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Positive Displacement vs. Centrifugal Pumps In Transfer Operations in Chemical Manufacturing

CENTRIFUGAL PUMPS HAVE A LONG HISTORY OF USE IN CHEMICAL-MANUFACTURING OPERATIONS, BUT FOR FLUID-TRANSFER APPLICATIONS A BETTER CHOICE IS POSITIVE DISPLACEMENT PUMP TECHNOLOGY

By Edison Brito

Among the many complex operations within chemical manufacturing, "transferring" may be the most important as it has responsibilities all along the chemical-production chain. That's why chemical manufacturers would be wise to consider employing positive displacement pump technology, rather than centrifugal, for their numerous fluid-transferring applications.

Introduction

Chemical manufacture includes some of the most complex industrial processes in the world. In fact, chemical manufacturing processes are so intricate that there are typically several "unit operations" within an overall process. These may include cracking, distillation and evaporation, gas absorption, scrubbing and solvent extraction, among others.

Within that family of unit operations, there is one that that stands out above the others in its importance to the total manufacturing process: Transferring. Simply put, transferring is nothing more than the process of transporting fluid from one point to another. In the real world of chemical manufacturing, however, transferring is so much more.

While many unit operations in chemical manufacturing pertain to one specific application within a much greater whole, fluid transfer is a jack-of-all-trades, with responsibilities all along the chemical-production chain. For example, raw materials can be transferred into storage tanks; the same raw materials can be moved into blending or mixing tanks; final formulations can be transferred into holding tanks; and finished products can be loaded into IBCs for delivery or two-gallon jugs for store shelves, just to name a few.

Because of the importance of the myriad transferring operations within the entire chemical-manufacturing process, facility operators need to identify the best pumping technology for the job, one that possesses the versatility to perform reliably and efficiently at any number of points in the production hierarchy. For many years, the go-to pumping technology for chemical-transfer processes has been the centrifugal pump, but this white paper will show why positive displacement pumps—specifically sliding vane and eccentric disc pump technologies—can, in actuality, be the right pump technology for the right application in chemical-transfer operations.

The Challenge

In the most basic of explanations, the volume of fluid that is sent from Source Tank A will increase in the Destination Tank B - (See Figure No. 1). As this operation takes place, the only variable in the hydraulic system is the static head that will change as the level in Tank A goes down while the level in Tank B goes up.

In many cases, when the tanks are big enough, the variation in the static head is assumed to be insignificant as a centrifugal pump is sized for a specific performance point, but in reality it will work over a range in the curve of its hydraulic performance. The size of this range will be particular for each case and can and should be evaluated.

In the same flow-head graphic, the performance of an equivalent positive displacement (PD) pump can ideally be represented as the yellow line that is designated "QM," which represents what a PD pump has to do to deliver the same volume in the same time as the centrifugal pump would when operating in a specific range. Also keep in mind that PD pumps, and particularly the ones with self-adjusting volumetric efficiency capabilities, like eccentric disc or sliding vane types, will consistently deliver the same flow rate across the pressure variation, regardless of the change in the pumping system's static head. As the discharge pressure of the system changes, PD pumps are able to provide a consistent flow rate.

Note that the operation of a centrifugal pump in a range becomes even more critical when the fluid has to be transferred from one source tank to several points or tanks

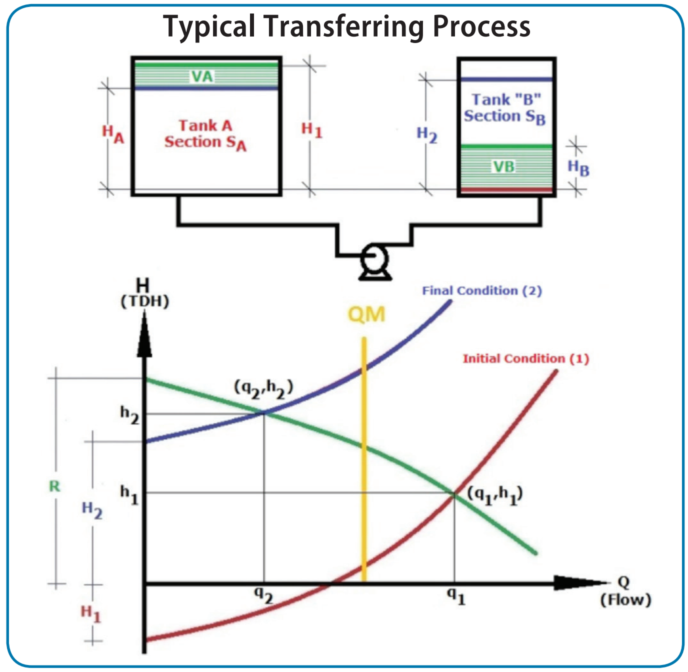


Figure 1

in the plant. In this case, the operation range will be wider and the delivery parameters will also be different from tank to tank.

