

PUMPS & SYSTEMS

ROTATING EQUIPMENT

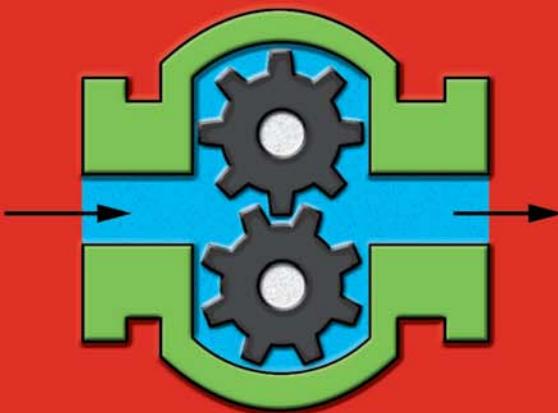
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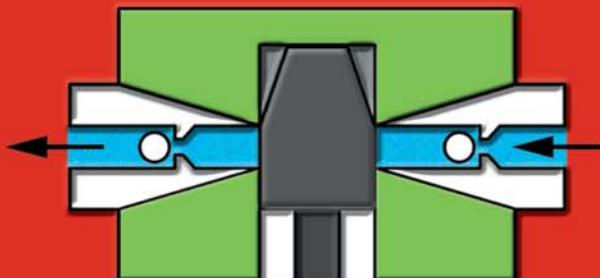
PCs and other
rotary PD pumps:
affordable and
cost-justifiable
solutions for metering



Minimizing the potential
for system failures
by your approach to
coupling alignment



Successful tools
and techniques—
how Aramco
continues to use
life cycle “engineering”
to grow its profits



Using PC Pumps and Other Rotary PD Pumps for Metering

Advances in technology now make these pumps an affordable and cost-justifiable option for just about any metering application.

Michael L. Dillon, President, seepex, Inc.

They don't pulsate. They can pump thick liquids. They have no valves to foul. They're rotary positive displacement pumps, and these days they're being used more and more in metering applications. That's because the combining of rotary pumps, like progressive cavity and gear pumps, with newly available drive, instrumentation and flow measuring technologies has resulted in PD pumps capable of delivering similar, or even superior performance to that of reciprocating pumps.

Here's How They Work

All positive displacement pumps,

both rotary and reciprocating, capture liquid in a defined cavity (Figure 1). These cavities are carried through the pump into the discharge piping, where the cavity is exposed to the operating discharge pressures. If the cavity is completely filled on the inlet side of the pump and there is no internal leakage in the pump, the pump will consistently deliver fluid from suction to discharge. The level of consistency of the discharge or the lack of variance in the discharge is generally regarded as the measure of the pump's ability to meter the volume delivered.

Traditionally, reciprocating pumps have been used to deliver variable controlled flow volume. This was

generally achieved by changing the stroke length of the piston movement to alter the size of the pump cavity (Figure 2). The stroke adjustment mechanism was typically less expensive than a mechanism that changed the number of strokes delivered per unit of time.

Most rotary pumps don't have the ability to change the volume of the cavity, but they can change the number of cavities delivered per unit in time. Because changing speed was generally more expensive than changing the stroke length, reciprocating pumps were more economical than rotary pumps for metering. Over the last few decades, though, electronics technol-

