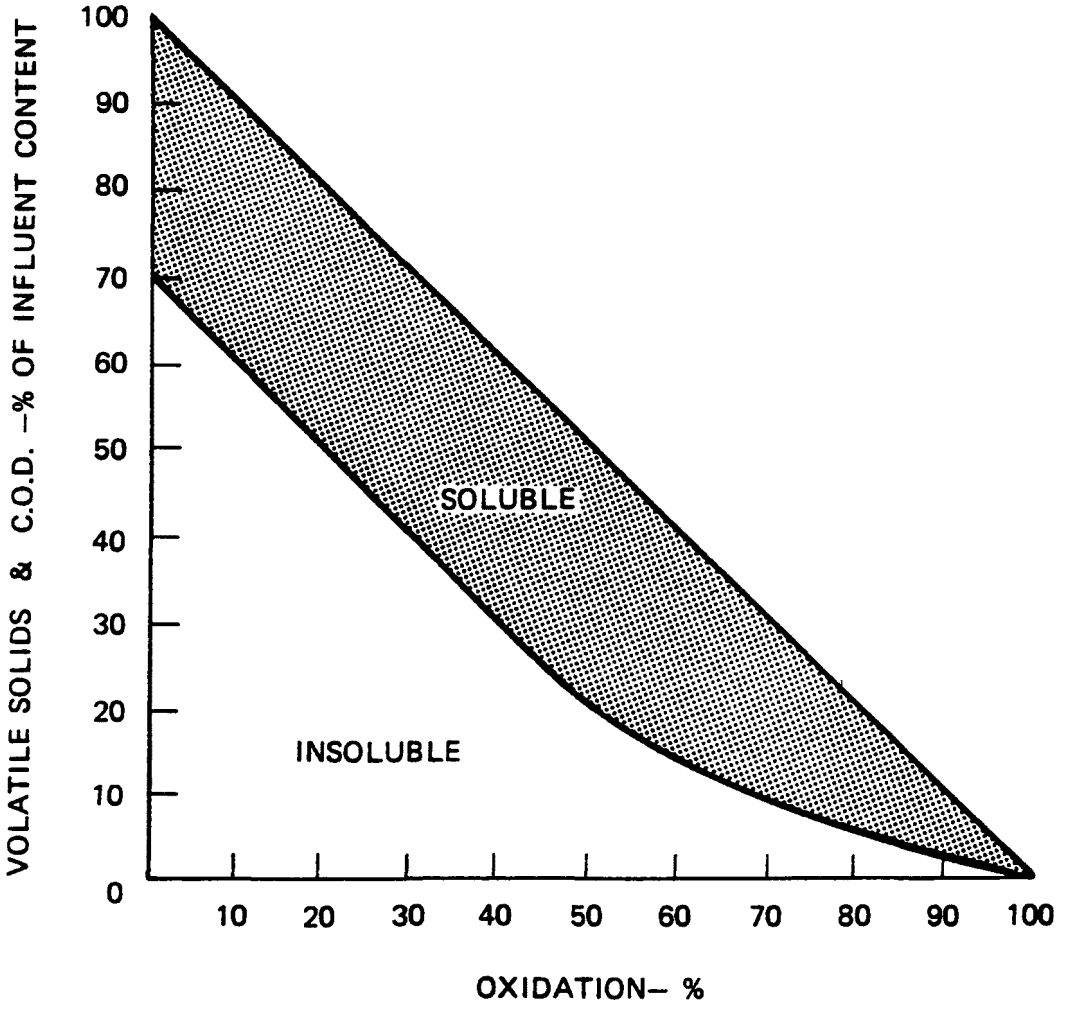


FIGURE 11. VOLATILE SOLIDS AND COD CONTENT OF SLUDGE TREATED BY WET AIR OXIDATION

The degree to which organic materials are oxidized is a function of temperature, reaction time, and the quantity of air (or oxygen) supplied. The process may be applied to dilute suspensions of sludge; however, a solids content between 4 and 6 percent minimizes reactor volume and allows a thermally self-sustaining reaction. Solids concentrations greater than approximately 10 percent create problems with mixing and with consequent mass transfer of the oxygen. There are insufficient data to indicate any advantage in using pure oxygen rather than air as the oxidant source, but studies are being conducted to evaluate the impact of oxygen enrichment and supercritical conditions on system performance and cost.

8.1 PROCESS CONFIGURATION AND COMPONENTS

Wet air oxidation, while generally simple in concept, requires a rather complex assemblage of equipment in order to carry out the process on a flow-through basis. The wet air oxidation process is shown schematically in Figure 12.

Sludge first passes through a grinder to reduce maximum feed solids size to less than 1/4 in. (0.64 cm). The resulting slurry is then pressurized. Oxygen is supplied in the form of high-pressure air; the amount of air required for complete oxidation of typical, domestic sludge solids is about 7.5 lbs per 10,000 Btu. The pressure required for successful wet air oxidation is that necessary to prevent phase charge (vaporization) at the design operating temperature.

The sludge-air mixture is then passed through one or more heat exchangers, where it is heated to close to the desired reaction temperature by the reactor effluent stream and introduced into the reactor for oxidation. Temperatures of between 400° and 700°F and pressures of between 500 and 1,800 psig are used, with detention times of 40 to 60 minutes. The oxidized slurry is cooled in the heat exchanger, gases are removed in a vapor-liquid separator, and the gases are reduced to atmospheric pressure through a pressure control valve. The gases are typically processed to eliminate odors, since wet air oxidation is known for its pungent, "musky" odor. Gas cleanup methods include wet scrubbing, activated carbon absorption, after burning with fossil fuel, and catalytic oxidation. With the last two methods, energy recovery is possible through the use of heat recovery boilers and gas-liquid heat exchangers.

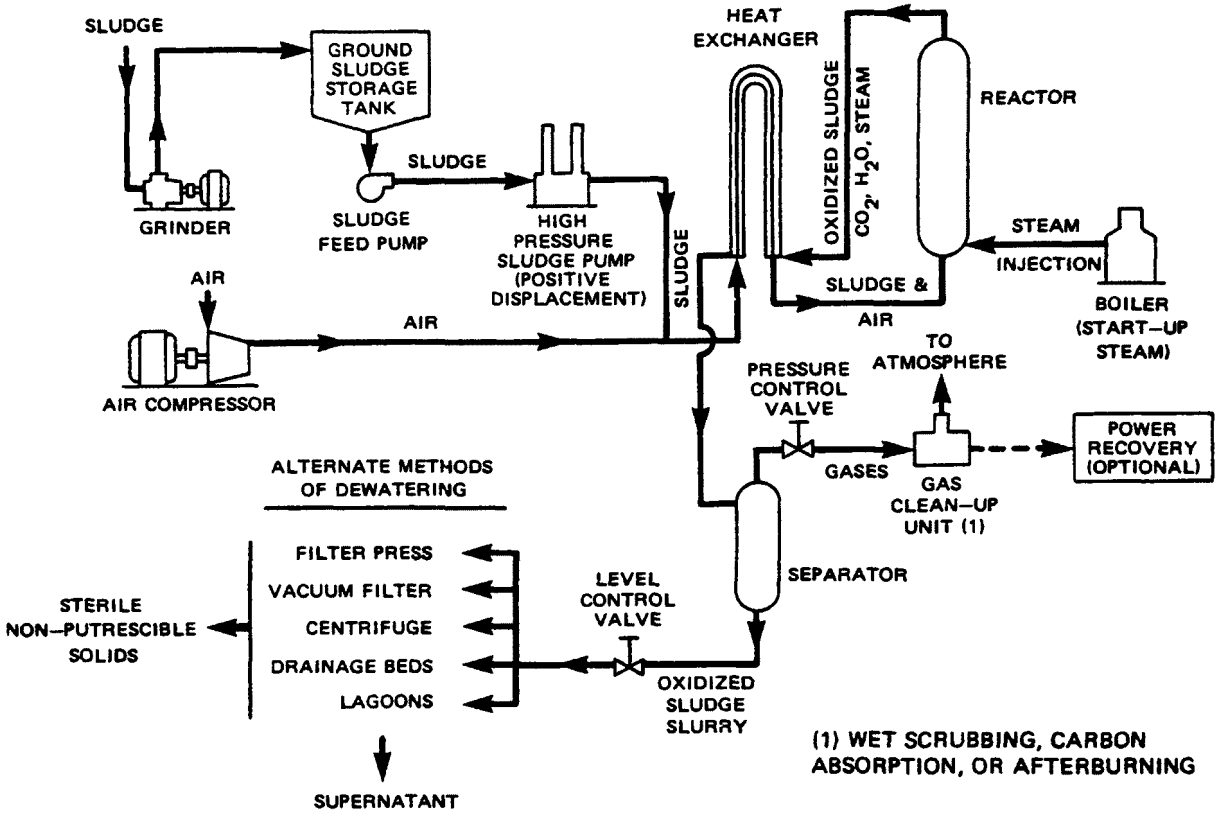


FIGURE 12. FLOW CHART FOR HIGH PRESSURE/HIGH TEMPERATURE WET AIR OXIDATION

Slurry from the gas-liquid separator passes through a liquid-level control valve and is dewatered for final disposal. At high degrees of oxidation, the residual solids resemble ash from thermal incineration. These residual solids are easily dewatered to a high solids content by conventional means, such as vacuum or pressure filtration. The liquid phase is recycled to the treatment plant or given separate treatment for reduction of the residual soluble organics.

High pressure/high temperature wet air oxidation processes generate excessive heat when they operate with a high heating value sludge and an adequate solids content (approximately 6 percent). Still, a source of high pressure steam (separate boiler or an existing plant system) must be provided for startup.

Because of the relatively high maintenance requirements (and subsequent low availability) of individual pieces of equipment in wet air systems, redundancy of virtually all of the individual system components described below is common.

The basic components of a wet air oxidation system are as follows:

- Grinders—These units are used to reduce sludge particle size. This reduction of particle size prevents problems with the handling of the sludge throughout the rest of the system and, more importantly, increases ratio of surface area to mass for the sludge particles.

- Low- and high-pressure feed pumps—Together, these pumps achieve the pressures necessary to support wet air (flameless) oxidation. Low-pressure pumps are typically centrifugal types, while high-pressure pumps are typically type positive displacement pumps.

- Heat exchangers—A series of heat exchangers are used to recover heat from the reactors effluent stream; this heat is used to preheat the incoming sludge/air mixture. Preheating is necessary if oxidation is to occur without the use of supplemental heat. In general, bundled, jacketed tube-type exchangers are used. Due to the corrosive/abrasive nature of sludge under high pressure, these units are typically constructed of stainless steel or, in some instances, titanium.

- Reactor—The reactor serves to provide the necessary residence time at the design temperature and pressure. Reactors are cylindrical in shape and constructed of either stainless steel or, in some cases, titanium.

- Startup boiler—The boiler provides the steam used as a source of supplemental heat during system startup.

- Separator—The separator is the pressurized vessel in which the oxidized sludge stream is split into two phases: the off-gases and the oxidized slurry. Automatic valves control the flow of gases and slurry from the separator.

- Decant tank—From the separator, the oxidized sludge slurry may be directed to what is, in effect, a gravity separator, or clarifier. The settled "ash" is pumped to a dewatering unit while the overflow, or decant, is typically either treated separately or returned to the plant headworks.

8.2 PROCESS CONTROL CONSIDERATIONS

Proper control of wet air oxidation consists primarily of maintaining, at the design flow rate, proper temperature and pressure conditions. This requires the operation and maintenance of a complex, maintenance-intensive system.

- Temperature/pressure—These are the primary control parameters which determine the degree of oxidation which will take place. As noted previously, the minimum pressure required at a given temperature is that needed to prevent vaporization of the water in the sludge. The following summarizes the relationship between temperature/pressure and the degree of oxidation achieved by a given system:

Oxidation category	COD Reduction, %	Temp., °F	Pressure, psi
Low	5	350 to 400	300 to 500
Intermediate	40	450	750
High	92 to 98	675	1,650

- Detention time—Must be adequate to permit oxidation to proceed to the desired degree, but should not be excessive (typically 40 to 60 minutes).

- Feed sludge percent solids—Typically 3 to 6 percent. Sludge that has too low a percentage of solids will require a supplemental heat source, while sludge that is much over 6 percent solids is difficult to pump at high pressure. Six percent solids is probably close to optimal for most systems.

- Volatile solids reduction—This is the primary performance evaluation criteria. It is likely to vary with site specific design criteria of the unit. Evaluate VSS reduction by comparing current operating data with 1) design criteria and 2) historical data on VSS reduction rates. Reduction should be commensurate with the temperature and pressure of the system.

- Decant—In a properly functioning system, the oxidized sludge should exhibit good settling characteristics, and decant solids should be relatively low (< 1,000 mg/l). The decant produced by wet air oxidation typically exhibits very high levels of organics, ammonia, and color, as follows:

Substances in Decant (liquor)	Concentration Range, mg/l (except as shown)
COD	100 to 17,000
BOD	3,000 to 15,000
NH_3-N	400 to 1,700
Phosphorus	20 to 150
Color	1,000 to 6,000 units

The recycle liquor can be very difficult to treat, offensive-smelling, and can upset wastewater treatment processes. The high concentrations of organics and ammonia illustrate the potential impact that recycling of the liquor can have on the wastewater treatment processes. It is important to recognize the significance of the recycle load in the management of the overall plant operation.

8.3 PROCESS PERFORMANCE EVALUATION

In evaluating a wet air oxidation system, the inspector should bear in mind the following:

- In virtually any plant in which it is installed, wet air oxidation will be by far the most complex, maintenance-intensive unit process.
- The strength of the decant liquor sidestream causes its handling to be a problem in many plants. The inspector should include an evaluation of the impact of this sidestream on plant operations in his/her inspection.

An inspection checklist is provided in Appendix A. This checklist is structured to aid the inspector in gathering the information needed to properly evaluate a wet air oxidation system. When evaluating one of these systems, the inspector should first obtain the manufacturer's O&M manual for the system being evaluated.

8.3.1 Design Evaluation

The inspector should consider the following when evaluating the capacity of a wet air oxidation system:

- The design capacity of each "train" in gpm, and the reactor detention time
- The intended temperature and pressure of operation
- The nominal (expected) heat value of the sludge to be processed.

In evaluating the systems configuration, consider:

- The level of redundancy provided, both in terms of number of "trains" and in individual units. The level of "availability" expected by the manufacturer (75 percent is typically specified and is optimistic) can affect the required redundancy. If individual units are "available" and can be shipped quickly when needed then the number of units needed on-site as "back-up" can be reduced.
- The "serviceability" of both the individual units specified, and of the overall system layout.
- Provisions for acid washing and manual scale removal
- Material of construction of the pumps, piping, heat exchangers and reactors.
- Decant handling—Adequate treatment should be provided to handle the decant, or the plant's wastewater treatment units (specifically biological treatment) should have been sized to accommodate the load imposed by this sidestream.
- Gas handling—There should be provisions to handle all off-gases. In addition, the decant tank, ash storage tanks, and dewatering facilities may require gas handling to control odor problems.

8.3.2 Operations and Maintenance Evaluation

The basic control parameters, discussed above, were:

- Temperature
- Pressure
- Feed rate
- Feed sludge percent of solids
- Volatile solids reduction.

In general, all of these parameters should be closely monitored, so as to detect deviations from design operating conditions. Given the complexity of wet air oxidation systems, and the differences that exist between the various systems in use, it is important that the manufacturer's recommended operating procedures form the basis for the operations strategy.

As most "operations" problems with wet air systems are in reality maintenance problems, it is important that a comprehensive preventive, and reactive maintenance program be in place. Such a program should include:

- Routine inspections of all components
- Scheduled cleaning/descaling of the piping, heat exchangers, reactors, and decanting system
- Procedures for evaluating operations data on a daily basis to detect impending problems
- Annual indepth inspection, to include pressure testing, and checks for pipe erosion and component fatigue.

9. INCINERATION

The incineration of sewage sludge reduces the total volume and mass of residuals generated by wastewater treatment and destroys all organic matter in the sludge. The resultant end-product is a sterile, odor-free ash containing inert particles and heavy metals.

Typically, sludge may be incinerated in either multiple-hearth or fluidized bed incinerators. However, other furnace types such as electric-infrared and rotary kiln have been used. Complete combustion of sludge results in the conversion of the combustible constituents into carbon dioxide, water, and sulfur dioxide. To ensure that complete combustion is achieved, excess air 20 to 150 percent more than theoretically required for combustion is supplied to the incinerator.

Municipal sewage sludge has a heat value ranging from less than 7,000 to 10,000 Btu/lb of dry solids. Primary sludges have higher heat values than secondary sludges. Higher heat values may be observed if there is a significant grease concentration present. Conversely, lower heat values may exist if the sludge was conditioned with inorganic chemicals. Although sludge contains a significant amount of combustible material, it cannot be burned autogenously (without supplemental fuel) unless it is dewatered to at least 25 percent solids. Since most of the supplemental fuel used in sludge incineration is needed to evaporate water from the sludge, incineration is typically preceded by a dewatering process to conserve fuel consumption.

To control air pollutants, all sludge incinerators are equipped with scrubbers. Most systems currently use wet scrubbers for particulate removal, the most effective being the Venturi impingement scrubber. The sludge incinerator scrubbers in present use will generally not remove the products of incomplete combustion, i.e., hydrocarbons, oxides of nitrogen and sulfur, carbon monoxide, and smoke. Therefore, proper operation that ensures complete combustion is essential for air pollution control.

The final step in sludge incineration involves ash disposal. The ultimate ash disposal method will be dependent on the heavy-metal concentration of the ash and its classification as a hazardous or nonhazardous waste. The ash is typically stored on an interim basis at the POTW site. The ash may be stored as a slurry in lagoons or stockpiled on the POTW grounds with ultimate disposal typically in landfills. Dry ash typically is very fine and is low in density. For this reason it is frequently transferred as a slurry and stored in lagoons on site, and wet down for truck transport.

9.1 PROCESS CONFIGURATION AND COMPONENTS

The two most common types of sludge incinerators employed are multiple-hearth or fluidized bed incinerators. The configuration and components of these two types of incinerators are presented in the following sections.

9.1.1 Multiple-Hearth Incinerator

A multiple-hearth incinerator is the type of incinerator that has been used most often for municipal wastewater sludge incineration. As Figure 13 shows, a multiple-hearth incinerator has a cylindrical steel shell around several solid refractory hearths and a central rotating shaft with rabble arms. The dewatered sludge enters at the top through a flapgate and drops down through the incinerator, from hearth to hearth, by the action of the rabble arms. The hearths are made of high-heat, heavy-duty fire brick. The drop holes are located in each hearth in such a manner that results in the sludge being alternately fed towards the periphery or central shaft as the solids fall from hearth to hearth. The capacity of these incinerators depends on the total area of the enclosed hearths. They are designed with diameters ranging from 54 in. to 21 ft. 6 in., and with 4 to 11 hearths. Capacities of multiple-hearth incinerators range from 200 to 8,000 lb/hr of dry sludge, with typical operating temperatures of 1,400° to 1,700°F.

Each hearth usually has two doors, fitted to cast iron frames and designed to close reasonably tight. Each door has an observation port that can be opened. Since the furnace may operate at temperatures of up to 2,000°F, the shaft and rabble arms are cooled by air supplied in controlled amounts from a blower located at the bottom of the shaft. The shaft is motor-driven and speed can be adjusted from approximately 0.5 to 1.5 rpm. Two or more rabble arms are connected to the shaft at each hearth. Each rabble arm has a central tube for conducting air from the central shaft to the end of the rabble arm. The air may be discharged to atmosphere or returned to the bottom hearth as preheated air for combustion purposes.

The rabble arms provide mixing action as well as rotary and downward movement of the sludge. Combustion air flow is countercurrent to that of the sludge. Some hearths have oil or gas burners to provide startup or supplemental heat. Sludge is constantly turned and broken into smaller particles by the rotating rabble arms. This process exposes the sludge surface to the hot furnace gases so that rapid and complete drying, as well as burning, of sludge occurs.

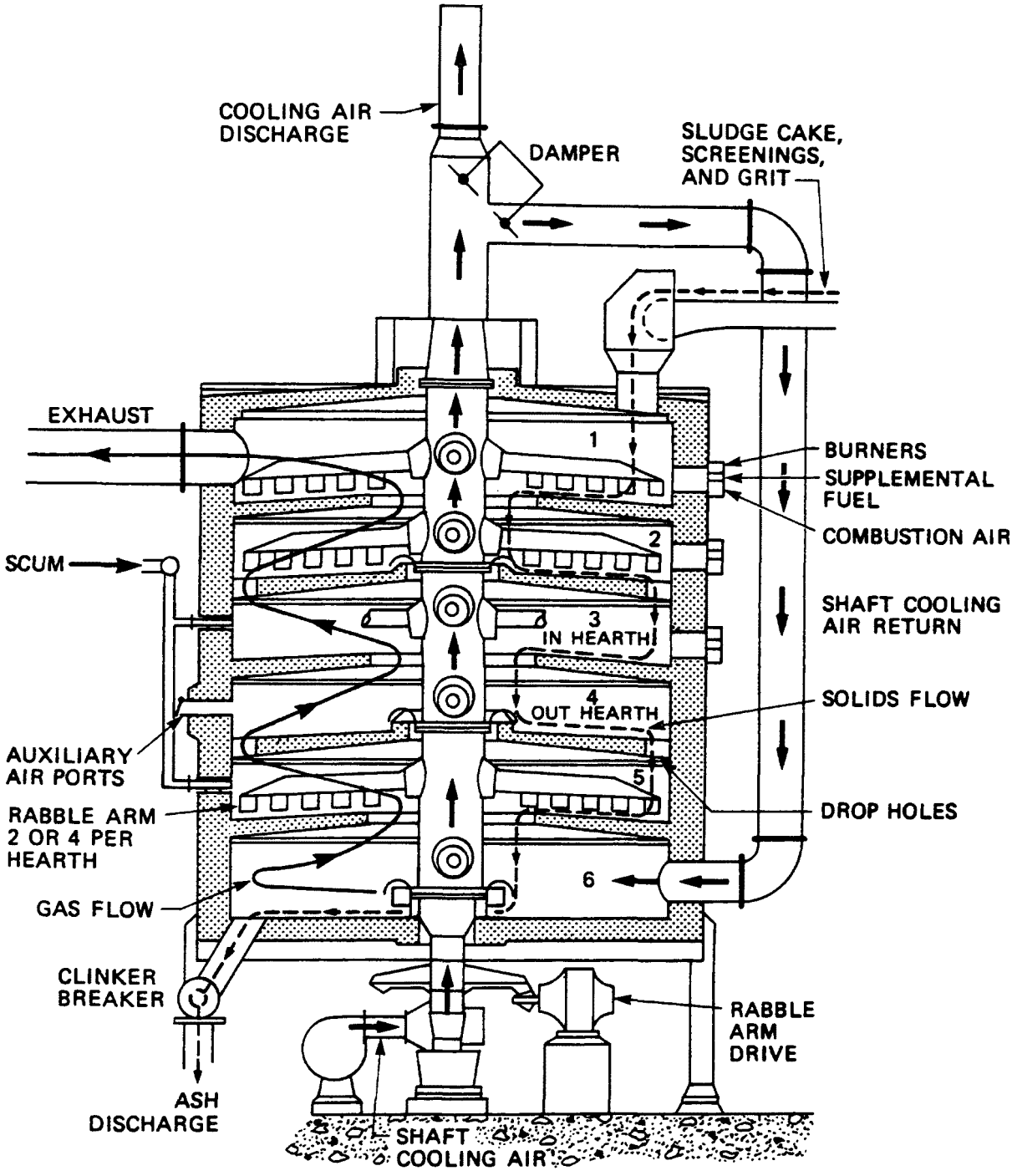


FIGURE 13. CROSS-SECTION OF A MULTIPLE-HEARTH FURNACE

The multiple-hearth system usually has an instrumentation system that sends operating data to a control panel. Temperatures can be recorded for each hearth, for exhaust gas, and for scrubber inlet gas. The temperature on each hearth can be controlled to within ± 40°F. Breakdowns such as burner shutdown, furnace over temperature, draft loss, and feed belt shutdown can be monitored. If there is a power or fuel failure, the furnace should be shut down automatically, and the shaft cooling air fan should be run on standby power to prevent shaft deformation.

9.1.2 Fluidized Bed Incinerator

The fluidized bed incinerator is a cylindrical refractory lined vessel with a grid near the bottom to support a sandbed. The grid is comprised of a series of tuyeres (air diffusers) through which combustion air is supplied. When the incinerator is shut down, the tuyeres prevent the sand from dropping down into the windbox. A typical fluid bed reactor used for combustion of wastewater sludges is shown in Figure 14. Dewatered sludge enters above the bottom grid, and air flows upward at a pressure of 3.5 to 5.0 psig to fluidize the mixture of hot sand and sludge. Auxiliary fuel can be supplied to the sand bed to maintain temperatures necessary for complete combustion to occur. The reactor is a single chamber unit where moisture evaporation and combustion occur at 1,400° to 1,500°F. Because of the large heat reservoir in the bed, and a rapid distribution of fuel and sludge throughout the bed, there is good contact between fuel and oxygen. The sand bed keeps the organic particles until they are reduced to mineral ash. The motion of the bed grinds up the ash material that is constantly stripped from the bed by the upflowing gases. The heat reservoir provided by the sandbed also allows faster startup when the unit is shut down for short periods, e.g., overnight. As an example, a unit can be operated 4 to 8 hours a day with little reheating after restarting because the sandbed is such a large heat reservoir.

Exhaust gases are usually scrubbed with treatment plant effluent. Particles are separated from the liquid in a hydrocyclone, with the liquid stream returned to the head of the plant. An oxygen analyzer in the stack controls the air flow into the reactor. The auxiliary fuel feed rate may be controlled by a temperature recorder. To lower fuel costs, an air preheater can be used with a fluidized bed.

