Just the Facts on Dewatering Systems

A review of the features of three major mechanical dewatering technologies

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Many comparative studies of mechanical sludge-dewatering systems have been reported, and each determines a cost-effective equipment selection based on a project's unique requirements. However, deciding which equipment ultimately is "best" is impossible.

Nevertheless, the claims and counterclaims made for particular types of mechanical dewatering devices tend to be more extreme than those put forth for other types of process equipment. In addition, experienced treatment personnel voice strong but diverse opinions about dewatering systems. This context makes evaluating available choices of dewatering equipment particularly difficult. A review of the features of each type of equipment may help dampen some of the "background noise" generated around mechanical dewatering systems.

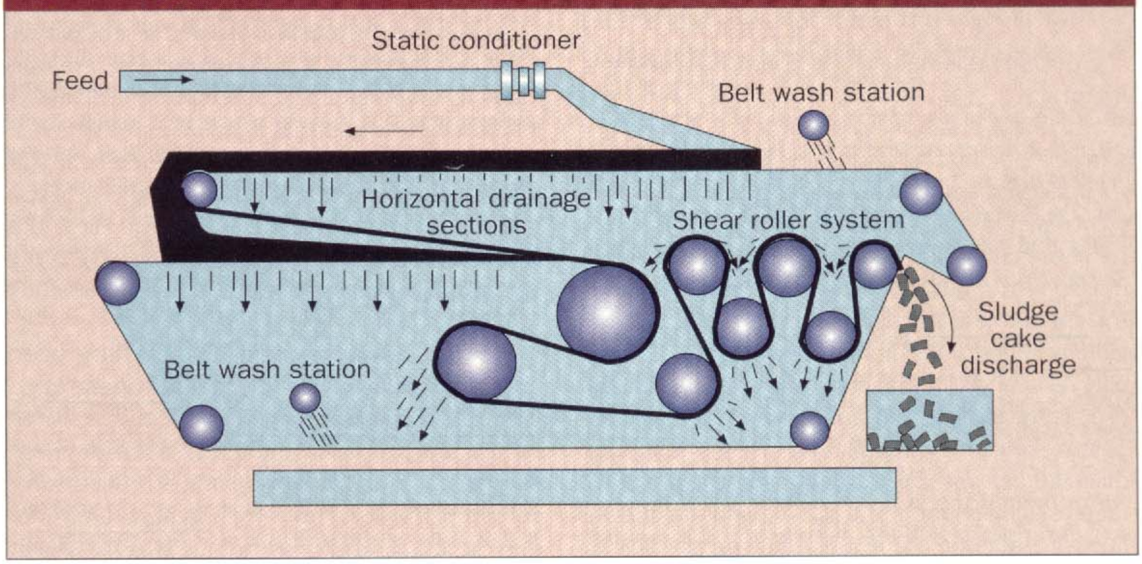
Belt Filter Presses

Basics. Belt filter presses dewater by squeezing sludge between two porous belts traveling over and under a series of rollers. Each roller in this progression is designed to exert greater pressure than the previous one. All belt presses include a polymer-conditioning stage; a gravity-drainage phase; a low-pressure, or wedge, zone; and a high-pressure zone (see Figure 1, below).

Belt filter presses became popular in the late 1970s and the 1980s, replacing vacuum filters in several large plants, because the belt presses consumed less power and fewer chemicals and produced higher cake solids. Because belt presses depend on polymer conditioning to dewater sludge, it is not surprising that their increased use coincided with the development of organic polymer flocculants.

The capacity and performance of a belt filter press are enhanced by effective gravity drainage. The size of drainage zones has been increased over time in most machines, and plows or chi-

Figure 1. Typical Belt Filter Press



canes have been added to turn and disturb the sludge blanket, facilitating the release of water. Depending on sludge type, well-flocculated sludge may release up to 75% of its water by gravity. Effective gravity drainage requires proper sludge conditioning and clean filter belts in the gravity zone. The belts in a belt filter press are washed continuously by a high-pressure water spray, making adequate water supply an important facility design consideration. Many installations use recycled final effluent as a washwater source.

The dewatered cake is guided off the final rollers by doctor blades, usually one for the upper roller and one for the lower. If the process is working correctly, the cake does not adhere to the upper belt and cracks as it is discharged from the lower roller. However, scraping of the cake from the lower-roller belt during the process indicates less than optimal performance and relatively low solids capture. Solids adhering to the belt are washed into the recycle stream; the cake is discharged to a belt conveyor running beneath the final lower roller. Filtrate and washwater usually drain from a curbed area beneath the press and are recycled to the head of the treatment plant.