Centrifugal pumps have traditionally been chosen by chemical manufacturers for transfer applications for a few reasons:

- A centrifugal pump is commonly the first choice with water-like fluids; a PD pump is usually considered when the fluid being handled is "viscous".
- It is one of the most well-known technologies that

Conditions (1) system's curve

$$H = -H_1 + c\,Q^2 \qquad \textit{(i)}$$

Conditions (2) System's curve

$$H = H_2 + c\,Q^2 \qquad \textit{(ii)}$$

Pump equation

$$H = R - M\,Q^2 \qquad \textit{(iii)}$$

General System equation:

$$H = (H_B - H_A) + c\,Q^2 \qquad \textit{(iv)}$$

Continuum mechanics, fluids incompressibility:

$$V_A = V_B$$

$$(H_1 - H_A) * S_A = H_B * S_B$$

$$H_B = (H_1 - H_A) * \frac{S_A}{S_B}$$

Replacing the value of H_B in *(iv)*

$$H = (H_1 - H_A) * \frac{S_A}{S_B} - H_A + c\,Q^2 \qquad \textit{(iv')}$$

For a generic point, *(iii)* = *(iv)* = *(iv')*, then

$$H = (H_1 - H_A) * \frac{S_A}{S_B} - H_A + c\,Q^2 = R - R * Q^2$$

Simplifying

$$R - H_1 * \frac{S_A}{S_B} + H_A\left(\frac{S_A}{S_B} + 1\right) = 2\,(c + M)\,Q^2$$

Derivative function:

$$\frac{\delta H_A}{\delta t}\left(\frac{S_A}{S_B} + 1\right) = 2\,(c + M) Q \frac{\delta Q}{\delta t} \qquad \textit{(v)}$$

Continuum mechanics, fluids incompressibility:

$$Q = -S_A \frac{\delta H_A}{\delta t} = +S_B \frac{\delta H_B}{\delta t}, \text{ and } \frac{\delta H_A}{\delta t} = -\frac{Q}{S_A} \qquad \textit{(vi)}$$

Replacing *(vi)* in *(v)*

$$-\frac{Q}{S_A}\left(\frac{S_A}{S_B} + 1\right) = 2\,(c + M) Q \frac{\delta Q}{\delta t}$$

Integration to t & Q

$$\int_0^{tf}\left(-\frac{\delta t}{S_A}\right)\left(\frac{S_A}{S_B} + 1\right) = \int_{q_1}^{q_2} 2\,(c + M)\delta Q$$

$$-\left(\frac{S_A}{S_B} + 1\right)\frac{t_f}{S_A} = 2(c + M)(q_2 - q_1)$$

$$t_f = \frac{2 S_A (c + M)(q_1 - q_2)}{\left(\frac{S_A}{S_B} + 1\right)} \qquad \textit{(vii)}$$

Evaluation of q_1 and q_2

$$-H_1 + c{Q_1}^2 = R - M{Q_1}^2 \text{ and } -H_2 + c{Q_1}^2 = R - M{Q_1}^2$$

Then

$$q_1 = \sqrt{\frac{R + H_1}{c + M}} \text{ and } q_2 = \sqrt{\frac{R - H_2}{c + M}} \qquad \textit{(viii)}$$

Replacing q_1 and q_2 in *(vii)*

$$t_f = \frac{2(c + M)\left(\sqrt{\frac{R + H_1}{c + M}} - \sqrt{\frac{R - H_2}{c + M}}\right) * S_A}{\left(\frac{S_A}{S_B} + 1\right)} \qquad \textit{(Solution)}$$

Now, for a fair and quantifiable comparison between different pumping technologies, the range of operation of the centrifugal pump and the equivalent PD pump must be fully defined (See CHART and Figure 1).

H and Q are the Total Dynamic Head and the Flow represented in the Q-H Axis chart.

