Positive Displacement Pumps Best Suited For Liquid-Transfer Applications

CENTRIFUGAL PUMPS HAVE A LONG HISTORY OF USE IN PROCESSES AND LIQUID TERMINALS, BUT POSITIVE DISPLACEMENT PUMP TECHNOLOGY CAN BE A BETTER CHOICE FOR TRANSFERRING LIQUIDS

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Among the many complex operations within manufacturing or liquid storage, "transferring" might be the most important as it has responsibilities across the processes and terminals. That's why operators and engineers would be wise to consider employing positive displacement pump technology, rather than centrifugal, for their numerous fluid-transferring applications.

Introduction

Pumping applications can range from being simple – fluid transferring operations that move product from one tank, container or truck to another – to complex and sensitive, such as chemical manufacturing and refining operations.

Because of the importance of the pumping process in the myriad transferring operations in the industry, 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 centrifugal pump has been the go-to pumping technology for transfer processes, but this white paper will show why positive displacement pumps can be the right pump technology for the right application in transfer operations.

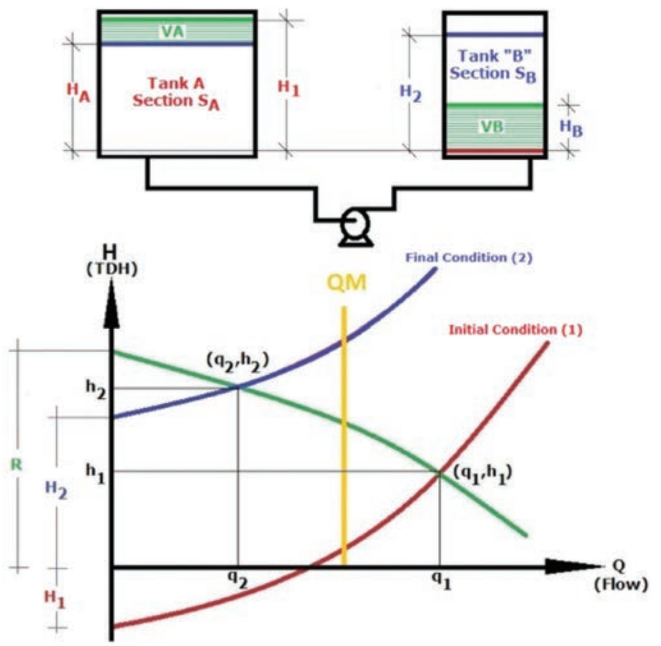
The Challenge

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 occurs, flow could be considered constant and the only variable in the hydraulic system is the static head that will change as the level in Tank A decreases while the level in Tank B increases.

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. In practice, however, 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 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 must do to deliver the same volume at the same time as the centrifugal pump would when operating in a specific range. Also, PD pumps, and particularly the ones with self-adjusting volumetric efficiency capabilities (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 provide a

FIGURE 1



consistent flow rate.

Note that the operation of a centrifugal pump in a range becomes even more critical when the fluid must be transferred from one source tank to several points or tanks in the plant or terminal. In this case, the operation range will be wider and the delivery parameters different from tank to tank.

Centrifugal pumps have traditionally been chosen for transfer applications by engineers, operators, facilities and terminal managers, and chemical manufacturers. A deeper analysis of their reasons might reveal that centrifugal technology is not always the best choice. Some common reasons for choosing centrifugal technology are:

- 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 (authors differ in defining what the appropriate value to consider a PD pump is but usually centrifugal pumps work reasonably well with fluids with viscosities lower than 300 SSU or 65 cSt; obviously to make the best decision there are other considerations such as materials of construction or metallurgy of the pump, regulations, required standards, efficiency, total cost of ownership, etc., among others.
- It is one of the most well-known pumping technologies that many operators are familiar with.
- It is believed that most of the time centrifugal pumps have a lower initial cost when compared to the cost of a PD pump.

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

- PD pumps are appropriate for more than high viscosity fluids. Some 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, vane, gear or screw, among others).

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.

