Comparing PD Pump Designs for Transferring Dewatered Sludge Cake

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An explanation of various positive displacement pump designs, their respective justification, and the compromises associated with each design. By understanding these limitations, specifiers can better decide which design best meets user expectations regarding performance, maintenance, installations costs, operating costs and biosolids characteristics.

The concept of using a positive displacement pump to transfer dewatered biosolids, commonly called *sludge cake*, is not new. However, the designs of the pumps used have evolved to increase their utility and reliability and have fallen in and out of favor for a variety of reasons.

Justification for Pumping

Using pumps to convey sludge cake offers numerous advantages over using conveyors for the same purpose. Because pumps can move cake through vertical sections of pipe, they can consume much less volume in a building than a conveyor that is limited in its degree of incline. Enclosing cake in a pipe is also much cleaner and eliminates all of the bearings and other wear points associated with a conveyor.

The tradeoff is that a typical pump is more technically complicated to apply and maintain than a conveyor. Pump speeds must also be matched to the output of the dewatering device, which can either require some extra labor, increased investment of an automated system, and/or increased maintenance skills.

Due to the viscosity, fibrous nature and high pressures associated with pumping sludge cake, only positive displacement pumps can be considered. All positive displacement pumps capture liquid in a defined cavity. Due to the high apparent viscosity of sludge cake, two major considerations are important in any pump design:

- The design must incorporate a mechanism to feed the material into the pump cavity, because atmospheric pressure will not be sufficient to move the cake through the restrictions that typically block the entrance to the cavity.
- The internal mechanisms in the pump must be relatively free of restrictions that increase backpressure when moving such a viscous product.

The most common reciprocating design is a type of piston pump adapted from designs typically used for pumping concrete. These pumps require some sort of screw feed device and a non-restrictive check valve system to accommodate the two requirements listed above.

Of the rotary PD pumps, the most commonly used is the progressive cavity (PC) design. Since PC pumps have cavities that are sealed by a compression fit between the rotor and stator, no valves exist to restrict the discharge. Various feed mechanisms are used on the inlets of these pumps.

Feed Mechanisms

The feed screws used to feed both of these designs really have two functions: to push the cake into the cavity and to lower the apparent viscosity of the cake.

Sludge cakes, like most water-borne slurries and sludge, are non-Newtonian liquids and are shear thinning. They are generally considered to be “thixotropic,” meaning the viscosity thins with both the amount of the shearing force and the length of time that the shearing force is applied.

Naturally, the thinner the liquid, the faster it can flow through the restrictions that block the entrance into the pump cavity. A suitable analogy would liken the entrance into the cavity of a positive displacement pump to the hole in the bottom of a Zahn cup that measures the viscosity of paint thinned for use in an aerosol spray gun. The thinner the liquid, the faster it flows through the hole. The lower viscosity measurement will be registered in SSU (Seconds Saybolt Universal).

The pump cannot move the liquid internally any faster than atmospheric pressure will allow the liquid to flow through the restrictions on the inlet side of the cavity. If the viscosity can be lowered, then the amount of time to fill the pump cavity can be reduced and the cycling activity of filling cavities can be increased.