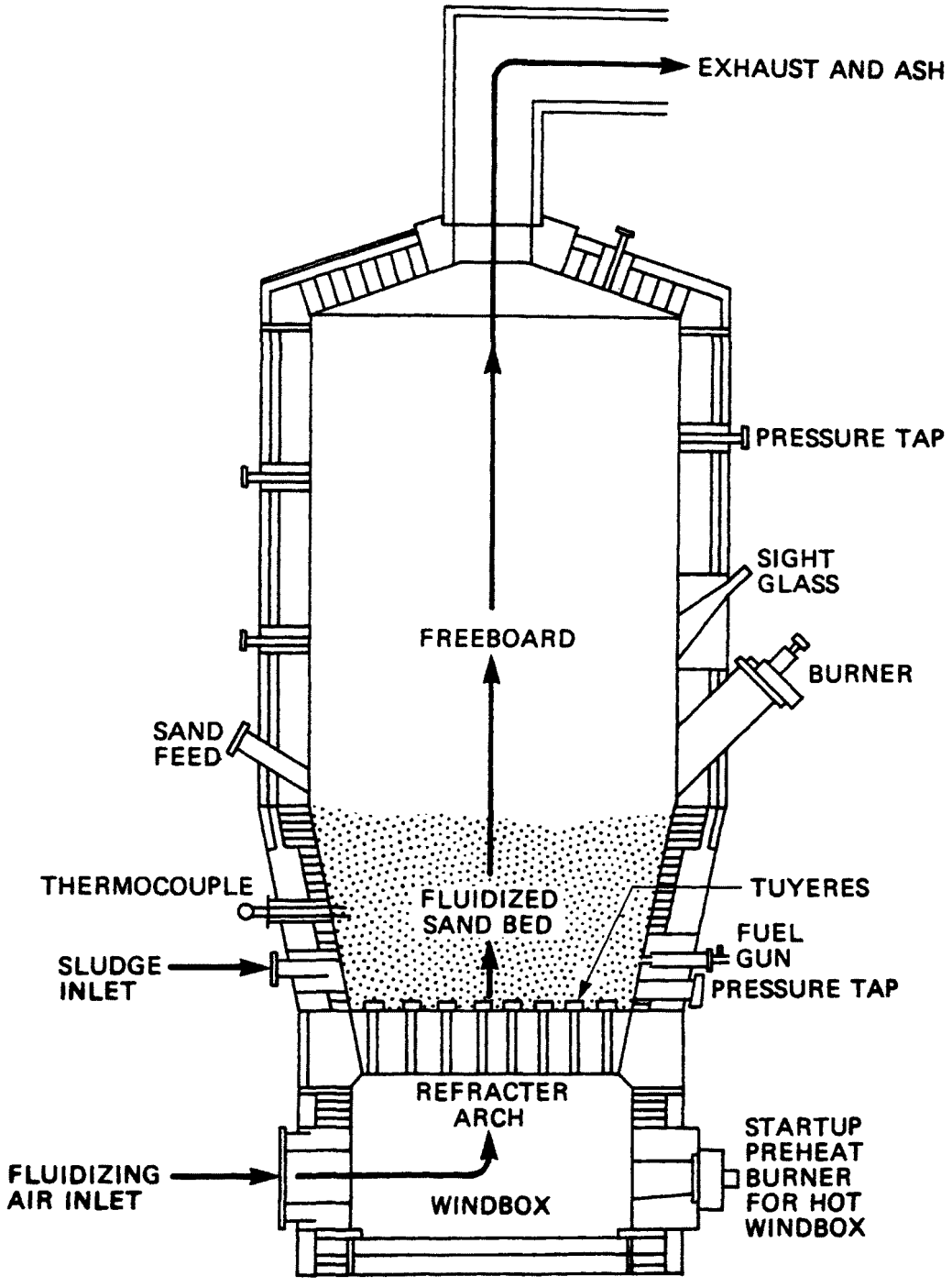


FIGURE 14. CROSS-SECTION OF A FLUIDIZED BED FURNACE

An instrumentation system is an inherent component of a fluidized bed incinerator. Thermocouples and pressure taps are installed at several locations to monitor the temperature or pressure at various points in the system.

9.2 PROCESS CONTROL CONSIDERATIONS

Economical and complete combustion in both incinerator types is dependent on an effective process control program. Frequent monitoring and comprehensive record-keeping are essential to an efficient incineration process. The parameters of primary concern are:

- Sludge cake total solids and volatile solids content
- Sludge feed rate
- Combustion air feed rate
- Drying, combustion, and freeboard zone temperatures
- Exhaust gas oxygen and carbon monoxide levels.

9.2.1 Sludge Cake Solids Content

To reduce auxiliary fuel requirements and to increase the incinerator throughput, the sludge must be dewatered prior to incineration. Increasing solids concentrations will generally reduce the fuel requirement, as there will be less water to evaporate before combustion. If sufficient volatiles are present, autogenous combustion may occur at total solids concentrations greater than 35 percent. Since the sludge solids concentration does not remain consistent, samples of sludge cake should be taken and analyzed at least once per shift.

9.2.2 Sludge Feed Rate

The feed rate should be monitored to determine the sludge loading rate to the incinerator. Sludge loading rate is the weight of wet sludge fed to the reactor per square foot of reactor bed per hour ($lbs/hr/ft^2$). Loading rates out of the normal range for that type of incinerator may indicate operating problems, poor management, or other items that may lead to noncompliance. If the incinerator is overloaded, then incomplete combustion will occur. Incomplete combustion will result in increased pollutant emissions and in odor levels in the exhaust stack.

The inspector should also check records of sludge loading rates to determine if the sludge feed rate is relatively constant. If there are rapid fluctuations in the sludge feed rate, the operator must vary the air feed and combustion temperature in order to ensure complete combustion. This makes the operation unsteady and causes early failure of many components due to excess wear and thermal stress. A constant sludge feed rate is desirable to avoid having to make these operating adjustments.

9.2.3 Air Feed Rate

The supplied air rate will vary depending on sludge constituents and moisture content. Excess air is the amount of air supplied beyond the theoretical air requirements for complete combustion. Providing sufficient excess air ensures complete combustion of organics and minimizes the emission of hazardous air pollutants. Since the feed rate and composition of the sludge vary, incinerator operators may have to vary air feed rates in order to maintain adequate excess air. If air rates are inadequate, complete combustion will not occur. Excessive air feed may result in higher emissions of nitrogen oxides, low combustion temperatures, or increased auxiliary fuel consumption depending on the amount of excess air. Generally, excess air supplies should be as follows:

- Multiple-hearth furnaces—100 percent or more excess air
- Fluidized bed furnaces—20 to 45 percent excess air
- Electric-infrared furnaces—30 to 70 percent excess air.

The air feed rate should be monitored to ensure adequate oxygen is supplied for complete combustion.

9.2.4 Temperature Monitoring

A combustion temperature of 1,200°F to 1,600°F is normal and considered necessary for oxidation of high molecular weight organics. However, operation temperatures above 1,800°F may result in increased emissions of metals, ash melting (slagging), and damage to the refractory material. Rapid changes in temperature indicate that there are operational problems that should be resolved. Temperature changes can be caused by many events, such as increased moisture in the sludge, changes in excess air, flame outs, and changes in the fuel values going to the incinerator. Several temperature locations are normally required to be monitored. The inspector should check that all thermocouples or other devices are in working order and are calibrated as required.

In a multiple-hearth furnace it is important to monitor the temperature at the individual hearths. As can be seen from Figure 15, several distinct processes are occurring at different hearth levels and temperatures. It is therefore imperative that the temperature in each zone is continuously monitored during sludge incineration. Additional temperature monitoring may be conducted on the preheated combustion air supply and stack exhaust gas.

In a fluidized bed incinerator, the temperature should be continuously monitored in the windbox, bed, freeboard, and exhaust sections. For complete combustion to occur, the bed temperature should be maintained at approximately 1,400°F. Excessively high bed temperatures may be due to excessive auxiliary fuel feed rates or high grease concentrations. The freeboard temperature is normally kept in the range of 1,500° to 1,600°F.

9.2.5 Exhaust Gas Monitoring

Generally, the oxygen content in the exhaust gas is maintained at between 3 and 6 percent. Low oxygen concentrations and increased carbon monoxide levels may be indicative of excess sludge loading rates, inadequate air supply rates, or excess auxiliary fuel rates. Periodic measurements of the following parameters should also be conducted: particulates, hydrocarbons, heavy metals, and oxides of sulfur and nitrogen.

The concentrations of oxygen and carbon monoxide in the exhaust or off-gas are also indicative of combustion efficiency. Combustion efficiency can be calculated as follows:

$$\text{Combustion Efficiency} = \frac{\text{Conc } CO_2 \text{ in exhaust gases}}{\text{Conc } CO_2 + CO \text{ in exhaust gases}}$$

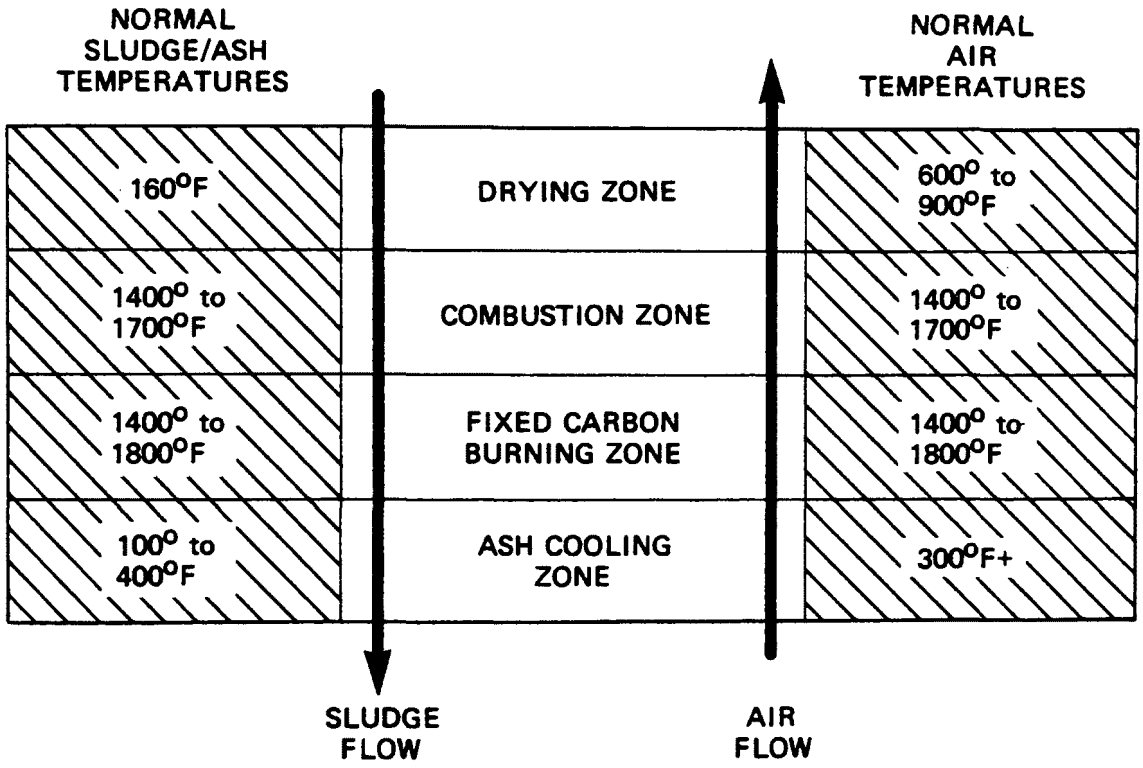


FIGURE 15. PROCESS ZONES IN A MULTIPLE-HEARTH FURNACE

9.3 PROCESS PERFORMANCE EVALUATION

Evaluation of the incineration process relies heavily on inspection of operating parameters. For all records of measurements taken automatically, the inspector should attempt to verify that data recorded are the same as those being measured. The inspector should record the time and reading of instruments during the facility inspection and compare them with the charts or printouts generated. It is very common for charts to be recording incorrect data. In particular, the inspector should verify the following parameters:

- Sludge feed rate—The inspector should look at incinerator records to determine the range of sludge feed rates. These rates should be compared to the values listed in the O&M manual as typical loading rates for that type of incinerator to see if the incinerator is overloaded.
- Percent solids of sludge feed—The inspector should look at operating records to determine the average solids content of sludge feed and the average rate of auxiliary fuel consumption as rapid or large changes in conditions can make incineration difficult and result in violations.
- Excess air—The inspector should evaluate both the amount of excess air and the variability of its supply.
- Combustion temperature—The inspector should inspect plant records to determine if the incinerator is operating at appropriate combustion temperatures, and should record temperatures at the time of the inspection directly from the instrument.
- Exhaust gas—The inspector should review records of oxygen and carbon monoxide content of the exhaust or off-gas to aid in the evaluation of combustion efficiency.

When evaluating the performance of a sludge incinerator, the inspector should obtain as much design and operating information as possible from the operation and maintenance manual. All sewage sludge incinerators constructed or modified after June 11, 1973 are required (under the New Source Performance Standards at 40 CFR Part 60) to have performance tests run as they come on line. These air pollution tests are frequently used to define the optimal range for the above described operating parameters. Also, the air pollution permit conditions should be reviewed prior to the inspection, as these will generally define operating conditions. Finally, the operation of the sludge dewatering should be evaluated concurrently with the incinerator inspection. The efficiency of the sludge dewatering system will significantly impact the operation of the incinerator. An inspection checklist for incinerators is included in Appendix A. This checklist is designed to assist the inspector in gathering the information necessary to evaluate incinerator operations.

10. COMPOSTING

Composting is the aerobic decomposition of the sludge organic constituents at elevated temperatures. Recently, some facilities have initiated anaerobic composting schemes for sewage sludge. Composted sludge from municipal wastewater treatment plants can contain significant levels of nutrients and may be suitable for use in soil enhancement for plant growth. Composting is performed to create a stable, humus-like material, and occurs in two phases: stabilization and maturation.

In the stabilization (active) phase, biological activity causes the temperature to rise to a thermophilic level, followed by a gradual decrease to ambient levels. The population of microorganisms increases rapidly as the temperature rises and easily oxidized organic compounds are metabolized. Excess released energy results in a rapid rise in temperature to the range of 40° to 60°C. At these temperatures, pathogenic organisms will be greatly reduced or completely destroyed. The ultimate rise in temperature is influenced by the availability of oxygen and the air flow through the compost piles.

As the energy source is depleted, biological activity slows and the temperature slowly returns to ambient levels. At this stage, maturation of any undegraded organic matter occurs. The composting process is complete when there is a marked drop in temperature and no subsequent significant increase in temperature occurs when the mature compost is aerated.

10.1 PROCESS CONFIGURATION AND COMPONENTS

Composting can be conducted in either unconfined or confined composting systems. Unconfined composting is conducted in either windrow piles or forced-air static piles. The basic steps to be followed in those two processes are similar, but the processing technology for the composting stage differs appreciably. In the windrow method, oxygen is drawn into the pile by natural convection and turning, whereas in the static pile method, aeration is induced by forced-air circulation.

Confined (in-vessel) composting is conducted in an enclosed container or basin. The systems are designed to minimize odor and process time by controlling environmental conditions such as air flow, temperature, and oxygen concentration.

The components of an unconfined composting operation generally include equipment for moving and mixing the compost mixture. A typical compost operation would include a dump truck, front end loader, drum screen, and a windrow turner or aeration blower assembly. The composting process can require the use of a large amount of land area.

10.2 PROCESS CONTROL CONSIDERATIONS

The efficiency of a composting operation is dependent upon the sludge characteristics, initial moisture content, uniformity of the mixture, frequency of aeration or windrow turning, and climatic conditions. The characteristics of the sludge being composted will affect the amount and type of bulking material that is required. The bulking material provides porosity, which facilitates moisture control for the sludge. Typically, recycled compost, wood chips, and sawdust are used as bulking agents.

Dewatered municipal sludges are usually too wet to satisfy optimum composting conditions. The optimum moisture content is in the range of 50 to 60 percent water. If the mixture is over 60 percent water, the proper structural integrity will not be obtained. If the moisture content is less than 40 percent, moisture may limit the rate of decomposition. The moisture content can be reduced by blending the sludge with a dry bulking material or recycled product, and dewatering the sludge to as great an extent as economically possible.

The dewatered sludge and bulking agent should be uniformly mixed. Uniform mixing will create the proper texture, ensure that the moisture is consistent throughout the pile, and allow air to flow through the pile and provide oxygen.

Sufficient air should be supplied to the pile, either by forced aeration or windrow turning, to maintain oxygen levels of between 5 and 15 percent. Insufficient oxygen levels will create anaerobic conditions, which will stop the composting and create odors. Excessive aeration can have the effect of cooling the pile, which in turn will slow the composting process. Oxygen and temperature readings should be monitored either continuously or several times per day. Readings should be taken at several locations within the pile.

To comply with the process to significantly reduce pathogens (PSRP) requirements of 40 CFR Part 257, the compost pile must be maintained at a minimum operating temperature of 40°C for at least 5 days. During this time, the temperature must be allowed to rise above 55°C for at least 4 hours to ensure pathogen destruction. Typically, this is done near the end of the active composting phase to prevent inactivation of the microbes responsible for metabolizing the organic fraction of the sludge.

To comply with the processes to further reduce pathogens (PFRP) requirements of 40 CFR Part 257, the in vessel and static aerated compost piles must be maintained at a minimum operating temperature of 55°C for at least 3 days. The windrow pile must be maintained at a minimum operating temperature of 55°C for 15 days. Additionally, there must be at least 3 turnings of the pile during this time period.

Climatic conditions play an important role in windrow composting. During wet weather conditions or in cold climates the compost time can significantly increase.

10.3 PROCESS EVALUATION

When evaluating the performance of a composting operation, the inspector will rely mostly on sensory observations. An inspection checklist is provided in Appendix A. This checklist is designed to assist the inspector in gathering the information required to evaluate the performance of the compost operation. Some of the key areas to be evaluated are briefly discussed below.

The inspector should visually inspect the piles to ensure they are mixed thoroughly. The mixed material should be relatively homogenous, without large clumps of sludge. The mixture should not look too moist or wet. If it does, the inspector should measure the moisture content.

The inspector should measure the temperature and oxygen levels throughout the compost piles. The operator's records should be inspected to ensure that the pile is meeting the time and temperature requirements in 40 CFR Part 257.

The inspector should inspect the compost site for signs of runoff. The runoff should be collected and treated. The runoff is usually returned to the treatment plant headworks.

Significant odors will generally be associated with the compost operations especially from active piles. Therefore, some sites may have odor control systems in operation. Odor from "cured" compost piles should be minimal if the organic fraction has been sufficiently reduced.

The finished compost should have a moisture content in the range of 40 to 50 percent and a volatile solids content of 40 percent or less.

11. CHEMICAL STABILIZATION AND CONDITIONING

Chemical conditioning is a process in which chemicals are added to sludge to improve its dewatering characteristics. Inorganic salts (commonly lime or ferric chloride) or organic compounds (long-chain polymers) may be used alone or in combinations to accomplish this conditioning. Conditioning does not itself reduce the quantity or water content of the sludge, but rather improves the efficiency of subsequent solids handling steps. The purpose of chemical stabilization is to make the sludge less odorous and putrescible and to reduce the pathogenic organisms, as well as improve the potential for dewatering the sludge.

Inorganic chemicals used for sludge conditioning commonly include ferric chloride, used alone or in conjunction with lime or alum, or lime used alone. Organic conditioning agents, usually referred to as polyelectrolytes or polymers, include a variety of long-chain organic molecules which may be either anionically or cationically charged or be electrically neutral.

Physically, wastewater sludges consist of a mixture of solid phases suspended in an aqueous solution of dissolved substances. The surfaces of the solid phase tend to acquire charge by preferential absorption of ions from the solution or by ionization of component functional groups. The solid phases of domestic wastewater sludges characteristically possess a negative charge. This electrostatic charge hinders the separation of the solid phase from the water in two ways: First, water molecules, being polar, are strongly attached to the surface of the solids. Second, the like charges on individual solid particles cause them to repel. Sludge conditioning addresses both of these problems by introducing molecules of opposite charge. These molecules attract the oppositely charged sludge particles, neutralize their surface charge, and agglomerate the smaller particles into larger, denser particles with low electrical charge.

Use of lime as a conditioning agent has the additional advantage that it will not only condition the sludge, but will biologically stabilize it as well. The addition of lime creates a highly alkaline environment that inactivates or destroys pathogens. Lime stabilization is practiced to meet the requirements of 40 CFR Part 257 (processes to significantly reduce pathogens), which states that sufficient lime must be added to produce a pH of 12 after 2 hours of contact. Because the addition of lime does not reduce the volatile organics, if the pH drops below 11, renewed bacteria and pathogen growth can reoccur. Therefore, the pH must be maintained at above 12 for 2 hours to ensure pathogen

destruction and to provide enough residual alkalinity so that the pH does not drop below 11 for several days.

11.1 PROCESS CONFIGURATION AND COMPONENTS

The configuration for chemical sludge conditioning usually consists of one or more bulk storage vessels for the conditioning of chemicals, chemical feeders to accurately add the chemical agents to the sludge, and a conditioning tank in which the conditioning chemicals and sludge are mixed. The conditioning tank is usually located immediately adjacent to the solids processing unit that will receive the conditioned sludge. The lime stabilization process uses the same type of equipment as conditioning, although the process can take place before or after dewatering.

Lime can be purchased in dry form. Depending on the size of the system, the lime may be purchased in bags, trucks, or rail cars. Large volumes are handled with screw conveyors, bucket elevators, or pneumatic transfer lines. The most common forms purchased are hydrated lime ($Ca(OH)_2$) and pebble quicklime (CaO). Because quicklime is hygroscopic, water tight and airtight storage must be provided. Attention should be given to dust control with manual handling or pneumatic transfer systems.

Pebble quicklime requires "slaking" (conversion of CaO to $Ca(OH)_2$ by mixing with water) prior to use. Commercial designs vary in regard to the combinations of water to lime, to slaking temperature and slaking time, in obtaining the "milk of lime" suspensions. Slaked lime requires only enough water to form the desired "milk of lime" slurry concentration (usually 3 percent).

Lime is not corrosive to steel and therefore steel, iron, rubber plastic, polyvinyl chloride (PVC), and concrete may be used for transfer and storage of lime or "milk or lime" solutions. Lime solutions rapidly cloud glass piping, therefore the use of glass rotometers on lime solution lines is not recommended.

Two types of feeders, volumetric and gravimetric, are used to meter dry lime. Volumetric feeders deliver fixed volumes of material; gravimetric feeders deliver constant weights of material. Variations in the bulk density of dry lime usually make gravimetric feeders more accurate. Lime solutions can be fed with positive displacement metering pumps.

Ferric chloride is usually purchased in liquid solution with a ferric chloride content of 35 to 45 percent. Shipping concentrates vary from summer to winter due to the relatively high crystallization temperature of solutions at these concentrations. Liquid ferric chloride is shipped in 5- and 13-gal carboys, tank trucks, and rail cars.

Ferric chloride is highly corrosive to iron and steel. Storage tanks and transfer lines should be constructed of fiberglass reinforced plastic (FRP), PVC, or rubber- or plastic-lined steel. Because of the tendency of ferric chloride solution to stain or deposit, glass tube rotometers are not appropriate. Feeding of ferric chloride solutions is usually accomplished with rubber diaphragm positive displacement pumps or rotodip pumps.

Alum (aluminum sulfate) is usually purchased in liquid form. The typical solution concentration is 49 percent as $A_l(SO_4)_2 \bullet 14H_2O$. Liquid alum is corrosive to mild steel, but not 316 stainless steel. Storage tanks and transfer lines should be constructed of 316 stainless steel, FRP, PVC, plastics, or lead. Feeding of alum solutions may be accomplished with positive displacement pumps, rotodip feeders, or centrifical pumps equipped with rotometers. Pumps should be constructed of 316 stainless steel or plastics.

Polymers (polyelectrolytes) may be purchased in dry or liquid form. Small systems most commonly purchase liquid polymer solution in 33- or 35- gal drums. Liquid polymer solutions are generally stored in 316 stainless steel, FRP- or plastic-lined tanks. These high-concentration solutions may be diluted in a day tank prior to feeding. Liquid polymers or dry polymer solutions are fed using metering pumps or rotodip feeders.

Larger systems purchase dry polymer, which is batch-mixed prior to use. Batch-mixing of dry polymers requires continuous mixing until all polymer is dissolved to prevent the formation of semisolid lumps commonly called "fish eyes." After the polymer is completely dissolved, it must be aged for 8 to 24 hours prior to use. Because of the tendency of dry polymer to absorb moisture, it is usually purchased in bags or cardboard drums rather than in bulk. Dry polymer should be stored in a cool, dry place. Extended storage should be avoided.

The chemical conditioning tank is usually located immediately adjacent to the subsequent solids processing unit. The tank's volume should be appropriate for the solids dewatering unit's capacity. If

chemical stabilization is not followed by dewatering, the chemical stabilization tank is sized based on the daily sludge volume treated. Construction materials for the tank and mixer should be appropriate for the sludge, and conditioning chemical, characteristics. For most municipal wastewater sludges, steel or concrete tanks may be used.

For chemical conditioning, sufficient mixing to completely disperse the conditioning chemicals should be provided. Mixing is accomplished by either diffused air or mechanical agitators. Excessive mixing which will break up the resulting floc through shear action, should be avoided. Storage of the floc after it has formed should be minimal to prevent it from settling in the tank, or require excessive mixing to keep in suspension. In contrast, the mixing requirements for lime stabilization may require more agitation to promote rapid and even mixing throughout the tank and keep solids in suspension.

11.2 PROCESS CONTROL CONSIDERATIONS

The primary means of process control for chemical conditioning is to vary the dosage of the conditioning chemicals. A rapid laboratory method for optimizing chemical dosage is the Standard Jar Test. This test uses a six-place paddle stirrer to mix equal samples of the sludge to be conditioned. Six different doses of a conditioning chemical can then be added and mixed. The mixer is then turned off and the sludge is observed. If enough of the conditioned chemical has been added, an immediate agglomeration of suspended solids will be noted, clear interstitial water will be present, and the suspended solids will settle in less than 5 minutes.

Although the Standard Jar Test is useful for determining chemical dosages, the true performance evaluation criteria for chemical conditioning is the product produced by the dewatering step. Excessive moisture content, filter media, blinding, poor cake release, or high filtrate or centrate solids, are all indications of poor chemical conditioning performance. Operating records for the conditioning/dewatering operation should correlate chemical dosages with dewatering system performance to determine long-term optimum conditioning requirements.

Feed rates for chemical conditioning of sludges are extremely variable depending on the process used, the nature of the sludge, and the type of chemical. Table 6 shows typical ranges of dosages.

TABLE 6. TYPICAL DOSAGE RANGES FOR CHEMICAL CONDITIONING

	$FeCl_3$, lb / Dry Ton Solids	Lime/lb CaO / Dry Ton Solids	Polymer lb/ / Dry Ton Solids
Raw primary + waste activated sludge	40 - 50	110 - 300	15 - 20
Digested primary + waste activated sludge	80 - 100	160 - 370	30 - 40
Elutriated primary + waste activated sludge*	40 - 125	—	20 - 30

* Elutriated sludge results from a process whereby the sludge is washed with fresh water or plant effluent to reduce the demand for conditioning chemicals and to improve settling of filtering characteristics (sludge handling and conditioning).

The lime stabilization process is mainly controlled by the pH of the sludge-lime mixture, lime dosage, and mixing time. Lime should be added continuously until the desired pH level is reached. This can be done manually or by an automatic pH control. If the control is manual, the operator must monitor the pH several times a shift. The lime needed to reach the desired pH level is affected by the type, chemical makeup, and percent solids of the sludge. Therefore, the exact dosage can only be determined by actual experimentation at the plant.

The sludge pH must be maintained at 12 for 2 hours for adequate stabilization (PSRP). The mixing time can be adjusted to provide a detention time in the tank of at least 30 minutes. The lime-treated sludge can also be transferred to a contactor vessel in which mixing is continued and additional lime is added, if necessary, to maintain the desired pH. Mixing time is usually a function of lime slurry feed rate and is not limited by the mixing capacity of the system. Therefore, mixing is best reduced by increasing the capacity of the lime slurry tank. In lime stabilization, the lime is frequently added after dewatering. This is a satisfactory means for achieving lime stabilization provided the lime and the sludge are thoroughly mixed.