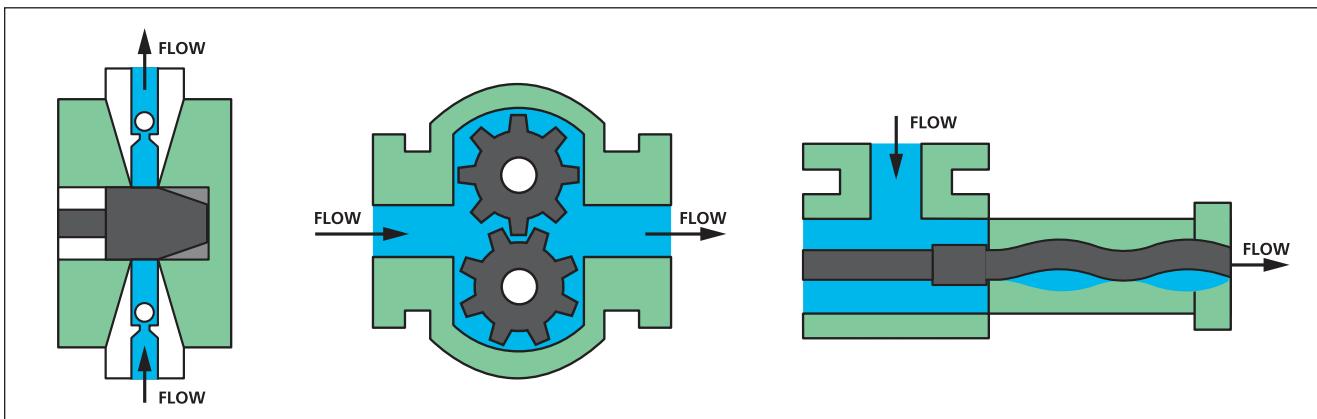


Figure 1. All positive displacement pumps capture liquid in a defined cavity.

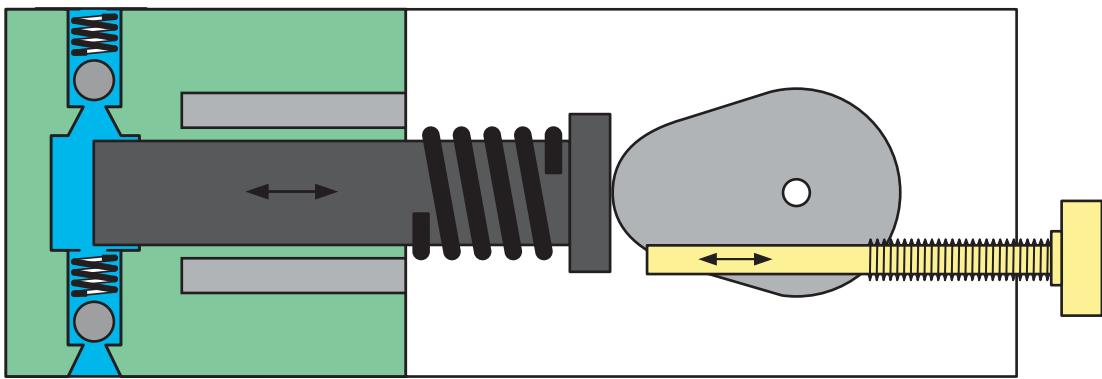


Figure 2. Stroke adjustment mechanism in a controlled volume reciprocating pump

ogy has been reducing the cost of varying the speed of electric motors, and increasing the use of automated or centralized control systems. The need for users to automate and control has tended to equalize the economics between the reciprocating and rotary pump designs, since both now use the same technologies to vary the delivery rate.

Design Differences

Reciprocating pumps generally:

- have the ability to reach higher differential pressures;
- are not dependent upon fluid viscosity to form a seal between the stationary and moving parts in the fluid end of the pump; and
- are especially good at preventing back-flow or "slip" in the pump, making output more linear with speed.

Rotary pumps generally:

- have reduced pulsation of the flow;
- have better net positive suction head capabilities that enable them to handle higher viscosity fluids;
- may be able to handle solids; and
- have no valves to clog, foul or leak.

Rotary pumps also have the capability for wider turndown or flow range capabilities when compared to reciprocating pumps that only use variance of the stroke length to achieve different flows. Additionally, many rotary pumps can reverse the direction of flow by reversing the direction of motor rotation. Due to internal valves, this can't be done with reciprocating pumps.

One of the problems with reciprocating pumps is pulsating flow. Because the piston or diaphragm in

a reciprocating pump is actuated by a cam or eccentric section of a rotating shaft, the actuating component during each stroke accelerates to a maximum velocity in mid-stroke and then decelerates to the end of the output stroke. The same action occurs on the inlet stroke, but there's no fluid output. The velocity of the fluid is similarly affected. The fluid has zero velocity and flow, followed by increased velocity and flow, followed by decreased velocity and flow, followed by a long period of no velocity or flow (Figure 3).