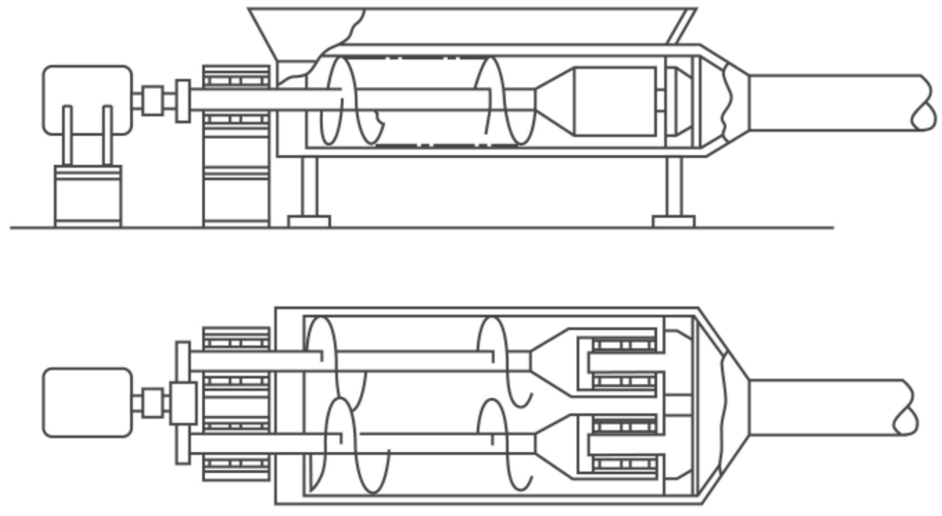

Figure 1. Schematic of a screw feed device used on either a piston or PC-type cake pump. A motor, speed reducer, timing gears, four sets of bearings, and at least two sets of stuffing boxes are required. The device is really one pump designed to feed another pump with higher-pressure capabilities.

Functionally, this means that the pump speed can be increased and a smaller, less expensive pump can be used if the cake apparent viscosity can be decreased. Again, the feed devices used on these pumps can have two functions: to fill the cavity and reduce the viscosity of the cake. This is a major difference between the function of the screws in a piston pump and their function in a PC pump.

Piston pumps typically use feed screws to fill the cylinder without creating a great deal of shear, while PC pumps typically use devices that try to minimize the viscosity of the cake. Increasing the diameter of the cavity and reducing intake restrictions is easier and often more advantageous for piston pump manufacturers than for a PC pump OEM. Conversely, adding a feed auger to the already rotating coupling rod on the inlet of the pump is easier for the PC pump manufacturer. For a piston pump OEM, a separate rotating auger mechanism must be added to feed the reciprocating pumping mechanism.

The tradeoff here is that the piston pump is almost always more expensive and has more moving parts, but the cake being discharged from this pump is usually of a higher viscosity. A typical complaint with a PC pump is that its cake looks runny and acts more like a liquid than a cake. Note, though, that the solids percentage has not been reduced. No water has been added. In a few hours, the sludge will revert to a more cake-like condition.

But without precautions, the cake from a PC pump can cause more of a housekeeping problem. To some users, this is an advantage: when filling any container, including a dump truck, a more liquid-type product has fewer air pockets and flows easier into corners than a true cake. However, some landfill operators may want a more cake-like product.

Continuous vs. Pulsating Flow

Another big difference between PC pumps and piston pumps is evidenced in system pressures. PC pumps produce flow on a continuous basis. In theory, they should not pulsate. In practice, air pockets are often captured in cake as it falls from a

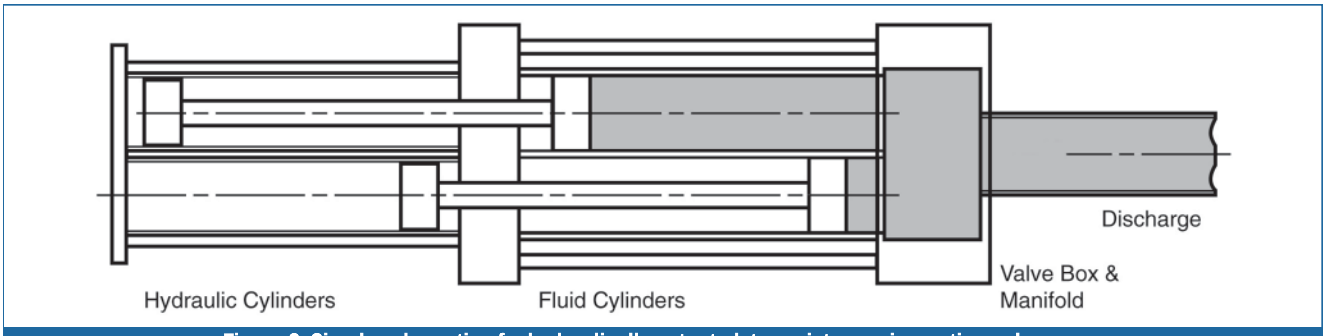

Figure 2. Simple schematic of a hydraulically actuated, two-piston reciprocating cake pump.

