United States Environmental Protection Agency | Water Engineering Research Laboratory Cincinnati OH 45268 | Office of Municipal Pollution Control Washington DC 20460

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EPA

# Design Information Report

## Centrifuges

***The U.S. Environmental Protection Agency has undertaken a program to help municipalities and engineers avoid problems in wastewater treatment facility design and operation. A series of Design Information Reports is being produced that identifies frequently occurring process design and operational problems and describes remedial measures and design approaches used to solve these problems. The intent is not to establish new design practices, but to concisely document improved design and operational procedures that have been developed and successfully demonstrated in field experiences.***

***With an increased emphasis being placed on environmental concerns associated with the disposal of sludges from wastewater treatment facilities, there has been a growing awareness of the need for improved efficiency and reliability in the performance of in-plant sludge treatment processes. Because of advances in centrifuge technology that have improved their efficiency and reliability, centrifuges are now a frequently considered alternative for the thickening and dewatering of wastewater treatment sludges.***

## Introduction

Centrifuges, recognized as potential machines for dewatering sludges as early as 1902 in Germany, were introduced to the United States during the 1920s and 1930s, but were subsequently abandoned when it was found that they required excessive operation and maintenance attention. In the 1960s, manufacturers began to design centrifuges specifically for wastewater sludge applications. In addition, sludge thickening and dewatering processes were improved with the introduction of polyelectrolytes for chemical sludge conditioning.

This report contains a brief description of the major components and operational principles of solid bowl, imperforate basket, and disc-nozzle centrifuges, followed by a discussion of centrifuge application to sludge thickening and dewatering. Common problems experienced at centrifuge installations are identified, including causes of problems, significant cost and plant performance impacts, and appropriate remedial measures. Finally, the relative advantages and disadvantages of each centrifuge and recommended approaches for design and operation are summarized.

## Description of Centrifuges

All centrifuges operate on the principle of centrifugal force created by the angular velocity of a rotating device. The resulting centrifugal acceleration is measured with respect to the acceleration of gravity (commonly referred to as "G"). When sludge is subjected to these centrifugal forces, particles will separate according to their specific gravity. Solids, being the heaviest sludge constituent, are forced to the periphery, and liquid, or centrate, remains nearer the axis of rotation.

Two of the three centrifuge types, solid bowl and imperforate basket, have applications to thicken or dewater various types of sludge, whereas disc-nozzle centrifuges are only applicable to waste activated sludge thickening.

### *Solid Bowl Centrifuge*

The solid bowl centrifuge consists of eight major components: base, cover, bowl, scroll, feed pipe, main bearings, gear unit, and backdrive. Revolving around a horizontal axis of rotation, the bowl and scroll make up the rotating assembly. The scroll rotates at a higher or lower speed than the bowl, known as the differential speed, reported to range from 5 to 80 revolutions per minute (rpm). A planetary or cyclo-gear-type gear unit works with a mechanical, hydraulic, or electrical backdrive assembly to produce the bowl/scroll differential speed.

Bowl design is generally in a compound cylindrical and conical shape, the relative proportions of which vary by manufacturer and specific application. Typical bowl length-to-diameter ratios vary from 2.5:1 to 4:1 (2). The scroll is a helical screw conveyor, fitted concentrically into the bowl. Both the bowl and the scroll are typically constructed of carbon steel or 300 series stainless steel. The outer edge of the scroll is constructed of replaceable abrasion-resistant tiles manufactured of ceramic, tungsten carbide, or another type of hard facing (2,4,7). Sludge feed slurry enters the centrifuge through a feed pipe in the central core of the scroll. Feed nozzles, projecting through the scroll, deliver sludge into the bowl.

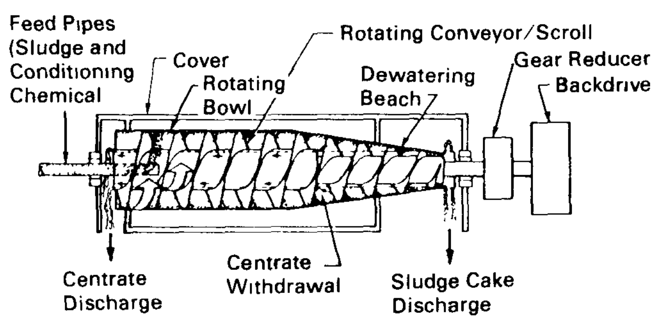
The centrifuge base provides a structure on which to mount and support the rotating assembly. Vibration isolators are installed between the base and its foundation, typically consisting of multiple springs designed to dampen the vibration produced by the centrifuge. A case serves as a guard and complete enclosure of the rotating assembly, thereby reducing noise levels and often directing solid and liquid discharge flow. Main bearings guide the bowl and scroll rotation and require a constant lubrication system. Most installations use a water cooling system to maintain safe bearing temperatures (2,9).

Solid bowl centrifuges are available in a variety of sizes. The largest units available for municipal sludge applications are 25 feet in length including the rotating assembly and backdrive and 14 feet in width including the rotating assembly and adjacent motor. The throughput capacity of these units vary with application. Feed rates of 100 to 200 gallons per minute (gpm) for dewatering and 400 to 600 gpm for thickening can be achieved for most municipal sludges. Two configurations for the solid bowl centrifuge, concurrent and countercurrent, are shown in Figure 1(a) and 1(b). These two types vary in their method of sludge feed and discharge. The concurrent configuration introduces sludge feed into the rotating assembly through the cylindrical end of the bowl. The orientation of the scroll helix draws settled solids in the direction of sludge feed toward the conical "beach section" and sludge discharge. The countercurrent configuration delivers sludge feed through the conical end of the bowl, and the scroll is oriented to draw solids against the direction of sludge feed toward the beach and sludge discharge.