Process control measurements should include:

- Continuous monitoring of the flow of the feed sludge to the conditioning or stabilization unit
- Continuous or periodic monitoring of the chemical dosage
- Daily sampling of feed sludge for total solids, suspended solids, and alkalinity.
- Daily sampling of conditioned sludge for suspended solids
- Continuous monitoring of pH in mixing tank
- Daily (or continuous) sampling of pH of stabilized sludge.

11.3 PROCESS PERFORMANCE EVALUATION

In evaluating chemical conditioning systems, the inspector is cautioned to bear in mind that the chemical conditioning operation and subsequent dewatering operation are interrelated. Poor performance of the dewatering operation may reflect improper operation of the conditioning step.

When evaluating the performance of a chemical stabilization process, the inspector should check the pH of the lime-treated sludge as it exits the mixing tank and 2-hour-old lime-treated sludge. An inspection checklist is included in Appendix A. The checklist is structured to aid the inspector in gathering the information needed to properly evaluate a chemical conditioning or chemical stabilization system.

11.3.1 Design Evaluation

In evaluating the design adequacy of chemical conditioning and stabilization systems, the inspector should consider the following:

- Chemical storage facilities—Storage facilities should be designed to maintain a 15- to 30-day inventory of chemicals based on average use. Smaller inventories could result in the facility running out if there is some disruption in the supply. Larger inventories may increase the likelihood that dry chemicals will absorb moisture and form lumps, or that solids or liquids will, through age, loose reactivity. Storage facilities should be watertight or airtight if appropriate. Dust control should be provided if needed.

- Operating strategy—There should be a well-defined operating strategy based on either bench scale testing or dewatering facility performance, to ensure that chemical dosage rates are adjusted in response to changing sludge characteristics.

- Safety—Because of the corrosive nature of dry conditioning chemicals, attention should be given to dust control measures, particularly when pneumatic transfer systems or manual handling are used. Storage, handling, and feeder equipment should be kept clean, with leaks and spills cleaned up immediately. Concentrated polymer solutions/and dried alum solutions are extremely slippery and if spilled will present a significant hazard to individuals working in the area.

- Calibration—Gravimetric feeders should be regularly calibrated and the calibration records maintained at the site. Similar calibration records should be kept for pH meters, and other control instrumentation.

- Redundancy—There should be sufficient redundancy in the system so that the failure of any one component (e.g., a metering pump) does not put the entire system out of service. Where possible, if more than one component is used all components should be the same make and model. This will minimize the spare parts inventory required and simplify maintenance activities.

- Mixing—Mixing of the chemical conditioning/stabilization tank is necessary to ensure intimate contact between the conditioning/stabilization chemicals and the solids. Under-mixing will result in poor solids capture in the dewatering step. Over-mixing is equally a problem, as it will break up the floc which has formed and redistribute fines into suspension. The mixer should be an appropriate size, and excessive mixing time should be avoided. Floc break-up or excessive mixing is not of concern for the chemical stabilization process.

- Conditioning tank detention time—The size of the conditioning tank should be appropriate for the dewatering step that follows it. For batch-type dewatering equipment (e.g., plate and frame pressure filters) only the solids required for one batch should be conditioned at one time. For continuous dewatering operations, detention time in the conditioning tank should be no longer than necessary to adequately mix the chemicals and allow the floc to form. Lime stabilization requires a minimum detention time of 30 minutes.

- Visual observations—A sample taken from the conditioning tank should show rapid agglomeration of solids, crystal clear interstitial water, and rapid settling tendencies. The supernate should not be cloudy or contain fines. A sample of the stabilized sludge should show a pH of 12.

12. VACUUM FILTER

Vacuum filters have been widely used for dewatering both raw and digested wastewater sludges. The earlier predominant methods were the drum or scraper-type rotary vacuum filters. The belt filter with natural or synthetic fiber cloth, woven stainless steel mesh, or coil springs media now predominate.

In vacuum filtration, a vacuum applied downstream of the media forces the liquid phase through the porous media, leaving behind the solids to form a cake. A horizontal cylindrical drum, covered with a porous medium, is partially submerged in a vat of liquid sludge. As it slowly rotates, vacuum applied immediately under the filter medium draws solids to form a cake on the surface of the filter medium. Suction continues to dewater the solids adhering to the belt as it rotates out of the liquid. Then the vacuum is stopped while the cake is removed, and the medium is washed by water sprays before reentering the vat.

Figure 16 shows the cutaway view of a vacuum filter. The drum surface is partitioned into several sections around its circumference. Each section is sealed from its adjacent section and the ends of the drum. A separate drain line connects each section to a rotary valve at the axis of the drum. Bridge blocks in the valve divide the sections into the three zones which correspond to the parts of the filtering cycle: the cake forming zone, the cake drying zone, and the cake discharging zone. A vacuum is applied to the cake forming zone and the cake drying zone of the valve. As each of the drain lines pass through the different zones in the valve the vacuum is applied to each of the drum sections.

Figure 17 illustrates the three operating zones encountered during a complete revolution of the drum. About 10 to 40 percent of the drum surface is submerged in a vat containing a previously conditioned sludge slurry. This portion of the drum is the cake forming zone. Vacuum applied to the submerged drum section causes filtrate to pass through the media and sludge particles to be retained on the media. As the drum rotates, each section is successively carried through the cake forming zone to the cake drying zone. This zone is also under vacuum and begins at the point where a drum section emerges from the sludge vat. The cake drying zone represents 40 to 60 percent of the drum surface and terminates at the point where vacuum is shut off to each successive section. At this point, the sludge cake and drum section enter the cake discharge zone, where sludge cake is removed from the media.

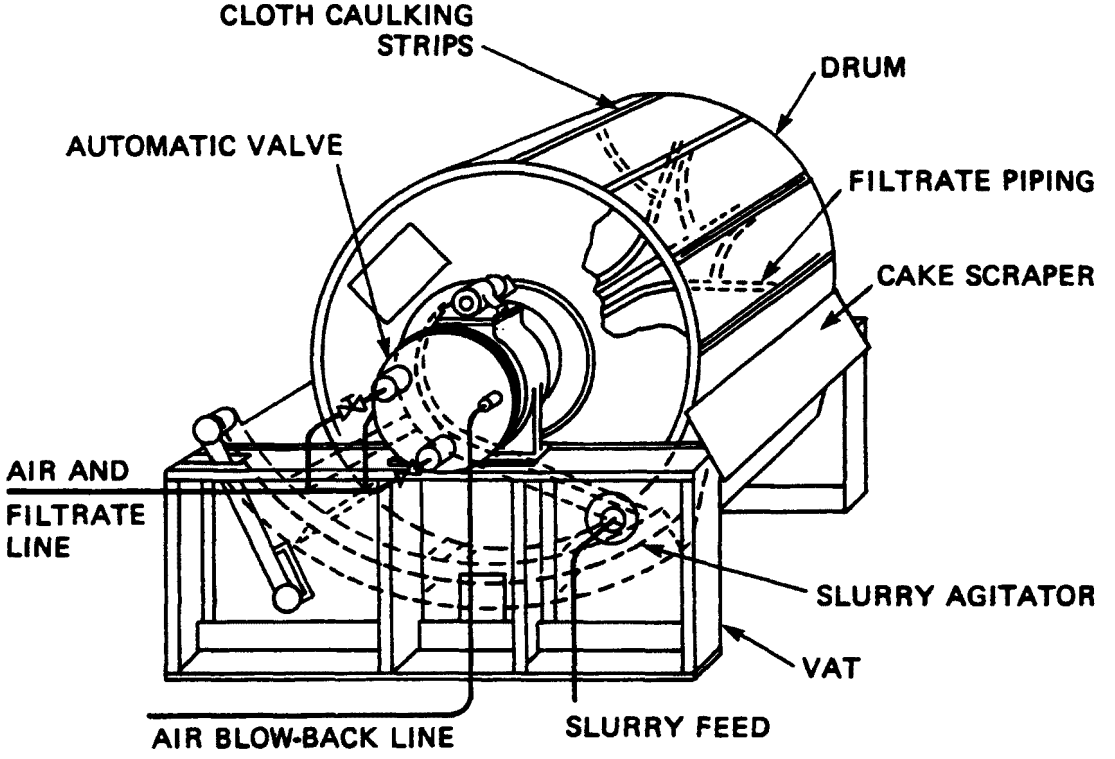


FIGURE 16. CUTAWAY VIEW OF A DRUM OR SCRAPER-TYPE ROTARY VACUUM FILTER

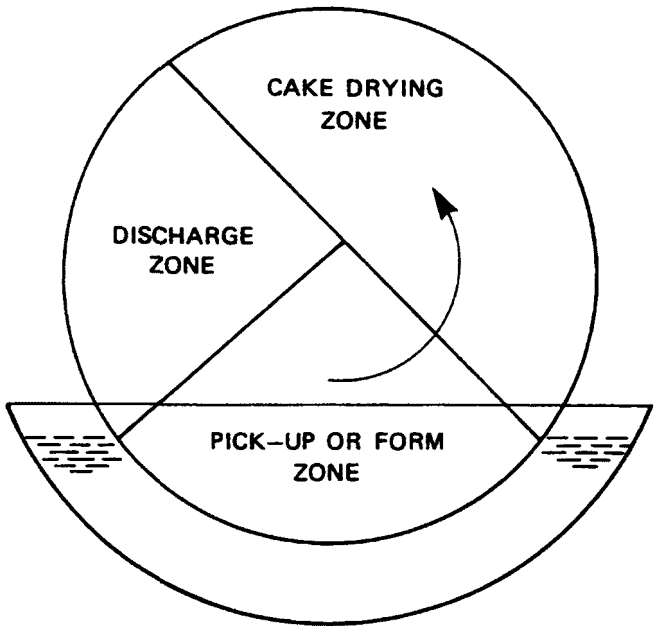


FIGURE 17. OPERATING ZONES OF A ROTARY VACUUM FILTER

12.1 PROCESS CONFIGURATION AND COMPONENTS

There are two variations of the vacuum filter: the drum filter and the belt filter. The drum filter operates continuously with vacuum applied in the cake forming zone and cake drying zone. In the cake discharge zone a positive air pressure is maintained in the segment just ahead of the sludge scraper blade to aid in removal of the dried cake. A fine spray may be used to clean the filter medium with a catching trough beneath to dispose of the washings. This type of filter has been largely replaced by the belt filter.

Belt rotary vacuum filters differ from the drum or scraper-type units in that the belt medium leaves the drum during cake discharge and washing. The belt medium may be of cloth or stainless steel mesh or coil springs.

- Cloth- or stainless steel mesh-medium filters—A traveling woven cloth (synthetic or natural-fiber) or metal mesh belt serves as the filter medium. At the end of the drying zone the belt leaves the drum, passing over a small-diameter discharge roll that facilitates cake discharge. There may also be a small-diameter curved bar between the point where the belt leaves the drum and the discharge roll. This bar aids in maintaining belt dimensional stability and adequate cake discharge. A scraper blade may also be present to obtain cake release from cloth media. The belt can be washed on both sides, if desired, before positioning back on the drum.

- Coil-medium filters—Two layers of stainless steel springs wrapped around the drum act to support the initial solids deposit in the cake forming zone. The solids, in turn, serve as the filter medium. When the two layers of springs leave the drum they are separated from each other. The sludge cake is lifted off the lower layer of coil springs, and discharged off the upper layer with the aid of a positioned tine bar. The two coil spring layers are then washed separately by spray nozzles and returned to the drum just before the drum reenters the sludge vat.

Tables 7 and 8 contain typical performance data for cloth and coil media as affected by type of sludge, chemical dosage, and feed solids concentrations.

The principal components of a vacuum filter system are illustrated in Figure 18. Sludge is drawn directly from clarifiers, holding tanks, or thickening tanks and discharged to a conditioning tank, where it is mixed (pump and agitator) with chemical coagulants (using pumps if chemical feed is automatic). The sludge is pumped through a feed chute to a vat under the filter. The vat is equipped with an agitator that uniformly distributes solids across the face of the filter. The filter drum drain lines are

TABLE 7. TYPICAL DEWATERING PERFORMANCE DATA FOR ROTARY VACUUM FILTERS-CLOTH MEDIA

Sludge Type	Feed Solids Conc. percent	Chemical Dosage[1] $FeCl_3$	kg/Mg dry solids CaO	Yield[2] kg dry solids/m^2/hr	CakeSolids percent
Raw P	4.5 - 9.0	20 - 40	80 - 100	17 - 40	27 - 35
WAS	2.5 - 4.5	60 - 100	120 - 360	5 - 15	13 - 20
P + WAS	3 - 7	25 - 40	90 - 120		18 - 25
P + TF	4 - 8	20 - 40	90 - 120	12 - 30	23 - 30
Anaerobically digested					
P	4 - 8	30 - 50	100 - 130	15 - 35	25 - 32
P + TF	3 - 7	40 - 60	150 - 200	15 - 35	18 - 25
P + WAS	5 - 10	40 - 60	125 - 175	17 - 40	20 - 27
Elutriated anaerobically digested					
P	5 - 10	25 - 40	0 - 50	20 - 40	27 - 35
P + WAS	4.5 - 8	30 - 60	0 - 75	15 - 35	18 - 25
Thermally conditioned					
P + WAS	6 - 15	0[3]	0	20 - 40	35 - 45

[1]All values shown are for pure $FeCl_3$ and CaO. Dosage must be adjusted for anything else.
[2]Filter yield depends to some extent on feed solids concentration. Increasing the solids concentration normally gives a higher yield.
[3]Some heat-treated sludge requires some conditioning to maintain recovery at a high level.
1 lb/ton = 0.5 kg/Mg
1 lb/ft^2/hr = 4.9 kg/m^2/hr

Key: P — Raw primary
WAS — Waste activated sludge
TF — Trickling filter

TABLE 8. TYPICAL DEWATERING PERFORMANCE DATA FOR ROTARY VACUUM FILTERS-COIL MEDIA

Sludge Type	Feed Solids Conc. percent	Chemical Dosage[1] $FeCl_3$	kg/Mg dry solids CaO	Yield[2] kg dry solids/m^2/hr	Cake Solids percent
Raw P	8 - 10	20 - 40	80 - 120	30 - 40	28 - 32
TF	4 - 6	20 - 30	50 - 70	30 - 40	20 - 32
P + WAS	3 - 5	10 - 30	90 - 110	12 - 20	18 - 25
Anaerobically digested					
P + TF	5 - 8	25 - 40	120 - 160	20 - 30	27 - 33
P + WAS	4 - 6	25 - 40	100 - 150	17 - 22	20 - 25
Elutriated anaerobically digested					
P	8 - 10	10 - 25	15 - 60	20 - 40	28 - 32

[1]All values shown are for pure $FeCl_3$ and CaO. Dosage must be adjusted for anything else.
[2]Filter yield depends to some extent on feed solids concentration. Increasing the solids concentration normally gives a higher yield.
1 lb/ton = 0.5 kg/Mg
1 lb/ft^2/hr = 4.9 kg/m^2/hr

Key: P Raw primary
WAS Waste activated sludge
TF Trickling filter

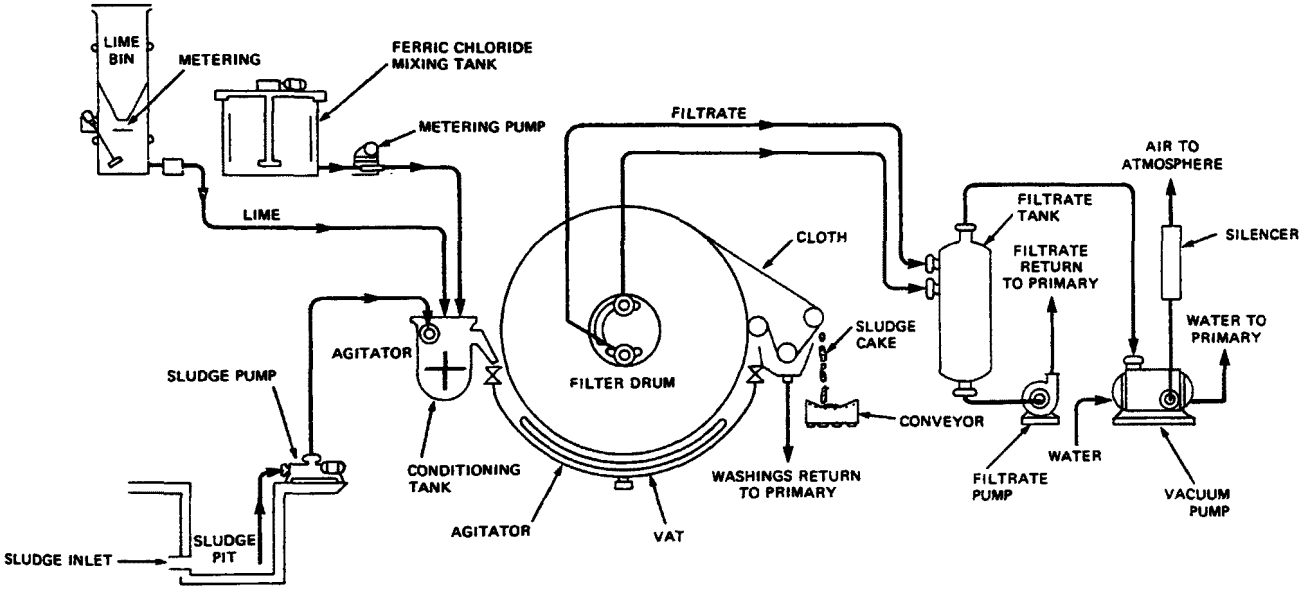


FIGURE 18. ROTARY VACUUM FILTER SYSTEM

connected to a combination vacuum receiver and filtrate pump prior to the vacuum pump. The principal purpose of the receiver is air-liquid separation of the filtrate. Air taken from the top of the receiver is discharged to the atmosphere through a wet-type vacuum pump, while water from the bottom is removed by a filtrate pump. Other components of the unit include water wash sprays.

12.2 PROCESS CONTROL CONSIDERATIONS

Optimum performance is one that balances maximum sludge cake output (yield), desired cake dryness and filtrate clarity (solids removal efficiency). Sludge cake dryness relates to the amount of solids in the filtrate: the drier the sludge cake, the higher the content of solids in the filtrate. The cake should not be dried more than is necessary for final disposal. At the same time, the filtrate solids should be kept to a practical minimum, as these solids impose a load on the plant treatment units receiving this filtrate. Principal design components that affect dewatering efficiency include:

- Type of sludge and conditioning—Primary sludge is easier to dewater than secondary biological sludges. Proper conditioning causes sludge to release its water and lowers the vacuum requirements.

- Solids concentration—The higher the suspended solids concentration of the feed sludge, the greater will be the production rate of the filter and the cake suspended solids concentration. The design range for the feed suspended solids concentration is between 3 and 10 percent. Below 3 percent it becomes difficult to produce sludge filter cakes thick enough or dry enough for adequate discharge from the filter media. If the concentration is greater than 10 percent, the sludge becomes difficult to pump, mix with chemicals, and distribute after conditioning to the filter. The sludge treatment processes preceding the dewatering process affect the feed suspended solids concentration to the filter and need to be designed and operated to achieve the optimum for the filter.

- Type of filter media—Considerations during the design selection process include desired liquid/solid separation, filtrate of acceptable clarity, easy release of filter cake, mechanical strength for long life expectancy, chemical resistance to the materials being handled, minimal resistance to filtrate flow, and minimal blinding or clogging. Monofilament fabrics seem the most resistant to blinding and have a long life; cloth filters produce cleaner filtrate. Coil springs perform poorly with sludges that contain particles that are extremely fine and resistant to flocculation.

Changes in the sludge characteristics may require minor adjustments to operating conditions to achieve optimum performance. The following operational factors impact filter performance:

- Vacuum level—Vacuum is controlled by:
  - Amount of conditioning—Proper conditioning causes sludge to release its water and lowers the vacuum requirements.
  - Drum speed—Vacuum rises with the drum speed.
  - Sludge level in filter vat—Vacuum drops as the vat level lowers.
- Degree of drum submergence—A full vat provides maximum cake forming time and minimum cake drying time, resulting in a thicker but wetter cake.
- Cycle time—The drum speed is controlled by a variable speed drive. The slower the drum speed, the thicker and drier the cake and the lower the vacuum needed. As the drum speeds up, it has less time to remove the water, and the vacuum increases to compensate for less time.

12.3 PROCESS PERFORMANCE EVALUATION

12.3.1 Design Evaluation

The principal design variables that impact the vacuum filter operation are conditioning chemicals (type and dosage), filter media used, feed solids concentration, and solids loading rate. Changes in upstream processes—including sludge production (volume or type), sludge mixture, conditioning procedures, and sludge holding times (before conditioning and dewatering)—can affect the efficiency of the filter performance. The inspector should evaluate whether the filter, when operating within design parameters, is able to achieve the desired cake characteristics and filtrate quality while keeping up with the sludge production.

12.3.2 Operation and Maintenance Evaluation

The inspector should evaluate whether the process control measurements being performed provide operators with the necessary information to determine filter performance and necessary changes. Adequate process control measures include testing the sludge feed and sludge cake for total solids once per day, and testing the filtrate for suspended solids once per day. Though not pertinent to filter process control, measuring the filtrate flow continuously and testing the filtrate for BOD on a regular basis will provide data for calculating the filtrate loading on the wastewater treatment unit processes.

The inspector should check to see that routine operating procedures are performed. The filter's O&M manual will provide the specific procedures to follow but the inspector can inquire about general procedures, such as whether the system is inspected at least twice a shift. When in operation, the vacuum valve, sludge influent valve, filtrate flow valve, and chemical conditioning valves should all be open, and the vat drain valve should be closed. The sludge pump, conditioning pump, conditioning tank agitator drive, and filter vat agitator should all be operating (operation of the filter vat agitator is optional depending on need). Drum and belt drives, and water sprays, should be operating.

The inspector should also check to see how often maintenance procedures are performed. The system should be shutdown periodically, and drain valves opened, lines flushed, the filter medium and tanks thoroughly washed and inspected, and drum chain lubricators checked. The inspector should also check the spare parts inventory to see if it includes the following:

- Drive mechanism parts such as sprockets, chains, gears, motors, bearings
- Vacuum mechanism parts such as hoses, fittings, pumps, gauges.

To evaluate filter performance, the inspector should visually check the following aspects of filter operation:

- Cake characteristics—Check to see that cake release is easy and that there is no excessive cake cracking before release. Thin cake with poor dewatering is indicative of poor performance; probable causes to check include filter media blinding, improper chemical coagulant dosage, inadequate vacuum or leaks in vacuum system or seals, excessive drum speed, or drum submergence too low.

- Blinding or clogging of filter media—Check the wash water pressure or quantity used. Blinding or clogging may also result from excessive amount of lime being added to the sludge for conditioning.

- High solids in filtrate—Probable causes would be an improper chemical coagulant dosage, low solids concentration in the feed sludge, filter media blinding, or excessive mesh size in filter media.

- Vibrating receiver—Probable causes would be:
  - A clogged filtrate pump; check filtrate pump output to see if it's clogged.
  - Air leak in the suction line.
  - A dirty drum face.
  - Missing seal strips.
- High vat level—Check to see if:
  - Feed rate is too fast
  - Drum speed is too slow
  - Drain lines are clogged
  - Vacuum pump is operating
  - Filtrate pump is off or clogged.
- Low vat level—Check to see if the feed rate is too fast or the vat drain valve is open (should be closed).

Some odors are generated by the vacuum filtration operation, but proper conditioning and ventilation should minimize the problem. For safety reasons, the work areas should be free of grease, sludge, oil, or other debris.

13. FILTER PRESS

The filter press is a batch device used to dewater sludges. There are several types of presses available, but the most common consists of vertical plates that are held in a frame and pressed together between a fixed and moving end. A cloth is mounted on the face of each individual plate. Despite its name, the filter press does not squeeze or press sludge. Instead, when the press is closed; the sludge is pumped into the press at pressures up to 225 psi and passed through feed holes in the trays along the length of the press. The water passes through the cloth, while the solids are retained and form a cake on the surface of the cloth. Filter presses usually require a precoat material (typically incinerator ash or diatomaceous earth) to aid in solids retention on the cloth and release of the cake. Sludge feeding is stopped when the cavities or chambers between trays are filled. Drainage ports are provided at the bottom of each press chamber. The filtrate is collected in these, taken to the end of the press, and discharged to a common drain.

13.1 PROCESS CONFIGURATION AND COMPONENTS

A typical vertical plate filter press is shown in Figure 19. The press consists of feed pumps gears, drives, chains, sprockets, bearing brackets, electrical contacts, suction lines and sumps, cloths, and rubber surfaces. All of these components require routine inspection and maintenance.

13.2 PROCESS CONTROL CONSIDERATIONS

If the filter press is operated as recommended, with sufficient washing and air drying time between cycles, the cake should have the highest possible solids content. The cake also should discharge from the press with a minimum of debris left behind. Discharge of a wet cake can lead to dirty cloths on the lower stile faces, making it difficult to obtain a good seal on this gasket area when closing the press.

It is usually possible to develop an excellent relationship between filtrate flow rate (which decreases as the cycle progresses) and cake moisture for a given sludge. That is, for any given filtrate flow rate a corresponding filter cake concentration can be expected.

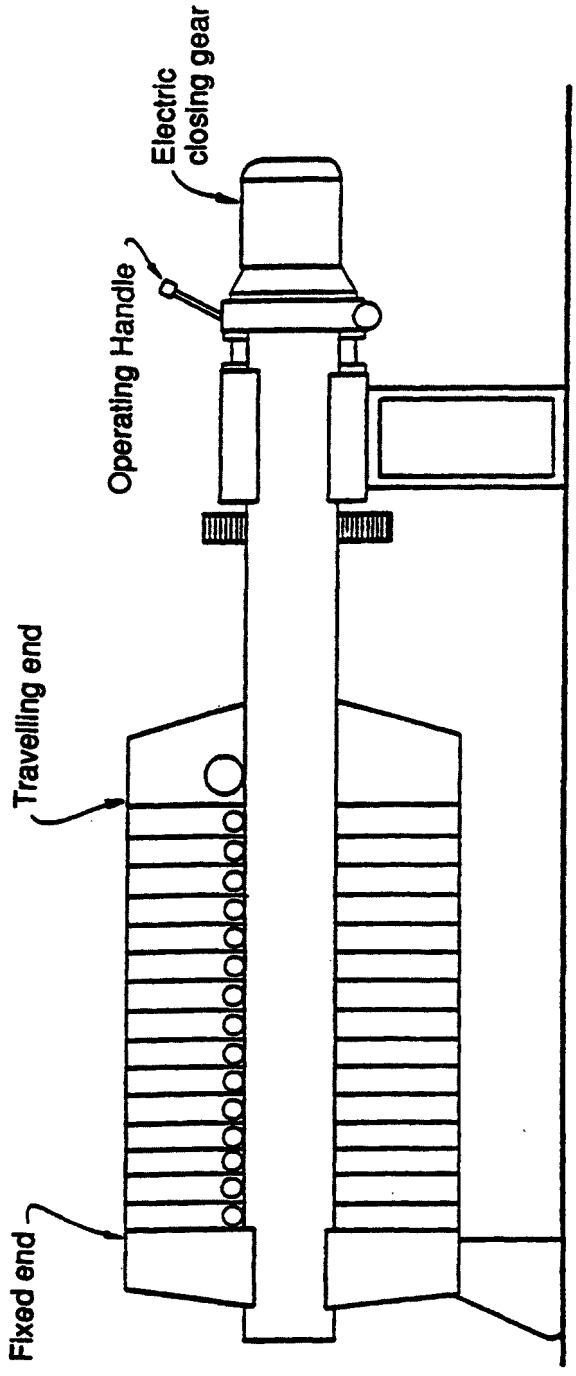


FIGURE 19. SIDE VIEW OF A FILTER PRESS

Whether or not to precoat is an operational question. The precoat is the placement of an initial coating on the filter cloth prior to application of the sludge. The precoat acts as an additional filtration membrane and also aids in a clean removal of sludge from the cloth. If the investment in a precoat system has been made, its use should reduce manpower requirements for media cleaning and may provide better performance.