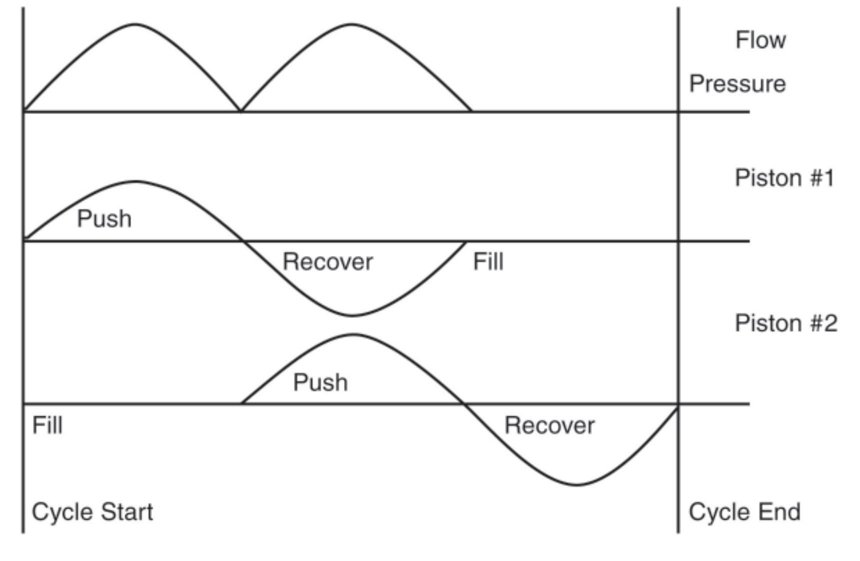

Figure 3. Typical velocity and flow profile with a reciprocating piston-type cake pump.

centrifuge or belt press into the pump. The air gets compressed and sometimes collects before it can be expelled, making it often seem as though the pump is pulsating. The pump does not really pulsate; it continually pumps.

Reciprocating pumps pulsate. Each cylinder must be evacuated. The piston must recover its entire length, then the cylinder must be filled. Most reciprocating piston pumps are hydraulically actuated. They often remain in an open position to allow filling for an extended period, compared to a mechanically operated reciprocating pump, where pistons simultaneously pump and recover.

This results in a relatively sporadic discharge from the end of the pump. The screw takes some time to feed and fill the piston. The piston must accelerate to a midpoint, decelerate to a stop and recover in the opposite direction, but with the same velocity profile. This not only results in sporadic flow, but the peak velocities must also be a minimum of twice the average of a constant flow profile – and they can reach three times that of a constant velocity pump due to the fill time.

Piston pumps must inherently generate two to three times the pressure of a PC pump to produce the same flow rates per minute or per hour as that of a PC pump for the same application. Piston pumps can no doubt generate more pressure than a PC pump, and an eight-stage or nine-stage PC pump is not typically recommended for any run of pipe longer than 450 linear feet, unless a boundary layer injection system is used.

Typically a PC pump manufacturer tries to size the discharge pipe for only 1-psi/ft of pipe and use a larger pipe diameter than a piston pump manufacturer. The piston pump manufacturer may recommend 2-psi/ft of pipe friction loss and a smaller pipe size because they can generate more pressure.

Pipe Sizing

I have a firm stance regarding pipe diameter sizing. In a PD pump (GPM x psi)/1714 = HP, so any decrease in pressure results in a power savings, along with less wear and tear on the pump.

A designer should take any opportunity to reduce wear and tear and power consumption, so selecting a larger pipe diameter always yields a long-term savings. Going to larger pipe sizes certainly diminishes the return, but this is an easy exercise to undertake and must be done on every cake pump application.