When the actual curves of the system and the pump are defined, c, M, Q represent known constants of the quadratic equations. Note that to simplify the mathematical analysis, the pump curve is expressed as a second-degree curve, although depending on the nature of the impeller, this can be another polynomial or logarithmic equation.

SA and SB are the areas of source Tank A and destination Tank B, respectively.

Volume VA = Volume VB is the amount of fluid transferred.

H1, H2, R are the points where the curves intercept the "H" Axis (Q=0, or Zero Flow), which are known for a given system: H1 & H2 are static heads geometrically defined and R is a characteristic of the pump curve. HA and HB represent the final condition at a given variation in time of h.

The value tf represents the time that the PD pump has to work to deliver the same amount of fluid as the centrifugal pump does while operating in a range; since the volumes VA, VB and their changes over time (H2, H1, HA, HB) are known, QM can be simply evaluated by dividing the volume pumped by tf.

has been used and probably a device that every operator is familiar with.

- It is believed that most of the time centrifugal pumps have a lower initial cost when compared to the cost of a positive displacement pump. Note that this is not necessarily the case.

In reality, PD pumps can quantifiably counteract the supposed advantages that centrifugal pumps may have:

- Contrary to what many engineers perceive, PD pumps are not only appropriate for fluids with high viscosity. PD pumps can easily move fluids that range from liquefied gases and water-like liquids (sliding vane pump) to medium and very viscous fluids (eccentric disc and vane).
- PD technologies like vane or eccentric disc have operated successfully in the chemical-manufacturing industry for more than a century.
- Initial costs can be similar when all the equipment, accessories and controllers are evaluated, and in many cases the total cost of ownership is lower over the operational lifespan of a PD pump.

When looking strictly at the performance of a centrifugal pump in chemical-transfer applications, however, a number of red flags pop up. Centrifugal pumps work best when they are operated at their Best Efficiency Point (BEP). Unfortunately, that BEP is rarely realized for an extended period of time during fluid-transfer operations, which results in flow rates that can fluctuate constantly. Admittedly, many facility operators are willing to live with fluctuations in flow rate. However, consistent operation off the BEP can lead to potential problems, not only from the equipment's operational point of view, but also in regard to the production process and the way the chemical is formulated. Note that the system, not the pump, dictates the operating conditions the pump must work in.

In the chemical process itself, whether mixing, blending or feeding a reactor, the amount of fluid sent has to be in accordance with specific guidelines and quantities that are sometimes only known by the chemical manufacturer. In these instances, a centrifugal pump will not provide constant flow unless it is controlled with proportional-integral-derivative (PID) loops, flow meters, recirculation lines and variable speed drives that make the pumping system more complicated and include electric and electronic components that, in many cases, have to work in hazardous areas and require special NEMA/ATEX ratings.

By comparison, the rate of fluid delivery with a PD pump

Despite opinions to the contrary, positive displacement sliding vane and eccentric disc pump styles possess the capability to effectively handle the wide array of fluid types that are used in chemical manufacturing, from water-like to very viscous.

that features self-adjusted efficiency (i.e. eccentric disc and vane) will be more consistent than a centrifugal pump. In the manufacture or formulation of chemicals or other products, the use of PD pumps with self-adjusted volumetric efficiency will also provide the manufacturer with a more reliable production rate from the chemical-quality point of view. Contrary to these self-adjusted volumetric efficiency technologies, centrifugal pumps lose efficiency as the means used to separate the high-pressure zone from the low-pressure zone of the pump wears out, whether wear rings, the internal casing tongue known as the "cutwater," or the impeller-casing clearance present in open-impeller pumps.

Also, when a centrifugal pump operates to the left of its performance curve, radial loads increase due to the way the pump generates pressure along its volute by reducing the fluid velocity (this is one of the reasons low-flow ANSI pumps have a circular volute). This method of operation will increase shaft deflection at the seal faces, increasing seal wear and adversely affecting the pump's life expectancy. Working to the left of the curve will also increase axial loads that can potentially overload the thrust bearings, especially in open-impeller and diffuser-type multi-stage centrifugal pumps. Finally, as a centrifugal pump operates close to the zero-flow point (zero efficiency), heat will be generated in levels that can be highly harmful to heat-sensitive chemicals or products themselves, which can also negatively affect safety.