If the press is operated as recommended, but performance is unsatisfactory, a different type of cloth may give better results. The addition of precoat may also aid in performance.

13.3 PROCESS PERFORMANCE EVALUATION

An inspection checklist is included in Appendix A. The inspection checklist is designed to assist the inspector in gathering the information needed to properly evaluate the performance of the pressure filter. When evaluating the performance of a pressure filter, the inspector should pay special attention to the overall condition and maintenance of the press. Mechanized parts should be inspected for wear, corrosion, and proper adjustment. Prior to filling, the operator should ensure that the plate filters are clean and have no holes. Small pinholes in the filter can significantly reduce the performance of the system.

The filter cake solids and cycle length can be compared against the performance data presented in Table 9. If the filter is not producing adequately high cake solids, the inspector should evaluate the following:

- Whether maximum feed pump pressures are being achieved.
- Whether the filter cloths are in good condition. The inspector should particularly note any tears or holes.
- Whether a precoat is used.
- Whether all filtrate drainage and sludge feed passages are free and unobstructed.
- Whether the manufacturer's procedures (especially end-of-cycle procedures) are being followed.

TABLE 9. TYPICAL RESULTS OF PRESSURE FILTRATION

Sludge Type	Conditioning	Feed Solids, %	Typical Cycle Length, Hr	% Solids Filter Cake Solids, %
Primary	5% $FeCl_3$, 10% lime 100% ash	5	2 1.5	45 50
Primary + $FeCl_3$	10% Lime	4*	4	40
Primary + 2 Stage	None	7.5	1.5	50
Primary + WAS	5% $FeCl_3$, 10% lime 150% ash	8*	2.5 2.0	45 50
Primary + (WAS $FeCl_3$)	5% $FeCl_3$, 10% lime	8*	3	45
(Primary + $FeCl_3$) + WAS	10% lime	3.5	4	40
WAS	7.5% $FeCl_3$ 250% Ash	5*	2.5 2.0	45 50
WAS + $FeCl_3$	5% $FeCl_3$, 10% Lime	5*	3.5	45
Digested Primary	6% $FeCl_3$, 30% Lime	8	2	40
Digested Primary + WAS	5% $FeCl_3$, 10% Lime 100% Ash	6-8*	2	45
Digest Primary + (WAS + $FeCl_3$)	5% $FeCl_3$, 10% Lime	6-8*	3	40
Tertiary Alum	10% Lime	4*	6	35
Tertiary Low Lime	None	8*	1.5	55

* Thickening used to achieve this solids concentration

14. BELT FILTER PRESS

Belt filters are designed to press sludge between two tensioned, moving belts that are porous. The belts are passed through various diameter rollers that squeeze out the water and thus generate a dried sludge that can easily be removed from the belts. Design is usually based on the sludge generation rate of the treatment plant rather than on the wastewater flow to the plant. Belt filter presses are advantageous in that, with minimal energy requirements, they are capable of producing a very dry cake. Conversely, this type of dewatering is very sensitive to sludge characteristics, is hydraulically limited, and has a short filter media life as compared with other dewatering devices that use filter media.

Although belt filters are available in numerous designs and may be quite complex, all operate under the same simple three-step process: chemical conditioning, gravity drainage, and compression.

Chemical conditioning is vital to the efficient operation of a belt filter press. Properly conditioned sludge results in flocculation of the small particles into larger stronger particles that bridge the openings in the filter belt and thus remain on the belt. Key to the selection of a chemical conditioner is the ability of the floc to withstand the pressures generated during the dewatering process without passing through the filter or squeezing out from between the belts. Polymers have been shown to be the most successful conditioning agent. Typically, cationic polymers are used, although a two-polymer system that uses a cationic polymer followed by either an anionic or nonionic polymer may ease cake removal from the belt. Attempts have been made to use other types of chemical conditioners, such as lime, without success. If lime is to be used to stabilize the sludge for landfilling, the lime should be added to the sludge after dewatering by the belt filter process.

Gravity drainage occurs as the conditioned sludge is discharged onto the moving belt. Free water (interstitial water in the sludge slurry) readily separates from the slurry and is recycled back through the treatment process. The efficiency of this drainage depends on the type of sludge, quality of the sludge, conditioning, belt screen mesh, and design of the drainage zone. Typically, gravity drainage occurs on a flat or slightly inclined belt for a period of 1 to 2 minutes. A 5 to 10 percent increase in solids concentration should be expected in the gravity drainage zone; that is, 1 to 5 percent feed produces 6 to 15 percent solids prior to compression. The uniform distribution of sludge across the belt is vital for maximum speed through the pressing operation, and to prevent blinding of the belt mesh, uneven belt tension, and distortion.

The final stage of the belt filtration process consists of compressing the sludge. This step is initiated as soon as the sludge is subjected to an increase in pressure. This pressure can come from the compression of the sludge between belts or from the application of a vacuum on the lower belt. The area where the belt filter begins to compress the sludge (known as the low-pressure zone or wedge zone) is key to preparing a firm, even sludge cake that can withstand the shear forces to which it is subjected by the rollers. As the sludge cake progresses through a series of rollers in the filter, high pressures are exerted by the upper and lower belts. This increased pressure causes flexing of the sludge cake, which results in the release of water and the further compaction of the sludge cake. Some belt presses have an independent high-pressure zone that uses additional belts or hydraulic cylinders to increase pressure and produce a drier cake.

Filter cake is removed from the belts using a scraper mechanism, which drops the sludge into a hopper or conveyor belt for transfer to the sludge management area. After the cake is removed, a spray of water is applied to the underside of the belt to rid the belt of any remaining solids. This spray rinse water is mixed with the filtrate and recycled back through the treatment plant, either to primary or secondary treatment.

Odors are often a problem with belt filter presses. These odors can be controlled by allowing adequate ventilation, by using fresh sludge or by using oxidizing chemicals. Potassium permanganate or hydrogen peroxide can be used to oxidize the odor-causing chemicals (predominantly hydrogen sulfide) into odorless compounds. In addition, using potassium permanganate can also improve the dewaterability of the sludge, reduce the amount of polymer required, and eliminate sulfide from the filtrate recycle.

14.1 PROCESS CONFIGURATION AND COMPONENTS

Typically, belt filter presses operate in a semicontinuous mode, based on the volume of sludge to be dried. Best results are achieved when the belt press is operated under the same conditions at all times, the lone variable being whether or not sludge is being applied to the belt. This ensures that once a steady state operation is achieved, variables such as application rate and roller speed will not change. Of course, as with any system, minor adjustments will occasionally be needed to fine-tune the unit to the changing conditions of the sludge.

Belt presses vary in size, roller configuration, filter porosity, and composition of belt material. In addition, some manufacturers offer vacuum-assisted belt presses that may increase the solids content of the sludge.

Belt filters are designed to provide a high solids content sludge at minimal cost. This is accomplished through six major systems in the press:

- Chemical conditioning
- Dewatering belts
- Rollers
- Belt tracking and tensioning system
- Controls and drives
- Belt washing.

14.1.1 Chemical Conditioning

Chemical conditioning typically takes place in a small tank (70 to 100 gallons) that is positioned approximately 2 to 3 ft before the belt filter, in a rotating drum attached to the top of the press, or in an in-line baffled injector. It is also recommended that a second small tank be installed further up the line (25 ft) in situations where a longer contact time may be needed to properly condition the sludge. These polymer conditioning units are typically supplied by the manufacturer along with the belt press. The feed point for any odor-suppressing oxidizer (e.g., potassium permanganate) should be upstream of the polymer feed point by a distance which will allow for approximately 1 minute of contact time prior to polymer addition.

14.1.2 Dewatering Belts

The dewatering belts, typically made of monofilament polyester fibers, come in various weave combinations, permeabilities, and particle retention capabilities—all of which influence performance of the press. The determination of the correct belt usually requires testing with actual sludge to determine the most appropriate belt construction parameters. For plants already in operation, this is a simple procedure. For newly designed plants, however, this evaluation must be based on information obtained from similar plants that are processing a similar type of sludge.

There are two basic types of belts, split and continuous. Split belts are joined together with a device called a clipper seam. Split belts are the most common type of belt and can be used on all types of belt presses. The continuous, or seamless belt, can only be used on certain presses and are more difficult to install, but may have longer life spans.

14.1.3 Rollers

The rollers are the main mechanical component of the belt press. The rollers set the pressure and force that dewater the sludge; therefore, the proper design and control of this equipment is necessary for a dry sludge cake. The number, size, and shaft diameter of the rollers are the key design parameters for a belt press. At a given belt tension, as roller diameter decreases, pressure on the cake increases.

14.1.4 Belt Tracking and Tensioning System

The belt tracking and tensioning system is the key control, once the number and size of the rollers have been determined and installed. Tensioning allows the press operator adjustments to match the sludge composition, while the tracking system ensures that the belt is operating at its maximum design efficiency. Poor tracking causes excessive wear on the belts as well as not providing the driest possible sludge.

14.1.5 Control and Drives

Process controls typically include automatic startup and shutdown, tracking and tensioning of belts, pressure gauges, operating time meters, and sludge and polymer pump controls. It is important that the startup and shutdown procedures are automated in the correct sequence to ensure additional manpower is not needed for this procedure. For example, starting the sludge pumps before the conveyor belt would cause a pile of sludge to build up that may interfere with the operation of the system. The polymer and sludge feed pumps must also shut off automatically if any operations downstream of these pumps should fail.

14.1.6 Belt Washing

The belt washing system is designed to apply a steady stream of water onto the backside of the belts after the cake has been removed. This allows the belt to track smoothly back around and apply a uniform layer of sludge. Occasionally, facilities will use recirculated water from the press as wash water, although operational problems are more likely to occur because of the high solids content recirculated. Washwater typically is applied at a rate of more than half the slurry application rate. Therefore, secondary effluent, rather than a potable water, is usually used as washwater to save costs.

14.2 PROCESS CONTROL CONSIDERATIONS

Once familiar with the equipment, the press operator should be able to evaluate the operation by visual inspection. Control of the sludge solids content leaving the belt press is affected primarily by five parameters:

- Chemical conditioning
- Percent solids of incoming sludge
- Loading rate of sludge
- Operating speed of the belt
- Compression of the rollers.

14.2.1 Chemical Conditioning

The appropriate polymer for chemical conditioning is usually determined by jar testing. The optimum dosage is the amount at which above that little or no increase in floc size or supernatant clarity is noted. Because sludge characteristics can change, as can chemical costs, many facilities have a dual polymer feed system that can feed either liquid or dry polymer. Underconditioned sludge will not drain well in the gravity drainage section, resulting in either an exceptionally wet sludge or uncontrolled discharge of slurry in that section. Overconditioned sludges drain so rapidly that the sludge does not have time to distribute uniformly over the belt. Overconditioned and underconditioned sludges both can cause blinding of the filter media. Inclusion of a sludge blending tank prior to the press can help to minimize this problem and ensure that the polymer is uniformly distributed through the slurry.

14.2.2 Percent Solids of Incoming Sludge

Generally, a thicker incoming sludge will produce a drier cake. Therefore, it is preferable to apply as thick a sludge as possible to the belt filter. This is quite often achieved through the use of a sludge thickening process prior to the application of the sludge to the belt press.

14.2.3 Loading Rate of Sludge

The application rate of sludge to the press has a significant effect on performance of the unit. Each unit will have a design operating range; the press should be operated within this range. A typical belt press will have a hydraulic loading rate of about 40 gpm/m (12 gpm/ft) of belt width. If the loading rate is too high or too low, the unit will not operate efficiently. Too high a rate of application can generate a poorly dewatered sludge, as can application of too low a rate of sludge. The ideal application rate is the maximum rate at which there is no noticeable drop in performance.

14.2.4 Operating Speed of the Belt

As the sludge application rate increases, the belt speed of the press should be increased. The actual speed of the unit depends on the desired characteristics of the sludge cake. Obviously, the slower the operating speed, the better the dewatering of the sludge. The optimum speed for any user's particular case is best determined through trial and error. Once the optimum speed is determined, little or no adjustment should be needed.

14.2.5 Compression of the Rollers

As with the speed of the belt, the best compression of the rollers should be determined through trial and error. Once set, the compression should not require adjustment.

14.3 PROCESS PERFORMANCE EVALUATION

When evaluating the performance of a belt press, the inspector should compare the actual operating conditions to the recommended operating conditions. Operating conditions for various types of sludges dewatered on a belt filter press are presented in Table 10. The inspection checklist in Appendix A is designed to assist the inspector in gathering the information and making the calculations required to make the comparison between actual operating conditions and design conditions.

TABLE 10. TYPICAL DATA FOR VARIOUS TYPES OF SLUDGES DEWATERED ON A BELT PRESS

Sludge Type	Feed Solids percent	Solids Loading Rate kg/hr/m belt width	Polymer Dose g/kg	Cake Solids percent
Raw				
P	3 - 10	360 - 680	1 - 5	28 - 35
WAS	0.5 - 4	45 - 230	1 - 10	20 - 35
P + WAS	3 - 6	180 - 590	1 - 10	20 - 35
P + TF	3 - 6	180 - 590	2 - 8	20 - 40
Anaerobically Digested				
P	3 - 10	360 - 590	1 - 5	25 - 36
WAS	3 - 4	40 - 135	2 - 10	12 - 22
P + WAS	3 - 9	180 - 680	2 - 8	18 - 35
Aerobically Digested				
P + WAS	1 - 3	90 - 230	2 - 8	12 - 30
P + TF	4 - 8	135 - 230	2 - 8	12 - 30
Oxygen Activated				
WAS	1 - 3	90 - 180	4 - 10	15 - 23
Thermally Conditioned				
P + WAS	4 - 8	290 - 910	0	25 - 40+

Key: P Raw primary
WAS Waste activated sludge
TF Trickling filter

14.3.1 Design Evaluation

In evaluating the design adequacy of a belt press, the inspector should consider the following:

- Press capacity—The system should be designed to handle sludge at the rate generated by the treatment plant. A backup system should be available for down times to prevent the accumulation or disposal of sludge.

- Belt tracking—The belt system should include an automatic adjusting device to periodically correct roller adjustment. This reduces labor requirements of manually adjusting the belts and is also more efficient at ensuring proper alignment.

- Spray nozzles—If the plant effluent or recycled filtrate is used as washwater, a high efficiency filtration system should be included prior to the spray nozzles to prevent clogging. Some spray nozzles will contain stainless steel brushes in the spray header to automatically clean the nozzles without removing them from the press. Also, the spray nozzles should be designed such that the stream of water reaches the entire surface of the belts.

- Process controls—Control equipment should be located away from the belt press, preferably in a control room, to protect these controls from the moist and corrosive operating conditions.

- System integration—The system should be designed and installed by one supplier. Typically, performance is more efficient when equipment comes from one supplier rather than from several.

14.3.2 Operation and Maintenance Evaluation

In evaluating the belt press operation, the inspector should consider the following parameters:

- Process controls—The following measurements should be conducted by the plant operators to ensure optimum operations:

  - Feed Slurry and Dewatered Sludge—The feed sludge and the dewatered sludge cake should be monitored for total solids and flow.

  - Filtrate and Wash Water—The filtrate and wash water should be monitored for biochemical oxygen demand, suspended solids, total solids, and flow.

- Filter Cake—The sludge cake should have a uniform thickness across the entire width of the belt without squeezing out the sides during operation. The scrapers also should remove the majority of the cake, with the wash water removing the residual sludge remaining on both sides of the belts.

- Preventive maintenance—Belt presses require a good preventive maintenance program because of their susceptibility to equipment malfunctions (many moving parts) and the corrosive nature of the waste. Preventive maintenance should include periodic inspections of:

  - V-Belts, drives, and gear reducers
  - Filter belts and tracking mechanism
  - Rollers, bearings, and bores
  - Bearing brackets
  - Baffles
  - Electrical contacts in starters and relays
  - Suction lines and pumps
  - Chemical mixing tanks and pumps.

15. SLUDGE DRYING BEDS

Drying beds are a widely used method of dewatering municipal sludge in the United States. They are generally used for dewatering well-digested sludge. Attempts to air dry raw sludge usually result in odor problems.

Digested and/or conditioned sludge is discharged onto a drying bed and allowed to dewater and dry under natural conditions. After the sludge is applied to the porous drainage media, dissolved gases are released and rise to the surface, floating the solids and leaving a layer of liquor at the bottom. The liquor drains through the porous media (usually sand) and is collected in the underdrain system and usually returned to the plant for further treatment. Drying beds drain very slowly at first, but after approximately three days, the rate of drying increases. As the sludge dries, cracks develop in the surface, allowing evaporation to occur from the lower layers and accelerating the drying process. After maximum drainage is reached, the dewatering rate gradually slows down and evaporation continues until the moisture content is low enough to permit sludge removal. Dry sludge may be removed periodically from the beds, by special conveyors or with other loading equipment, for ultimate disposal.

Chemical addition (such as polymers) has been used to enhance drying bed performance. In northern climates, a freeze/thaw/drain cycle has been used to allow use of outdoor beds in regions that experience sub-freezing weather. Reed beds (in which plant growth in the beds is encouraged) have also been used.

15.1 PROCESS CONFIGURATION AND COMPONENTS

Drying beds for sludge dewatering are operated in parallel. Most facilities provide more than one drying bed to ensure that there will be enough available drying space to handle the digested sludge generated by the treatment process.

Drying beds generally consist of 1- to 3- ft high retaining wall enclosing a porous drainage media. The drainage media may be made up of various sandwiched layers of sand and gravel, combinations of sand and gravel and cement strips, slotted metal media, or a permanent porous media.

Of these, the sand and gravel beds, shown in Figure 20, are most common. Generally, sand and gravel beds are comprised of 4 to 9 in. of sand (0.3 to 1.2 mm diameter) over an 8- to 18-in. layer of gravel (gravel size is usually 1/8 to 1 in. diameter). The water drains to an underdrain system which

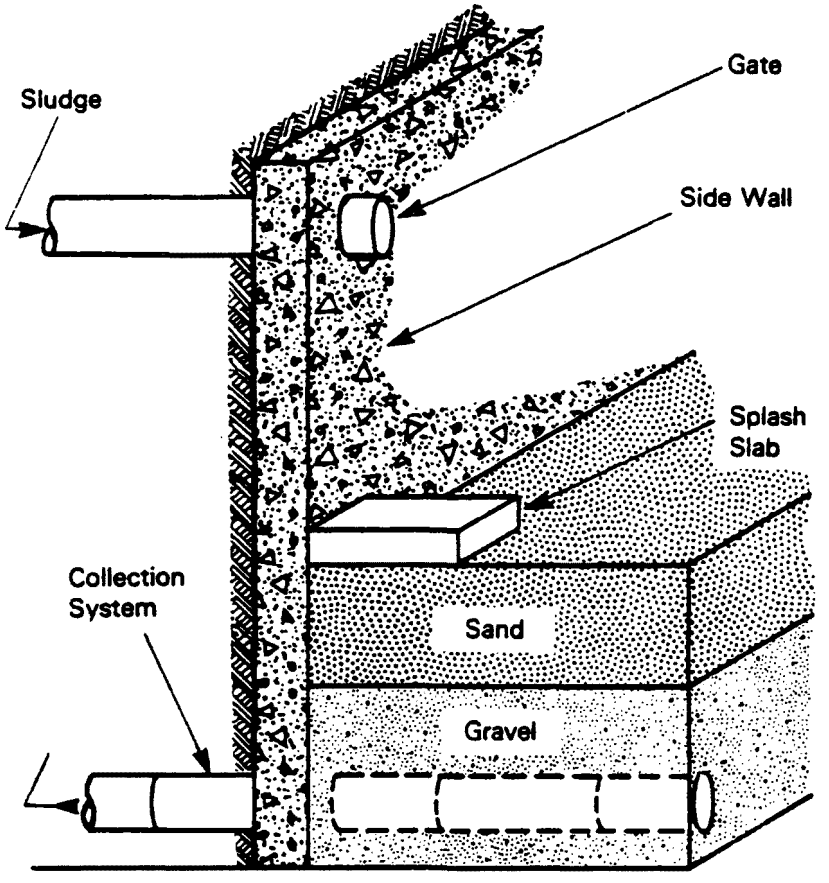


FIGURE 20. TYPICAL SAND AND GRAVEL DRYING BED CONSTRUCTION

consists of perforated pipe at least 4 in. in diameter. The underdrain pipes are usually spaced between 8- and 20-ft apart, depending on the size of the beds. The pipes must have a slope of at least 1 percent to allow the drainage water to flow back to the treatment plant.

Another type of drying bed in use is a paved drying bed (Figure 21). Typically, these beds have either a concrete or asphalt paved surfaced sloping at least 1.5 percent towards a drainage media consisting of sand over gravel. The stabilized sludge is put on the paved portion and the water drains down the slope to the drainage media. The water then collects in an underdrain pipe that runs the length of the drainage media.

Another less common type of drying bed is the wedge-wire (or wedgewater) drying bed (Figure 22). The bed consists of a shallow rectangular watertight basin fitted with a false floor of stainless steel or preformed polyurethane panels. These panels have wedge-shaped slotted openings of 0.01 in. (0.25 mm). The false floor is made watertight with caulking where the panels abut the walls. An outlet valve to control the rate of drainage is located underneath the false floor. Water or plant effluent enters the bed from beneath the panels (or wedge-wire septum) until a depth of approximately 1 in. (2.5 cm) over the wedge-wire septum is attained. This water serves as a cushion that permits the sludge as it is slowly introduced to float without causing upward or downward pressure across the wedge-wire surface. The water further prevents compression or other disturbance of the colloidal particles. After the bed is filled with sludge, the initially separate water layer and the drainage water are allowed to percolate away at a controlled rate, through the outlet valve. After the free water has been drained, the sludge further concentrates by drainage and evaporation until there is a requirement for sludge removal.

The final type of drying bed available is a vacuum-assisted drying bed. These beds are relatively uncommon. They consist of a reinforced concrete bottom ground slab, a layer of stabilized aggregate several inches thick, and a rigid multimedia top. This space between the concrete bottom slab and the rigid multimedia top is also the vacuum chamber and is connected to a vacuum pump. Sludge is applied to the surface of the multimedia top until it is entirely covered. The vacuum system is then started to remove the water from the sludge.

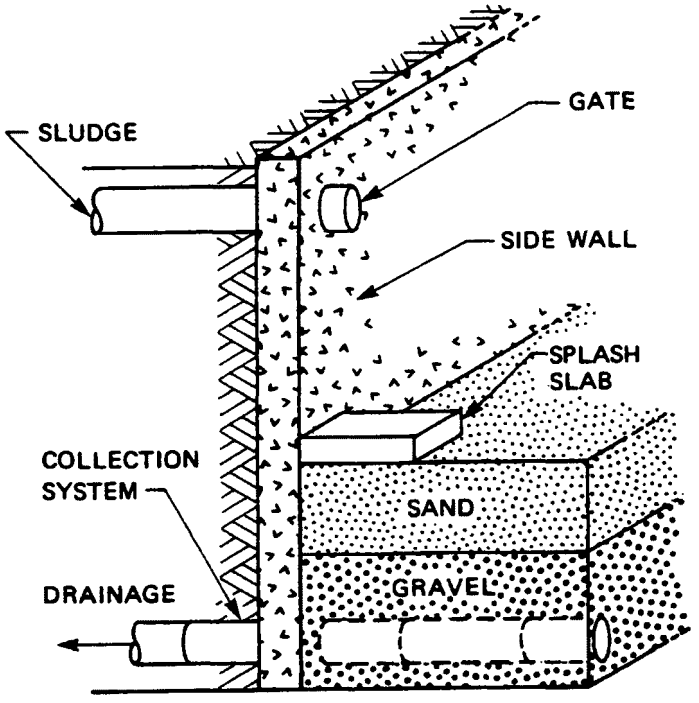


FIGURE 21. TYPICAL PAVED DRYING BED CONSTRUCTION

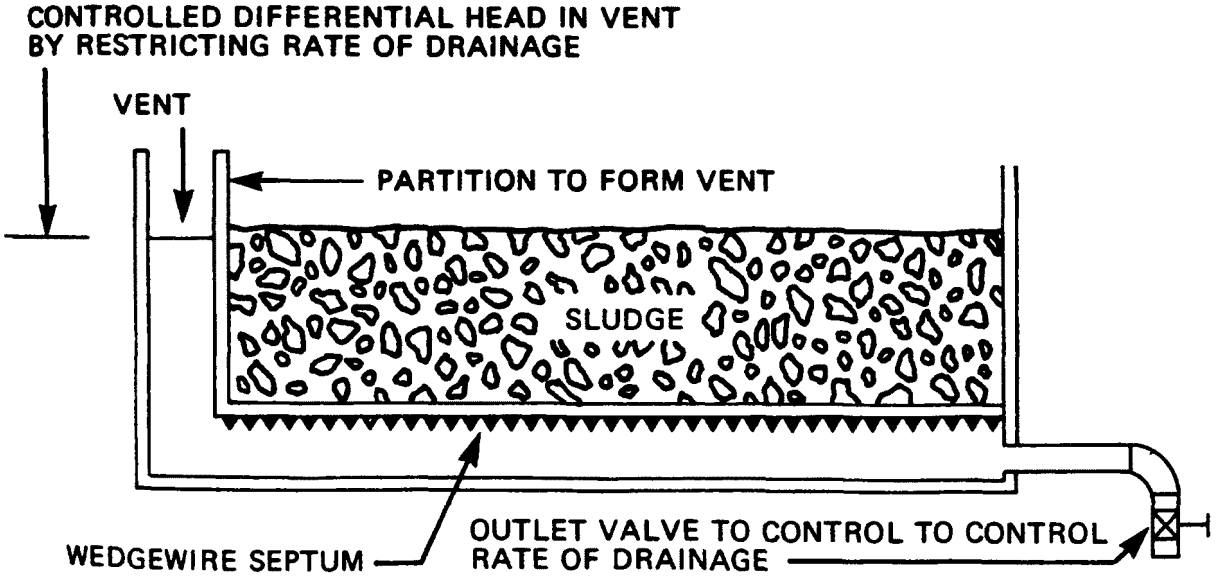


FIGURE 22. CROSS-SECTION OF A WEDGE-WIRE DRYING BED

Drying beds are sometimes enclosed in a green-house type glass structure or have roofs covering them to increase drying efficiency in wet or colder climates. In addition, enclosing the drying beds helps to control odor and insects, and improves the overall appearance of the plant. It is important that totally enclosed drying beds are well-ventilated to allow moisture to escape. Enclosed beds generally need only 67 to 75 percent of the area required for an open bed.