Theory. Filtration obeys Darcy's law for flow through porous media:

$$Q = PA/\mu LR \qquad (1)$$

where
Q = filtrate flow;
P = pressure drop;
A = filtration area;
μ = absolute viscosity of the filtrate;
L = cake thickness; and
R = specific resistance.

Specific resistance (R) is comprised of two factors:

$$R = r + R_m \qquad (2)$$

where
r = specific resistance of the cake; and
R_m = resistance of the filter medium.

These equations show that pressure must be developed for filtration to occur and that one factor, specific resistance (r), is a characteristic of the sludge. Sludge conditioning is used to lower specific resistance. The inverse of specific resistance ($1/r$) is the sludge's "filterability."

Cake thickness is a function of feed rate to the machine, belt speed, and filterability. The pressure increases throughout the run to maintain filtrate flow. As Equation 1 indicates, if the press is fed at a rate exceeding the sludge's filterability or if the pressure between rollers increases too rapidly, extrusion will result. The concept of specific resistance applies to all pressure-filtration systems, including recessed-plate filtration.

Pressure is developed in a belt press by three forces:

- torque of the drive motor pulling the belts through the press (F_1);
- tension on the belts due to the tensioning cylinders (F_2); and
- elasticity of the filter belts (F_3).

$$\text{Pressure (lb/in.}^2\text{)} = 2(F_1 + F_2 + F_3)/D \qquad (3)$$

where
D = roller diameter.

Pressure increases as roller diameter decreases, but the effective force at any roller depends on the tangent length of belt entering and leaving the roller, and the belt's angle of wrap around the roller. In a typical belt press, as the cake is passed through the machine, roller diameter decreases and angle of wrap increases, effectively increasing squeeze pressure on the cake; the pressure increases gradually between rollers.

Operations and maintenance. The success of a belt filter press depends on proper conditioning. Polymer and sludge must be well mixed, and optimal polymer dosage should be determined based on jar testing and operational experience. The process may be upset by variations in polymer dosage, sludge feed rate, or feed solids. Thus, belt presses require careful monitoring to respond to changes and prevent upsets. Progressing-cavity or rotary-lobe pumps with adjustable-speed drives are recommended for sludge and polymer feed. These positive-displacement pumps provide a steady flow rate to the machine.

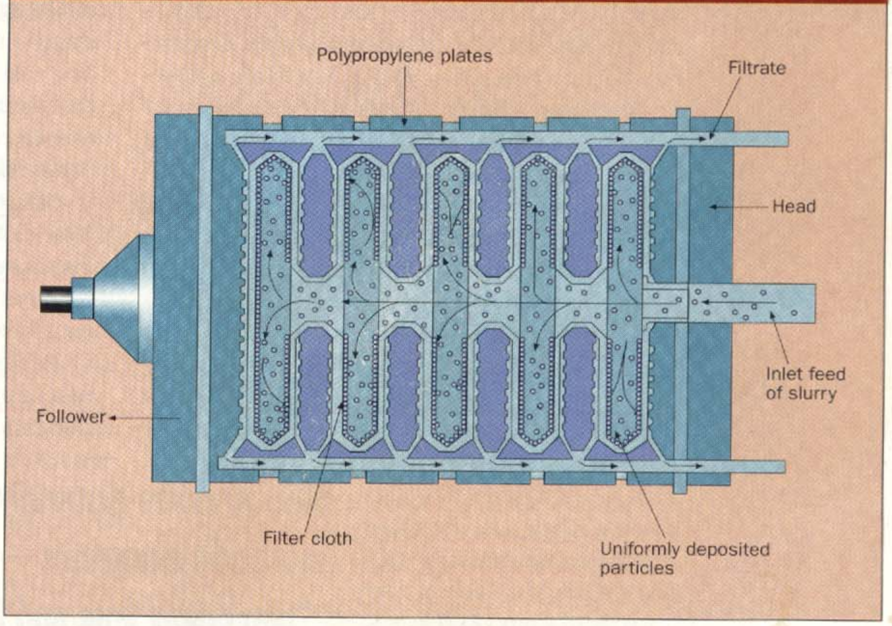
Even distribution of the sludge across the width of the filter belt provides the greatest capacity. Manufacturers offer various means for sludge distribution that may be tested for effectiveness. Belt speed can be adjusted to optimize loading and distribution, and press capacity can be measured as hydraulic or solids loading. Belt filter presses with adequate gravity drainage areas are more likely to be solids-limited.

