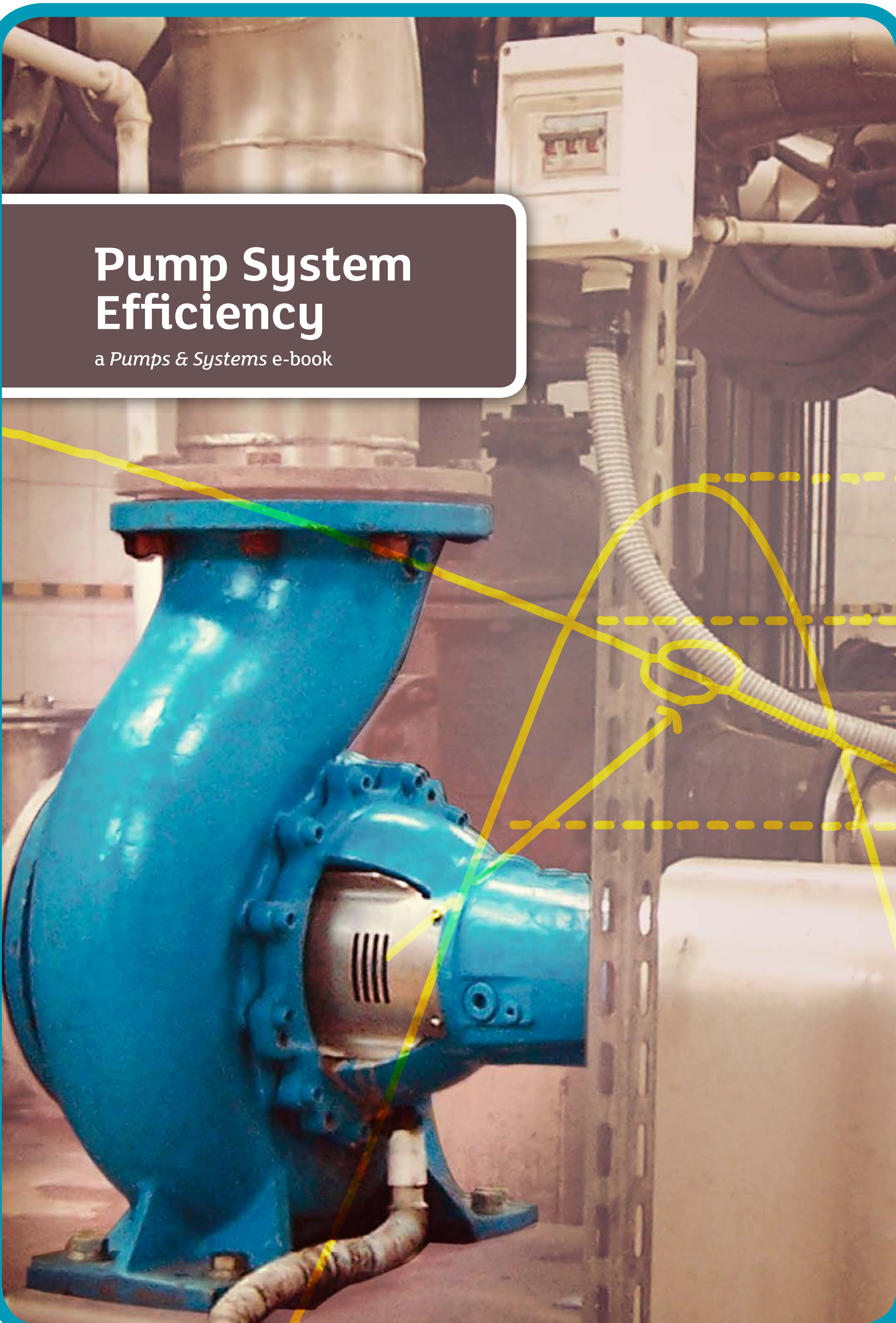
Pump System Efficiency

a *Pumps & Systems* e-book



Pump Efficiency

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How to Optimize Centrifugal Pump Operation

First of Two Parts

By **Amin Almasi**

Centrifugal pumps are commonly used for most liquid pumping services. For viscous liquids, positive displacement pumps often perform better; however, many engineers specify positive displacement pumps for services where centrifugal pumps would be more effective.

Some engineers believe the technology offers better flexibility or more operational advantages without considering the specific application.

The truth is that variable-speed centrifugal pumps can effectively handle many medium-viscosity liquids—even those with suspended solids or other contaminants.

Centrifugal pumps can safely handle liquids with between 7 and 15 percent contamination if special design measures are implemented, such as corrections to the pump curves.

In terms of reliability, pump curves deserve more attention no matter the nature of the application. During the selection process, plotting an application's operating points can mean the difference between saving and losing money.

Best Efficiency Point

The best efficiency point (BEP) is the most stable operating condition for a pump. If a pump operates away from the BEP, the resulting unbalanced load increases.