15.2 PROCESS CONTROL CONSIDERATIONS

Treatment plant operations have less control over the performance of drying beds than they do over mechanical dewatering systems. Performance of drying beds is affected by such factors as weather, sludge characteristics, the design of the drying bed, chemical conditioning, and the depth of sludge. To qualify as Processes to Significantly Reduce Pathogens (PSRP), a drying bed must meet the operating parameters in 40 CFR Part 257. Not more than 9 in. of sludge can be applied to the drying bed and what is applied must be left to dry for 3 months. During 2 of the 3 months the average daily temperature must be above 0°C (32°F). Air-dried sludge does not meet Processes to Further Reduce Pathogens (PFRP) requirements unless used in conjunction with another treatment process that qualifies as PFRP.

Through experience, each operator will determine the optimum depth of sludge that can be applied to the drying beds. The typical depth of application is 8 to 12 in. Factors that should be considered when applying sludge to the bed are the type of sludge and the moisture content. Generally, sludge with a high grit content will dewater rapidly, while sludge containing grease drain slower. The age of the sludge is important as well. Aged sludge dries slower than new sludge. Primary sludge dries faster than secondary sludge and digested sludge dries faster than raw sludge. It is important that wastewater sludge be well digested for good drying. In well-digested sludge, gases tend to float the sludge solids and leave a clear liquid layer, which drains through the sand. Other factors affecting the depth at which sludge is applied include the area of sand bed available and the need to draw sludge from the digesters. Fresh sludge should never be applied on top of dried sludge in a bed. The exception would be if reed beds are used.

A thinner layer of sludge will dry more rapidly, permitting quick removal and reuse of the bed. An 8 in. layer should dry in about 3 weeks in the open during reasonably dry weather. A 10 in. layer of the same sludge will take 4 weeks, so that the 25 percent additional sludge actually takes 30 percent more time to dry. In some cases it may be desirable to apply sludge in a layer thinner than 8 inches. The best operation can only be determined by trial and error, and may also vary seasonally.

Chemicals can be used on sludges that are hard to dewater or for overloaded beds. The chemicals most commonly added to sludges to aid in dewatering are alum, ferric chloride, and organic polyelectrolytes. Chemical conditioning of sludge was discussed earlier under Chemical Stabilization and Conditioning.

The best time to remove dried sludge from drying beds depends on a number of factors, such as subsequent treatment by grinding or shredding, the availability of drying bed area for application of current sludge production, labor availability, and, of course, the desired moisture content of the dried sludge. Sludge can be removed by shovel or forks at a moisture content of 40 percent; however, if it is allowed to dry to 60 percent moisture, it will weigh only half as much and is still easy to handle. If the sludge gets too dry (80 to 90 percent solids), it will be dusty and will be difficult to remove because it will crumble as it is removed. The useful capacity of the drying beds can be maximized by always removing the sludge as soon as it has reached the desired dryness.

15.3 PROCESS PERFORMANCE EVALUATION

15.3.1 Design Evaluation

An inspection checklist for sludge drying beds is provided in Appendix A. The checklist is designed to assist the inspector in gathering the information required to adequately evaluate drying bed operations. While drying beds are rather simple in nature, the inspector should be aware that there are certain factors that affect the design adequacy of the beds for a particular plant. The most important consideration when evaluating the adequacy of a drying bed is the solids loading on a dryweight basis, applied yearly, per square foot of drying bed area. Drying beds are normally sized based upon required square feet of bed area per capita served by the treatment plant. The area required depends on climate and sludge conditioning prior to drying. By using a covered bed, the drying efficiency is increased.

Covered beds can handle a higher solids loading rate than uncovered beds. Table 11 shows typical performance in terms of solids loading rate and moisture content of dried sludge for covered and uncovered beds.

TABLE 11. TYPICAL PERFORMANCE DATA FOR DRYING BEDS

	Open Beds	Covered Beds
Solids loading rate $lb/yr/ft^2$	up to 25	up to 40
Moisture content of dried sludge, percent	50 to 60	50 to 60

Another design consideration an inspector will want to evaluate is the method of sludge cake removal from the drying beds. Most plants remove the sludge cake manually, which requires that the sludge be dried between 30 and 40 percent solids. Mechanized systems only require the cake to have a 20 to 30 percent solids content, thus reducing the amount of drying time. A reduction in drying time allows more sludge to be handled.

15.3.2 Operations and Maintenance Evaluation

Sludge drying beds are relatively simple to operate and maintain, but certain steps must be taken to ensure good performance and aesthetics. After sludge is applied to the beds, lines should be drained and flushed with water to prevent plugging and high pressures caused by gases resulting from the decomposing sludge.

After the sludge cake is removed from a sand media filter, the bed should be levelled and raked to ensure that it can drain sludge properly. The depth of the sand should be checked regularly. More sand should be added when the depth is below 4 inches.

Odors, flies and vegetation growth on the beds are other problems (excepting plant growth on reed beds) that may occur in the drying beds. These should all controlled. Odors are typically treated with chemicals. These are either sprayed into the air to mask the odor, or are added to the sludge to prevent the odor. Flies are controlled by the destruction of breeding, or by traps and poisons. They are most effectively controlled in the larvae stage by sprinkling calcium borate or borax in the sludge, especially in the cracks of the drying cake. Vegetation is easily controlled either by physically removing the plant, or, in bad cases, by using herbicides.

16. SLUDGE DRYING LAGOONS

Sludge lagoons are similar to sand beds in that sludge is periodically drawn from a digester, placed in a lagoon, and removed after a period of drying. Unlike sand drying beds, drying lagoons do not have an underdrain system for drainage water removal. Lagoons operate by periodically decanting the supernatant back to the treatment plant and by evaporation. Sludge lagoons are periodically dredged to remove sludge for ultimate disposal.

16.1 PROCESS CONFIGURATION AND COMPONENTS

Treatment plants using lagoons for sludge dewatering should have more than one lagoon on site. The units are operated in parallel; allowing the plant operator to apply sludge to one lagoon while leaving another lagoon to dry. Sludge lagoons are very basic treatment units. Some lagoons have plastic or rubber bottom linings, while many others have a natural earth base. Supernatant and rainwater drain-off points are normally provided on most lagoons. The drain-off liquid is usually returned to the plant for further treatment. Unlike drying beds, lagoons are always open and not covered to protect from the weather. Covering lagoons is impractical due to their larger size.

16.2 PROCESS CONTROL CONSIDERATIONS

Very little process control can be performed on drying lagoons once the sludge has been applied. The plant operator does have control over the type of sludge being applied to the lagoon. Untreated or lime-treated sludges, and sludges with a strong supernatant, are generally not suited for dewatering in a lagoon. These types of sludges cause odor problems in the treatment plant.

Lagoon performance is dependent upon climatic conditions. Geographic areas that have high annual precipitation and/or low temperatures are not suited for sludge dewatering lagoons. Lagoons are best utilized in regions that are hot and arid. Operators should ensure that sludge is evenly distributed across the basin during application. In most regions with drying lagoons, the depth of the applied sludge after excess supernatant has been drawn off should not exceed 15 in. to prevent excess drying time. In arid regions, the sludge can be applied to a greater depth due to the higher evaporation rate. Sludge takes a long time to dewater in a lagoon. Generally, if sludge is applied to a depth of 15 in. or less, it will usually dry between 40 and 60 percent solids in 3 to 5 months, depending on the weather. When sludge is to be used for soil conditioning, it can be stored for further drying. One operational approach for

lagoons is a 3-year cycle in which the lagoon is loaded for 1 year, dries for 18 months, is cleaned, and is then allowed to rest for 6 months.

16.3 PROCESS PERFORMANCE EVALUATION

16.3.1 Design Evaluation

The factor determining the design of the sludge lagoons is the solids loading rate. A solids loading rate typically used in the design of lagoons is 2.2 to 3.4 lb/yr/ft^3 of lagoon capacity. Other designs are 1 ft^2/capita for primary digested sludges in a dry climate, and 3 to 4 ft^2/capita for activated sludge plants where the annual rainfall is greater than 36 inches. A 2 ft-high dike with a sludge depth of 15 in. (after decanting) is often used. Sludge removal is normally done using a front end loader. The moisture content of sludge cake in most areas, except for the more arid, is too high to permit removal by manual means.

16.3.2 Operation and Maintenance Evaluation

Overall, operation and maintenance of sludge lagoons requires little effort on the part of the plant operator. There are, however, some things that should be done to create a good maintenance program. The lagoon dikes and liner should be regularly inspected, and any damage should be repaired to prevent sludge leaking. Before applying sludge to the lagoon, the bottom of the basin should be leveled and any vegetation growing there removed. Sludge application lines and valves should be regularly checked. In the winter, the sludge lines should be drained to prevent freezing. Excess rain or snow that has accumulated on the lagoon should be decanted to increase evaporation efficiency. In addition, weeds, odors, and insects should be kept to a minimum.

Records must be kept on the sludge loading, percent solids in sludge and decant, quantity and depth in the lagoon, date sludge is applied, drying time and rainfall. This will provide the operator with the information necessary to determine the optimal time of sludge removal from the lagoon by comparing sludge moisture content with time for drying under particular climatic conditions.

An inspection checklist for sludge lagoons is provided in Appendix A. The checklist is designed to assist the inspector in gathering the information required to adequately evaluate drying lagoon operations.

17. HEAT DRYING

Heat drying is used to reduce moisture content and pathogens in stabilized or conditioned sludge. Sludge that has been heat-dried may then be used as fertilizer, soil amendment, or, since the water content and volume is considerably reduced, the sludge may be used as cover material in a landfill. Sludge is usually prepared for heat drying by mechanical dewatering to reduce its moisture content. The resulting sludge cake is then heat dried to reduce moisture from an initial level of roughly 80 percent to a level of 5 to 10 percent in the finished product. Heat drying is distinct from incineration in that the solids are held to temperatures too low (140° to 200°F) to result in destruction of organic matter. Heat drying is usually accomplished by direct heat transfer involving interaction of hot gases with sludge particles or through indirect heat transfer where a heated surface transfers heat to the sludge cake. Water vapor is removed by a flow of moist gas, most often air.

Types of air flows in sludge dryers can be cocurrent (moving with the sludge flow), countercurrent (moving against the sludge flow) or crosscurrent (moving across the sludge flow). In most direct drying operations (flash, spray, and some rotary dryers), odor distillation is minimized, and energy efficiency is best accomplished by using a cocurrent air flow.

The three stages of heat drying are initial drying, steady-state drying, and final drying. Initial drying occurs during a short period as the sludge temperature and drying rate are raised to the level of steady-state drying; little drying occurs during this first phase. During steady-state drying, the longest of the phases, the temperature at the interface between the wet sludge and the gas is kept at the wet bulb temperature of the gas. In this phase, where drying occurs most rapidly, moisture evaporated from the surface of the material is replaced by moisture from the interior of the sludge. Final drying is the phase during which the surface of the sludge is only partially saturated and, although the temperature at the sludge-gas interface is higher, drying rates are significantly lower than during the steady-state phase.

Regulations addressing Processes to Further Reduce Pathogens in sludge (40 CFR Part 257) define 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 percent 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.

A correctly operated heat drying process that maintains temperatures at these levels should ensure the reduction of pathogens (such as bacteria, viruses, or helminth ova) below detectable levels (EPA, 1989).

Heat drying produces a dried sludge material, a moist exhaust gas, and sometimes a liquid sidestream. Dusty, odorous or contaminated materials are not easily accepted for use as fertilizer or soil conditioner. Some level of finishing of the dried sludge (screening, pelletizing or granulating) may be required. Exhaust gases may need afterburning to reduce odors and particulates. Other techniques used in treating exhaust gases include cyclonic dust separators, wet scrubbers, electrostatic precipitators, and baghouses. Liquid sidestreams are sometimes produced by these air pollution control devices. These sidestreams are often returned to the headworks of the POTW, but may sometimes require separate treatment.

Flash dryers and rotary dryers are the more common types of heat drying techniques employed in the United States. Other methods include spray dryers, and a patented multiple-effect evaporation method known as the Carver-Greenfield process. Each of these techniques is discussed in the following sections.

17.1 PROCESS CONFIGURATION AND COMPONENTS

17.1.1 Flash Dryer

Flash drying rapidly removes moisture through spraying or injecting solids into a stream of heated gas. A typical flash drying process, marketed by CE-Raymond, is shown in Figure 23. The first step in flash drying involves mechanical mixing of some portion of the waste stream of previously dried sludge with wet sludge cake to improve handling characteristics. The resulting sludge mix and hot gases

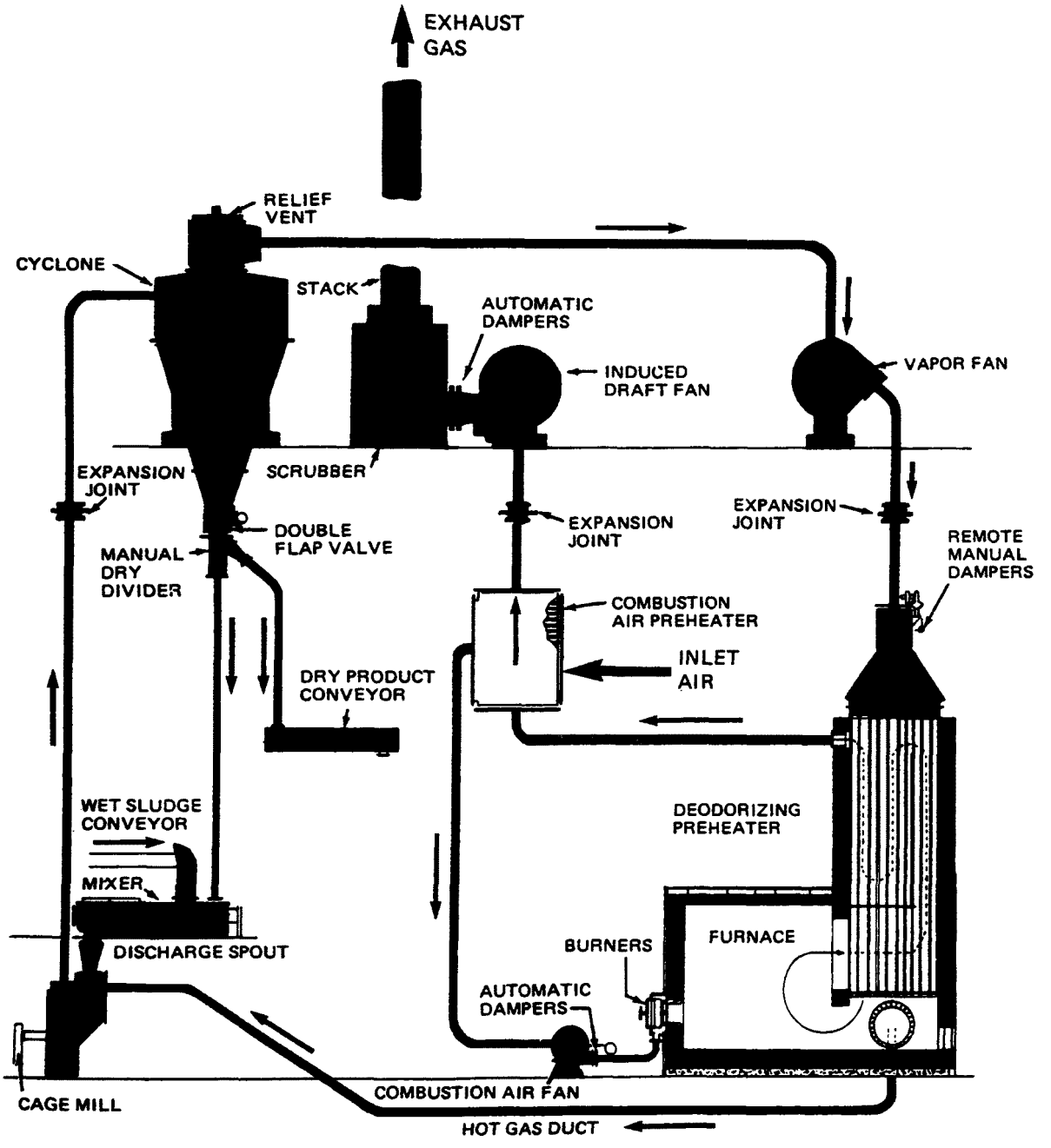


FIGURE 23. FLASH DRYER SYSTEM (COURTESY CE-RAYMOND)

from the incinerator are mechanically agitated in a cage mill. Air velocities in the cage mill are typically 65 to 100 ft/sec, with inlet gas temperatures reaching 1,300°F. This stage accomplishes the drying in a matter of seconds. A cyclonic dust separator is used to separate the solids from the gas stream, which are then passed on to the deodorizing preheater and incinerator. Exhaust gases then pass through a combustion preheater, together with inlet air. A portion of this mixture is exhausted to the atmosphere after scrubbing.

17.1.2 Rotary Dryer

The components common to rotary dryers are shown in Figure 24. Rotary dryers function in a manner similar to horizontal cylindrical kilns. Sludge is prepared for processing in rotary dryers, as for flash dryers, by mixing with previously dried sludge. The resulting sludge cake/dried sludge mixture is added to one end of the dryer. The rotation of the cylinder (5 to 8 rpm) as well as different internal arrangements of vanes, paddles or other devices agitate and break up the material, facilitating moisture transfer. Often, rotary dryers are slightly tilted to facilitate transport of the sludge through the device. Other designs use a central shaft with agitators to transport and agitate the sludge mixture. Heating of the sludge in direct rotary dryers occurs as hot gases (1,200°F) are passed through the rotating cylinder at speeds ranging from 4 to 12 ft/sec. Indirect rotary dryers use a jacket carrying hot gases to heat the steel cylinder's surfaces. Sometimes the central shaft is similarly heated. Indirect-direct rotary dryers direct the hot gases used to heat the surfaces through the drying sludge material before venting. Residence time for sludge passing through the dryer ranges from 20 to 60 minutes. As with flash drying, the resulting gases are passed through a cyclonic dust separator to separate out coarser particles of dried sludge. Options for the exhaust gases from the cyclone are shown in Figure 25.

17.1.3 Spray Dryer

Spray-drying operations, like flash drying, result in nearly instantaneous drying of the sludge particles. Three steps are involved: liquid atomizing, gas/droplet mixing, and drying of the liquid droplets. Centrifugal dishes or bowls are most commonly used as atomizers, although some installations use high-pressure nozzles. Atomizing breaks the liquid sludge into fine droplets, exposing greater surface to the hot gases used to dry the sludge. The atomizing device directs the droplets into a vertical tower where they pass downward through a rising gas stream introduced at roughly 1,300°F (705°C).

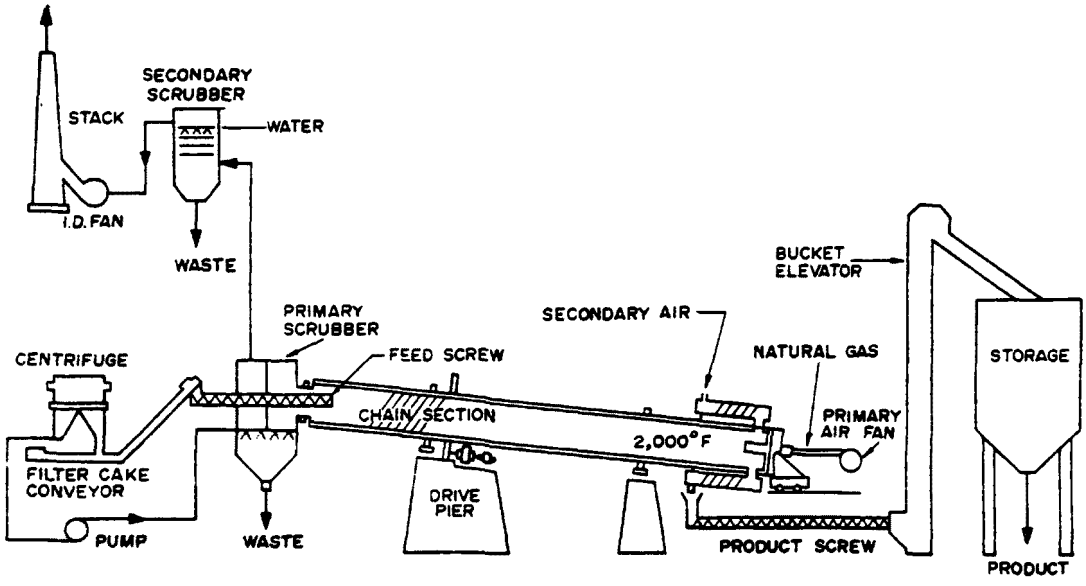


FIGURE 24. ROTARY KILN DRYER

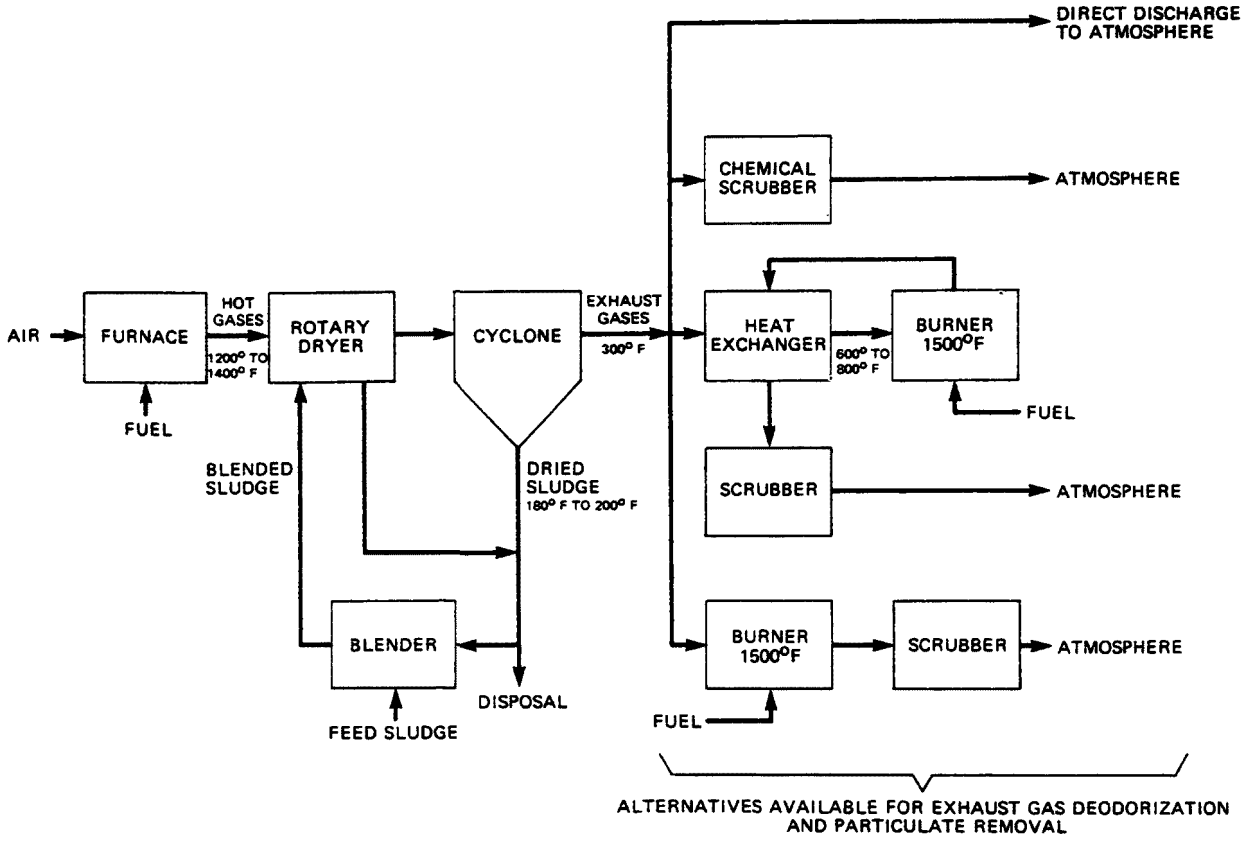


FIGURE 25. SCHEMATIC FOR A ROTARY DRYER

The droplets lose their moisture, fall through the gas stream and are collected at the bottom of the dryer. The gas stream is passed through a cyclonic dust separator before being exhausted through air pollution control devices.

17.1.4 Carver-Greenfield

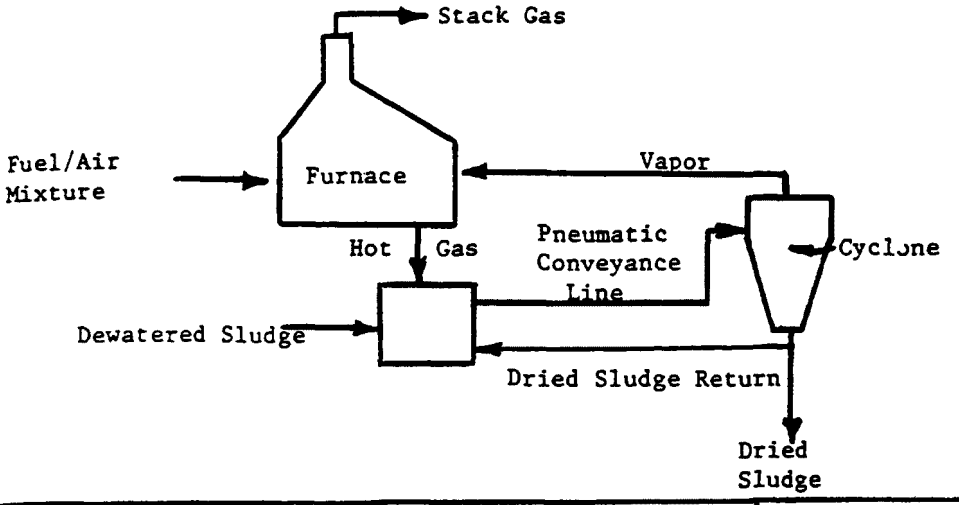
The patented Carver-Greenfield Process, marketed by Foster Wheeler Energy Corporation and Dehydro-Tech Corporation, uses multiple-effect evaporation to remove moisture from a mixture of sludge and light oil. Major steps in this process involve oil/sludge mixing, multiple-effect evaporation, oil-solid separation, and condensate-oil separation. Oil helps the sludge/oil slurry maintain flowing characteristics and minimizes the formation of scale and corrosion of heat exchanging surfaces. After it is mixed, the slurry is passed through a grinder to minimize clogging of the evaporator tubes. Water is removed from the slurry by falling-film evaporation as the material flows down evaporator tubes in a thin film. Steam generated as the slurry passes through the evaporator tubes is used to heat subsequent tubes, enhancing the efficiency of heat transfer. Oil remaining in the sludge is centrifuged out of the resulting product. Miscibility characteristics of the light oil used facilitate separation of the oil from water in the condensate. Condensate water from the evaporation and separation processes will contain ammonia and dissolved organic materials, requiring additional treatment in most cases. Gases exhausted from this process should be sent to a boiler or incinerator for odor removal through thermal destruction.

17.2 PROCESS CONTROL CONSIDERATIONS

Larger facilities may operate heat drying equipment on a continuous basis, while smaller facilities may only operate dryers on a shift or intermittent basis. The inspector should review the POTW's normal procedures in this regard. Startup and shutdown procedures should be clearly spelled out to avoid process inefficiencies.