Normally, users request a certain repeatability of flow or degree of variance from a metering pump. While reciprocating pumps may be very good at producing repeatable flows over long periods of time-like a minute or an hour or a day-they're not very good at producing repeatable flows in short periods of time, like a second or a fraction of a second. This problem could be minimized (but not eliminated entirely) using multiple pistons or diaphragms. Such methods, though, would increase the cost of the pump significantly and remove the possibility of using conventional stroke length adjustments to vary flow. There are, however, some radial piston

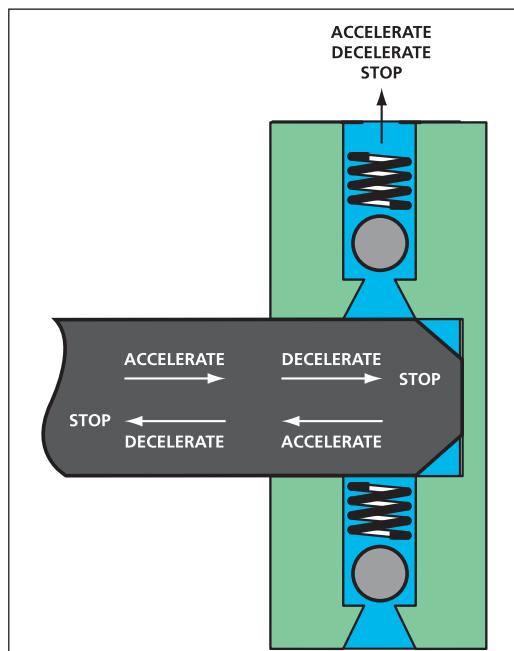


Figure 3. Changes in velocity in the reciprocating member of a pump translate into varying flow velocities in the pump discharge.

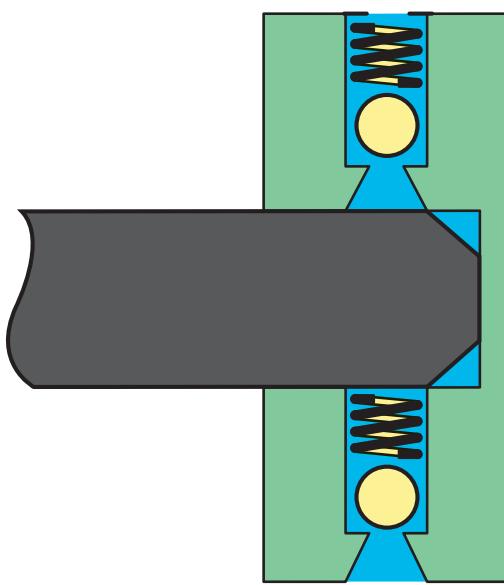


Figure 4. Valves act as a restricting orifice into pumping chamber.

designs that use a variable swash plate to vary stroke length—but, at an increased price.

A common alternative is the use of pulsation dampers, which act like mufflers. The more the user dampens the output, the higher the demand he/she places on the efficiency and longevity of the pumping system.

Gear, lobe, sliding vane and flexible impeller pumps all discharge multiple cavities during each revolution, so they have performance equivalent to reciprocating pumps with multiple pistons. Screw pumps and progressive cavity pumps have discharge flow profiles that essentially have no pulsation.

Although this article focuses on progressive cavity pumps, with some limitations, most of the following techniques are applicable to other rotary positive displacement pumps.

What's Different About PCs?

Progressive cavity pumps are somewhat unique because they generally employ a compression fit

between the rotating pump member and the stationary pump member that is most often constructed of a synthetic elastomer. Other rotary pumps use similar construction, including rotary lobe pumps and gear pumps which coat the rotating member of the pumping elements with an elastomer. The compression fit reduces slippage or back-flow in the pump, so the performance curve is more like a reciprocating pump with valves on thin viscosity liquids.

As fluid viscosity increases, a tolerance fit can be used, and both the rotating and stationary components in the pumping elements can be made of rigid materials like metals or thermoplastics. Amount of slip in all cases is a function of viscosity, internal tolerances and differential pressure. In the case of pumps with elastomeric components, hardness of the elastomer also affects the amount of slip in a given application.

Controlling "Slip"

The presence of slip in rotary PD pumps is often cited as a reason to avoid them on metering applications. However, reciprocating pumps are also prone to back flow or slip. This is basically a function

of how well and how quickly the check valves seat and seal. If the discharge valves do not immediately seat during the intake stroke, a portion of the pumped liquid will slip back into the pumping chamber.