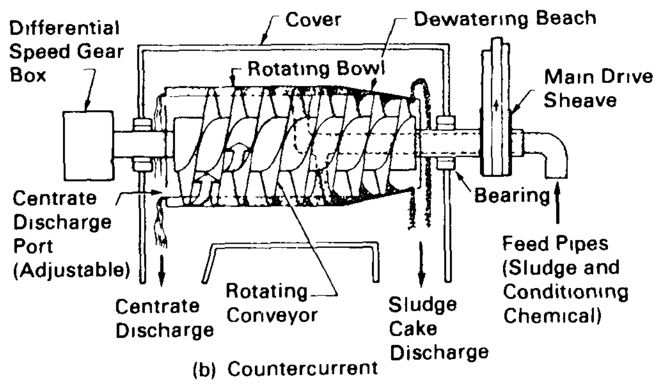
Two philosophies are upheld regarding the speed of rotation of solid bowl centrifuges. Low-speed centrifuges operate at gravitational forces below 1,100 G, whereas high-speed centrifuges operate above 1,100 G (16). Proponents of low-speed centrifuges argue that operating at lower speed results in less energy consumption, less noise, and lower maintenance costs (5). High-speed centrifuge proponents suggest that operating at higher speed increases performance, increases capacity, and reduces the need for polymer conditioning. The introduction of improved wear-resistant construction materials for rotating assemblies has reduced the maintenance costs associated with high speed centrifuges. Thus, high speed centrifuges have increased in popularity for municipal sludge thickening and dewatering.

Basic operation of the continuous feed, solid bowl centrifuge consists of introducing sludge into the rotating assembly. Centrifugal forces cause the liquid portion to form a ring-shaped pool about the axis of rotation. Pool depth is controlled by a circular weir plate located at the cylindrical end of the bowl, and clarified liquid, or centrate, is discharged by overflowing the weir plate. The differential speed creates a net rotation of the scroll within the bowl. This causes solid particles, settled along the inner wall of the bowl, to be dragged in the direction of the scroll helix orientation toward the conical "beach" section of the bowl. As solids are drawn up the beach, they emerge from the liquid pool and drain off a portion of free water before being discharged.

**Figure 1. Solid bowl centrifuge schematic.**




(a) Concurrent




(b) Countercurrent

Note Centrifuge Bases are Not Shown

Source 15

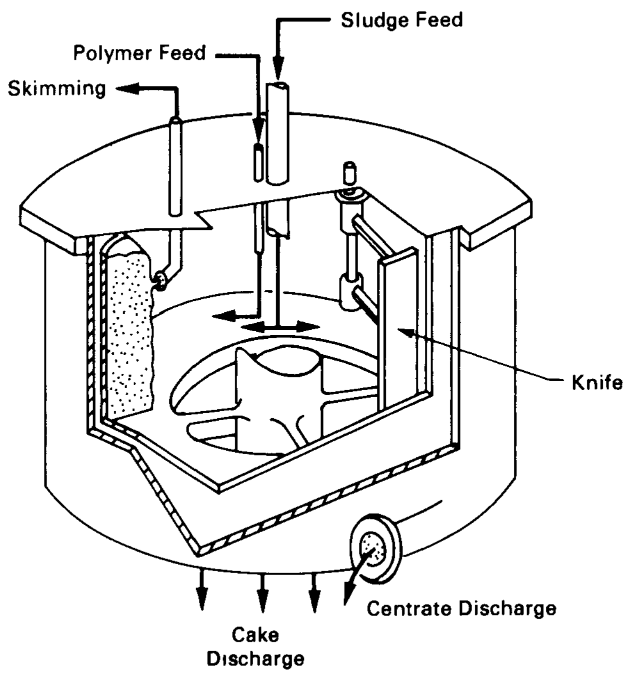
### *Imperforate Basket Centrifuge*

The imperforate basket centrifuge is composed of a cylindrical basket rotating about a vertical axis. Figure 2 shows a simplified schematic of the top fed, bottom driven basket centrifuge, illustrating the general location of sludge and polymer feed pipes, centrate discharge, skimmer, knife, and cake discharge (15). Basket centrifuges are typically constructed of stainless steel to inhibit corrosion and wear of wetted parts. The largest units are approximately four feet in diameter and are capable of achieving rotational velocities of up to 1,400 rpm, creating centrifugal accelerations of 1,300 G. These units have an average throughput capacity of 60 gpm.

The imperforate basket centrifuge process cycle includes acceleration, sludge feed, skimming, deceleration, and unloading, followed by acceleration to begin another cycle (6). Cycle times range from 15 to 30 minutes, during which sludge feed is discontinued for up to three minutes for skimming and unloading operations (9). When polymer sludge conditioning is used, polymer is added directly to the basket.

Near the end of the cycle, sludge feed is discontinued, triggering activation of the skimmer and deceleration of the basket. The skimmer will remove the remaining clarified liquid. Once the basket has decelerated to the unloading speed (70 to 100 rpm), a knife will slowly move horizontally toward the basket wall, scraping off solids that subsequently drop through the cake discharge at the bottom of the basket (15). Upon completion of cake removal, the skimmer and knife retract, allowing the basket to accelerate and begin a new cycle.