The load usually peaks at shutoff, at which point long-term operation can reduce pump component life and reliability.

Pump design usually determines the best operating range, but pumps should generally operate within 80 percent to 109 percent of the BEP. This range is more ideal than practical, and most operators should decide on an optimized operating range before selecting a pump.

The net positive suction head required ($NPSH_R$) often restricts a pump's operating range with regard to its BEP. At flows significantly higher than the BEP, a significant pressure drop within the suction passages and piping will dip below the $NPSH_R$ level. This pressure drop can result in cavitation and damage to the pump.

As pump components wear and degrade, new clearances are opened. The pumped liquid begins to recirculate more often compared with new pumps. Recirculation can have a harmful impact on the pump's efficiency.

Operators should examine pump curves with respect to the whole operation. Pumps operating in a closed-loop or recycling service should operate close to BEP or about 5 to 10 percent to the left of the BEP. Based on my experience, closed-loop systems have less attention paid to their pump performance curves.

In fact, some operators fail to check alternative operating points or the recycling flow ranges on the pump curve. Recycle service flow can vary widely, which is why operators must locate and evaluate all possible operating points on the pump curve.

Extreme Operating Points

In batch transfer services, pumps move liquid from vessels or tanks with varying liquid levels at the suction and discharge. The pumps fill the vessel or tank at the discharge and empty liquid at the suction. Some batch transfer services require control valves, which can significantly change the differential pressure.

The pump head constantly changes, but the rate of change could be high or low.

Batch transfer services have two extreme operating points, one for the highest head and another for the lowest head. Some operators mistakenly match a pump's BEP with the operating point at the highest head, forgetting other head requirements.

The selected pump will operate to the right of the BEP, providing unreliable and inefficient performance. In addition, the pump is bigger than actually required because the pump train is sized so the operating point with the highest

Pump design usually determines the best operating range, but pumps should generally operate within 80 percent to 109 percent of the BEP.

head is near the BEP.

At the lowest head operation point, the wrong pump selection will result in more power consumption, lower efficiency, more vibration, shorter seal and bearing life and less reliability. All these factors contribute to significantly higher initial and operational costs, including more frequent unscheduled shutdowns.

Find the Mid-Point

Optimal pump selection for batch transfer services depends on locating operating points at the highest head to the left of the BEP and at the lowest head to the right of BEP.

The resulting pump curve should include operating points that account for several additional factors, including $NPSH_R$. The pump should operate near the BEP most of the time—roughly, the mid-point between the highest and lowest head.

Generally, all operating points should be identified and the pump operation should be evaluated for all possible operating points.

An important consideration would be the pump operation and an estimation of the pump operating point on the pump curve, when the pump is slightly degraded. For some pump applications, such as batch transfer services, with great differences between the highest and the lowest head points, variable-speed centrifugal pumps should be used. ■

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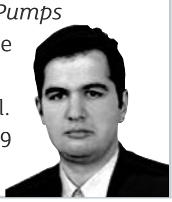

CENTRIFUGAL PUMPS are a popular choice in many plants because they are simple and reliable, and have a light-weight and compact design. Increased use of centrifugal pumps in many applications, such as process applications, in recent decades has occurred for four reasons:

- Advances in the centrifugal pump seal technology
- Modern hydrodynamic and rotordynamic knowledge and modeling
- Advanced manufacturing methods to produce accurate rotating parts and complex components with reasonable costs
- The ability to simplify the control through the use of modern control technology, particularly modern variable speed drives (VSDs)

How to Optimize Centrifugal Pump Operation

Second of Two Parts

By **Amin Almasi**

Incorrect piping can result in hydraulic instability and cavitation in a pump system, among other problems. To prevent cavitation, the focus should be on the suction piping and the suction system design. High levels of noise and vibration could be caused by cavitation, internal recirculation and air entrainment—damaging conditions for seals and bearings.

Pump Recycle Line

When a centrifugal pump—particularly a small pump—must operate at different operating points, a recycle line can return some of the pumped liquid. The pump can continue to operate efficiently and reliably at the best efficiency point (BEP). Recycling liquid wastes some power, but the amount can be insignificant for a small pump.

A recycled liquid should be routed back to the suction source instead of the suction line. Suction line connections can cause turbulences at the pump suction, resulting in operational problems and even damage. The recycled liquid should be routed back to the other side of the suction tank instead of the pump suction intake point. Often, a suitable baffling plate arrangement or other similar design can ensure recycling without turbulence.

Parallel Operation

Multiple smaller pumps in parallel operation are often necessary when a single large pump is not available for some high-flow applications. For example, some pump manufacturers may not supply a pump frame large enough for a high-capacity pumping unit. Some services require an operating flow range so wide that a single pump cannot function economically. For these services where the power rating is high, the recycling or operation of a pump far from its BEP can result in significant power waste and reliability issues.