Because an operator can observe the process and control key variables, manual operation of belt presses is relatively simple. Polymer batches can be prepared manually each day, and sludge feed rate can be adjusted for the desired run time. However, although manual operation may be appropriate for one or two presses, it becomes too much work in plants with multiple presses. Most functions can be automated to accommodate such situations.

The main mechanical components of a belt filter press are rollers and their bearings, which are subject to corrosion from constant exposure to spray water and filtrate while the press is operating. Bearing and roller replacement are a common cause of major maintenance work.

The equipment's belt-tensioning system typically is hydraulically or pneumatically actuated. Upper and lower belts each have a guide roller that pivots to maintain belt alignment, and the guide system usually includes a paddle or sensor to track belt location. Guide systems may require periodic inspection and adjustment.

Figure 2. Flow-pattern in A Recessed-plate Filter Press



Filter-belt life depends on several factors, including sludge type and belt weave and material. A 1984 survey found that belt life varied between 1000 and 5000 hours, with an average of 2700 hours at the plants surveyed. Odor and safety concerns related to hydrogen sulfide emissions have been addressed successfully by adding potassium permanganate to the sludge feed. Odors also should be considered in ventilation system design.

Recessed-plate Filter Presses

Basics. Recessed-plate filter presses are among the oldest types of dewatering devices applied to municipal sludge, and they continue to be used when the highest cake solids are required. Conditioned sludge is pumped into a series of fixed-volume chambers, and the equipment's feed pump must be able to develop the required terminal filtration pressure. Each chamber is lined with a filter cloth to retain the solids. During the filling phase, free water is released and passes through the cloth (see Figure 2, above). As the chamber fills with solids, pressure builds and the consolidation phase begins. During consolidation, terminal pressure is reached and filtrate flow rate declines. Additional cake is formed until a setpoint of low filtrate flow is reached to determine the end of the cycle.

Press capacity is determined by the number of plates and chambers the press contains. The plates are supported on a structural frame with a shifting mechanism to separate the plates one at a time. Large presses have automatic plate-shifting systems. During filtration, the plates are squeezed by a hydraulic ram that seals together the cloths on the plates and resists the filtration pressure developed by the filter feed pump.

Although the press operates unattended during filtration, the system uses a batch process that requires regular operator attention to fill and unload the press. When filtration is finished, compressed air should be used to blow out the core (the sludge-distribution conduit formed by the hole in the center of each plate). The core is filled with partially dewatered sludge at the end of the filtration cycle.

The presses usually are mounted on the floor above a conveying system or containers that receive the sludge. The cakes drop as each chamber is opened successively. Recessed-plate filter presses achieve the highest solids content in the cake and have the highest rate of solids capture, compared to belt presses and centrifuges.

Theory. Like a belt press, a recessed-plate filter press follows Darcy's law for porous media. However, cake thickness is fixed, and pressure and filtration rates are variable. The fill phase, analogous to gravity drainage in the belt filter press, is where most of the water is removed at low differential pressure. The consolidation phase is similar to the high-pressure zone (phase) of a belt filter press. Pressure is determined by filter feed-pump output. The presses generally are designed to operate at 689.5 kPa (100 psig) or 1551 kPa (225 psig) terminal pressure. Progressing-cavity and piston-membrane pumps have been used as filter-feed pumps in these systems. The progressing-cavity pump must have variable-speed and high turndown-ratio capabilities to meet the low flow requirement at the end of the cycle. The piston-membrane pump automatically compensates for increasing pressure by bypassing hydraulic fluid and reducing the pump's stroke volume.

Operations and maintenance. Conditioning chemicals usually are required for successful filter press dewatering, except in certain cases when the feed sludge's inorganic content is high (for example, ash residual from wet-air oxidation). Filter presses generally rely on inorganic chemicals — most commonly lime and ferric chloride — for conditioning. Although these chemicals typically produce a dewatered cake with more than 40% solids content, their use increases the mass that must be disposed. Using lime also is associated with ammonia releases, particularly in applications involving anaerobically digested sludge. This must be considered in overall facility design, including ventilation requirements.