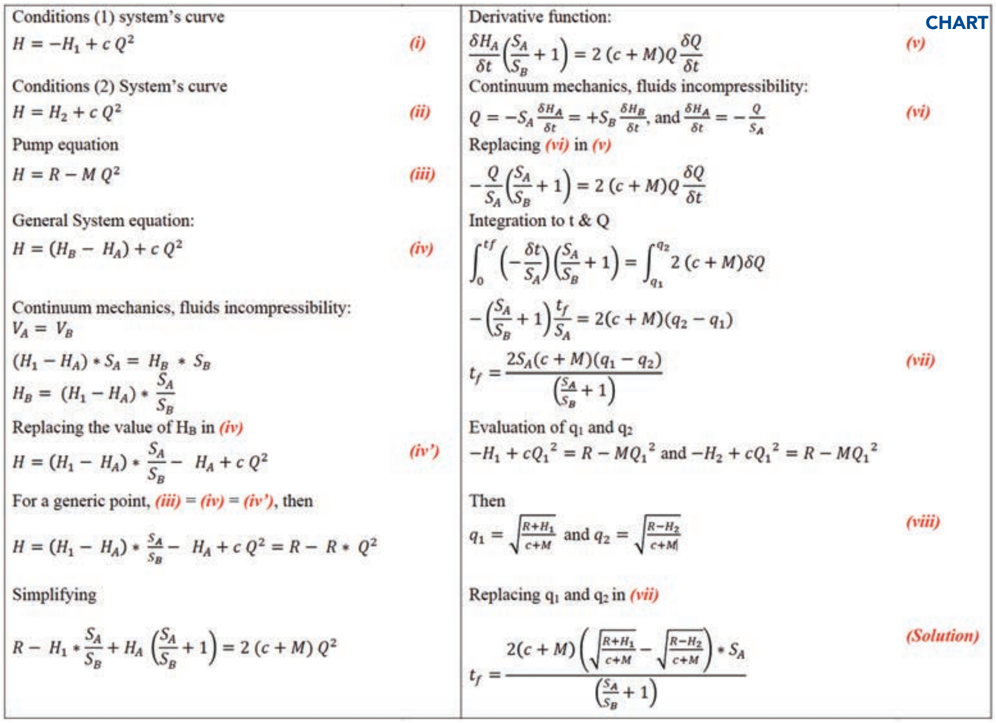
SA and SB are the areas of source Tank A and destination Tank B, respectively.

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 must 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.

CHART



Conditions (1) system's curve

$$H = -H_1 + c\,Q^2 \tag{i}$$

Conditions (2) System's curve

$$H = H_2 + c\,Q^2 \tag{ii}$$

Pump equation

$$H = R - M\,Q^2 \tag{iii}$$

General System equation:

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

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)*

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

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:

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

Continuum mechanics, fluids incompressibility:

$$Q = -S_A\frac{\delta H_A}{\delta t} = +S_B\frac{\delta H_B}{\delta t}, \text{ and } \frac{\delta H_A}{\delta t} = -\frac{Q}{S_A} \tag{vi}$$

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

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

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

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

Evaluation of q_1 and q_2

$$-H_1 + cQ_1{}^2 = R - MQ_1{}^2 \text{ and } -H_2 + cQ_1{}^2 = R - MQ_1{}^2$$

Then

$$q_1 = \sqrt{\frac{R+H_1}{c+M}} \text{ and } q_2 = \sqrt{\frac{R-H_2}{c+M}} \tag{viii}$$

Replacing q_1 and q_2 in *(vii)*

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

- PD technologies have operated successfully in the industry for more than a century.
- Initial costs can be similar when all the equipment, accessories and controllers are evaluated. In many cases, the total cost of ownership is lower over the operational lifespan of a PD pump.

However, when looking strictly at the performance of a centrifugal pump in transfer applications, there are several red flags. Centrifugal pumps work best when operating at their Best Efficiency Point (BEP). Unfortunately, that BEP is rarely maintained for an extended period during fluid-transfer operations, which results in flow rates that can constantly fluctuate. Admittedly, many facility operators are willing to live with fluctuations in flow rate. However, consistent operation below the BEP can lead to potential problems, not only regarding equipment's functionality but also with the production process and the way a product is formulated or stored. Note that the system, not the pump, dictates the specific point of operation (flow and head) of a centrifugal pump.

In processes, whether mixing, blending or feeding a reactor, the amount of fluid sent must be per specific guidelines and quantities that are sometimes only known by the user or 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, work in hazardous areas and require special NEMA/ATEX ratings.

By comparison, the rate of fluid delivery with a PD pump 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 or transfer process from tank to tank in a liquid terminal, the use of PD pumps with self-adjusted volumetric efficiency will also provide the user with a more reliable rate from the product quality point of view and the operating times of the terminal. 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 ("cutwater") or the impeller-casing clearance present in open or semi-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 use 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 products, 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 arise. Specifically, the level of net positive suction head (NPSH) required increases, which may cause cavitation. Because fluid-transfer operations in process or liquid terminals are managed in batches, an insufficient NPSH condition might 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 transfer applications include:

- Mechanical issues, mainly caused by vibration when the pump is working away from its BEP. Note that these vibrations will also tend to reduce the mechanical seal life, which is an expensive component of the centrifugal

Positive displacement pumps possess the capability to effectively and efficiently handle a wide array of fluids that are used in processes and stored in liquid terminals, from water-like to highly viscous.

pump, and its replacement/repair will likely increase the equipment downtime.