At the other end of the spectrum, when a centrifugal pump works to the right of its performance curve other problems can be created. Specifically, the level of net positive suction head (NPSH) required increases, which may cause cavitation to occur. Since the fluid-transfer process in the chemical industry, particularly when handling specialty chemicals, is managed in batches, an insufficient NPSH condition may be more complicated to detect, but it will deteriorate the pump's operational capabilities continuously, meaning that the pump's ability to handle any cavitation that occurs will be compromised. Other potential performance-robbing concerns for centrifugal pumps in chemical-transfer applications include:

- Mechanical issues, mainly caused by vibration, when the pump is working off its BEP. Note that these vibrations will also tend to reduce the mechanical seal life, which is an expensive component of the centrifugal pump.
- Overheating due to low-flow operation
- Product leakage along the pump shaft due to shaft deflection (overhung impellers)
- Inability to run-dry. This is even more critical when centrifugal pumps are magnetically driven and the internal lubrication is performed by the pumped media. Running dry can result in a catastrophic failure for a magnetically driven pump.
- Inability to strip lines
- Inability to self-prime; pump must be filled with fluid in order to operate
- Susceptibility to cavitation from entrained gases
- Fluid-handling capabilities of the pump are affected, sometimes dramatically, with changes in the viscosity of the fluid, which can occur due to modifications and adjustments in the process, or simply by changes in temperature

Make no mistake, centrifugal pumps are perfectly acceptable options in a wide array of fluid-transfer applications—and have been proven to perform reliably for many years. The goal here is to point out that there is a better, more efficient, more reliable option for many of the fluid-transfer operations that occur in chemical manufacturer.

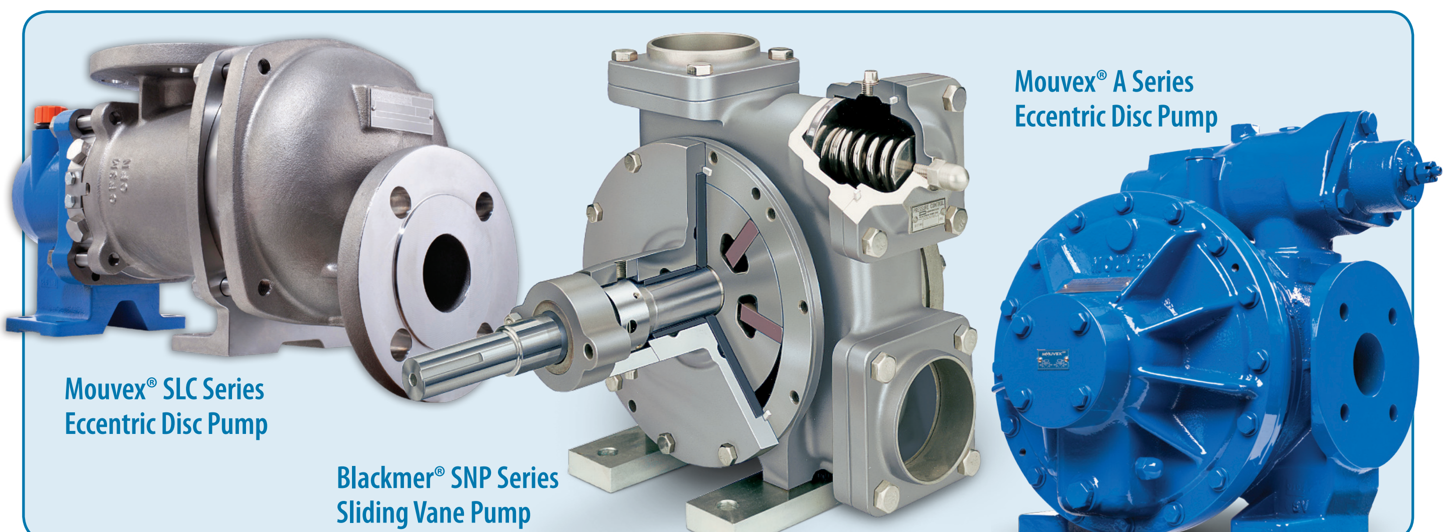
The Solution

The case is being made for PD pumps over centrifugal pumps. Unlike centrifugal pumps, the design of PD pumps allows them to produce a constant flow at a given speed, no matter what the discharge pressure is. In other words, PD pumps are constant-flow machines, which is critical in chemical-manufacture applications that may require precise dosing rates.