Nomograms estimate friction losses for sludge cake in pipe, but some quick rules-of-thumb can also be used for initially estimating friction losses. For sizing PC pumps, I recommend an estimated apparent viscosity of 250,000-cPs for 20 percent solids and 450,000-cPs for 30 percent solids with a simple computer program utilizing the well-known Hazen and Williams formulas.

This rule has proven relatively successful over time as an initial estimate. Most pump manufacturers offer demonstration or trial equipment, and it is always desirable (if possible) to run a trial with a length of straight pipe to measure friction loss and infer an apparent viscosity.

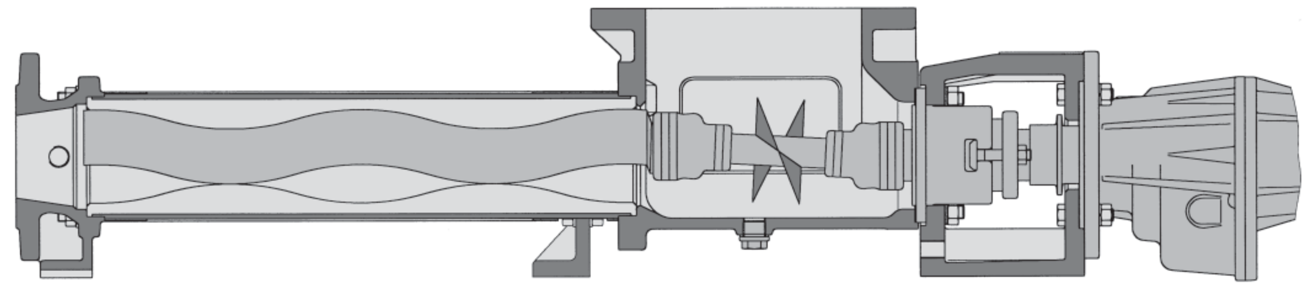

Figure 4. The most basic open hopper PC pump design.

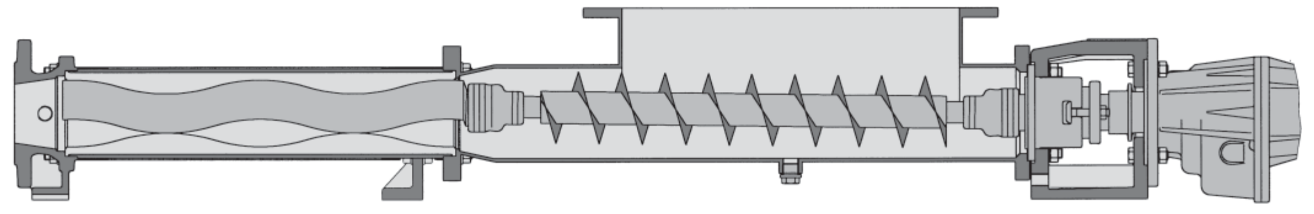

Figure 5. The next generation PC pump design.

PC Pumps

The feeding mechanisms in progressive cavity pumps have changed substantially over the last two decades and are headed in at least two different directions. One direction is towards more positive feeding. The other is towards higher shear forces to further reduce apparent viscosities.

The original pumps used 40 to 50 years ago had simple open inlets with an auger welded to the eccentrically rotating coupling rod, between the drive shaft and the rotor. The most basic open hopper PC pump (see Figure 4) has an auger on the coupling rod, no extension tube, and cast iron fixed dimension inlet housing. This design is suitable for discharge from gravity thickeners and solids of no more than 10 percent.

The next generation PC pump (see Figure 5) typically included an extension tube that enclosed the auger in an area between the inlet hopper and the cavity created by the rotor and stator. The auger is designed to feed at a rate about 30 percent greater than the capacity of the pumping cavity to ensure more positive feeding. The circulation of the cake in the extension tube imparts additional shear that helps to reduce the apparent viscosity of the cake and promote better filling of the cavity.