- 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 almost every magnetically driven pump. When talking about seal-less magnetically driven sliding vane pumps, there is a new design that allows indefinite dry run; this is especially important for top unloading, dry prime, suction lift, pipeline strip or to empty the source tank without baffles that reduce the potential formation of vortexes that could induce air or vapor to the suction of the pump. These conditions on other magnetically driven pumps, regardless of the technology, could be catastrophic.
- Inability to strip lines.
- Inability to self-prime; pump must be filled with fluid to operate.
- Susceptibility to cavitation from entrained gases.
- Fluid-handling capabilities of the pump are affected, sometimes dramatically, by changes in the viscosity of the fluid, which can occur due to modifications and adjustments in the process, or simply by changes in temperature

This is not to say centrifugal pumps are inadequate. They are proficient in a wide array of fluid-transfer applications—and have been proven to perform reliably for many years. The goal is to identify a better, more efficient, more reliable option for many of the fluid-transfer operations that occur in processes or storage terminals.

The Solution

HXL - 10" Blackmer® (VANE)

PD pumps are a better option than centrifugal pumps for fluid-transfer applications. 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 the liquid terminal and process markets. For this document, there are three types of PD pump technologies that outperform centrifugal pumps in transfer applications:

MAGNES 4" – Blackmer®
(VANE - Magnetically driven)

Sliding Vane. Sliding vane pumps feature a rotor with a series of vanes that retract and slide out as the rotor turns. This sliding motion creates chambers into which the liquid flows, and as the rotor turns, the liquid is moved to the outlet where it is discharged as the pumping chamber compresses. Each revolution of the rotor displaces a constant volume of fluid with little chance for slippage. Variances in pumping pressure have little effect on the sliding vane pump's flow rate, and the open flow profile provides a gentle and shear-sensitive environment within the pump.

The operation of a sliding vane pump allows it to deliver volumetric consistency throughout its operational life. They also have a wide range of liquid-handling capabilities, being able to process ultra-thin liquids (0.2 cP) up to those with a 22,500 cP thickness without affecting their performance. These pumps also don't need lubrication, allowing them to handle liquids with or without lubricating properties.

Sliding vane pumps also offer zero shaft leakage with a magnetic-coupled model, 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 that also allow the strip of the pumping lines, even in an explosive ATEX or hazardous environment.

G-FLO – Mouvex®
(ECCENTRIC DISC)

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 eccentric bearing rotates the disc, producing 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. Because 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.

G Series – EnviroGear®
(GEAR)

Gear. The principle of the gear pump is simple. Fluid is transferred by the gears from the low-pressure suction zone to the high-pressure discharge zone of the pump. The seal between these two areas is achieved by the contact of the gears themselves and the crescent present in the head. Bushings and other critical areas get lubrication from the pumping media. For these reasons, gear pumps are preferred and highly effective at pumping fluids with medium-to-high viscosity up to 50,000 cP. With appropriate clearances, gear pumps can be used to pump thin fluids down to 5 cP. Mechanical seals are not necessary for proper functionality as gear pumps can be magnetically driven. Hardened internal materials can be specified if abrasives or high-pressure operations are required. This well-known pump technology is found not only in processes but also in several operations in manufacturing plants as well as loading and unloading operations. With a long history of adoption in multiple applications, as well as its ease of operation and maintenance, operators have selected this technology for their fluid-transfer needs time and time again.

Here is a summary of the benefits that PD pumps offer when transferring fluids:

- The PD pump delivers constant flow across the range of pressures that the pumping system may require, which is critical in processes and storage terminals. Centrifugal pumps, meanwhile, require extra sensors and a variable frequency drive (an added cost) to achieve this capability, which also makes installation more complicated.
- PD pumps like eccentric disc, gear, lobe, progressive cavity or vane, deliver low-shear operation, another crucial consideration when handling many raw materials that are sensitive to this effect.
- Sliding vane and eccentric disc pumps can run dry and strip discharge lines, which is very important when different products are processed through the same pumps. Centrifugal pumps, if they are run dry for too long, will suffer catastrophic failure.
- As the level of the suction or source tank decreases, there is a high possibility that air or vapor will get introduced to the suction of the pump, which could substantially decrease the delivery of the pump; note that centrifugal pumps are designed to work with non-compressible fluids, while some PD pumps (sliding vane or some screw pumps) can work with compressible fluids or a mix of liquid-gas.

  When a liquid-gas is the actual product, technologies like vane, screw or regenerative turbine* (peripheral or lateral) should be evaluated.

  *Regenerative turbine pumps are rotodynamic but are not part of the centrifugal family; its performance curve more closely resembles PD pumps than centrifugal.