**Figure 2. Imperforate basket centrifuge schematic.**



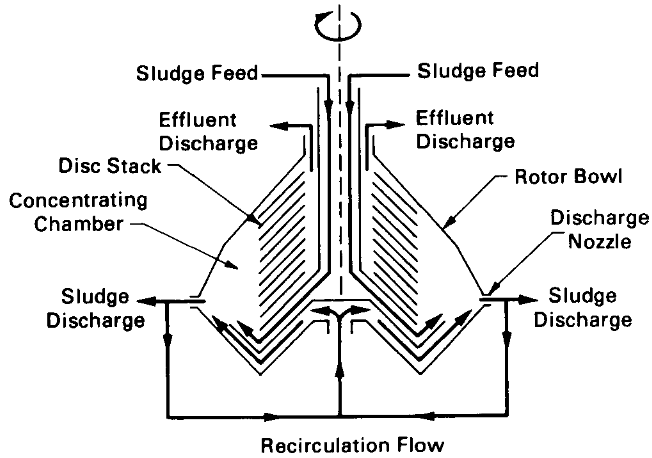

Source: 15

### *Disc-Nozzle Centrifuge*

The disc-nozzle centrifuge rotating mechanism is comprised of several conical-shaped discs stacked one upon another, enclosed within a rotor bowl that rotates about a vertical axis. Around the periphery of the rotor bowl are numerous cylindrical discharge nozzles. The entire rotating mechanism is contained within a housing assembly that is compartmentalized to receive and direct sludge feed, sludge discharge, recirculation, and effluent discharge. The discs and rotor bowl are typically constructed of corrosion-resistant stainless steel. The housing assembly is either stainless steel or bronze. Disc-nozzle centrifuges are available in a variety of sizes. The largest units have an average throughput capacity of 200 to 300 gpm and operate at rotor speeds of up to 4,200 rpm, creating centrifugal forces of 6,500 G. These units have a rotor bowl over three feet in diameter contained within a six foot diameter housing assembly. The support assembly and drive train can reach an overall height of ten feet. A top driven, top fed machine configuration is shown in Figure 3.

Disc-nozzle centrifuge operation involves continuous feed of sludge to the bottom of the spinning rotor, where centrifugal forces move the heaviest solid particles directly to the edge of the bowl. Lighter particles will pass through the spaces between the discs. The disc spacing, typically 1.3 mm (0.05 in), acts to minimize settling distance (15). Particles will settle on the underside of the discs and accumulate

**Figure 3. Disc-nozzle centrifuge schematic.**




Source: 15

until their mass is great enough to force them to the periphery of the disc and subsequently to the edge of the rotor bowl. Clarified liquid flows between the discs and overflows the top of the rotor bowl through an effluent discharge. Solid particles collected along the periphery of the bowl are discharged through small cylindrical nozzles, usually 1.3 to 2.5 mm (0.05 to 0.10 in) in diameter (1,12). The nozzles act to reduce the solids discharge rate, thereby increasing the retention time and accumulation of particles in the concentrating chamber of the rotor bowl. A variable portion of the discharged sludge may be recirculated to the rotor bowl, undergoing further concentration. The recirculation rate can be controlled manually by the operator or automatically by external controls that respond to sludge viscosity or density.

## System Assessment

Advances in centrifuge technology, including improved design and construction materials, have increased centrifuge applications for thickening and dewatering municipal sludges. Although centrifuges have recently achieved greater acceptance for municipal installations, certain conditions may make the selection of a centrifuge inappropriate. Variable sludge characteristics make process control difficult and a high level of operator skill is required to maintain optimum centrifuge performance. Variable sludge characteristics often result from seasonal changes, industrial waste contributions, or flow and load variations related to combined sewers. Some sludge types limit centrifuge application. These include septic or old sludges containing solid particles that are less dense and more difficult to separate by centrifugation. In addition, literature sources indicate that waste activated sludge with a sludge volume index (SVI) greater than 150 significantly reduces centrifuge performance in thickening applications (9,10, 17).

The selection among the three centrifuge types for thickening and dewatering municipal sludges should be based on desirable sludge feed types, integration with other treatment plant process elements, and suitable plant size. In general, solid bowl centrifuges have the most widespread use, due to high throughput capacity and applications for sludge thickening or dewatering. Imperforate basket centrifuges are also capable of thickening or dewatering, but have lower throughput capacity. Disc-nozzle centrifuges have limited municipal sludge thickening applications.

Table 1 lists typical thickening and dewatering performance for solid bowl centrifuges on various types of sludges. Many solid bowl centrifuge thickening installations operate without polymer sludge conditioning, but all dewatering installations require varying polymer dosage to achieve satisfactory cake solids concentration and centrate quality. Solid bowl manufacturers consider pretreatment of sludge feed unnecessary in most situations, but field experience has shown that screenings and grit should be reduced for successful centrifuge operation. Considering the variety of solid bowl centrifuge sizes and capacities currently manufactured, their application is well suited for both small and large treatment plants.