This design is often provided with a fabricated housing that allows the sludge cake to fall vertically into the pump, instead of building up on the sides of a shallow sloped transition hopper in a standard housing. This design could handle sludge to about 17 percent and works very well on the discharge from gravity thickeners.

Counter-rotating bars with paddles were added to the pumps to prevent bridging of sludge cake above the feed auger (see Figure 6). Without these bridge breakers, it was common for the auger to drill a hole in the cake. But when placed in close proximity to the auger, these bridge breakers could generate substantial amounts of additional shearing energy that could also significantly reduce the apparent viscosity of the sludge cake.

This design was generally effective at handling centrifuge discharge at over 35 percent solids. It has also been successfully used to mix calcium oxide (CaO) into the sludge to produce an exothermic reaction in the sludge, or increase the pH significantly to produce a Class B or Class A biosolids. Total solids could exceed 52 percent.

The most effective of these designs include a separate variable speed drive for the bridge breakers (since their primary role is to generate shear), while the pump speed can be regulated to meet the discharge rate from the dewatering device.

Until about ten years ago, all PC pump manufacturers had similar designs until some of them decided to adapt the system used by piston pump manufacturers. The advantage of this approach is that the screw feed mechanism can be conveniently located directly below the discharge of the dewatering device and the pump, like a piston pump, can then be placed in a more suitable position.

The unfortunate aspect of this design is now the user really has two pumps to maintain. The screw feeder must now generate a positive pressure that not only pushes cake into the pumping cavity, but also overcomes any friction loss in a transition chamber or pipe between the screw feeder and the pump. This is a difficult job for a simple screw-feeding device.

As a result, these twin-screw feeders have become quite complicated and maintenance-prone. Each shaft must be reinforced with bearings, driven with a motor and gears and sealed to prevent leakage. Naturally, bearings are not typically designed to operate in an environment of pressurized sludge,

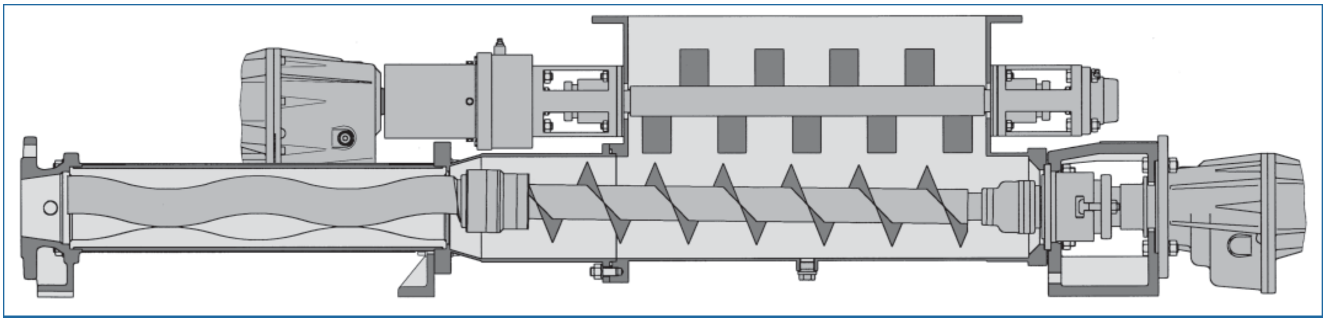

Figure 6. Counter-rotating bars with paddles, or bridge breakers, were added to the pumps to prevent bridging of sludge cake above the feed auger.