R81 – Ebsray®
(REGENERATIVE TURBINE)

- Overall, PD pumps are much more operationally efficient

One drawback of rotary PD pumps is they can't operate 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. Even with a relief valve in place, it is not recommended to run a PD pump indefinitely against a closed discharge valve.

The chart *(on the next page)* illustrates a real-world example of the total cost of operation for a PD pump against two models of competitive centrifugal pumps. As mentioned, the initial cost is often the main reason why chemical manufacturers, process engineers or terminal operators and managers will choose centrifugal pump technology over a PD pump for their fluid-transfer applications.

S Series - Blackmer®
(TWIN SCREW)

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 remarkable. 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 exponentially as the years progress.

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

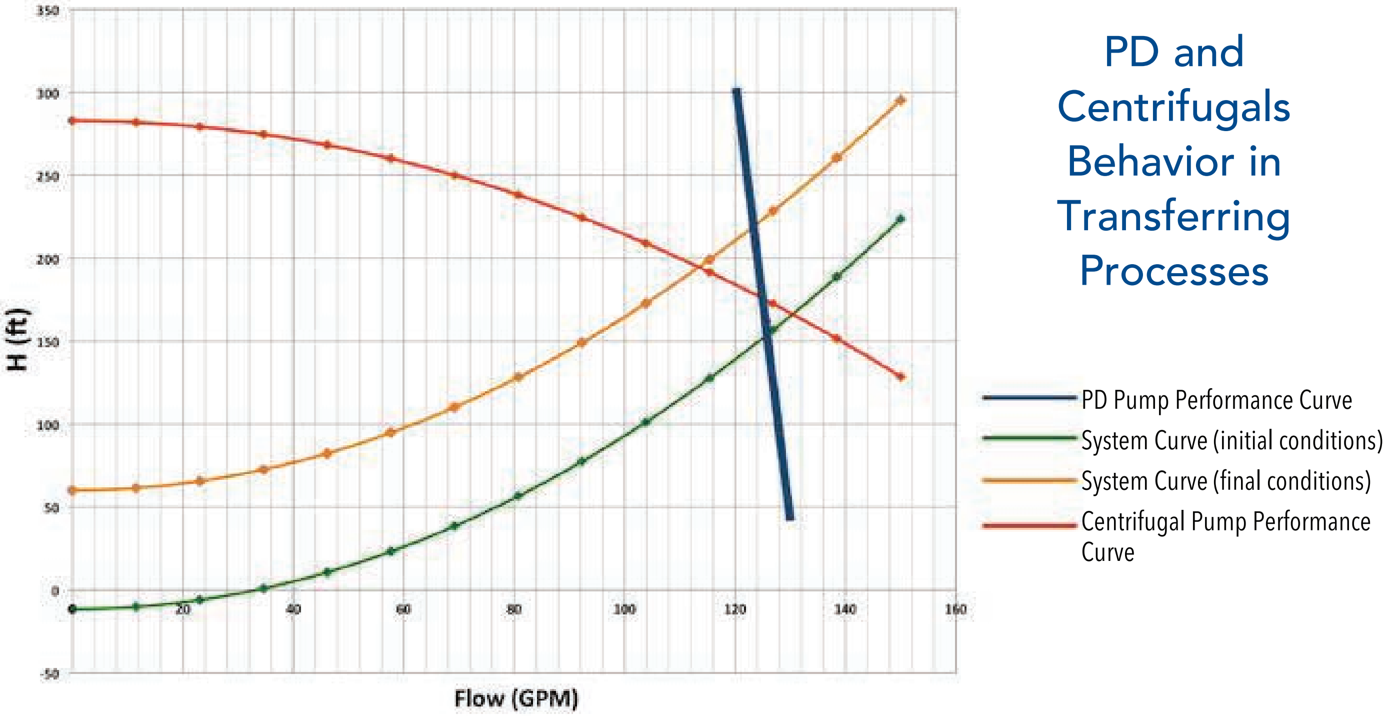
PUMP TYPE[1]	OPERATING COST (YR.)[2]	1ST YEAR	2ND YEAR	3RD YEAR	4TH YEAR	5TH YEAR
Positive Displacement	$1,548[1]	$1,548	$3,096	$4,644	$6,191	$7,739
Centrifugal Model #1	$3,808	$3,808	$7,616	$11,424	$15,232	$19.040
Centrifugal Model #2	$4,032	$4,032	$8,064	$12,096	$16,128	$20,160

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

With a trend of tightening operating budgets, finding those extra dollars to save on operational costs is worthwhile. For years, centrifugal pumps have been reliable workhorses in many aspects of manufacturing and storage terminals, 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 needs, 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 and help optimize the bottom line.

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