Most of the more expensive reciprocating metering pumps will use strong springs to effect positive sealing in the valves. Some will even employ tandem valves to minimize back-flow on both the suction and discharge sides of the pumping cavity. While this ensures a more predictable flow, it also increases the amount of work done by the pump, as well as manufacturing costs and absorbed power requirements. Moreover, adding components to any mechanical system increases the likelihood of mechanical failure. Certain reciprocating pumps, such as air or mechanically operated double diaphragm designs, do not use springs at all to effect proper seating of the valves. Seating is accomplished with simple ball check valves or rubber flapper valves that rely on gravity and the differential pressure to properly seat. In these units, there is always some slippage in the pump that is affected by fluid viscosity and the differential pressure.

Valves on the intake side of the pump also impede the flow of material into the pumping chamber, increasing the net positive suction head required, NPSH_r (Figure 4). This is accentuated with higher viscosity fluids.

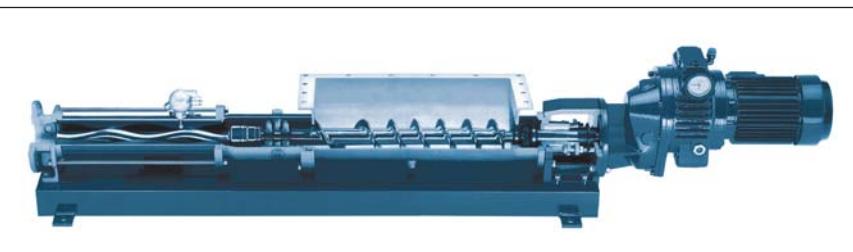


Figure 5. Open hopper progressive cavity for viscous materials

Viscosity Issues

All positive displacement pumps have to run at a lower speed as the viscosity of the fluid increases. The inlet into the pumping chamber is an orifice. The more restrictive the design of the orifice, the longer it takes for material to fill the pumping chamber.

There are really only two ways to solve this problem: either slow the pump to a lower speed to allow enough time to fill the pumping chamber, or change the design of the entry orifice so there is less restriction. The usual way of altering this design is to use a larger pump that has a larger entrance port and operates at a slower speed. Some rotary pumps (lobe pumps and progressive cavity pumps) are available with optional square or rectangular inlets that significantly open up the inlet into the pumping chamber so very viscous materials can be pumped and metered (Figure 5). If the pumping cavity is not filled and the pump cavitates, flow can't be controlled.

Cavitation Issues

Cavitation can be very difficult to recognize in reciprocating pumps. In PCs, gear pumps and screw pumps, cavitation is normally recognized by pulsing flow. Since reciprocating pumps pulsate anyway, cavitation is normally recognized only after the pump has been damaged, or often by the presence of "knocking noises" in the pump. Knocking noises occur as material vaporizing from the pressure drop coming through the entry orifice collapses back into a liquid as it is pressurized in the pumping chamber. Because many metering applications are for low flows and use small pumps knocking noises often go undetected.

While valves have the definite ability to eliminate slip, making the prediction of the flow rate easier, they also contribute to cavitation,

making the prediction of the flow rate more difficult. Valves also add another mechanical component to the pumping system that can fail. Any problem with the valves negates the metering capability of a reciprocating pump.

Case History: Hypochlorite Metering

A large East Coast electric utility had been using mechanically actuated diaphragm pumps to feed sodium and calcium hypochlorite into its intake water lines to kill algae and mussels. But these pumps would routinely vapor lock when the liquid in the feed tanks went below a certain level. A secondary problem with this application was the free chlorine gas that was frequently present when these pumps were disassembled. Maintenance personnel complained of headaches, nausea and nasal or lung irritations after repairing the pumps. After checking references from a hypochlorite producer that had replaced centrifugal pumps with progressive cavity pumps due to high shear, the utility elected to try the PC pumps. Since installing the PC pumps, the utility has experienced no "gas" locking problem at this site. The utility has since installed more PC pumps on hypochlorite service in other power plants.

The Real Problem

It's apparent that the real problem with rotary PD pumps is slip. Pump design, differential pressure and the material being pumped have dramatic effects on the amount of slip. For materials of moderate viscosity (200-2,000 cPs), gear pumps can be used reliably for metering applications. Due to internal clearances, though, they're not reliable for metering thin fluids like water, alcohol or ketones. On the other hand, rotary PD pumps with a compression fit between the stationary and rotary parts (ie. certain lobe pumps, some gear pumps and PCs) can be used

for these applications.