Typical thickening and dewatering performance of imperforate basket centrifuge on various types of sludges is shown in Table 2. Generally, pretreatment of the basket centrifuge feed sludge for removal of grit and screenings is not required. Polymer sludge conditioning may not always be necessary to achieve desired cake solids concentration and centrate quality. Although basket centrifuges are versatile in municipal wastewater applications, their use is generally limited to smaller treatment plants for two reasons. First, their relatively low basket speed limits clarification and compaction of sludge solids. Second, the maximum average capacity (including "no flow" time periods of skimming and unloading) of the largest units seldom exceeds 60 gpm (8,9).

Disc-nozzle centrifuges are used exclusively for thickening waste activated sludge in municipal sludge processing. Attempts to thicken mixed sludges resulted in excessive discharge nozzle wear and plugging (9). Table 3 lists the typical waste activated sludge thickening performance of disc-nozzle centrifuges. Sludge feed pretreatment is generally required to reduce the frequency of maintenance downtime for rotor bowl and discharge nozzle cleaning. This pretreatment train typically consists of rotary screens, grit cyclones, and in-line strainers. Although high throughput capacity (200-300 gpm) makes disc-nozzle centrifuges suitable for both small and large treatment plants, the overall system complexity and the advancement of solid bowl centrifuge technology has virtually eliminated disc-nozzle centrifuges from the municipal sludge thickening market.

## Problem Assessment

The problems associated with the use of centrifuges for thickening and dewatering municipal wastewater treatment plant sludge may be categorized as equipment quality/design problems, system integration problems, and process operation and maintenance (O&M) problems. Each problem has been evaluated to determine its cause, significant impacts on plant performance and O&M costs, and remedial measures that may be taken to correct the problem.

### *Equipment Quality/Design Problems*

Problems in this category relate to centrifuge defects and malfunctions, fatique and wear of centrifuge

Table 1. **Typical Performance of Solid Bowl Centrifuge***

| Solid Bowl Centrifuge Application | Sludge Type | Feed Solids Concentration (%) | Average Cake Solids Concentration (%) | Dry Polymer Used Per Dry Feed Solids (mg/kg) | (lb/ton) | Solids Recovery (%) |
|---|---|---|---|---|---|---|
| Thickening | Raw waste activated | 0.5-1.5 | 3-8 | 0 | 0 | 80-90 |
| Thickening | Raw primary plus waste activated (60:40) | 0.5-3.0 | 4-8 | 0 | 0 | 85-95 |
| Dewatering | Raw primary | 5-8 | 25-36 | 500-2,500 | (1-5) | 90-95 |
| | | 5-8 | 28-36 | 0 | (0) | 70-90 |
| Dewatering | Anaerobically digested primary | 2-5 | 28-35 | 3,000-5,000 | (6-10) | 98+ |
| | | 9-12 | 30-35 | 0 | (0) | 65-80 |
| | | 9-12 | 25-30 | 500-1,500 | (1-3) | 82-92 |
| Dewatering | Anaerobically digested primary irradiated at 400 kilorads | 2-5 | 28-35 | 3,000-5,000 | (6-10) | 95+ |
| Dewatering | Waste activated | 0.5-3 | 8-12 | 5,000-7,500 | (10-15) | 85-90 |
| Dewatering | Aerobically digested waste activated | 1-3 | 8-10 | 1,500-3,000 | (3-6) | 90-95 |
| Dewatering | Thermal conditioned primary & waste activated | 9-14 | 35-40 | 0 | (0) | 75-85 |
| | | 13-15 | 29-35 | 500-2,000 | (1-4) | 90-95 |
| Dewatering | Primary & trickling filter | 7-10 | 35-40 | 0 | (0) | 60-70 |
| | | | 30-35 | 1,000-2,000 | (2-4) | 98+ |
| Dewatering | High lime | 10-12 | 30-50 | 0 | (0) | 90-95 |
| Dewatering | Raw primary & waste activated | 4-5 | 18-25 | 1,500-3,500 | (3-7) | 90-95 |

*Data obtained from plant contacts and Reference 15.

parts, and high maintenance items associated with centrifuges. These problems may relate to equipment quality (defects), or to equipment design (selection of materials that cannot withstand normal wear). Problems associated with ancillary equipment are discussed in the section addressing system integration problems.

**Excessive scroll wear**—Predominantly due to abrasive grit, this has historically been a serious problem for solid bowl centrifuges; but with the introduction of hard surfacing, such as sintered tungsten carbide tiles, scroll wear has been significantly reduced. Annual maintenance costs are on the order of 1 percent to 10 percent of initial capital cost for scroll rebalancing, resurfacing, and servicing the gear unit. In older installations, a retrofit of the scroll with improved hard surfacing can reduce scroll wear. Centrifuge downtime associated with scroll rebuilding may be minimized by obtaining a spare rotating assembly. Scroll wear can also be reduced by installing an automatic backdrive control that responds to changing torque load on the scroll, effectively limiting the abrasive wearing forces.

**Excessive vibration and noise**—This problem, although not particularly widespread in existing installations, is an important design consideration. Improperly designed mounting platforms, inadequate vibration isolators, improper building construction or material selection, and an unbalanced rotating assembly are causes of vibration and noise. Excessive vibration can reduce the operating life of bearings and rotating assemblies, and high noise levels are considered operator health concerns. Vibration and noise are best controlled by adhering to manufacturers' specifications for mounting platform and vibration isolator design and by using sound-absorbing, acoustical construction materials in centrifuge rooms. Use of disposable ear plugs is a low-cost method of mitigating noise problems.