Physical control considerations in heat drying involve maintaining as constant a process rate as possible. Table 12 provides suggestions for monitoring operational parameters. A diagram provided with the table illustrates the sample locations discussed in the table. Careful monitoring of the process using observation as well as analytical testing will result in more efficient and predictable processing of sludge. If temperature ranges necessary for proper operation of the drying processes are not maintained,

TABLE 12. SUGGESTED MINIMUM AND OPTIONAL MONITORING FOR HEAT DRYING PROCESSES



		Sample Frequency	Sample Location	Sample Method	Reason for Sample
Suggested Minimum	Percent Solids	1/day	Dewatered Sludge Dried Sludge	Grab	Process Control
	Temperature	Continuous	Furnace, Stack gas, dewatered and dried sludge	Record Continuously	Process Control
	Sludge Feed Rate	Continuous	Dewatered Sludge	Record Continuously	Process Control
	Oxygen	Continuous	Stack Gas	Record Continuously	Furnace Control
	Particulates	As required by APCD*	Stack Gas	Record or Grab	Air Pollution Control
	SO_2, NO_x, CO, CO_2	As required by APCD*	Stack Gas	Record or Grab	Air Pollution Control
	Fuel Consumption	Continuous	Furnace Input	Record Continuously	Furnace Control
	Air Flow	Continuous	Furnace Input	Record Continuously	Furnace Control
Optional	Ash Content	1/month	Dried Sludge	Grab	Determine characteristics prior to use or disposal.
	Nutrient Content	1/month	Dried Sludge	Grab	
	Density	1/month	Dried Sludge	Grab	
	Toxicity	1/month	Dried Sludge	Grab	

*Air Pollution Control District

alarms or other devices should signal operators of unsuitable conditions to enable rapid correction of problems.

Process control also requires frequent inspection and monitoring of the heat drying components. Procedures should call for inspection of heat drying equipment on a regular basis. An odor-free product with proper percent moisture indicates a properly functioning system. Procedures should call for checking and noting various parameters such as operating temperatures and pressures; and sludge, feed, fuel, and air flow rates.

Maintenance of the proper moisture content in sludge cake processed by rotary or flash dryers is especially critical to proper functioning of these systems. Too much moisture in the sludge feed can create serious energy inefficiencies. The proper mixture of incoming sludge and previously dried sludge fed to rotary or flash dryers is also a critical variable. Conveyance equipment used in rotary dryers and flash dryers may be prone to clogging if the mixture of wet sludge and previously dried sludge is allowed to reach too high a moisture content, but an adjustment of the respective flows of material to obtain a drier mix can resolve this problem. The proper mixture should be determined by trial and error at a level that permits easy handling without caking.

Efficient operation of heat drying also requires that the quantity of hot gases used in the process be optimized. Dusting problems may limit air flow rates, especially in rotary dryers. The quantity of hot gas should be just sufficient to dry the sludge. The optimum gas flow, in turn, depends on the sludge mixture produced and should be determined through operational results. Dusting problems may limit air flow rates, especially in rotary dryers. Operating temperatures should be maintained at levels recommended by the manufacturer of the process. Too low a temperature will not result in sufficient drying; too high a temperature can result in high energy costs.

17.3 PROCESS PERFORMANCE EVALUATION

The inspector should review the facility from the standpoint of its design as well as its operation and maintenance procedures. An inspection checklist is provided in Appendix A. This checklist is designed to aid the inspector in gathering information needed to properly evaluate a heat drying system.

17.3.1 Design Evaluation

The inspector should investigate the presence of common design shortcomings. The first of these is the development of large clumps or "clinkers" in the dried sludge. Grinding equipment may be used to process the sludge as part of finishing the dried material for distribution, or preprocessing might be considered.

Another common design problem involves excessive wear and corrosion to mixers, air locks, dampers, cage mills, and other metal equipment. POTWs with only coarse screening for grit removal may have greater problems with abrasion. Also, high pressure nozzles used to atomize sludge during spray drying are susceptible to abrasion and clogging. Centrifugal dishes or bowls are more common for this reason.

Another significant design problem can result from inadequate or improperly designed air pollution controls resulting in unacceptable particulates or odors. The inspector should review the design specifications for air pollution equipment installed to address these pollutants. Most commonly, odors are removed by afterburning and particulates by scrubbing, precipitation or baghouses.

Capacities of equipment and storage areas are an important design issue. Heat drying equipment is usually available in various design modules ranging from handling capacities of 40 to 2,400 tons/h of wet sludge cake. The inspector should review the capacities of the processes and associated storage capacities by first reviewing the number and capacities of dryers being used. If the drying operation is continuous, sufficient excess drying capacity should exist to allow dryers to be taken out of service for maintenance activities while maintaining treatment for all sludge produced. A minimum of 3 days of peak production is suggested (EPA, 1979). In cases where drying operations are not continuous, storage facilities should be adequate for peak sludge cake production during off-shift periods as well as for scheduled maintenance activities. Similarly, adequate storage facilities for dried product must be available if distribution is undertaken. If sales or distribution of dried sludge are seasonal, this capacity may need to be quite large. In processes calling for incineration or subsequent processing of the dried sludge, storage requirements will depend on the capacities of these processes. For this reason, and to eliminate space requirements, stockpiling should be minimized by seeking a regular market or outlet for the material.

17.3.2 Operations and Maintenance Evaluation

System performance, measured as the percent moisture in the finished product, can range from 2 to 10 percent. The inspector should review the manufacturers' operations manuals to determine the target moisture percentage for which the system was designed.

As previously mentioned, conveyances, drying shells and other sludge handling equipment can be easily eroded through the abrasive action of dried sludge. Ferric chloride, often used as a dewatering aid, can result in corrosive conditions which accentuate this problem. Procedures at the facility should call for frequent, regular inspections of parts and equipment. Plant components used in heat drying, which should be regularly inspected as part of standard plant procedures, include the following:

- Drives and gear reducers
- Sludge belt conveyors
- Pneumatic conveyers and pumps
- Bearings and bearing brackets on all equipment
- Cage mills and mixers
- Electrical contacts in all equipment, especially relays and starters
- Burners
- Furnaces and ancillary equipment.

Periodic pro-active replacement of heavily used components may be necessary. Proper coatings should be used to minimize wear and corrosion. *The WPCF Manual of Practice Number 17: Paints and Protective Coatings for Wastewater Treatment Facilities* provides useful information on this topic.

Heat exchangers and other components exposed to high temperatures and/or scaling should be regularly inspected on a schedule recommended by the manufacturer. In cases where certain equipment demonstrates a predictable service life, regular replacement should be scheduled under plant maintenance procedures.

The inspector should check to ensure that pathogen reduction is occurring in accordance with 40 CFR Part 257. Check to be certain that temperatures cited earlier for pathogen reduction are maintained.

The inspector should determine whether adequate storage exists for sludge feed and dried product. Dried product should not be exposed to rewetting. This can allow regrowth of organisms and subsequent decomposition with associated odors. Dried product should be stored in a manner that will minimize the potential for rewetting or fires.

As reviewed above, most heat drying processes generate an exhaust with odors and particulates. In evaluating air pollution control equipment, the inspector should review the exhaust gas treatment devices and associated manufacturers' operational specifications. The inspector should also review limits and monitoring requirements found in plant air permits, as well as records of monitoring results kept at the plant. Particulate removal efficiencies as high as 96 to 97 percent may be required. Table 12 outlines suggested monitoring of air pollutants and other operational parameters.

Table 13 presents a troubleshooting guide for heat drying operations. Problems addressed include improper drying, decreased flow in pneumatic lines, decreased flow in fans and ducts, excessive particulate emissions, and excessive odors. Probable causes, recommended monitoring to confirm problems, and suggested solutions are provided.

Safety should always be of concern at POTWs. In particular, the complex equipment and high temperatures used in heat drying can create numerous opportunities for employee injury. Heavy dust and/or grease can cause fire hazards due to the combination of combustible particles, rapid air velocities, and high temperatures. Inspection procedures should include careful review of potential fire hazards from grease or dust accumulation and provide for prompt housekeeping to minimize hazards. Fire-fighting procedures should have been taught to personnel and appropriate equipment should be available.

Safety procedures should also specify monitoring techniques to minimize the potential for hazards during grab sampling from hot equipment. Warning signs should be placed at locations where workers are likely to contact hot surfaces. Equipment that could create hazards when malfunctioning (such high-speed fans) should be equipped with warning sensors and recording devices to help signal and predict breakdowns.

TABLE 13. TROUBLESHOOTING GUIDE FOR HEAT DRYING OPERATIONS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Sludge not properly dried.	1a. Furnace temperature too low.	1a. Furnace temperature.	1a. Increase temperature as required.
	1b. Ratio of wet to dried sludge too high.	1b. Moisture content of wet/dry sludge mixture.	1b. Change ratio to provide drier mixture.
	1c. Quantity of hot combustion gases sent to dryer too low.	1c. Hot gas flow.	1c. Increase flow of combustion gases.
	1d. Moisture content of feed sludge too high.	1d. Percent solids of feed sludge.	1d. Check operation of dewatering equipment preceding heat drying equipment. Increase percent solids output.
2. Decreased sludge flow in pneumatic lines.	2a. Caking or blockage of line with wet mixture of sludge.	2a. Moisture content of wet/dry sludge mixture.	2a. Change ratio to provide drier mixture.
3. Decreased flow in fans and ductwork.	3a. Grease accumulation.	3a. Visually inspect ducting, fans.	3a. Steam clean equipment as required.
4. Excessive particulates in stack gas.	4a. Faulty or poorly operating pollution control equipment.	4a. Pollution control equipment.	4a. Correct operation of pollution control equipment - see manufacturer's manual.
5. Excessive odors in stack gas.	5a. Temperature of afterburner too low.	5a. Afterburner temperature.	5a. Operate afterburner between 1,200-1,400°F (650-700°C).

18. DISINFECTION

Wastewater sludge disinfection, the destruction or inactivation of pathogenic organisms in the sludge, is carried out principally to minimize public health concerns. Destruction is the physical disruption or disintegration of a pathogenic organism, while inactivation, as used here, is the removal of a pathogen's ability to infect. Another concern is to minimize the exposure of humans and domestic animals to pathogens in the sludge. At the present time in the United States, the use of procedures to reduce the number of pathogenic organisms is a requirement before the distribution or sale of sludge or sludge-containing products for use as a soil amendment, or before land application. Since the final use or disposal of sludge may differ greatly with respect to public health concerns, and since a great number of treatment options effecting various degrees of pathogen reduction are available, the system chosen for reduction of pathogens should be tailored to the demands of the particular situation. Apart from the sludge stabilization methods discussed elsewhere in this manual, another method for achieving additional disinfection involves irradiation of the finished sludge.

To make inspection easier using this manual, this section on disinfection is organized somewhat differently than the preceding ones dealing with other solids handling processes. After addressing the four categories of pathogens and pathogen reduction by the previously described sludge treatment processes, this discussion is subdivided into two major sections that each deal with one of the two methods of irradiation, beta and gamma. The appropriate configuration and component, control considerations and process performance evaluations are all discussed under each irradiation method.

18.1 PATHOGENS

A pathogen, or pathogenic agent, is any biological organism that can cause disease in the host organism. Those organisms or agents fall into four broad categories: viruses, bacteria, parasites, and fungi. Viruses, bacteria, and parasites are the primary pathogens that are present at some levels in sludge as a result of human activity. Fungi are secondary pathogens and are only numerous in sludge when given the opportunity to grow during some stage of the treatment or storage process.

18.1.1 Viruses

Viruses are obligate parasites and can only reproduce by dominating the internal processes of host cells and using the hosts' resources to replicate themselves. Therefore, viral levels will not increase in sludge. Different viruses show varying resistance to environmental factors such as heat and moisture.

Typical total virus concentrations in untreated wastewaters are 1,000 to 10,000 plaque-forming units (PFU) per 100 ml; treated effluent concentrations are 10 to 300 PFU per 100 ml. Wastewater treatment, particularly chemical coagulation or biological processes followed by sedimentation, concentrates viruses in sludge. Raw primary and waste activated sludges typically contain 10,000 to 100,000 PFU per 100 ml.

18.1.2 Bacteria

Bacteria are single-celled organisms that range in size from slightly less than one micron (μ) in diameter to 5μ wide by 15μ long. Among the primary pathogens, only bacteria are able to reproduce outside the host organism. They can grow and reproduce under a variety of environmental conditions. High heat is more effective for inactivating bacteria, although some species form heat-resistant spores. Pathogenic bacterial species generally grow best at a pH between 6.5 and 7.5. The ability of bacteria to reproduce outside a host is an important factor. Although sludge may be disinfected, it can be reinoculated and recontaminated.

18.1.3 Parasites

Parasites include protozoa, nematodes, and helminths. Pathogenic protozoa are single-celled animals that range in size from 8μ to 25μ. Protozoa are transmitted by cysts, the nonactive and environmentally insensitive form of the organism. Their life cycles require that a cyst be ingested by a human or another host. The cyst is transformed into an active organism in the intestines, where it matures and reproduces, releasing cysts in the feces. Due to their need for a host organism, parasites, like viruses, do not increase in numbers in sludge.

Nematodes include roundworms and hookworms. These organisms may reach sizes up to 14 in. in the human intestine, and may invade other tissues. This situation is especially common when man ingests the ova of a roundworm common to another species, such as the dog. The nematode does not stay in the intestine, but migrates to other body tissue, such as the eye, and encysts. The cyst, similar to that formed by protozoa, causes inflammation and fibrosis in the host tissue. Pathogenic nematodes cannot spread directly from human to human. The ova discharged in feces must first embryonate at ambient temperature, usually in the soil, for at least 2 weeks.

Helminths include flatworms, such as tapeworms, that may be more than 12 in. (30 cm) long. The most common types in the United States are associated with beef, pork, and rats. Transmission occurs when man ingests raw or inadequately cooked meat, or the eggs of the tapeworm. In the less serious form, the tapeworm develops in the intestine, maturing and releasing eggs. In the more serious form, it localizes in the ear, eye, heart or central nervous system.

Parasite cysts are insensitive to many sludge treatment processes although, as sludge ages, viable cysts decrease. Heat is effective against cysts; radiation may also be effective.

18.1.4 Fungi

Fungi are single-celled nonphotosynthesizing organisms that reproduce by developing spores, which form new colonies when released. Fungi are secondary pathogens in wastewater sludge, and large numbers have been found growing in compost. The pathogenic fungi are most dangerous when the spores are inhaled by people whose systems are already stressed by a disease such as diabetes or by immunosuppressive drugs. Fungi spores, especially those of *Aspergillus fumigatus*, are ubiquitous in the environment and have been found in pasture lands, hay stacks, manure piles, and the basements of most homes.

18.2 PATHOGEN REDUCTION DURING SLUDGE TREATMENT PROCESSES

Sludge stabilization processes are ideally intended to reduce putrescibility, decrease mass, and improve treatment characteristics such as dewaterability. Many stabilization processes also accomplish substantial reductions in pathogen concentrations. In addition, some dewatering processes reduce pathogen levels. These processes have been discussed previously. Federal regulations (40 CFR Part 257) specify holding times and temperatures that are considered adequate to achieve pathogen reduction by each sludge stabilization process. These operational requirements are summarized in Table 14. Additional processes, evaluated and approved by the Pathogen Equivalency Committee, are listed in Table 15.

TABLE 14. OPERATING PARAMETERS FOR ACHIEVING PATHOGEN REDUCTION

Sludge Treatment Process	Processes to Significantly Reduce Pathogens (PSRP)*	Processes to Further Reduce Pathogens (PFRP)**
Aerobic Digestion	60 days at 15°C 40 days at 20°C Volatile solids reduction (VSR) of at least 38%	10 days at 55 - 60°C with VSR at least 38%
Anaerobic Digestion	60 days at 20°C 15 days at 35 - 55°C VSR of at least 38%	N/A
Heat Treatment	N/A	180°C for 30 minutes
Wet Air Oxidation	N/A	Must reduce pathogens to level equivalent to other PFRPs.
Incineration	N/A	Must reduce pathogens to level equivalent to other PFRPs.
Composting	5 days at 40°C and temperature must exceed 55°C for 4 hours during this period	Within-vessel 3 days at 55°C Static aerated pile 3 days at 55°C, Windrow 15 days at 55°C with a minimum of 5 turnings of pile
Chemical Stabilization	Product pH of 12 after 2 hours of contact	N/A
Air Drying Beds	At least 3 months with sludge piled to a maximum depth of 23 cm/9 in. Two months of this period temperatures must average above 0°C on a daily basis	N/A
Heat Drying	N/A	Sludge temperature > 80°C Moisture content reduced to 10%
Electron and Gamma Ray Irradiation	N/A	Dosage at least 1.0 at megarad at room temperature (20°C) (used in conjunction with PSRP which reduce volatile solids)
Pasteurization	N/A	70°C for 30 minutes (used in conjunction with PSRP which reduce volatile solids)

*PSRPs reduce, but do not eliminate pathogens. PSRPs typically achieve a 90% reduction in virus and bacteria.
**PFRPs reduce pathogens to below detectible levels.

TABLE 15. 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.	Conditional PFRP

18.3 PATHOGENIC DESTRUCTION USING BETA IRRADIATION

Beta rays (high-energy electrons) are projected through wastewater sludge, by an appropriate generator, to destroy or inactivate pathogens. The electrons produce both biological and chemical effects as they scatter off material in the sludge. Direct ionization by the electrons may damage molecules of the pathogens, particularly the DNA in bacteria cell nuclei, and the DNA or RNA of the viruses. The electrons also induce secondary ionizations in sludge as they penetrate. Secondary ionization directly inactivates pathogens, and produces oxidizing and reducing compounds that in turn attack pathogens.

The pathogen-reducing power of the electron beam (e-beam) depends on the number and the energy of electrons impacting the sludge. E-beam dose rates are measured in rads; one rad is equal to the absorption of 4.3×10^{-6} Btu per pound of material. Since the radiation distributes energy throughout the volume of material regardless of the material penetrated, the degree of disinfection with an irradiation system is essentially independent of the sludge solids concentration, within the maximum effective penetration depth of the radiation. The penetrating power of electrons is limited, with a maximum range of 0.2 in. (0.5 cm) in water or sludge slurries, when the electrons have been accelerated by a potential of 1 million volts (MeV).

For e-beam disinfection to be effective, some minimum dosage must be achieved for all sludge being treated. This effect is attained by dosing above the average dosage desired for disinfection. One method used to ensure adequate disinfection is to limit the thickness of the sludge layer radiated so that ionization intensity of electrons exiting the treated sludge is about 50 percent of the maximum initial intensity. If electron irradiation is combined with some other stabilization process and is operated at a dosage of 1.0 megarad at room temperature, the pathogen destruction will meet the PFRP requirements.

18.3.1 Process Configuration and Components

The major system components of an electron irradiation unit (shown in the schematic in Figure 26) include: sludge screener, sludge grinder, sludge feed pump, sludge spreader, electron beam power supply, electron accelerator, electron beam scanner, and sludge removal pump. A concrete vault houses the electron beam, providing shielding for the workers from stray irradiation, especially X-rays. X-rays are produced by the interaction of the electrons with the nucleus of atoms in the mechanical equipment and in the sludge. The pumps must be progressive cavity or similar types to ensure smooth

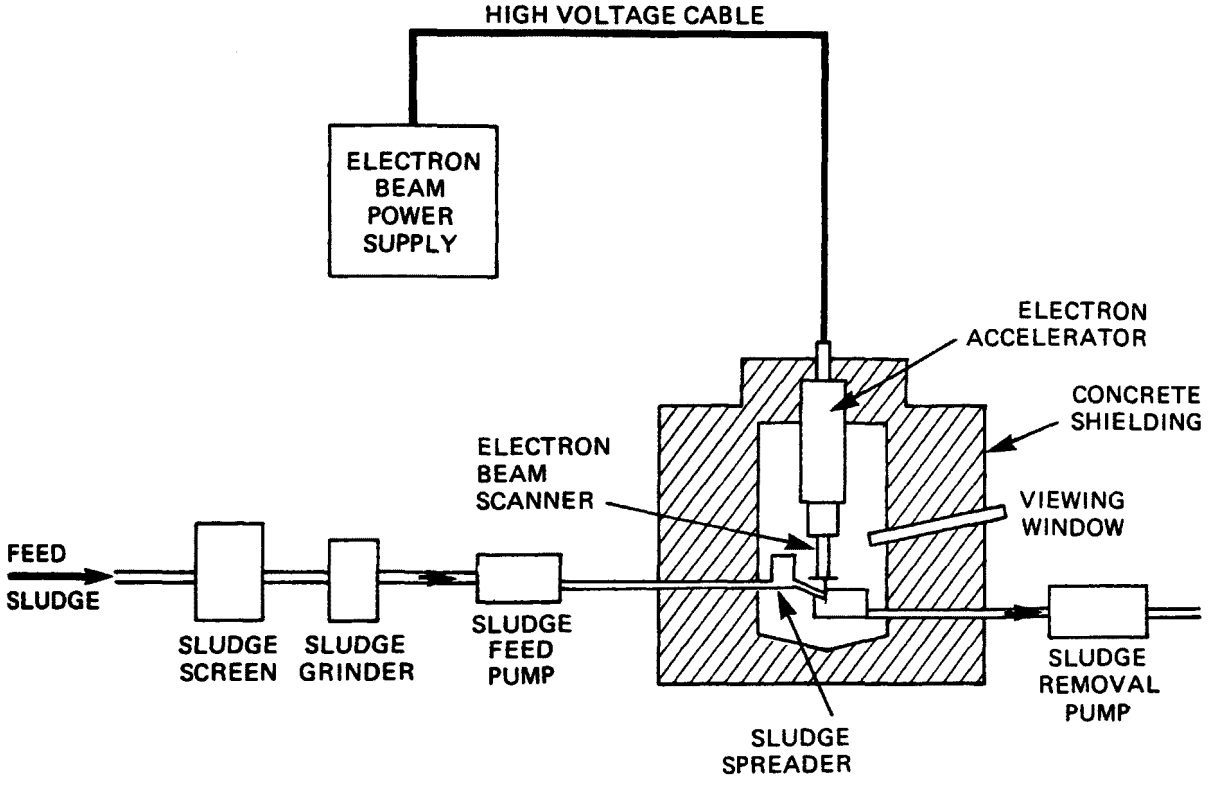


FIGURE 26. EQUIPMENT LAYOUT FOR ELECTRON IRRADIATION FACILITY

sludge feed. Screening and grinding of sludge prior to irradiation is necessary to ensure that a uniform layer of sludge is passed under the e-beam.

18.3.2 Process Control Considerations

The electrons are first accelerated. They leave the accelerator in a continuous beam that is scanned back and forth at 400 times per second across the sludge. The sludge is scanned as it falls free in a thin film from the end of the inclined ramp. The dosage is varied by adjusting the height of the underflow weir and, hence, the sludge flow rate.

Instrumentation needs for an e-beam facility should include flow measurement of and temperature probes in the sludge streams entering and leaving the irradiator. Alarms as well as monitoring should be used to indicate variation in sludge flow and high or low radiation doses.

18.3.3 Process Performance Evaluation

The inspector should review pathogen reduction records to evaluate unit performance and to evaluate the process control measurements. These measures include testing the sludge before and after radiation to calculate pathogen reduction, recording the temperature of the sludge stream before and after leaving the irradiation unit, and recording the sludge flow and radiation dosage.

The inspector should inquire about the routine operating procedures. The unit O&M manual should be consulted to determine the specific procedures that should be followed. Valves and pumps should be operational and subject to periodic maintenance. The O&M manual should also be consulted to determine the periodic maintenance procedures and frequency.

Safety measures such as warning signs for radioactive material or X-rays, audible alarms for radiation and critical equipment, and periodic testing of emergency safety procedures and equipment should be evaluated.

18.4 PATHOGEN DESTRUCTION USING GAMMA IRRADIATION

Gamma irradiation produces effects similar to those from an electron beam. However, gamma rays differ from electrons in two major ways. First, gamma rays are very penetrating; a layer of water 25 in. (64 cm) thick is required to stop 90 percent of the rays from a cobalt-60 (CO-60) source; in comparison, a 1-MeV electron can only penetrate about 0.4 in. (1 cm) of water. Second, gamma rays result from decay of a radioactive isotope. Decay from a source is continuous and uncontrolled; it cannot be turned off and on. The energy level (or levels) of the typical gamma ray from a given radioactive isotope are also relatively constant. Once an isotope is chosen for use as a source, the applied energy can only be varied with exposure time.

If gamma irradiation is combined with some other stabilization process and is operated at 1.0 megarad at room temperature, the pathogenic destruction will meet the PFRP requirements.

18.4.1 Process Configuration and Components

Two general types of gamma systems have been proposed for wastewater sludge disinfection. The first is a batch-type system for liquid sludge, where the sludge is circulated in a closed vessel surrounding the gamma ray source (depicted in Figure 27). Dosage is regulated by detention and source strength. The second system is for dried or composted sludge. A special hopper conveyor is used to carry the material for irradiation to the gamma ray source. Conveyor speed is used to control the dosage.

Instrumentation should include radiation detectors, and flow metering for the wet sludge system. When either facility is operating, arrangements must be made for periodic radiation safety inspection. The disinfection effectiveness should also be tested by periodic sampling of the sludge before and after disinfection.

18.4.2 Process Performance Evaluation

As with the beta irradiation, process performance evaluation of a gamma irradiation unit involves review of process control measurements and pathogen reduction records to evaluate unit performance. These measures include testing the sludge before and after radiation to determine pathogen reduction, recording the sludge flow and monitoring source strength. The inspector should inquire about

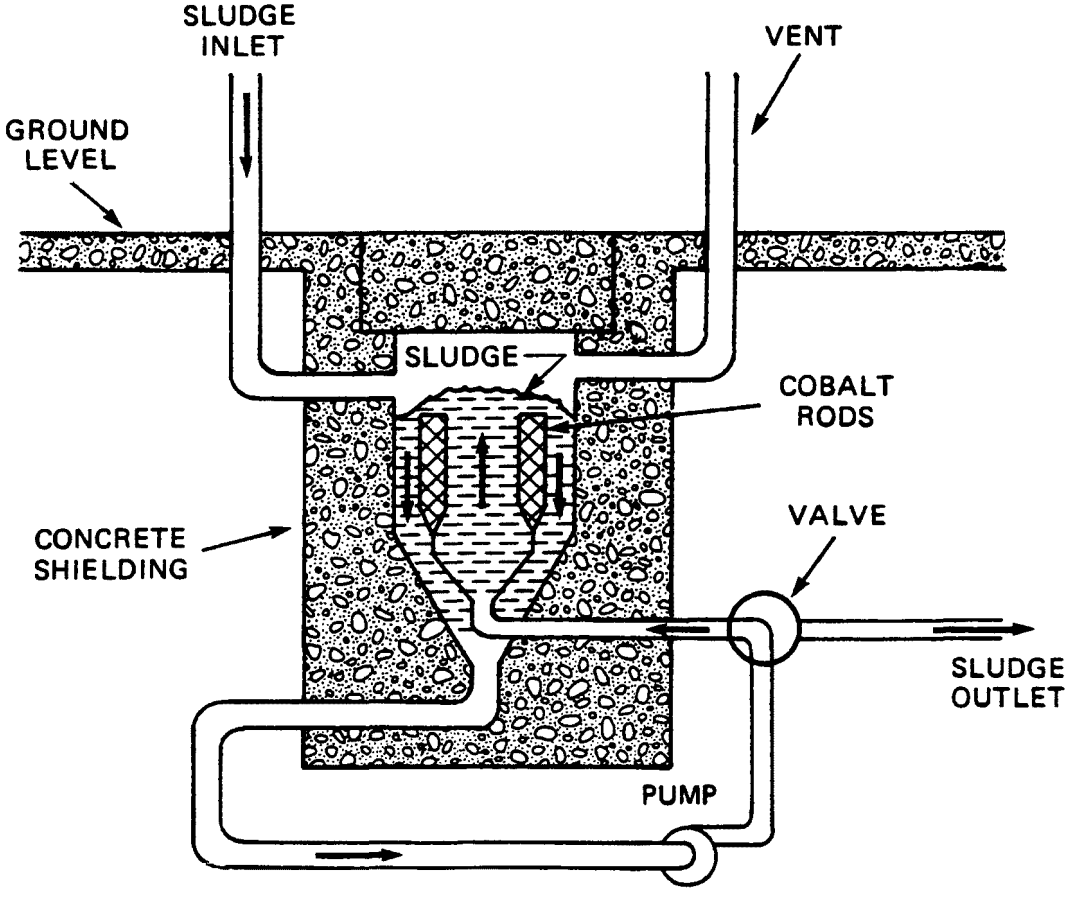


FIGURE 27. SCHEMATIC OF GAMMA IRRADIATION FACILITY

routine operating procedures, periodic maintenance, and radiation detection alarms and inspections and other emergency and routine safety procedures.