There are some large screw pumps and gear pumps used for metering of thinner fluids that do not use a compression fit in the pumping elements. By using very precise machining methods, the internal tolerances are held to a very small limit. These pumps tend to be quite expensive and are used for either very high flow rates or differential pressures (like fuel transfer from tankers), or for very aggressive chemicals that attack elastomers.

Controlling Slip Electronically

Electronics technology now offers a range of solutions-varying in complexity, cost and degree of accuracy-for controlling slip in rotary PD pumps. As these technologies become more common, the expense and complexity of these solutions will decline.

Variable Speed Drive Options

The least expensive method of controlling slip is to use a variable speed drive, so that flow is predictable even though not directly correlated with speed. This can be done with a calibration tube on the inlet side of the pump to measure actual flow rates. Using a programmable calculator and matrix algebra, the performance of the pumping system on a particular liquid can be defined. Then a curve can be generated that shows the speed required to meet a specific flow requirement. The author described this technique almost two decades ago in a previous article (Ref. 1).

By calculating the flow curves for two different speeds, with a minimum of three pressure data collection points for each curve, flow rate can be calculated through interpolation if the speed and differential pressure are known. This is probably the least expensive way to

meter differing flow rates with a rotary PD pump. A different calibration should be made for each different pumped fluid to allow for the effect of differing viscosity on slip and performance.

Some sort of tachometer is required to accurately measure the rpm. It can be part of the drive, an inductive pick-up on the motor, gear or pump shaft or a hand-held portable unit; but it must provide a discrete parametric output.

The key to any metering system for a rotary pump is the feedback system that assures that the pump is operating at the required speed to produce the desired flow rate. Variable speed AC and DC drives have become very sophisticated, reliable and economical, with the capability to add a number of feedback signals.

In smaller power requirement applications, DC drives are the best choice. They are typically less expensive in these ranges and offer very high turndown ratios with excellent starting torque capabilities with a wide variety of commonly available options and accessories. Typically, a SCR (Silicon Controlled Rectifier) or a PWM (Pulse Width Modulated Rectifier) changes AC current into DC current in the motor controller. The SCR unit is usually the least expensive option. Today it's common to find SCRs capable of providing a 50:1 turndown ratio. PWM units can typically offer wider turndowns (100:1 is common) and use less energy.

Drive Accuracy Is Important

When selecting a DC drive, it is important to recognize that the accuracy of the drive is defined by its ability to hold a given speed. One of the problems with DC motors is that they tend to slow down as loads increase. In a motor, this slowing is also referred to as "slip". Load will

change in the motor if viscosity or pressures change in the pumping system. While the drive may be promoted as having no more than a 1% or 2% variation in speed, the fine print will define this as a percentage of the base motor speed. If speed of the motor is 1,750 rpm, then the drive is only guaranteed to have a speed fluctuation of no more than 15.5 rpm. With a SCR that has a 50:1 turndown ratio, at the low speed of 35 rpm, a 15-rpm fluctuation could mean a speed or flow inaccuracy of 43%.

Two types of control feedback accessories are commonly used to counteract slip. The less expensive system is a "current feedback loop". This device compares the current used in both the rotating (armature) and stationary (field) windings in the motor to match current with load demand to provide stable motor speed. This will generally enable the drive to be accurate within 2% of the selected speed over the drive's entire turndown range.

A second type of feedback is a tachometer feedback loop. Here, a tachometer is furnished with the motor and the actual motor speed is provided to the drive electronics. The drive will then modify the current to supply the correct speed. While both analog and digital tachometers and drives are available, they have the same inherent function. Just make sure that a digital drive is used with a digital tachometer and vice versa. Programmable meters enable users to not only see readout performance in rpm, but other engineering units as well.

Almost all variable frequency drives (VFDs) offer internal feedback loops to minimize motor slip, which also occurs in AC motors. Users don't have to worry about purchasing a number of options to make the drive suitable for a metering pump application. The main limitation of AC drives

is their turndown ratio. Without external constant speed blowers on the motor, most VFDs used on fan-cooled motors are limited to a lowest operating frequency of 10 Hz. The motor runs at such a slow speed that the fan will not blow sufficient air across the motor to cool it. These units can only provide a 6:1 turndown ratio.