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Manually operating a filter press in a small plant is simple. Batches of sludge are preconditioned and fed to the press, and no monitoring is required during the filtration cycle. If cake-release is good, the cake will drop cleanly from the cloth when the plates are shifted. On larger units, plate shifting is automatic; a power-assisted plate shifter usually is provided on smaller units.

Facilities with multiple presses will need a fully automatic system for efficient operation. In this type of facility, automatic sludge conditioning maintains proper chemical dosages, while automation of the filtration cycle includes opening and closing the press and blowing out the core at the end of a cycle. The plate-shifting step is initiated manually so the facility can prepare to receive the cake drop.

Polymer conditioning has been used with some success in recessed-plate filter press dewatering. High cake solids are possible, but cycle times are long and the cake often sticks to the cloth, requiring assistance for its removal. Residual solids often remain on the cloth, reducing solids capture and requiring more frequent cleaning. Filtration cycle times with lime and ferric conditioning range between 90 and 120 minutes. With polymer conditioning, filtration cycles may exceed 180 minutes and tend to dewater the core, making core blowout ineffective. An advantage of polymer conditioning is that it produces a cake with fewer inert solids, enabling more sludge to be processed per cycle than when lime and ferric chloride are used. The cake produced contains more volatile solids than is the case with inorganic conditioning and therefore can be disposed using incineration or other thermal processing.

Cake release may be improved by precoating the filter cloths with a filter aid, such as fly ash, cellulose materials, or diatomaceous earth. This process requires facilities to prepare and pump the precoat, usually with a high-flow centrifugal pump.

Recessed-plate filter press installations are mechanically complex. A system's many components may include conditioning tanks, mixers, and multiple chemical-feed systems and feed pumps. Ferric chloride, which is highly corrosive, requires corrosion-resistant facilities and extreme caution in handling. The press has a hydraulic power-pack system and other mechanical accessories for plate shifting and washing, as well as drip trays. Although most of the component systems generally are reliable, each requires routine inspection and lubrication.

Filter cloths require periodic washing. Larger presses have automatic washers that work well but require a high-pressure pumping system to supply spray water. In some installations, the press can be filled with an acid cleaning solution, which is effective in removing scale deposits when lime is used for conditioning. However, acid washing reduces filter-cloth life, and replacing filter cloths is labor-intensive. More generally, filter-cloth life varies depending on sludge type, conditioning, and washing frequency.

Solid Bowl Centrifuges

Basics. Centrifuges have been used for sludge thickening and dewatering since the 1930s. The type used in modern municipal treatment plants is the horizontal solid bowl decanter (see Figure 3, p. 52). As in the case of the other two major types of mechanical dewatering equipment, design of the solid bowl centrifuge was adapted from equipment used in other industries. In an early application, a decanter-type centrifuge was used as a cream separator.

A solid bowl centrifuge is a continuous-feed unit in which sludge feed is accelerated against the inside wall of a rotating bowl. After the solids and liquid separate, the solids are removed by a scroll conveyor, and the liquid is discharged through weirs or skimmer tubes. The bowl is conical so that, as the solids are conveyed, they are lifted out of the liquid to dry on a "beach" before being discharged.

The centrifugal gravity (G) force is developed using a rapidly rotating bowl. The scroll turns slightly faster or slightly slower than the bowl to create a differential speed that determines the solids removal rate. (Higher differentials result in higher solids removal rates.) Dewatering centrifuges require polymer conditioning and retain solids in the bowl longer than a thickening centrifuge. The polymer dosages required are similar to those used in belt press filtration.

The centrifuge bowl is enclosed completely by a cover and supported by bearings in a base that has outlets for dewatered solids and removed liquid. (As in the other methods, solids are referred to as "cake," but the liquid phase is called centrate.) The liquid can be piped away from the unit and recycled to the plant for treatment, and the solids can be contained in a pump, conveyor, or container as they are discharged. This allows odor from the process to be contained and ventilated separately, reducing operator exposure and minimizing ventilation requirements. Centrifuges generally have a supply of flushing water connected to the inlet piping but do not require continuous washwater.