**Inadequate instrumentation for lubrication system**—The main bearings of solid bowl centrifuges require constant lubrication, typically provided by a pressurized or splash-type lubrication system. Inadequate instrumentation for monitoring oil flow may preclude proper maintenance of lubrication systems and result in excessive bearing wear. The capability to

**Table 2. Typical Performance of Imperforate Basket Centrifuge***

| Imperforate Basket Centrifuge Application | Sludge Type | Feed Solids Concentration (%) | Average Cake Solids Concentration (%) | Dry Polymer Used Per Dry Feed Solids (mg/kg) | (lb/ton) | Solids Recovery (%) |
|---|---|---|---|---|---|---|
| Thickening | Raw waste activated | 0.5-1.5 | 8-10 | 0 | (0) | 85-90 |
| | | 0.5-1.5 | 8-10 | 500-1,500 | (1 0-3.0) | 90-95 |
| Thickening | Aerobically digested | 1-3 | 8-10 | 0 | (0) | 80-90 |
| | | 1-3 | 8-10 | 500-1,500 | (1 0-3.0) | 90-95 |
| Thickening | Raw trickling filter (rock & plastic media) | 2-3 | 8-9 | 0 | (0) | 90-95 |
| | | 2-3 | 9-11 | 750-1,500 | (1.5-3.0) | 95-97 |
| Thickening | Anaerobically digested primary & rock trickling filter sludge (70:30) | 2-3 | 8-10 | 0 | (0) | 95-97 |
| | | 2-3 | 7-9 | 750-1,500 | (1.5-3.0) | 94-97 |
| Dewatering | Raw primary | 4-5 | 25-30 | 1,000-1,500 | (2-3) | 95-97 |
| Dewatering | Raw trickling filter (rock or plastic media) | 2-3 | 9-10 | 0 | (0) | 90-95 |
| | | 2-3 | 10-12 | 750-1,500 | (1.5-3.0) | 95-97 |
| Dewatering | Raw waste activated | 0.5-1 5 | 8-10 | 0 | (0) | 85-90 |
| | | 0.5-1.5 | 12-14 | 500-1,500 | (1.0-3.0) | 90-95 |
| Dewatering | Raw primary plus rock trickling filter (70.30) | 2-3 | 9-11 | 0 | (0) | 95-97 |
| | | 2-3 | 7-9 | 750-1,500 | (1.5-3.0) | 94-97 |
| Dewatering | Raw primary plus waste activated (50 50) | 2-3 | 12-14 | 500-1,500 | (1.0-3.0) | 93-95 |
| Dewatering | Raw primary plus rotating biological contactor (60:40) | 2-3 | 20-24 | 0 | (0) | 85-90 |
| | | 2-3 | 17-20 | 2,000-3,000 | (4-6) | 98+ |
| Dewatering | Anaerobically digested primary plus waste activated (50 50) | 1-2 | 12-14 | 0 | (0) | 75-80 |
| | | 1-2 | 10-12 | 750-1,500 | (1.5-3.0) | 85-90 |
| | | 1-2 | 8-10 | 2,000-3,000 | (4-6) | 93-95 |
| Dewatering | Aerobically digested | 1-3 | 8-11 | 0 | (0) | 80-95 |
| | | | 12-14 | 500-1,500 | (1.0-3.0) | 90-95 |

*Data provided in Reference 15.

monitor both oil flow and pressure is recommended to assist operators in lubrication system maintenance. An in-line sight glass may be installed to permit visual checks of oil flow.

**Erosion or failure of feed pipes and feed nozzles**—This solid bowl centrifuge problem results from abrasive grit wear and rag accumulation. Replacement costs range from $400 per stainless steel feed nozzle to $1,400 for a stainless steel feed pipe. In addition, at least one day of labor is required to replace either part. The use of hard facing material such as tungsten carbide or ceramic liners for nozzles and stainless steel feed pipes cost-effectively reduces wear. Improving feed grinder performance may reduce the frequency of plugging in the feed pipes.

***System Integration Problems***

Problems in this category relate to the ancillary equipment required for a complete centrifuge installation, such as instrumentation, pumps, grinders, or conveyors.

**Insufficient area for equipment maintenance**—It is an important design consideration to provide adequate maintenance area for centrifuge systems. Poor layouts are difficult to remedy and often result in longer centrifuge downtime for even routine maintenance. Solid bowl centrifuge system design should include considerations for removal of the rotating assembly and for in-house maintenance on the scroll including the routine replacement of wearing surfaces (tiles). In addition, provisions should be made

**Table 3. Typical Waste Activated Sludge Thickening Performance of Disc-Nozzle Centrifuge***

| Capacity | | Feed Solids Concentration | Underflow Solids Concentration | Solids Recovery |
|---|---|---|---|---|
| l/min | (gpm) | (%) | (%) | (%) |
| 570 | (150) | 0.75-1.0 | 5-5.5 | 90+ |
| 1,510 | (400) | — | 4.0 | 80 |
| 190-300 | (50-80) | 0.7 | 5-7 | 87-93 |
| 230-1,020 | (60-270) | 0.7 | 6.1 | 80-97 |
| 250 | (66) | 1.5 | 6.5-7.5 | 87-97 |
| 760 | (200) | 0.75 | 5.0 | 90 |

**Data provided in Reference 15.*
*Note: Indicated performance is without polymer sludge conditioning.*

for direct access by monorail or bridge crane to any centrifuge mounting or maintenance area.