Specifically, two types of PD pump technologies have the capability to outperform centrifugal pumps in chemical fluid-transfer applications:

Sliding Vane. The design of sliding vane pumps features a series of vanes in the pump rotor that slide out as they wear, which means that the pump is able to deliver volumetric consistency throughout its operational life, or until the vanes wear to a point that they need to be replaced. Sliding vane pumps also offer zero shaft leakage (magnetic coupling), non-galling operation, stainless-steel or ductile-iron construction for versatility in handling corrosive liquids, chemical-duty mechanical seals, low-to-medium shear and agitation, and self-priming and dry-run capabilities, even in an explosive ATEX or hazardous environment.

Eccentric Disc. This pump technology features a disc that is placed inside a pump cylinder. The disc is driven by an eccentric bearing that is installed



on the pump shaft. This creates four distinct pumping chambers that increase and decrease in volume as the disc is rotated by the eccentric bearing, producing both suction and discharge pressures as the chambers move in pairs that are 180 degrees apart. This ingenious method of operation ensures that the fluid passes through the pump at a constant and regular flow rate. This style of operation also eliminates any possibility of pulsation within the pumped fluid, and since the pump does not depend on clearances to facilitate product flow, any slip or loss in volumetric efficiency is negligible. Additionally, with the no-mechanical-seals option, there are no surfaces present where products that are difficult to seal and prone to crystallization can adhere and cause damage, which eliminates a maintenance concern.

Because of the sliding vane or eccentric disc pump's method of operation, the list of benefits that they can offer fluid transfer in chemical manufacture is extensive:

- The PD pump delivers constant flow across the range of pressures that the pumping system may require, which is critical in chemical production. Centrifugal pumps, on the other hand, require extra sensors and a variable frequency drive (which are an added cost) to achieve this capability, which also makes installation more complicated.
- PD pumps deliver low-shear operation, another crucial consideration when handling many raw materials in chemical production
- Sliding vane and eccentric disc pumps can run dry and strip discharge lines, which is very important when different chemical compositions are being run through the same pumps. Centrifugal pumps, if they are run dry for too long, will fail catastrophically.
- As the level of the suction or source tank goes down, there is a high possibility that air or vapor will get introduced to the suction of the pump, which may substantially decrease the delivery of the pump; note that centrifugal pumps are designed to work with non-compressible fluids, while some PD pumps, such as sliding vane, can work to some levels with compressible fluids.
- Overall, PD pumps are much more operationally efficient

One drawback of rotary PD pumps is that they aren't capable of operating against a closed valve on the discharge side of the pump because it has no shutoff head. This potential problem is overcome, however, with the placement of a relief/safety valve on the discharge side of the pump.

The chart below illustrates a real-world example of total cost of operation for a PD pump against two models of competitive centrifugal pumps. As mentioned, initial cost is often a main reason why chemical manufacturers will choose centrifugal pump technology over a PD pump for their fluid-transfer applications.

While the initial cost of a PD pump could be a few hundred dollars more than a centrifugal pump, the monetary savings through the first five years is truly eye-opening. Because the PD pump relies on less horsepower to operate, the annual operating cost for the PD pump can be nearly 60% lower than that of the more inefficient centrifugal pump. Because of this, the total cost savings that are realized when a PD pump is used instead of a centrifugal pump increase significantly as the years progress.

Evaluation of the range of operation of a centrifugal pump and the equivalent PD pump:

Pump Type [1]	Operating Cost (Yr.) [2]	1st Year	2nd Year	3rd Year	4th Year	5th Year
Positive Displacement	$1,548 [3]	$1,548	$3,096	$4,644	$6,191	$7,739
Centrifugal Model #1	$3,808	$3,808	$7,616	$11,424	$15,232	$19,040
Centrifugal Model #2	$4,032	$4,032	$8,064	$12,096	$16,128	$20,160

Notes:

(1) Pump types compared are: PD Sliding Vane from Blackmer®; Centrifugals are ANSI B73.1, from various manufacturers.

(2) Yearly Operating Cost is based on 3,000 hours of operation at a rate of $0.1 per kWh, or $223 per pump horsepower.