No units have been installed in the U.S.A. although Sandra Laboratories in Albuquerque, NM successfully operated a pilot facility designed to treat dried sludge conveyed through the unit in bulk or in bags.

APPENDIX A

INSPECTION CHECKLISTS FOR SLUDGE TREATMENT PROCESSES

This appendix contains checklists that correspond to each of the unit processes described in Appendix A. The checklists were developed to assist the inspector in conducting evaluations of the processes and in documenting the inspection findings. The checklists are included as a separate appendix to facilitate quick access. The page number of each checklist in listed below.

Checklist	Page Number In Appendix
Gravity Thickening	A-3
Dissolved Air Flotation Thickening	A-7
Centrifugation	A-13
Aerobic Digester	A-17
Anaerobic Digester	A-23
Heat Treatment/Wet Air Oxidation	A-29
Incineration	A-35
Composting	A-41
Chemical Stabilization/Conditioning	A-49
Vacuum Filter	A-55
Filter Press	A-61
Belt Filter Press	A-65
Sludge Drying Beds	A-69
Sludge Drying Lagoons	A-73
Heat Drying	A-77
Beta or Gamma Irradiation	A-83

PERFORMANCE EVALUATION
GRAVITY THICKENER

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Number of units _____ In operation _____
2. Type of sludge thickened: _____

   Ratio of combined sludges (secondary: primary) _____
3. What is the thickener diameter? _____ ft
4. What is the thickener depth? _____ ft
5. What is the thickener volume? _____ gal
6. What is the thickener design overflow rate? _____ gal/day/ft^2
7. What is the thickener design solids loading rate? _____ lbs/day ft^2
8. What is the supernatant return location? _____
9. Is the thickener covered? ☐ Yes ☐ No

   If so, is it properly ventilated? ☐ Yes ☐ No
10. Are off-gases treated? ☐ Yes ☐ No

II. PROCESS INFORMATION

1. What is the sludge application rate? _____ gal/day or _____ lbs/day
2. What is the frequency of sludge application? _____ min/hr
3. What is the thickened sludge pumping rate? _____ gal/day
4. What is the frequency of thickened sludge application? _____ min/hr
5. What is the influent sludge concentration? _____ % solids
6. What is the thickened solids concentration? _____ % solids
7. What is the supernatant TSS concentration? _____ mg/l
8. What is the supernatant BOD concentration? _____ mg/l
9. What is the sludge blanket depth? _____ ft

II. PROCESS INFORMATION (Continued)

10. Are floating solids or gas bubbles present? ☐ Yes ☐ No

11. Are there odors in the vicinity of the thickener? ☐ Yes ☐ No

12. Is chemical conditioning used? ☐ Yes ☐ No
(If yes, refer to chemical conditioning/stabilization section)

13. Dosage based on: ☐ Jar tests ☐ Operating experience ☐ Other _____

14. Describe the operating strategy for the thickener: _____

_____

_____

_____

_____

15. Are adequate operating records maintained? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**

2. Is there adequate equipment redundancy? ☐ Yes ☐ No**

3. Is the spare parts inventory adequate? ☐ Yes ☐ No**

4. Housekeeping adequate? ☐ Yes ☐ No**

5. Are effluent weirs level and clean? ☐ Yes ☐ No**

6. Visual evidence of short circuiting in the thickener? ☐ Yes** ☐ No

7. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

8. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

3. Ventilation: _____

_____

4. Chemical: _____

_____

5. Trip/slip/fall: _____

_____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
DISSOLVED AIR FLOTATION (DAF) THICKENER

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Number of units: _____ In operation: _____
2. Period of operation: _____ hrs/day _____ days/week
3. Type of sludge fed: ☐ Primary Sludge ☐ Secondary Sludge ☐ Combined

   If combined sludge, what is the ratio by volume? _____
4. Thickener shape: _____ sq ft
5. Thickener size: _____ sq ft
6. Thickener volume: _____ cu ft _____ gal
7. Design influent flow: _____ gal/day
8. Subnatant return location: _____

II. PROCESS INFORMATION

1. Describe operational strategy: _____

   _____

   _____

   _____
2. Sludge feed rate: _____ gal/day _____ lbs/day
3. Daily operating time: _____ hr

			Monitoring Frequency
4.	Raw sludge solids concentration:	%	
5.	Thickened sludge solids concentration:	%	
6.	Subnatant suspended solids content:	%	
7.	Floating sludge depth:	in	
8.	Effluent recycle ratio:	%	
9.	Air flow rate:	cu ft/min	
10.	Retention tank pressure:	psig	

II. PROCESS INFORMATION (Continued)

11. Is sludge being effectively removed by the skimmer? ☐ Yes ☐ No**

12. Is the skimmer operated continuously? ☐ Yes ☐ No

13. Duration of typical skimmer on/off cycle: _____

14. Avg. operating speed of skimmer: _____ ft/min

15. Are the effluent weirs clean and level? ☐ Yes ☐ No**

16. Is effluent clear and relatively free of solids? ☐ Yes ☐ No**

17. Is polymer used? (If so, what type?) _____

    Refer to Chemical Conditioning/Stabilization Section.

18. Hydraulic loading rate

    (Raw sludge plus recycle flows divided by surface area): _____ gal/min/ft^2

19. Solids loading rate

    (Solids application rate divided by surface area): _____ lbs/hr/ft^2

20. Air to solids ratio

    (Air flow rate divided by solids application rate): _____ %

21. Percent solids removal efficiency: _____ %

22. Location of supernatant return in plant: _____

    supernatant return rate: _____ gal/day

    Supernatant solids concentration: _____ mg/l _____

23. Are adequate operating records maintained? ☐ Yes ☐ No**

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**

2. Is there adequate equipment redundancy? ☐ Yes ☐ No**

3. Is the spare parts inventory adequate? ☐ Yes ☐ No**

4. Housekeeping adequate? ☐ Yes ☐ No**

5. Are air diffusers and tanks inspected at least once per year? ☐ Yes ☐ No**

6. Are mixing, pumping, and blower equipment inspected annually for worn blades and impellers? ☐ Yes ☐ No**

III. MAINTENANCE INFORMATION (Continued)

7. Are air filters serviced at regular intervals? ☐ Yes ☐ No**

8. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

9. What is the currently mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

3. Ventilation: _____

_____

4. Chemical: _____

_____

5. Trip/fall: _____

_____

V. OTHER OBSERVATIONS

_____

_____

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_____

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

COMPARISON OF ACTUAL DISSOLVED AIR FLOTATION CONDITIONS TO DESIGN AND TYPICAL CONDITIONS

PARAMETER	ACTUAL	DESIGN	TYPICAL
Hydraulic Loading gpm/sq ft			0.5-2.0
Solids Loading lb/hr/sq ft			0.5-2.0
Raw Sludge Concentration mg/l			5,000
Subnatent TSS Concentration mg/l			<100
Solids Removal Percent w/Flotation Aid w/o Floating Aid			95 50-80
Air to Solids Ratio			0.03
Depth of Floating Solids (inches)			8-24
Floating Solids Concentration (Percent)			3-7

PERFORMANCE EVALUATION
CENTRIFUGATION

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. What type of centrifuge is present?

   ☐ Solid Bowl ☐ Basket ☐ Disc Nozzle

2. Manufacturer's name: _____

3. Is the centrifuge used for _____ thickening or _____ dewatering purposes?

4. Number of units _____ Number in operation _____

5. Type of sludge processed _____

6. Design Criteria:

   Sludge feed solids concentration range (min - max) _____ %

   Sludge feed rate _____ gal/min _____ lbs dry solids/hr

   Solids capture _____ %

   Expected solids concentration of centrifuged sludge _____ %

   Motor operating current _____ amperes

   Bearing operating temperature _____ °F

II. PROCESS INFORMATION

1. Describe the operating strategy: _____

2. What is the operating period? _____ hr/day

   _____ days/week

3. What is the sludge feed rate? _____ gal/min _____ lbs dry solids/hr

4. What is the total solids concentration of the feed sludge? _____ %

5. What is the total solids concentration of the centrifuged sludge? _____ %

6. What is the total solids concentration of the centrate? _____ %

II. PROCESS INFORMATION (Continued)

7. What is the solids capture? _____ %

8. Location of centrate return in plant: _____

9. Is the feed sludge chemically conditioned prior to centrifuging? ☐ Yes ☐ No

   (If yes, refer to chemical conditioning/stabilization checklist for additional evaluation parameters.)

10. What is the operating temperature of the bearings? _____ °F

11. What is the motor operating current under load? _____ amperes

12. What is the monitoring frequency of the following:

    Sludge feed rates _____

    Feed sludge solids _____

    Centrifuged sludge solids _____

    Centrate solids _____

    Motor operating current _____

    Bearing temperatures _____

13. Is the centrifuge flushed during the shutdown phase? ☐ Yes ☐ No

    If yes, for what period of time? _____

14. Are there excessive blockages in the sludge feed pipe due to rags? ☐ Yes ☐ No

15. Is there excessive wear of internal components due to high concentrations of grit? ☐ Yes ☐ No

16. Does the sludge feed rate to the centrifuge result in excessive motor current or frequent torque overloads? ☐ Yes ☐ No

17. Does the centrifuge show signs of excessive vibrations? ☐ Yes ☐ No

18. Are the operating records adequate? ☐ Yes ☐ No

19. Are there documented standard operating procedures for startup and shutdown of the centrifuges? (If yes, attach copy to report.) ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**

2. Is there adequate equipment redundancy? ☐ Yes ☐ No**

3. Is the spare parts inventory adequate? ☐ Yes ☐ No**

III. MAINTENANCE INFORMATION (Continued)

4. Is the housekeeping adequate? ☐ Yes ☐ No**

5. What is the frequency of major overhauls? _____

5. Are air diffusers and tanks inspected at least once per year? ☐ Yes ☐ No**

6. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

8. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

3. Ventilation: _____

_____

4. Chemical: _____

_____

5. Trip/fall: _____

_____

V. OTHER OBSERVATIONS

_____

_____

_____

_____

_____

_____

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
AEROBIC DIGESTER

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Type of Digester (check one):

   ☐ Primary ☐ High Rate ☐ Secondary ☐ Low Rate

2. Number of units: _____ In operation: _____

3. Type of sludge digested:

   ☐ Primary Sludge ☐ Secondary Sludge ☐ Combined Sludge

   If combined sludge, what is the ratio by volume? _____

4. Mode of operation: ☐ Batch ☐ Semi-Batch ☐ Continuous

5. Digester dimensions (L x W x D) _____ ft

6. Total volume of digester: _____ cu ft _____ gal

7. Design sludge application rate: _____ gal/day _____ lbs/day

8. Design volatile solids loading: _____ lbs/cu ft/day

9. Hydraulic retention time: _____ days

10. What type of aeration equipment is used: _____

11. If diffused air is used do air diffusers require frequent cleaning? ☐ Yes ☐ No

12. Aeration source: ☐ Air ☐ Pure Oxygen

13. Air supply capacity: _____ CFM/1,000 cu ft _____ horsepower (HP/1,000 cu ft)

14. Are the digesters open or covered: _____

II. PROCESS INFORMATION

1. Describe operational strategy: _____

   _____

   _____

   _____

2. Sludge application rate: _____ gal/day _____ lbs/day

3. Frequency of application: _____ hr

II. PROCESS INFORMATION (Continued)

		Monitoring Frequency
4.	Raw sludge solids concentration: _____ %	
5.	Raw sludge volatile solids content: _____ %	
6.	Digested sludge solids concentration: _____ %	
7.	Digested sludge volatile solids content: _____ %	
8.	Digested sludge removal rate: _____ gal/day _____ lbs/day	
9.	Reactor solids concentration: _____ %	
10.	Reactor volatile solids content: _____ %	
11.	Reactor temperature (average): _____ °f	
12.	Reactor dissolved oxygen: _____ mg/l	
13.	Reactor pH: _____	
14.	Sludge recycle rate to the digester: _____ ft	

15. Are there foaming problems? ☐ Yes ☐ No

16. Are there odor problems? ☐ Yes** ☐ No

17. Location of supernatant return in plant: _____

Supernatant return rate: _____ gal/day

Supernatant solids concentration: _____ mg/l_____

18. Are adequate operating records maintained? ☐ Yes ☐ No**

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**
2. Is there adequate equipment redundancy? ☐ Yes ☐ No**
3. Is the spare parts inventory adequate? ☐ Yes ☐ No**
4. Housekeeping adequate? ☐ Yes ☐ No**
5. Are air diffusers and tanks inspected at least once per year? ☐ Yes ☐ No**
6. Are mixing, pumping, and blower equipment inspected annually for worn blades and impellers? ☐ Yes ☐ No**
7. Are air filters serviced at regular intervals? ☐ Yes ☐ No**

III. MAINTENANCE INFORMATION (Continued)

8. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

9. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

3. Ventilation: _____

_____

4. Chemical: _____

_____

5. Trip/fall: _____

_____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

COMPARISON OF ACTUAL AEROBIC DIGESTER CONDITIONS TO DESIGN AND TYPICAL CONDITIONS

PARAMETER	ACTUAL	DESIGN	TYPICAL	40 CFR 257
Solids Retention Time (days)			10-20	From 60 days at 59°F to 40 days at 68°F
Temperature (Fahrenheit)			>59	
Volatile Solids Reduction %				38
Volatile Solids Loading (lb VS./cu ft/dy)			0.024-0.14	
Air Requirements Diffuser System (cfm/1,000 cu ft) Activated Sludge Primary & Activated Sludge			 20-35 >60	
Air Requirements Mechanical System (hp/1,000 cu ft)			1.0-1.25	
Dissolved Oxygen Minimum (mg/l)			1.0-2.0	
Reactor pH			>6.5	

PERFORMANCE EVALUATION
ANAEROBIC DIGESTER

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Type of digester (check one):

   ☐ Primary ☐ High Rate ☐ Secondary ☐ Low Rate

2. Number of units: _____ In operation: _____

3. Type of sludge digested:

   ☐ Primary Sludge ☐ Secondary Sludge ☐ Combined Sludge

   If combined sludge, what is the ratio by volume? _____

4. Type of cover: ☐ Fixed ☐ Floating

5. Sludge application rate: _____ gal/day _____ lbs/day

6. Digester diameter: _____ ft

7. Digester depth: _____ ft

8. Total volume of digester: _____ cu ft _____ gal

9. Design volatile solids loading: _____ lbs/cu ft/day

10. Hydraulic retention time: _____ days

11. Digester heating mechanism: _____

12. Digester mixing mechanism: _____

II. PROCESS INFORMATION

1. Describe operational strategy: _____

   _____

   _____

   _____

2. Sludge application rate: _____ gal/day _____ lbs/day

II. PROCESS INFORMATION (Continued)

		Monitoring Frequency
3.	Raw sludge solids concentration: _____ %	
4.	Raw sludge volatile solids content: _____ %	
5.	Digested sludge solids concentration: _____ %	
6.	Digested sludge volatile solids content: _____ %	
7.	Digested sludge removal rate: _____ gal/day _____ lbs/day	
8.	Digester volatile acids: _____ mg/l	
9.	Digester pH: _____	
10.	Digester temperature: _____ °F	
11.	Digester alkalinity: _____ mg/l	
12.	Volatile acids/alkalinity ratio: _____	
13.	Depth of scum blanket: _____ ft	
14.	Depth of grit layer: _____ ft	
15.	Gas production: _____ ft^3/day	
16.	Gas composition: a. Methane _____ %	
	b. Carbon dioxide _____ %	
	c. Hydrogen sulfide _____ %	

17. Active digester volume (total digester volume LESS scum and grit layer): _____ ft^3/day

18. Volatile solids loading (volatile solids application rate PER active digester volume): _____ lbs/ft^3/day

19. Volatile solids reduction: (sludge application rate times percent volatile solids reduction): _____ lbs/day

20. Gas production rate per lb. Volatile solids reduced (gas produced divided by volatile solids reduction): _____ ft^3/lb VS Destroyed

21. Solids retention time (digester solids mass divided by solids discharge rate) _____ day

22. Location of supernatant return in plant: _____

Supernatant return rate: _____ gal/day

Supernatant solids concentration: _____ mg/l _____

23. Are adequate operating records maintained? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**
2. Is there adequate equipment redundancy? ☐ Yes ☐ No**
3. Is the spare parts inventory adequate? ☐ Yes ☐ No**
4. Housekeeping adequate? ☐ Yes ☐ No**
5. Are regular inspections made of:
   a. Gas safety devices? ☐ Yes ☐ No**
   b. Gas piping system, compressors and scrubbers? ☐ Yes ☐ No**
   c. Water seals? ☐ Yes ☐ No**
   d. Manometers? ☐ Yes ☐ No**
   e. Digester structure and heat transfer system? ☐ Yes ☐ No
   f. Scum blanket build-up? ☐ Yes ☐ No
   g. Pumping system? ☐ Yes ☐ No
6. Components out of service

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)
7. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

   _____
2. Electrical: _____

   _____

IV. SAFETY CONSIDERATIONS (Continued)

3. Ventilation: _____

4. Chemical: _____

5. Trip/fall: _____

6. Confined space: _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

COMPARISON OF ACTUAL ANAEROBIC DIGESTER CONDITIONS TO DESIGN AND TYPICAL CONDITIONS

PARAMETER	ACTUAL	DESIGN	TYPICAL	40 CFR 257
Solids Retention Time				From 60 days at 68°F to 15 days at 95-131°F
Temperature (Fahrenheit)			98	
Volatile Solids Reduction %				35
pH			6.8 to 7.2	
Gas Production Per Pound VS. Added (cu ft/lb VS. Added)			6-8	
Per Pound VS. destroyed (cu ft/lb VS. destroyed)			16-18	
Gas Composition (%)				
Methane			65-69	
Carbon Dioxide			31-35	
Hydrogen Sulfide			Trace	
Volatile Acids Conc. (mg/l)			200-800	
Alkalinity Conc. (mg/l)			2,000-3,500	
Volatile Solids Loading				
Low-Rate (lb VS./cu ft/day)			0.02-0.05	
High-Rate (lb VS.cu ft/day)			0.05-0.15	
Solids Retention Time (days)				
Low-Rate			30-60	
High-Rate			10-20	

PERFORMANCE EVALUATION
HEAT TREATMENT/WET AIR OXIDATION

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Manufacturer: _____ ☐ Wet Air ☐ Heat Treatment
2. Number of units(trains): _____ Number in service: _____
3. Type of sludge treated: ☐ Primary ☐ Secondary ☐ Chemical ☐ Mixed

   If mixed, what is the ratio by volume? _____
4. Design sludge flow (influent) per unit ____gpm.
5. Design reactor temperature _____°F
6. Design reactor pressure _____psig.
7. Design air feed_____scfm
8. Design influent solids concentration_____percent. Design solids loading_____lbs/hr per train.
9. Number of heat exchangers per train _____.
10. Material of construction:

    a. Heat exchangers: _____

    b. Reactors: _____
11. Describe decant treatment/handling: _____

    _____

    _____
12. Describe off-gas handling: _____

    _____

    _____
13. Describe decant and dewatering air treatment: _____

    _____

    _____

II. PROCESS INFORMATION

1. Describe the process control strategy: _____

_____

_____

_____

2. Describe process control monitoring, including points monitored, parameters and frequency: _____

_____

_____

_____

3. Influent sludge flow/unit _____ gpm Reactor temperature(s) _____ °F

   Reactor pressure(s): _____ psig Air feed rate _____ scfm

4. Influent sludge solids _____ % Influent volatile solids _____ %

5. Influent particle size (Max) _____ in

6. Influent chloride conc. _____ mg/l Influent corrosivity _____

7. Volume of sludge treated daily _____ gal Dry solids treated daily _____ lbs

8. Hours of operation per day _____ Hours of operation per week _____

9. Percent volatile solids in treated sludge _____.

10. Percent solids:

    a. Reactor effluent _____.

    b. Decanted sludge _____.

    c. Dewatered sludge _____.

    d. Decant _____.

11. Recycle liquor flow _____ gpd

12. Is odor a problem? _____ How often? _____

13. Are alarms provided for:

    a. Equipment failures ☐ Yes ☐ No

    b. High/low pressure ☐ Yes ☐ No

    c. High/low temperature ☐ Yes ☐ No

II. PROCESS INFORMATION (Continued)

14. Describe operational problems: _____

_____

_____

15. Are operating records adequate? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**
2. Is there adequate equipment redundancy? ☐ Yes ☐ No**
3. Is the spare parts inventory adequate? ☐ Yes ☐ No**
4. Is general housekeeping adequate? ☐ Yes ☐ No**
5. Has the availability of any train been less than 75%? Describe: _____

_____

_____

6. Frequency of acid washing: _____. Frequency of solvent washing: _____
7. Frequency of general inspections: _____
8. Frequency of scale inspections:
   a. Heat exchangers _____
   b. Reactors _____
   c. Piping _____
   d. Decant tank _____
9. Mass of scale removed manually per year _____ lbs
10. Frequency of pressure system check _____.
11. Has fitting, piping and elbow erosion been a problem? ☐ Yes ☐ No

    If yes,:
    a. Is plant grit removal adequate? _____
    b. Is plant screening adequate? _____
    c. Is plant sludge degritting provided? _____

III. MAINTENANCE INFORMATION (Continued)

12. Components out of service:

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

13. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

3. Ventilation: _____

_____

4. Chemical: _____

_____

5. Trip/fall: _____

_____

6. Confined space: _____

_____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

COMPARISON OF ACTUAL HEAT TREATMENT/WET AIR OXIDATION CONDITIONS TO DESIGN AND TYPICAL CONDITIONS

PARAMETER	ACTUAL	DESIGN	TYPICAL	40 CFR 257
Sludge Flow per Unit gpm				Sludge must be maintained at 180 degrees C. for 30 minutes.
Reactor Temperature (Far.) Heat Ttmt.			350-400	
Wet Air			400-700	
Detention Time (Min.) Heat Ttmt.			15-40	
Wet Air			40-60	
Reactor Pressure (psig) Heat Ttmt.			250-400	
Wet Air			500-1,500	
Air Feed lbs/10,000 BTU			7.5	
Influent Solids Percent			3.6	
Solids Loading lbs/hr train				
Decanted Sludge TSS Concentration mg/l			<1,000	
Dewatered Sludge TSS Concentration mg/l			30-50	

PERFORMANCE EVALUATION
INCINERATION

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. What type of incinerator is used?

   ☐ Multiple hearth (MH) ☐ Fluidized bed (FB)

   Other (specify) _____

2. Number of units _____ Number in operation _____

3. Incinerator dimensions:

   Height _____ ft Diameter _____ ft Area _____ ft^2

4. For MH: Number of hearths _____

5. Air blower capacity _____ scfm

6. Theoretical air requirements _____ scfm

7. Design sludge loading rate ($lbs/ft^2/hr$ or lbs/hr): avg _____ max _____

8. Type of auxiliary fuel used: _____

9. Type of air pollution control device: _____

10. Height of incinerator stack: _____

II. PROCESS INFORMATION

A. Describe the operating strategy: _____

_____

_____

_____

B. Sludge Feed	Monitoring Frequency
1. Thickened Sludge:	
Total Solids _____ %	
Volatile Solids _____ %	

II. PROCESS INFORMATION (Continued)

B. 2. Dewatered Sludge Cake:

		Monitoring Frequency
Total solids _____	%	
Volatile solids _____	%	

3. Thickened sludge feed rate to dewatering system: _____ gal/hr

How often is it monitored? _____

4. Average sludge loading rate to the incinerator: _____ lbs/ft^2/hr or lbs/hr

C. Incinerator

1. What is the operating period? _____ hr/day _____ days/week

2. Does the facility monitor and record the following:

	Monitoring Frequency
☐ Pressure drop across the air pollution control equipment	
☐ Oxygen concentration of exhaust gas	
☐ Operating temperature of every hearth in multiple hearth furnaces or the bed and freeboard temperature of fluidized bed incinerators	
☐ Fuel feed to the incinerator	

3. What are the incinerator operating temperatures?

a. Multiple Hearth

Upper hearths (drying) _____

Middle hearths (combustion) _____

Lower hearths (cooling) _____

Stack exhaust _____

b. Fluidized Bed

Preheated air _____

Bed _____

Freeboard _____

Stack exhaust _____

c. Is the combustion temperature relatively stable or does it fluctuate significantly?