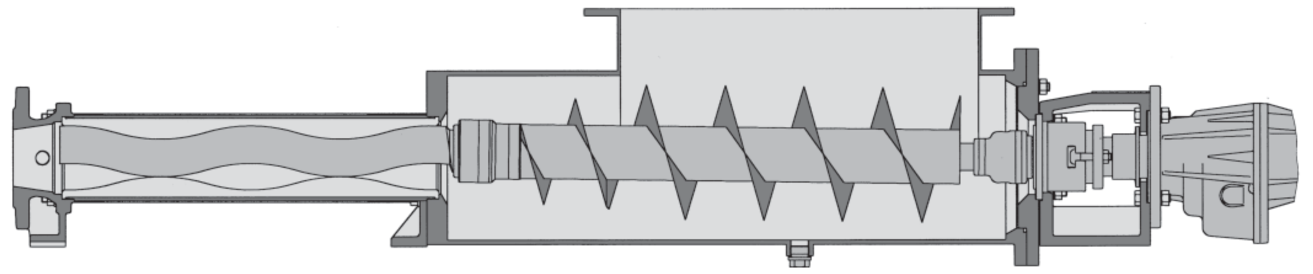

Figure 7. An enlarged auger, attached to the eccentrically rotating coupling rod, and an enlarged extension tube allow a feed rate on the auger that is 3X greater than the capability of the pumping elements.

so they become a constant point of maintenance concern.

Progressive cavity pumps have many unique characteristics. The cavity created between the rotor and stator does not change its shape as it moves through the pump. It has no valves. It does not inherently pulsate. It has relatively low internal velocities because the rotating parts have relatively small diameters and it is a pump designed with a bearing on each end. On the end with the motor, the pump has traditional tapered roller bearings, lubricated with oil or grease, like any other rotary pump.

On the other end, the polished and hardened helical rotor is rotating inside a rubber-lined tube. In other applications, this configuration is easily recognized as a marine bearing that is common in marine vessels ranging from 21-ft inboard ski boats to Dallas-class attack submarines. Rubber, with water as a boundary layer, is amazingly slippery. All of the progressive cavity pump manufacturers, at least in their early years, purchased stators from manufacturers of marine bearings.

As such, this bearing provides an excellent support for a feed and/or shearing auger that enables the PC pump to handle sludge cake and other highly viscous products, without adding additional wearing parts or maintenance points. Though it contains as much as 40 percent solids, sludge cake is still mainly water and maintains the lubricating qualities that allow the stator to operate as a marine bearing.

The cake handling capabilities of the PC pump are easily improved by using the eccentrically-rotating coupling rod and any attachments (like an auger) to more efficiently reduce the apparent viscosity of the cake so that higher viscosities and solids percentages can be pumped.

By increasing the diameter of the auger and the extension tube so that it overfeeds at a rate of 200 percent instead of 30 percent, the cake is circulated and sheared a great deal prior to entry into the pumping element. During the past ten years, this common design has proven quite acceptable and reliable for handling the discharge from belt-filter presses at solids percentages approaching 30 percent.

An enlarged auger attached to the eccentrically rotating coupling rod and an enlarged extension tube allow a feed rate on the auger that is three times greater than the capability of the pumping elements (see Figure 7). Circulation of the cake in the extension tube dramatically reduces the apparent viscosity of cakes up to 30 percent solids so they can be easily pumped. Still, this pump only requires one stuffing box and one set of bearings, both being subjected to only atmospheric pressure.

However, industry constantly demands more efficient dewatering devices to reduce the amount of water that must be transported in sludge cake, thus requiring the feed mechanism into the pump be made increasingly more efficient and effective.

Because the rotor in the pump has to rotate eccentrically, no method really exists to attach an auger to the coupling rod and create a truly positive pressure in the extension tube. Here, the auger feed system used in a piston pump has a clear advantage. The latest design for PC pumps overcomes this limitation (see Figure 8).

By adding a ribbon auger that is attached to a plate fixed to the pump drive shaft, behind the concentrically rotating universal joint, a true feed auger mechanism can now be available in a PC pump without having to add an expensive, maintenance prone separate feed auger system. This device allows the PC pump to easily handle biosolids up to 40 percent.