Theory. Unlike filtration devices, centrifuges use the principle of accelerated sedimentation (see Figure 4, p. 53). In a sedimentation device, separation of solids and liquid is governed by Stokes' law:

$$V = [g \times (\rho_{solid} - \rho_{liquid}) \times d^2]/1800\mu \qquad (4)$$

where

V = settling velocity of a solid particle;

g = acceleration due to gravity;

ρ_{solid} = density of the solids;

ρ_{liquid} = density of the liquid;

d = mean diameter of the solid particle; and

μ = viscosity of the liquid phase.

Settling velocity is proportional to the difference in density between the liquid and solids and the square of the diameter of the solids particles. In a centrifuge, g is replaced by G, which is function of bowl speed:

$$G = (2\pi N/60)^2 \times R \qquad (5)$$

where

N = rotational speed of the bowl; and

R = bowl radius.

The solids retained in the bowl will have

Comparison of Mechanical Dewatering Systems

Belt Filter Press

Advantages

Low power consumption
Easy to operate and maintain
Relatively low capital cost per unit
Continuous-flow device

Disadvantages

Attention to roller bearings required (bearings may be prone to failure)
High-volume washwater required
Frequent belt replacement required
Operators exposed to odor and aerosol mists
Sensitive to changes in feed and conditioning
Can lose solids quickly (cleanup required)

Recessed Plate Filter Press

Advantages

Highest solids cake
Highest solids capture
Reliable, repeatable batch process
Inorganic conditioning handles a variety of difficult sludges
Simple to operate

Disadvantages

Mechanically complex
High capital cost
Labor-intensive cloth replacement
Inorganic conditioning increases solids needing disposal
Use of lime liberates ammonia from anaerobically digested sludge
Polymer-conditioned cakes prone to poor release

Solid Bowl Centrifuges

Advantages

High-solids cake
Small space requirement relative to capacity
Continuous-flow unit
Minimal operator attention required when stable operation is achieved
Odors and sludge contained with low operator exposure
Ventilation requirements reduced
Easy cleanup

Disadvantages

High power consumption (electrical service must account for high starting loads)
Noisy
Experience required to optimize performance
Process performance difficult to monitor
Special structural considerations may be necessary
Subject to abrasive wear

attained a sufficiently high settling velocity to enable them to reach the bowl wall in a time period that is shorter than the retention time of the liquid stream in the machine. Fine solids may escape capture, which is one reason polymer is required, because it increases particle size. Retaining the solids in the bowl while subjecting them to the high G force compresses them, releasing more water. The ability to adjust and control the differential speed between the bowl and the conveyor is essential for successful dewatering.

Operations and maintenance. If a centrifuge were used for dewatering without polymer conditioning, either the cake's solids content or the solids-capture rate would be unacceptable. Centrifuge performance is a balance of the competing process goals of solids dryness and solids capture. Dewatering is a function of G and solids retention time in the bowl: The longer the retention time, the more likely solids will be lost. Faster bowl speeds increase the G force, which enhances dewatering but increases turbulence and reduces solids capture. Centrifuges are specified to maintain 95% or more solids capture while meeting manufacturers' advertised cake solids. Although it may be possible to squeeze out additional dewatering performance at the expense of solids capture, the economics of recycle loading must be considered.

Feed rate, polymer dosage, and differential scroll speed can be adjusted during operation to optimize performance. Bowl speed generally is not adjustable while the centrifuge is running, but sheaves and belts can be changed to run the bowl at higher or lower speeds.

One drawback to using a centrifuge is that operators cannot see the process in action. Each machine should be equipped so that operators may view and sample the centrate stream and sample dewatered solids. Although they are relatively difficult to monitor, centrifuge operations usually are quite stable. Also, such developments as automatic control of torque on the solids conveyor scroll have reduced the need for process monitoring.