_____

II. PROCESS INFORMATION (Continued)

C. 4. For FB incinerators: What are the pressure readings for the following:

Windbox _____ inches of water

Bed _____ inches of water

Freeboard _____ inches of water

5. If available, provide the following exhaust gas information:

Concentration of CO_2: _____ %

Concentration of CO: _____ %

Concentration of O_2: _____ %

Concentration of N_2: _____ %

6. What is the average combustion efficiency? _____ %

7. What is the actual air feed rate? _____ scfm

8. What is the percentage of excess air to the incinerator? _____ %

9. What is the auxiliary fuel feed rate? _____ gal/hr _____ gal/ton solids incinerated

10. How often and in what quantities is scum incinerated? _____

D. Air Pollution Control

1. Is the facility subject to NSPS requirements? ☐ Yes ☐ No

2. Is the facility subject to mercury monitoring requirements? (emits more than 160 grams mercury per day) ☐ Yes ☐ No

3. Is the facility subject to beryllium monitoring? ☐ Yes ☐ No

4. Is the facility subject to PCB monitoring? ☐ Yes ☐ No

5. Is the facility in compliance with its air emission standards? ☐ Yes ☐ No

6. If no, list parameters not in compliance:

Parameter	Emission Rate	Date

II. PROCESS INFORMATION (Continued)

D. 7. What is the pressure drop across the air pollution control device? _____ inches of water

8. What is the average rate of particulate emissions? _____ lbs/tons solids incinerated

9. Obtain copy of last emissions performance test results and attach to this report.

E. Ash Management

1. How much ask is produced? _____

2. Is the ash handled ☐ wet or ☐ dry?

3. How is the ash stored prior to disposal? _____

_____

_____

4. How is the ash disposed? _____

_____

_____

5. Is this disposal method in accordance with 40 CFR 257 or 261-268? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**

2. Is there adequate equipment redundancy? ☐ Yes ☐ No**

3. Is the spare parts inventory adequate? ☐ Yes ☐ No**

4. Is housekeeping adequate? ☐ Yes ☐ No**

5. How often and in what quantities is sand replaced in the FB incinerator?

_____

6. What is the frequency of calibration of all temperature and pressure sensors? _____

7. How often are the freeboard water spray nozzles replaced in the FB incinerator? _____

8. How often is the incinerator shutdown and the interior inspected? _____

9. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

10. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

3. Ventilation: _____

_____

4. Chemical: _____

_____

5. Trip/fall: _____

_____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
COMPOSTING

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Composting method (check one): ☐ In-Vessel ☐ Windrow ☐ Aerated Static Pile

2. Type of sludge composted:

   ☐ Primary Sludge ☐ Septage ☐ Secondary Sludge ☐ Combined Sludge

   If combined sludge, what is the ratio by volume? _____

3. Composting capacity: ____ dry tons solids/day at ____ % total solids

4. Pile or in-vessel dimensions: _____

5. Bulking agent used: _____

6. Sludge to bulking agent mix ratio: _____

7. Composting period: Active phase _____ days Curing phase _____ days

8. Is finished compost screened: ☐ Yes ☐ No

   If yes, what type of screen is used: _____

9. Expected finished compost characteristics

   Production rate: _____ yd^3/dry ton sludge moisture content: _____ %

   Volatile solids content: _____ %

10. Number of air blowers: _____

11. Total blower capacity: _____ scfm

12. Method of mixing windrow or in-vessel contents: _____

    _____

13. Ancillary equipment (loaders, dump trucks, etc.):

Type	Quantity

I. DESIGN INFORMATION (Continued)

14. Type of odor control system: _____

II. PROCESS INFORMATION

1. Describe operational strategy: _____

2. Dewatered sludge cake characteristics:

		Monitoring Frequency
Total solids content: _____	%	
Volatile solids content: _____	%	
Moisture content: _____	%	

3. Sludge processing rate: _____ dry tons solids/day

4. Sludge to bulking agent mix ratio: _____

5. Is the pile uniformly mixed: ☐ Yes ☐ No**

6. Actual composting period Active phase _____ days Curing phase _____ days

7. Describe the monitoring locations for temperature: _____

8. Average active phase temperature: _____ °C

9. Is the temperature uniform throughout the compost mixture: ☐ Yes ☐ No

10. Is the mixture maintained at a minimum of 40°C for five days and at a temperature exceeding 55°C for four hours to meet the PSRP requirements of 40 CFR Part 257? ☐ Yes ☐ No**

11. For Static Aerated Pile and In-vessel operations is the mixture maintained at a minimum of 55°C for three days to meet the PFRP requirements of 40 CFR Part 257? ☐ Yes ☐ No**

12. For Windrow operations is the mixture maintained at a minimum of 55°C for fifteen days and the pile turned at least five times to meet the PFRP requirements of 40 CFR Part 257? ☐ Yes ☐ No**

13. Describe the monitoring locations for oxygen: _____

II. PROCESS INFORMATION (Continued)

14. Average active phase oxygen level: _____ %

15. Is the oxygen content uniformly distributed throughout the compost mixture: ☐ Yes ☐ No

16. How often are the windrow piles turned and what is the determining factor for turning the piles?

_____

17. Static Aerated Pile or In-vessel Methods

    a. Are the blower run times adjusted during the active phase? ☐ Yes ☐ No

    b. If the blower run times are adjusted, what is the controlling factor? _____

    c. Aeration type: _____ Forced-pressure _____ Vacuum-induced

    d. Is the odor control system in use? ☐ Yes ☐ No ☐ NA

    e. Has the system experienced freezing of blower or air lines during cold weather periods? ☐ Yes ☐ No

18. Are there odor problems: ☐ Yes ☐ No

    If yes, provide source(s): _____

19. Is there an insect or rodent problem at the site? ☐ Yes ☐ No

20. Is runoff from the site collected? ☐ Yes ☐ No

    If yes, How is it treated? _____

21. Finished compost characteristics

    Production rate: _____ yd^3/dry ton sludge

    Moisture content: _____ %

    Volatile solids content: _____ %

22. How is finished product stored on site? _____

    _____

23. How much finished product is currently on-site? _____ yd^3

24. Describe how the finished product is distributed: _____

    _____

II. PROCESS INFORMATION (Continued)

25. What is the monitoring frequency of:

    a. Feed sludge quality and quantity: _____

    b. Finished product quality: _____

    c. Temperature and oxygen levels in compost mixture: _____

    d. Blower run times: _____

26. Is there a written standard operating procedure (SOP)? ☐ Yes ☐ No

    If yes, attach a copy to this report.

27. Are adequate operating records maintained? ☐ Yes ☐ No**

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**
2. Is there adequate equipment redundancy? ☐ Yes ☐ No**
3. Is the spare parts inventory adequate? ☐ Yes ☐ No**
4. Is housekeeping adequate? ☐ Yes ☐ No**
5. What is the frequency of calibration of the temperature and oxygen probes? _____
6. Static air piles: How often are the air distribution lines cleaned to ensure uniform air flow? _____
7. Components out of service

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)

8. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

   _____

2. Electrical: _____

   _____

IV. SAFETY CONSIDERATIONS

3. **Ventilation:** _____

4. **Chemical:** _____

5. **Trip/fall:** _____

6. **Airborne Pathogens (Aspergillus):** _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

COMPARISON OF ACTUAL COMPOSTING CONDITIONS TO DESIGN AND TYPICAL CONDITIONS

PARAMETER	ACTUAL	DESIGN	TYPICAL
Moisture Content of Influent Sludge (%)			50-60
Temperature of Compost Pile (°F)			120-150
Oxygen Level within Compost Pile (%)			5-15

NOTE: As per 40 CFR 257:

PSRP requires that the sludge must be maintained at 104°F for five days, must exceed 131°F for at least four hours.

PFRP requires that for Within Vessel and Forced Air Static piles, the temperature must be at least 131°F for 3 days. Windrow piles must maintain a temperature of 131°F or more for at least 15 days and during this period the windrow must be turned a minimum of 5 times.

PERFORMANCE EVALUATION
CHEMICAL STABILIZATION/CONDITIONING

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. What type of sludge is being conditioned (primary, waste activated, combined) _____?
2. What is the design rate of the conditioning system _____ gal/day?
3. Chemical(s) used for conditioning:

   _____ purchased (dry) (as liquid)

   _____ purchased (dry) (as liquid)

   _____ purchased (dry) (as liquid)
4. Chemical storage inventory _____ days?
5. Is chemical feed system ☐ manual ☐ automatic?
6. If dry feeders used, are they ☐ volumetric or ☐ gravimetric?
7. Are feeders automatically paced? ☐ Yes ☐ No

   Paced to: ☐ Flow ☐ pH ☐ Sludge concentration

II. PROCESS INFORMATION

1. Describe operational strategy: _____

   _____

   _____

   _____
2. Conditioning chemical concentration as fed to sludge?

   _____ (mg/l)(lbs/gal)(%)

   _____ (mg/l)(lbs/gal)(%)

   _____ (mg/l)(lbs/gal)(%)
3. Current chemical dosage rates?

   _____ (lbs/dry ton solids)

   _____ (lbs/dry ton solids)

   _____ (lbs/dry ton solids)

II. PROCESS INFORMATION (Continued)

4. Dosages based on: ☐ Jar tests ☐ Operating experience ☐ Other _____

5. Conditioning tank mixing? ☐ insufficient ☐ adequate ☐ excessive

6. Visual observations of conditioning tank sample: _____

_____

_____

7. Describe the operating strategy: _____

_____

_____

8. Are adequate operating records maintained? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**

2. Is there adequate equipment redundancy? ☐ Yes ☐ No**

3. Is the spare parts inventory adequate? ☐ Yes ☐ No**

4. Housekeeping adequate? ☐ Yes ☐ No**

5. Are adequate calibrations done and records maintained? (pH meters, flow meters, scales, etc.) ☐ Yes ☐ No**

6. Visual evidence of excessive dust in the area? ☐ Yes** ☐ No

7. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

8. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

IV. SAFETY CONSIDERATIONS (Continued)

2. Electrical: _____

3. Ventilation: _____

4. Chemical: _____

5. Trip/slip/fall: _____

6. Confined space: _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

COMPARISON OF ACTUAL CHEMICAL STABILIZATION/CONDITIONING CONDITIONS TO DESIGN AND TYPICAL CONDITIONS

PARAMETER	ACTUAL	DESIGN	TYPICAL
CHEMICAL FEED RATE lb/dry ton solids			
A. Ferric chloride			
a. Ray Primary Sludge + WAS			40-80
b. Digested Primary Sludge + WAS			80-100
c. Elutriated Primary + WAS			40-125
B. Lime			
a. Raw Primary Sludge + WAS			110-300
b. Digested Primary Sludge + WAS			160-370
c. Elutriated Primary + WAS			---
C. Polymer			
a. Raw Primary Sludge + WAS			15-20
b. Digested Primary Sludge + WAS			30-40
c. Elutriated Primary + WAS			20-30

NOTE: As per 40 CFR 257:

Chemical Stabilization processes must produce a pH of 12 after 2 hours of chemical contact.

PERFORMANCE EVALUATION
VACUUM FILTER

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Manufacturer: _____
2. Number of units: _____ Number in service: _____
3. Media: ☐ Cloth ☐ Coil springs
4. Design loading _____ lbs(dry)/sq ft/hr/unit Design vacuum: _____ inches Hg
5. Effective area/unit _____ sq ft Gross design load unit _____ lbs(dry)/hr
6. Type of sludge treated: ☐ Primary ☐ Secondary ☐ Chemical ☐ Mixed

   If mixed, what is ratio by volume? _____
7. Design influent solids concentration _____ %
8. Design drum speed(range) _____ rpm. Percent submergence (range) _____
9. Location of filtrate return in plant: _____
10. Sludge pumping: ☐ automatic ☐ manual
11. Chemical conditioning used: _____
12. Chemical feed: ☐ automatic ☐ manual
13. Adequate alarms provided? ☐ Yes ☐ No

II. PROCESS INFORMATION

1. Describe operational strategy: _____

   _____

   _____

   _____
2. Describe process control monitoring, including points monitored, parameters and frequency: _____

   _____

   _____

   _____

II. PROCESS INFORMATION (Continued)

3. Influent sludge flow/unit _____ gpm Influent sludge solids _____ %

4. Solids loading _____ lbs(dry)/sq ft/hr per unit.

5. Percent solids in cake: _____. Yield _____ lbs(dry)/sq ft/hr per unit

6. Vacuum: _____ inches Hg

7. Efficiency of solids capture _____ %

8. Hours of operation per day _____. Hours of operation per week _____.

9. Frequency of pump operation _____ min/hr

10. Percent solids:

    a. Cake _____

    b. Filtrate(TSS) _____

11. Filtrate flow _____ gpd

12. Does cake separate freely? ☐ Yes ☐ No

13. Does the media blind? ☐ Yes ☐ No

14. Describe operational problems: _____

    _____

    _____

15. Are operating records adequate? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**

2. Is there adequate equipment redundancy? ☐ Yes ☐ No**

3. Is the spare parts inventory adequate? ☐ Yes ☐ No**

4. Is general housekeeping adequate? ☐ Yes ☐ No**

5. Has the availability of any unit been less than 75%? Describe: _____

    _____

6. Frequency of general inspections:

    a. Vacuum system: _____ / ____

    b. Chemical feed system: _____ / ____

III. MAINTENANCE INFORMATION (Continued)

c. Media: _____ / _____

d. Pumps: _____ / _____

e. Cake conveyor: _____ / _____

7. Has fitting, piping and elbow erosion been a problem? ☐ Yes ☐ No

If yes,:

a. Is plant grit removal adequate? _____

b. Is plant screening adequate? _____

c. Is plant sludge degritting provided? _____

8. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

9. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

2. Electrical: _____

3. Ventilation: _____

4. Chemical: _____

5. Trip/fall: _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
FILTER PRESS

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Number of units _____ In operation _____
2. What is the filter process volume? _____ ft^3
3. Is sludge pumping ☐ Manual ☐ Automatic?
4. Design sludge feed rate: _____ gal/day
5. Design feed solids: _____ %

II. PROCESS INFORMATION

1. Describe operational strategy: _____
2. What is the average volume of influent sludge flow? _____ gal/day
3. What is the influent sludge percent solids? _____ %
4. Operating period: _____ days/week _____ hrs/day
5. What is the concentration of solids in the sludge cake? _____ %
6. What is the TSS concentration of the filtrate? _____ mg/l
7. Are chemical conditioners used? ☐ Yes ☐ No
   If Yes, what type of chemicals are used? _____
   (refer to Section on Stabilization/Chemical Conditioning)
8. Is chemical feed ☐ manual ☐ automatic?
9. Are the filter plates clean and free of pinholes? ☐ Yes ☐ No
10. Does the monitoring program meet the operations and maintenance manual recommendations? ☐ Yes ☐ No
11. Are operating records adequate? ☐ Yes ☐ No
12. Are the filter plates precoated? ☐ Yes ☐ No
    If yes, with what? _____

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**
2. Is there adequate equipment redundancy? ☐ Yes ☐ No
3. Is the spare parts inventory adequate? ☐ Yes ☐ No
4. Housekeeping adequate? ☐ Yes ☐ No**
5. Components out of service

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)
6. How often is the media cleaned? _____
7. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

   _____
2. Electrical: _____

   _____
3. Ventilation: _____

   _____
4. Chemical: _____

   _____
5. Trip/slip/fall: _____

   _____
6. Confined space: _____

   _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
BELT FILTER PRESS

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Number of units _____ In operation _____
2. Mode of operation: ☐ Batch ☐ Semi-Batch ☐ Continuous
3. Operating period: _____ hours/day _____ days/week
4. What type of sludge is being processed ☐ Primary sludge ☐ Secondary sludge ☐ Combined sludge

   If combined sludge, what is the ratio by volume? _____
5. What is the design sludge feed rate _____ gal/day _____ lbs/hr
6. What is the design feed solids concentrations? _____ % solids
7. What is the belt width? _____ (ft) (meters)
8. Polymer feed system? ☐ Liquid ☐ Dry ☐ Both
9. Where can polymer be added? _____
10. Wash water makeup: ☐ Plant effluent ☐ Recycled ☐ Potable water

II. PROCESS INFORMATION

1. What is the current sludge application rate? _____ gal/day or _____ lbs/hr
2. Influent sludge solids content? _____ % solids (average) _____ % solids (maximum)
3. Belt speed? _____ ft/second
4. Polymer dosage? _____ gpm _____ lbs/ton
5. Dosage based on: ☐ Jar tests ☐ Operating experience ☐ Other _____
6. Dewatered sludge solids contents? _____ % solids (average) _____ % solids (maximum)
7. Filtrate flow rate? _____ gpm
8. Filtrate TSS content? _____ mg/l
9. Where is filtrate returned to plants? _____
10. Solids recovery? _____ %
11. Are there odor problems? ☐ Yes** ☐ No

II. PROCESS INFORMATION (Continued)

12. Is an odor control system installed? ☐ Yes ☐ No

13. Odor control chemicals used? _____

_____

14. Describe the operating strategy: _____

_____

_____

15. Are adequate operating records maintained? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**
2. Is there adequate equipment redundancy? ☐ Yes ☐ No**
3. Is the spare parts inventory adequate? ☐ Yes ☐ No**
4. Housekeeping adequate? ☐ Yes ☐ No**
5. Does belt show evidence of wear? ☐ Yes** ☐ No
6. Belt tension properly adjusted? ☐ Yes ☐ No**
7. Components out of service

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)
8. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

IV. SAFETY CONSIDERATIONS (Continued)

3. Ventilation: _____

4. Chemical: _____

5. Trip/slip/fall: _____

6. Confined space: _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
SLUDGE DRYING BEDS

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Type of drying bed ☐ Sand ☐ Wedge-wire ☐ Paved ☐ Vacuum
2. Are the beds ☐ Enclosed ☐ Covered ☐ Open?
3. Type of sludge applied: ☐ Primary ☐ Secondary ☐ Combined

   If combined, what is the ratio by volume? _____
4. Sludge application rate: _____ gal/day
5. Number of separate drying bed compartments: _____
6. Total surface area: _____ ft^2
7. Population served by the treatment plant: _____
8. Drying area provided: _____ ft^2
9. Do the beds have an underdrain system? ☐ Yes ☐ No

II. PROCESS INFORMATION

1. Describe operational strategy: _____

   _____

   _____

   _____
2. Is the sludge digested before application? ☐ Yes ☐ No
3. Average sludge application rate: _____ gal/day
4. Solids loading rate: _____ gal/day
5. Typical drying time: _____ days
6. Average percent solids in the sludge cake: _____ %
7. Sludge removed ☐ Manually ☐ Mechanically?
8. Typical average sand depth in sand drying beds: _____ in

II. PROCESS INFORMATION (Continued)

9. Where does the drainage return to? _____

10. What is the average TSS of the drainage water returning to the plant? _____

11. Are there splash plates or diffusion devices in place when sludge is being applied to the beds? ☐ Yes ☐ No

12. What is the average depth that sludge is applied to the drying beds? _____ in

13. Are odors a problem? ☐ Yes ☐ No

14. Are flies a problem? ☐ Yes ☐ No

15. Is record keeping adequate? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Do plant personnel rake and level the sand beds after sludge is removed? ☐ Yes ☐ No

2. Are sand beds maintained to a depth of at least 4 in. of sand? ☐ Yes ☐ No

3. Is there excessive vegetation growing on the drying beds? ☐ Yes ☐ No

4. Is there any leakage of sludge from one compartment to another? ☐ Yes ☐ No**

5. Are sludge lines flushed out to prevent freezing in cold weather? ☐ Yes ☐ No

6. Is there an adequate preventative maintenance program? ☐ Yes ☐ No

7. Is there adequate equipment redundancy? ☐ Yes ☐ No**

8. Is the spare parts inventory adequate? ☐ Yes ☐ No**

9. Housekeeping adequate? ☐ Yes ☐ No**

10. Are adequate calibrations done and records maintained? (pH meters, flow meters, scales, etc.) ☐ Yes ☐ No**

11. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

12. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

2. Electrical: _____

3. Ventilation: _____

4. Chemical: _____

5. Trip/fall: _____

6. Confined space: _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
SLUDGE DRYING LAGOONS

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Number of lagoons: _____
2. Total volume of lagoons: _____ gal
3. Total lagoon surface area: _____ ft^2
4. Sludge application rate: _____ gal/day
5. Type of sludge applied to the lagoon: ☐ Primary ☐ Secondary ☐ Combined

   If combined, what is the ratio by volume? _____
6. Total population served by treatment plant: _____

II. PROCESS INFORMATION

1. Describe operational strategy: _____

   _____

   _____

   _____
2. Is the sludge digested before application? ☐ Yes ☐ No
3. Average sludge application rate: _____ gal/day
4. Solids loading rate: _____ gal/day
5. Typical drying time: _____ days
6. Solids concentration in dried sludge: _____ %
7. Are the lagoons rested after sludge removal? ☐ Yes ☐ No

   If yes, for how long? _____
8. Is there a provision to draw off supernatant or precipitation? ☐ Yes ☐ No

   Where does the supernatant go? _____
9. Are there any odor problems? ☐ Yes ☐ No

II. PROCESS INFORMATION (Continued)

10. Are there any insect problems? ☐ Yes ☐ No

11. What is the average depth that sludge is applied to in the lagoon? _____ in

12. Are records adequate? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there excessive weed growth on the lagoons? ☐ Yes ☐ No

2. Are all of the partitions in all of the dikes in good repair to prevent sludge leaking from the lagoon? ☐ Yes ☐ No

3. Are the sludge feed lines flushed to prevent freezing in cold weather? ☐ Yes ☐ No

4. Is there an adequate preventive maintenance program? ☐ Yes ☐ No**

5. Is there adequate equipment redundancy? ☐ Yes ☐ No**

6. Is the spare parts inventory adequate? ☐ Yes ☐ No**

7. Housekeeping adequate? ☐ Yes ☐ No**

8. Are adequate calibrations done and records maintained? (pH meters, flow meters, scales, etc.) ☐ Yes ☐ No

9. Components out of service

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)

   _____ Out of service _____ days in _____(year)

10. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

2. Electrical: _____

3. Ventilation: _____

IV. SAFETY CONSIDERATIONS

4. **Chemical:** _____

5. **Trip/fall:** _____

6. **Confined space:** _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
HEATING DRYING

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Manufacturer: _____

2. Number of units: _____ Number in service: _____

3. Type unit(s): ☐ Rotary ☐ Flash ☐ Spray ☐ Carver-Greenfield ☐ Other

4. Design loading _____ lbs(dry & wet)/hr/unit

5. Type of sludge treated: ☐ Primary ☐ Secondary ☐ Chemical ☐ Mixed

   If mixed, what is the ratio by volume? _____

6. Design wet cake moisture content _____ % Design dry cake moisture content _____ %

7. Dewatering technology in use: _____

8. Sludge finishing: ☐ Classified ☐ Pelletized ☐ Granulated

9. Air pollution control used: _____

10. Parameters limited(air) and limits: _____

    _____

11. Does air pollution equipment generate liquid sidestreams?

    Describe: _____

    How handled?: _____

    Where directed to?: _____

12. Type of air flow: ☐ Concurrent ☐ Countercurrent ☐ Crosscurrent

    Design air velocities: _____ fpm

    Design gas temperature: _____ °F

13. Is wet cake mixed with dry cake? ☐ Yes ☐ No

    If so, design mix ratio: _____

14. Is wet cake ground?: _____

I. DESIGN INFORMATION (Continued)

15. Capacity of:

    a. Wet cake storage: _____ tons/cu yds

    b. Dry cake storage: _____ tons/cu yds

    Is dry storage provided? ☐ Yes ☐ No

16. Adequate alarms provided? ☐ Yes ☐ No

II. PROCESS INFORMATION

1. Describe operational strategy: _____

2. Describe process control monitoring, including points monitored, parameters and frequency: _____

3. Wet cake moisture _____ %. Dry cake moisture _____ %. Moisture of mixed sludge (if mixing is practiced): _____ %.

4. Solids loading _____ lbs(dry and wet)/hr per unit

5. Yield _____ lbs(dry & "wet")/hr per unit

6. Hours of operation per day _____. Hours of operation per week _____.

7. Outlet gas temperature: _____ °F. In-vessel gas temperature: _____ °F.

   Air flow rate _____ scfm

8. Problems with wet and/or dry cake handling; describe: _____

9. Problems with dry cake; dust,odors,contamination,etc.; describe: _____

10. Problems with "clinkers" in dry sludge? ☐ Yes ☐ No

II. PROCESS INFORMATION (Continued)

11. Compliance with air permits; describe: _____

12. Describe operational problems: _____

13. Are operating records adequate? ☐ Yes ☐ No

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No
2. Is there adequate equipment redundancy? ☐ Yes ☐ No
3. Is the spare parts inventory adequate? ☐ Yes ☐ No
4. Is general housekeeping adequate? ☐ Yes ☐ No
5. Has the availability of any unit been less than 75%? Describe: _____
6. Frequency of general inspections:
   a. Conveyor/pneumatic systems: _____ / _____
   b. Mixing system: _____ / _____
   c. Air heating systems: _____ / _____
   d. Air pollution control systems: _____ / _____
7. Has abrasion/corrosion-related wear of equipment been a problem; if so, describe: _____
8. In spray systems; has nozzle wear or clogging posed problems; if so describe: _____

III. MAINTENANCE INFORMATION (Continued)

9. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

10. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

** Please elaborate in V. OTHER OBSERVATIONS

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

3. Ventilation: _____

_____

4. Chemical: _____

_____

5. Trip/fall: _____

_____

6. Confined space: _____

_____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

PERFORMANCE EVALUATION
BETA OR GAMMA IRRADIATION

Facility Name:	NPDES Permit:
Contact Name:	Telephone:
Inspector Name:	Date:

I. DESIGN INFORMATION

1. Number of units _____ In operation _____
2. Type of sludge: ☐ Primary ☐ Secondary ☐ Combined

   If combined, what is ratio by voluem? _____
3. Mode of operation: ☐ Batch ☐ Continuous
4. Dosage _____
5. Steel-lined concrete vault for radiation source (gamma)? ☐ Yes ☐ No
6. Steel-lined source handling pool (gamma)? ☐ Yes ☐ No
7. Radiation alarm (gamma)? ☐ Yes ☐ No
8. Fire suppression system (gamma radiation unit for compost)? ☐ Yes ☐ No

II. PROCESS INFORMATION

1. Describe operational strategy: _____

   _____

   _____

   _____
2. Sludge flow rate (for beta ray radiation unit): _____ gal/hr
3. Influent sludge temperature (for beta ray radiation unit): _____ °C
4. Effluent sludge temperature (for beta ray radiation unit): _____ °C
5. Dosage: _____
6. Conveyor speed (gamma radiation unit for compost): _____ ft/sec
7. Detention time (batch-type gamma radiation unit: _____ min
8. Influent pathogen concentration: _____ mg/l
9. Effluent pathogen concentration: _____ mg/l
10. Frequency and duration of operation: _____ days/week _____/shift

II. PROCESS INFORMATION (Continued)

11. How frequent is operation inspected? _____ hrs/day

12. Sludge pumping: ☐ Manual ☐ Automatic

13. How often do the sludge pumps run? _____ min/hr

14. If multiple units are used, is the flow distributed evenly? ☐ Yes ☐ No

15. Is the process control monitoring program adequate for the O&M manual recommendations? ☐ Yes ☐ No

16. Are operating records adequate? ☐ Yes ☐ No

17. Visual observations of the process: _____

_____

III. MAINTENANCE INFORMATION

1. Is there an adequate preventative maintenance program? ☐ Yes ☐ No**

2. Is there adequate equipment redundancy? ☐ Yes ☐ No**

3. Is the spare parts inventory adequate? ☐ Yes ☐ No**

4. Housekeeping adequate? ☐ Yes ☐ No**

5. Are adequate calibrations done and records maintained? (pH meters, flow meters, scales, etc.) ☐ Yes ☐ No**

6. Components out of service

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

_____ Out of service _____ days in _____(year)

7. What is the current mechanical condition of the unit? ☐ Good ☐ Poor**

IV. SAFETY CONSIDERATIONS

Hazards noted (describe):

1. Moving equipment: _____

_____

2. Electrical: _____

_____

IV. SAFETY CONSIDERATIONS (Continued)

3. Ventilation: _____

4. Chemical: _____

5. Trip/fall: _____

6. Confined space: _____

V. OTHER OBSERVATIONS

VI. PROCESS SCHEMATIC

(Sketch or replace with plant schematic)

APPENDIX B

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BIBLIOGRAPHY

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