**Inadequate mixing system in sludge holding tanks**—Failure to provide adequate mixing can result in highly variable sludge characteristics, making performance optimization difficult. In addition, unmixed holding tanks may freeze during periods of cold weather. The design of holding tank mixing systems will vary with sludge type. For aerobic sludges, satisfying the aeration requirements may be more critical than mixing requirements. Holding tank covers should be considered for cold regions.

**Lack of sampling locations**—Regardless of the mixing system used it is important to monitor, by sampling, solids concentration of sludge feed, sludge cake, and centrate. Difficulty in optimizing centrifuge performance is often a direct result of insufficient sampling locations. Existing facilities with this problem should consider retrofitting their sludge feed lines, centrate discharge piping, and sludge discharge conveyance equipment with sampling taps.

**Performance limitations of polymer feed systems**—Performance limitations associated with polymer feed systems include insufficient polymer dilution capacity to compensate for lower demand during periods of low feed solids concentration and insufficient number of polymer injection points for complete mixing with feed sludge. Generally, these situations result in excessive polymer consumption. In-line dilution of polymer is recommended after initial batch mixing to ensure optimum mixing and dilution. Polymer manufacturers' product data sheets provide in-line dilution recommendations for their products. At least three points of injection for polymer mixing with sludge feed are recommended. These injection points are just before the centrifuge inlet or directly into the basket centrifuge, ahead of the sludge feed pump, and immediately after the sludge feed pump. These locations allow operators to optimize polymer mixing with sludge feed (10).

**Progressive cavity feed pump wear**—This problem is commonly experienced in facilities with high grit levels. Uncontrolled wear can reduce pump capacity and diminish the accuracy of flow measurement and control devices that are based on pump motor speed. Alternative feed pumps, centrifugal and rotary lobe, are less susceptible to grit-related wear.

**Insufficient system interlocks, instrumentation, or controls**—This design problem is more prevalent in older installations lacking adequate interlock or control packages. Interlocks should provide total centrifuge system shutdown with the occurrence of any system component failure, including pretreatment devices, polymer feed system, the centrifuge unit, sludge cake conveyor, and centrate return. Advances in manufacturers' instrumentation and control packages and the introduction of magnetic and sonic flow meters have improved process control, simplifying centrifuge performance optimization.

**Poor grinder performance**—Typically a result of overloading with sticks, grit, and rags, poor grinder performance causes several other related centrifuge problems, including feed pipe plugging and scroll binding. Grinder problems may be abated by regularly scheduled servicing, including blade sharpening.

**Sludge discharge and conveyor problems**—Centrifuge system designers should avoid belt conveyor layouts that allow a free fall of sludge from the centrifuge discharge at heights greater than two feet above the conveyor, or that allow belt conveyors to be designed at an incline. Allowing a free fall discharge of sludge may result in sludge splatter and spills. Sludge may accumulate at the base of an inclined conveyor resulting in sludge spills and conveyor overloading. An additional maintenance problem associated with belt conveyors is the grit-related wear of moving parts. Screw conveyor problems are commonly caused by undersizing and by clogging with rags. Several remedial measures include reducing centrifuge throughput to stay within conveyor capacity, adding baffles to the discharge chute to minimize splatter, and replacing undersized conveyors.

**Bowl/scroll binding**—This problem occurs in solid bowl centrifuge installations having deficiencies in the removal of rags, fibers, and scum. These materials may accumulate between the scroll tip and the bowl wall until the allowable torque on the scroll is exceeded, triggering an automatic shutdown switch.

Extensive labor is required to disassemble and clean the rotating assembly. Remedial measures include adding grinders to the sludge feed, routine flushing of the bowl, discontinuing the disposal of scum with waste activated sludge, and installing an automatic backdrive control that appropriately adjusts differential speed to prevent excessive scroll torque variations.

**Frequent nozzle plugging**—This problem, common to disc-nozzle installations, is directly attributed to grit and scum accumulation and indirectly attributed to insufficient pretreatment of the waste activated sludge feed. Nozzle cleaning is the most significant cause of maintenance downtime. Disc-nozzle installations generally require extensive sludge feed pretreatment units, adding considerable cost to the system and increasing plant recycle loads. Regular steam cleaning of the disc stack and nozzles can reduce the frequency of plugged nozzles.

**Odor problems**—Processing odorous sludge, including anaerobically digested or chlorine oxidized sludges, warrants additional air handling considerations for odor control in centrifuge installations. Minimum ventilation rates on the order of six air changes per hour during summer and three air changes per hour in the winter should be considered. Higher rates and treatment of the exhaust air may be needed if particularly odorous sludges are to be handled. It may be more cost-effective to treat exhaust air from the centrate discharge chute instead of allowing odors to escape into the room and then treating room air.

***Process O&M Problems***

Process O&M problems relate to improper operating procedures, inadequate routine maintenance, and lack of knowledge and understanding of the centrifuge system.

**Operator training**—An incomplete understanding of centrifuge operation and maintenance makes it difficult to optimize centrifuge performance. Operators often favor one or two variables for process control which may limit sludge processing capacity and increase polymer consumption. High operator turnover and lack of adequate instrumentation to monitor centrifuge performance are typical causes of O&M problems. The machine characteristics and process variables and their effects on centrifuge performance are summarized in Table 4. Machine characteristics vary between manufacturers and their limitations on process flexibility should be considered in centrifuge selection and specification.