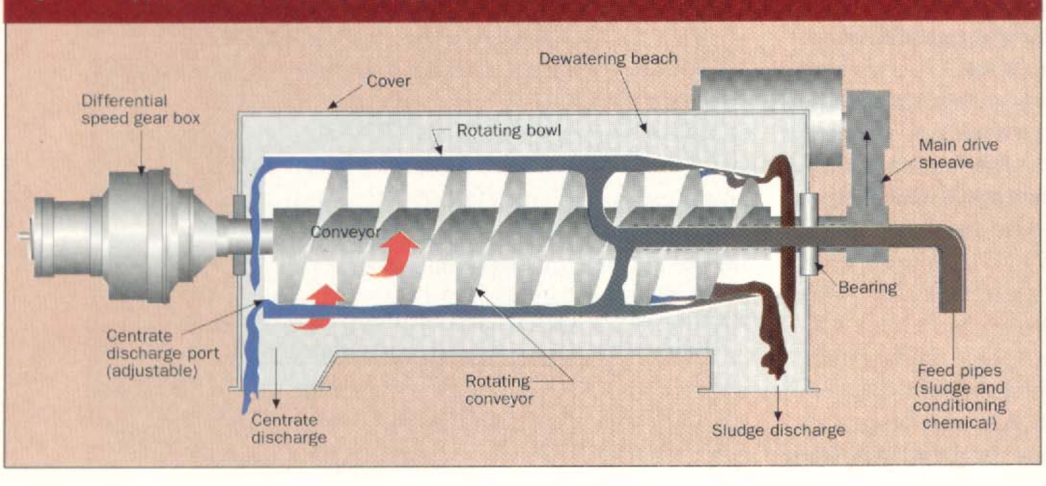
Centrifuges tend to require less operator attention than a belt press or recessed-plate filter press. However, centrifuges are susceptible to upset due to changes in feed characteristics. Adjustable-speed progressing-cavity pumps or rotary-lobe pumps offer the best option for maintaining consistent feed conditions for both sludge and polymer. Centrifuge operations can be fully automated, but starting the bowl and putting feed to the machine usually are done manually.

Cake from a centrifuge can be conveyed in several ways, including using belt or screw conveyors, or pumping using an open-throat progressing-cavity pump or hydraulic-ram pump. Designing a cake-pumping system requires careful evaluation and consultation with equipment suppliers, as very high pressures can develop due to the extreme viscosity of dewatered sludge cake. Pumping offers the advantage of totally enclosed conveyance and operational simplicity.

Despite centrifuges' mechanical complexity, routine maintenance is relatively simple. The manufacturer's service department usually performs the major maintenance or repair work needed for such systems. Because the bowl, scroll, and solids-discharge ports are subject to abrasive wear, manufacturers have incorporated hard surfaces and replaceable components in critical areas. These improvements, along with enhanced grit removal systems, have lengthened the operating life of centrifuges between major overhauls of the large rotating parts.

Structural support systems for centrifuge installations are similar to those required for belt filter press systems and less complex than those needed for recessed-plate systems. Although a large centrifuge may require structural modifications to add mass below the machine supports, installation generally is the simplest among the three major mechanical dewatering devices. Centrifuges also require the least space for equivalent dewatering capacity. A

Figure 3. Typical Solid Bowl Centrifuge



bridge crane or lifting system is helpful for removing the bowl and conveyor.

Recent Developments

Belt press and centrifuge manufacturers continue to make incremental improvements in equipment design, especially with respect to increasing cake solids. Centrifuge manufacturers began incorporating high-solids technology around 1992, primarily in response to innovations enabling belt filter presses to produce a higher-solids cake. A high-solids centrifuge incorporates improved wear-resistance features, faster bowl speed (and, therefore, a higher G force), a higher torque rating for scroll conveyors, and better control of differential speed to hold solids in the machine longer.

Belt press manufacturers are responding with presses featuring panel enclosures to control odor and contain spray. Newer designs incorporate longer gravity drainage sections and more pressure rollers to improve dewatering performance. Given these developments, side-by-side comparisons would be necessary to determine whether belt filter presses or centrifuges would produce higher solids or use less polymer.

The basic recessed-plate filter press has remained unchanged for some time. However, a recent development involving membrane filter presses is intriguing. A membrane filter press is a type of recessed-plate filter press that uses a pressurized membrane to squeeze additional water from the filter cake. Air or water typically is used to pressurize the membrane. However, by using hot water as the squeeze fluid in the membrane and simultaneously pulling a vacuum on the filtrate lines, it is possible to achieve more than 95% solids before discharge from the press. In addition, the desired dryness may be selected based on cycle time under drying conditions. This system also offers the potential side benefit of clean release using polymer conditioning. The temperatures used pasteurize the sludge to meet Class A biosolids criteria for pathogen reduction. Untreated sludges would have to be dried to 90% total solids to meet vector attraction requirements, but stabilized sludges could be discharged at a lower solids content. No installations have adopted this technology for use on wastewater sludges, and capital and operating costs need to be analyzed, but the potential to produce a dewatered Class A sludge cost-effectively without double or triple handling is worth investigating. Centrifuge manufacturers also are developing an *in situ* drying system.

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