Positive displacement pumps are constant torque devices and VFDs used to drive them need to provide constant output torque. (A constant torque drive can be used up to 100 Hz as a constant horsepower drive. If used as such, with a four-pole induction motor, operating at 3000 rpm, this will allow a 10:1 turndown ratio. This is actually better for the motor as it will run in a cooler environment.) A more expensive, high performance version of the VFD, called a Vector Drive also has become available. Their integral feedback systems make them very accurate. They also use TENV (totally enclosed non-ventilated) or TEBC (totally enclosed blower cooled) motors. These drives offer maximum performance with turndown ratios as high as 1000:1.

The new AC and DC drives with higher turndowns allow speed reduction to be accomplished electronically with enough performance to also provide flow variation, thus eliminating the need for mechanical speed reduction. The customer can gain a higher performance variable speed system with fewer components at a price comparable to a fixed speed system.

All of these systems require users to occasionally, but regularly, recalibrate their pumps. This is true for any pump. Internal components, including valves and valve seats, can wear, or fluid rheology may change, affecting the pump performance.

The final word on using rotary pumps for metering applications is the use of a flowmeter feedback loop to the drive. Most electronic

flowmeters offer output signals that are compatible with both AC and DC electronic drives. Although some drives have integrated proportional integral derivative (PID) controllers, stand-alone PIDs can be used on any drive that will accept an external follower signal. This is, most commonly, a 4-20 ma (analog) signal or a 5-volt DC (digital) square wave signal. Again, it's important to make sure that all of the sending and receiving devices are compatible.

With the use of these electronic technologies, a pump can be as accurate as a flowmeter, some of which advertise accuracies with as little as < 0.1% variation.

Case History: Soft Drink Production

One of the country's largest soft drink bottling plants was becoming "locked-in" by residential development of surrounding properties. In the past they had always produced a syrup from concentrate and stored it in large vats. From the vat it was sent to the bottling line where it was diluted with carbonated water.

As the number of products to be bottled increased (regular, diet, caffeine free, etc.) and as the company bottled other types of beverages, it no longer had adequate physical space to store syrup in vats. At this point the company considered the use of continuous blending systems to make the syrup.

Because consistency in taste and quality are so important in the soft drink industry, the pumping systems used must be extremely accurate and repeatable. For this project, an outside consulting/manufacturing firm provided four skids, each with seven PC pumps. The pumps were all equipped with either vector drive AC or PWM controlled DC motors. The output of each pump was monitored with a coriolis type flow meter and flow rate was determined by computer.

Coriolis meters recalibrate a system

several times per second, but they can't tolerate any pulsation. Reciprocating and several rotary pumps could not be used in this application because the system constantly would be correcting itself from reading varying flows. With the new PCs, each different soft drink "recipe" can be programmed into the computer and different ingredient "totes" can be rapidly connected to the system. As a result, this plant no longer requires vats to store syrup and has an unlimited capacity for new types of products.

Summary

New electronic drives now enable rotary positive displacement pumps to offer relatively pulsation-free performance with turndown ratios as high as 1000:1. These new systems allow rotary pumps to compete favorably in price with reciprocating metering pumps. In many ways, they're more reliable than reciprocating pumps. Moreover, in a number of applications, rotary pumps offer more exact metering performance than reciprocating pumps. Coupled with a flowmeter feedback loop, an electronically controlled rotary PD pumping system will self-correct for wear, slip, changes in viscosity and power fluctuations. Electronic advances have gotten these systems down to such an affordable and cost justifiable level that they should be considered for just about any metering application.

References

1. Chemical Engineering, Vol. 92, Issue 15, July 22, 1985 Dillon M., St. Clair K., Kline P., "Predicting Flow Rates from Positive Displacement Rotary Pumps", Chemical Engineering, Vol. 92, No. 15, pp. 57-60, 1985.

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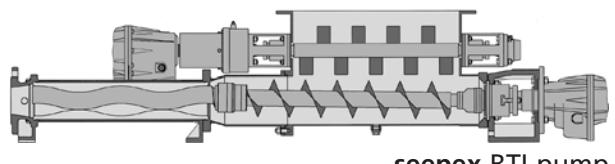
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