**Polymer selection and dosage optimization**—Indiscriminate polymer selection will not provide the most efficient use of polymer, since various polymers do not produce the same results. Polymer selection should begin with a review of manufacturers' product data sheets. These product data sheets will provide a general indication of the polymer's suitability for centrifugation. Generally, cationic polymers are used for municipal wastewater sludges, especially for waste activated sludges. Anionic polymers are frequently used for alum sludges and high pH sludges. However, there is no definitive way to select a polymer without conducting bench scale testing with samples of the plant sludge. The laboratory jar test is a simple method of polymer performance evaluation and comparison. Polymer dosage rates may be optimized by the jar test or the capillary suction test.

**Table 4. Machine Characteristics and Process Variables Affecting Centrifuge Performance**

| Adjustment | Centrate Quality | Cake Solids Concentration |
|---|---|---|
| Solid Bowl Centrifuge (6) | | |
| 1. Machine Characteristics* | | |
| —increase bowl length | Improve | Cannot predict |
| —increase bowl diameter | Improve | Reduce |
| —increase beach angle | Reduce | Improve |
| —increase bowl speed | Improve | Improve |
| —increase conveyor pitch | Reduce | Improve |
| —move inlet closer to beach | Improve | Reduce |
| 2. Process Variables | | |
| —increase feed rate | Reduce | Improve |
| —increase temperature of feed sludge | Improve | Improve |
| —add polymer | Improve | Improve |
| —increase differential speed | Reduce | Improve |
| —increase pool depth | Improve | Reduce |
| Imperforate Basket Centrifuge | | |
| 1. Machine Characteristics* | | |
| —increase basket speed | Improve | Improve |
| 2. Process Variables | | |
| —increase feed rate | Reduce | Improve |
| —increase temperature of feed sludge | Improve | Improve |
| —add polymer | Improve | Improve |
| —increase cycle time | Reduce | Improve |
| —increase skimming | Reduce | Improve |
| Disc Nozzle Centrifuge | | |
| 1. Machine Characteristics* | | |
| —increase rotor speed | Improve | Improve |
| —increase disc size | Improve | Improve |
| —increase disc spacing | Reduce | Cannot predict |
| 2. Process Variables | | |
| —increase feed rate | Reduce | Improve |
| —increase recirculation rate | Cannot Predict | Improve |
| —increase temperature of feed sludge | Improve | Improve |

*Fixed by manufacturers' designs.

The ultimate test is within the operating centrifuge. Sludge characteristics are frequently subject to change including seasonal variation. Therefore, it is recommended that weekly laboratory testing be conducted to optimize polymer dosage and selection, or as frequently as determined through operating experience (10).

**Polymer foaming**—This problem is related to excessive polymer dosage (3,13). In severe cases, polymer foam can be forced through the discharge chutes, creating polymer spills that are difficult to clean up and present potential safety hazards from slippery surfaces. Polymer foaming can be associated with a lack of sludge conditioning testing (jar tests or capillary suction tests) and with inadequate dosage control in the polymer feed system. Dosage control can be improved by the use of dry polymer feed systems with automatic batch mixing.

**Scale formation and struvite deposition in the centrifuge**—Scale formation can result from the centrifugation of lime stabilized sludge, or from the presence of other mineral salts in the sludge feed. Struvite is a crystalline ammonium-magnesium-phosphate associated with anaerobically digested sludge and sludge having high levels of soluble phosphorus. Identified causes of scale and struvite build up include inadequate bowl cleaning and batch mixing of alkaline polymer solution with plant effluent. The accumulation of scale and struvite decreases centrifuge solids capture efficiency and requires extensive labor to remove the deposits from pipe and bowl surfaces. Several cleaning methods are available including regular hot flushing of the centrifuge and piping with scale-removing solutions, using hydrated lime in place of quicklime for stabilization of sludge, selecting non-alkaline polymer solutions, and adding chelating agents to prevent scale and struvite deposition. Laboratory and performance testing should be conducted prior to selection and bulk purchases of non-alkaline (low pH) polymers.

**Hydraulic overloading of solid bowl centrifuges**—In addition to potential performance deterioration, hydraulic overloading may result in rotating assembly seal failure and lubrication system contamination. Seal replacement requires considerable labor and material expense, compounded when the bearing and lubrication systems are contaminated. The most effective remedial measure for this problem is to educate operators on the hydraulic capacity limitations of their centrifuges.

**Solid bowl centrifuge backdrive seizure**—This problem is experienced in facilities that infrequently use their centrifuges. The lubricant can drain from the bearing assemblies during extended downtime, resulting in bearing corrosion and seizure. A regular maintenance program of lubrication and manually turning the rotating assembly during idle periods prevents seizure of the backdrive unit.

**Excessive sludge feed period in basket centrifuges**—The sludge feed period per cycle is a process variable controlled by the operator. Longer feed periods generally improve the sludge solids concentration, but may result in harder cake formation on the inner wall of the basket. Hard cake solids have caused the knife to chatter during the unloading phase of the process cycle. In addition, excessive chatter may result in unloading knife stress failure. The remedial measure for this problem is to impose an operational limit on the sludge feed period.

## Summary

The selection of centrifuge systems for use in municipal sludge treatment requires careful consideration of their application to either thickening or dewatering. Solid bowl centrifuges are most widely used because of their high throughput capacity and applications for thickening or dewatering. Imperforate basket centrifuges are also capable of thickening or dewatering, but they have relatively low throughput capacity. Disc-nozzle centrifuges are limited to thickening waste activated sludge. Each centrifuge type has, by nature of design or operation, relative advantages and disadvantages for municipal sludge thickening and dewatering as summarized in Table 5.