Again, the pump can be fabricated so the hopper matches the discharge dimensions of the dewatering device. The auger feeds at almost five times the capacity of the rotor and stator. A

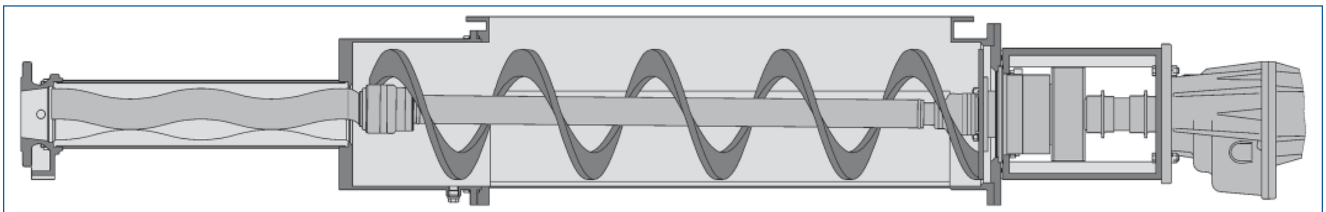

Figure 8. A true feed auger mechanism can be available in a PC pump by adding a ribbon auger attached to a plate fixed to the pump drive shaft behind the concentrically rotating universal joint.

thick urethane liner in the hopper of the pump supports it. To date, none of the liners, with installations exceeding four years in operation, have ever required replacement.

A variant of the cake pump with a concentrically rotating auger has a separate variable speed drive dedicated to the auger (see Figure 9). The auger can then be not only used to feed material into the pumping cavity, but it can be also used as a separate shear inducing or mixing device.

This design can be used to add calcium oxide or calcium hydroxide for treating biosolids. Industrially, it has been used to handle pigments discharged from plate and frame filter presses that exceed 75 percent solids and to mix milled grains with hot water to prepare "wort" in breweries and distilleries. It is also being used to handle spent grain discharged from centrifuges in ethanol plants.

Boundary Layer Injection

Another common appurtenance used when pumping dewatered biosolids is a boundary layer injection system, which consists of an injection pump and an injection flange designed to insert a layer of liquid between the pipe wall and the slug of sludge moving through the pipe.

Piston pumps must inherently generate two to three times the pressure of a PC pump to produce the same flow rates per minute or per hour as that of a PC pump for the same application.

These systems can typically cut the friction loss associated with pumping sludge cake to one-half or less. In certain cases, especially when a highly diluted solution of polymer flocculent is used as the boundary layer, friction loss can be reduced by as much as 85 percent. These can be used really on any type of cake pump, as it affects the piping system and not the pump. Except as mentioned above, it reduces the differential pressure, which in turn reduces the operating power required and wear and tear on the entire system.

Conclusion

Cake pumps require some type of feed device to push dewatered solids into the pumping cavity of either a piston-type or a PC-type cake pump. The device can help to reduce the apparent viscosity of the cake as well as feed it into the pumping cavity.

The efficiency and characteristics of this feed device can define the character of the cake that is discharged into a storage or transport device. High shear feed devices will produce

Figure 9. A variant of the cake pump with a concentrically rotating auger has a separate variable speed drive dedicated to the auger.

a cake that is temporarily a lower viscosity, which may be aesthetically undesirable. Using equipment that is designed for higher capacities and will operate at lower speeds and shear rates can reduce this effect.

Piston pumps are designed to handle higher pressures and to pump cake over longer distances through smaller diameter pipes than PC pumps. A comparison solely based on pressure capabilities of the two designs is not appropriate, since PC pumps produce a constant output with pressures being one-half to one-third of the pressure spikes that occur as a function of the varying velocities and flows associated with reciprocating pumps.

The feeding systems used on all of these pumps vary a great deal. Some are quite complicated and trade some of the problems associated with highly sheared, low viscosity cake discharges with complicated, maintenance prone feed systems that amount to using two pumps where one pump can be effectively used.

Using appropriate shearing and feeding devices, along with boundary injection systems, pressures can be minimized and cake can be pumped over substantially long distances (exceeding 2,000-ft) with relatively inexpensive, efficient and reliable equipment.

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