(3) This example is based on the following performance parameters for the PD Pump: 126 gpm at 80 psig; Centrifugals: Range 114 gpm at 190 feet and 130 gpm at 165 feet. As previously stated, in a transferring process a centrifugal will work in a range. Please see combined operation in Figure 2 (Page 6).

Fluid pumped is an aqueous solution: Sp.Gr 1.0 at 300 SSU.

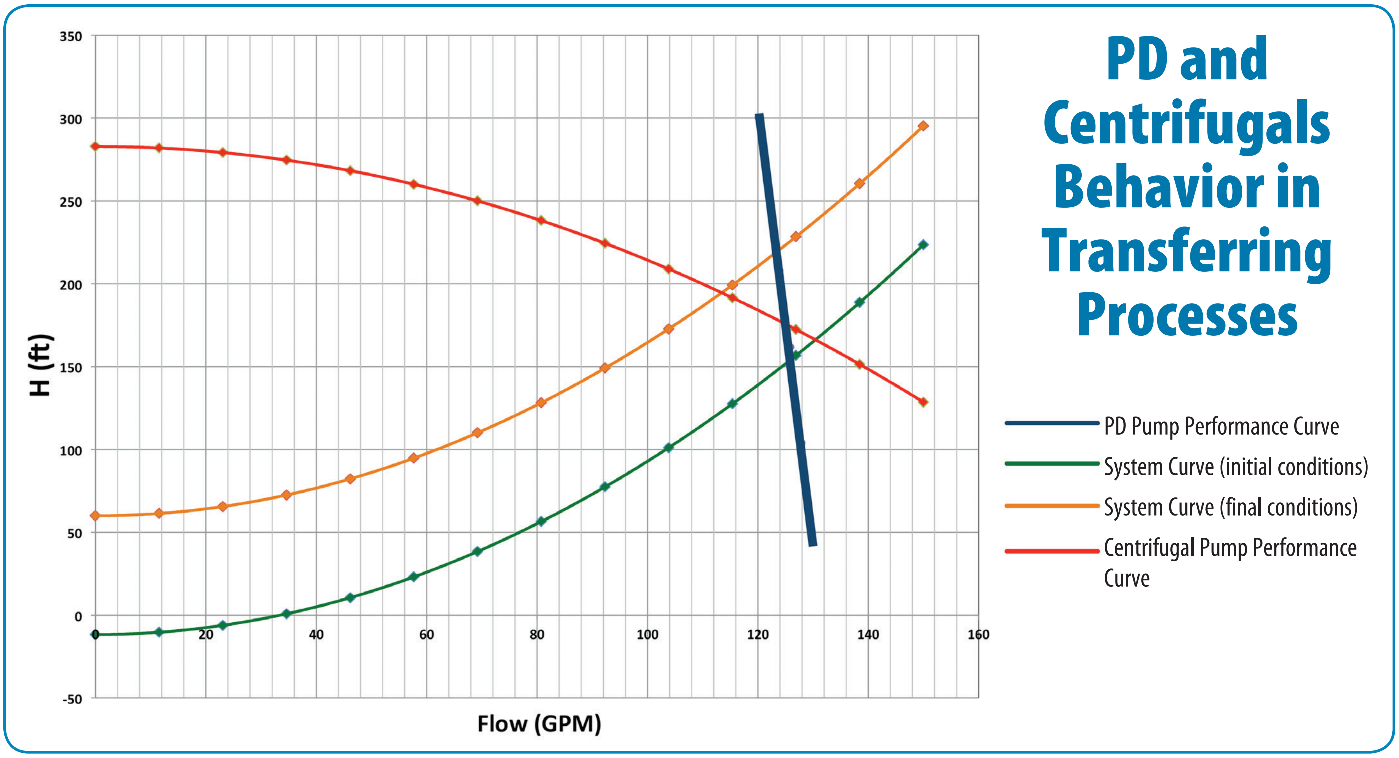


Figure 2

Conclusion

In these days of rapidly tightening operating budgets, finding those extra dollars to save in operational costs are worth their weight in gold. For years, centrifugal pumps have proven to be reliable workhorses in many aspects of chemical manufacturing, but when the fluid-transferring process is looked at specifically, the benefits of centrifugal pump performance begin to wane. That's why, for fluid transfer in chemical manufacturing, open-minded plant operators should be willing to consider PD pumps for their fluid-handling needs. Their overall design and method of operation make them ideal for a wide array of transfer applications, while they will also help optimize the bottom line.

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