In order to minimize the impact of design and operating problems and to improve centrifuge performance, the following approaches to design, operation, and training are recommended.

### *Design Approaches*

- Provide adequate instrumentation to monitor oil flow as well as oil pressure in hydraulic bearing lubrication systems to prevent loss of lubricant flow to the main bearings.
- Provide hard facing materials on centrifuge parts that are normally subjected to high wear, such as scrolls, feed ports, and feed tubes.
- Investigate the applicability of centrifuges, possibly including pilot studies and/or laboratory analyses of sludges, early in the design process. Centrifuges may not be the dewatering device to select if the sludge feed characteristics are highly variable, or if the sludge is expected to contain a significant amount of grit.
- Provide adequate floor space and hoisting equipment for proper equipment maintenance, removal, and installation.
- Provide appropriate equipment mounting components and foundation design to minimize centrifuge vibration.

**Table 5. Advantages and Disadvantages of Disc-Nozzle, Imperforate Basket, and Solid Bowl Centrifuges**

| Advantages | Disadvantages |
|---|---|
| **Disc Nozzle** | |
| Relatively high throughoput in a limited area. | Thickens waste activated sludge only. |
| Polymer is not required for satisfactory performance | A complex pretreatment system is required |
| Odors can be easily contained, and a relatively small air volume treated, if needed. | Recycle loadings from pretreatment systems are high. |
| | Skilled operations and maintenance staff are required for this relatively complex operation. |
| **Imperforate Basket** | |
| Thickening and dewatering of waste activated and mixed sludge. | Batch operation limits unit capacities. |
| Especially well suited to handling difficult sludges (e.g., aerobically digested). | Special structural support is required to support the centrifuge, due to its bottom discharge. |
| Resistant to grit and clogging, requiring no sludge pretreatment. | Sludge conveying options are limited due to bottom discharge and batch operation. |
| Provides maximum flexibility for handling variable sludge characteristics. | Operators must depend on the result of a previous batch run for process optimization |
| **Solid Bowl** | |
| Thickening and dewatering of waste activated and mixed sludge | Potentially high maintenance costs. |
| Relatively high throughput in a limited area. | Operating costs may be higher due to polymer. |
| Odors can be easily contained, and a relatively small air volume treated, if needed | Adequate grinding of the sludge feed must be provided to prevent plugging. |
| Somewhat adaptable to varying sludge characteristics. | Relatively skilled operators are required for optimum results. |

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- Provide polymer systems that are capable of delivering an adequate polymer dose at low solids concentrations (0.5 percent) in the sludge feed.
- Consider alternatives to progressive cavity sludge feed pumps, including centrifugal or rotary lobe pumps.
- Provide interlocks between the centrifuge and ancillary equipment, such as feed pumps, grinders, polymer systems, sludge conveying devices, and centrate pumps, to ensure system shutdown in the event that a system component fails.
- Provide instrumentation to allow plant staff to determine centrifuge process variables, such as sludge and polymer feed rates and the bowl-scroll differential speed.
- Design sludge conveying systems to avoid steep inclines, and to ensure adequate conveyor capacity. Effort should be made to provide the most simple, direct discharge from the centrifuge. Ideally, dewatering centrifuges should discharge directly into a disposal container or vehicle, and thickened sludge to a blending or holding tank.
- Provide adequate ventilation systems for odor control.
- Consider specification of acoustical construction materials for centrifuge buildings and rooms to reduce noise levels.
- Provide standby ancillary equipment, such as grinders and pumps, to reduce centrifuge downtime when this equipment fails.
- Consider the feasibility of providing temperature control of sludge feed as a process variable. Increasing sludge temperature improves centrifuge performance, but may create odor problems.

### *Operational Approaches*

- Consider purchasing a spare rotating assembly to minimize downtime during routine scroll maintenance, such as replacement of worn tiles.
- Perform grinder and degritter maintenance to minimize centrifuge plugging by rags and grit-related wear. Facilities that stabilize sludge with quicklime should maintain optimum performance of grit removal devices in lime slaking systems.
- Conduct polymer testing regularly, especially prior to bulk purchases of polymer. Jar tests, capillary suction tests, and full-scale operating tests should be used where possible. This testing should optimize polymer dosage and application points to achieve the most efficient, economical operation possible.
- Monitor centrifuges for accumulation of scale, especially during initial startup period. If scale formation occurs, actions should be taken to remove the scale and prevent its accumulation.

- Keep maintenance records for tracking chronic maintenance problems and for scheduling preventive maintenance.
- Perform routine centrifuge flushing to prevent problems related to solids and rags accumulation.

***Training***

Proper operator training will improve process efficiency and reduce costs. Training in the following areas should be provided to all personnel who are involved in the operation and maintenance of centrifuges:

- Process and machine control variables, their impacts on solids throughput and centrate quality, and how each variable is monitored and adjusted.
- Process data collection and evaluation.
- Process troubleshooting procedures.
- Preventive maintenance requirements and procedures, including record keeping.
- Process and system economic considerations.
- Operation, maintenance, control theory, and troubleshooting procedures for the overall centrifuge system, encompassing support equipment.

Training should be provided in the above areas during plant start-up, and as an ongoing program, especially when new personnel are placed in charge of the centrifuge installation.

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