When pumps operate in parallel, each pump produces a lower flow rate compared with that pump when operated alone. When two identical pumps operate in parallel, the total flow is less than two times each pump's flow. Despite particular application needs, parallel operation is often employed as a last solution. In many cases, for example, two pumps in parallel operation are preferable to three or more, if possible.

The parallel operation of pumps can be a risky and unstable operation. Pumps for parallel operation require careful selection and delicate operation and monitoring.

Each pump curve needs to be similar—within 2 to 3 percent of tolerances. The combined pump curve must remain relatively flat.

Pump Piping

Poor piping design will easily translate into high pump vibration, bearing problems, seal issues, premature failure of pump components or catastrophic failures. Suction piping is particularly important because the liquid should arrive at the pump impeller eye with the right pressure and temperature, among other operating conditions. Smooth, uniform flow will decrease the risk of cavitation and lead to reliable pump operation.

Piping and passage diameter has a significant effect on head. As a rough estimate, the pressure loss from friction would be inversely proportional to the fifth power of the pipe diameter.

For example, a 10 percent increase in the pipe diameter could result in about 40 percent reduction in the head loss. In the same way, an approximately 20 percent increase in the pipe diameter could result in a 60 percent reduction in the head loss.

In other words, the frictional head loss would be less than 40 percent of the head loss at the original diameter. The importance of net positive suction head (NPSH) in pumping applications makes pump suction piping design a significant factor.

The suction piping should be as simple and straight as possible, with minimum overall length. A centrifugal pump should usually be provided with a straight run of about six to 11 times the suction piping diameter to avoid turbulences.

A temporary suction strainer is generally required, but a permanent suction strainer is usually discouraged.

Low flow—usually lower than 50 percent of BEP flow—results in several hydrodynamic problems, including noise and vibration from cavitation, internal recirculation and air entrainment.

Reducing $NPSH_R$

Piping and process engineers sometimes attempt to reduce the NPSH required ($NPSH_R$) compared with an increase in the NPSH available ($NPSH_A$). Reducing $NPSH_R$ is a difficult and costly process with few options because $NPSH_R$ is a function of the pump design and the pump speed.

Impeller eye and overall pump size are important considerations for pump design and selection. A pump with a larger impeller eye can offer a smaller $NPSH_R$.

However, a larger impeller can result in some operational and hydrodynamic issues, such as recycling problems. Slower pumps usually require less NPSH; faster pumps require more.

Pumps equipped with specially designed large-eye impellers could result in high recirculation issues, lowering efficiency and reliability. Some low-$NPSH_R$ pump designs feature such low speeds that the overall efficiency is not economical for the application. These low-speed pumps also suffer from a low reliability record.

Large, high-pressure pumps suffer from physical site constraints, such as the pump location and the suction vessel/tank arrangement, that prevent end users from finding a pump with an $NPSH_R$ to fit the limits.

In many renovation projects, the site layout cannot be changed, but the site still requires a large, high-pressure pump. In these cases, a booster pump should be used.

A booster pump is a smaller, low-speed pump with a low $NPSH_R$. The booster pump should offer the same flow rate as the main pump. A booster pump is usually installed in close proximity upstream of the main pump.

Determining the Cause of Vibration

Low flow—usually lower than 50 percent of BEP flow—results in several hydrodynamic problems, including noise and vibration from cavitation, internal recirculation and air entrainment. Some pumps can resist suction recirculation instabilities at very low flows, sometimes as low as 35 percent of BEP flow.

For other pumps, the suction recirculation could be seen at about 75 percent of BEP flow. The suction recirculation can result in some damage and pitting, usually at around halfway along the pump impeller vanes.

Discharge recirculation is a hydrodynamic instability that can also be seen at a low flow. This recirculation can occur from improper clearances at the discharge side of the impeller or impeller casing. This also results in pitting and other damage.

Vapor bubbles in the liquid stream can result in instability and vibration. The cavitation usually damages the eye of the impeller. The noise and vibration from cavitation may be similar to other malfunctions, but a pump inspection at the location of pitting and damages on the pump impeller can usually reveal the root cause.

Gas entrainment is commonly seen when pumping liquids close to their boiling point or when complex suction piping encourages turbulence to occur. ■

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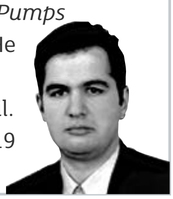

Efficiency Monitoring Saves Plants Millions

Editor's Note: *While running a pump at its best efficiency point (BEP) saves money, reduces downtime and improves performance, many plant managers are unaware of how their equipment is actually performing. The following real-world scenario is intended to illustrate the importance of monitoring pump efficiency.*

By **Lev Nelik, Ph.D., P.E.**

Jim, a maintenance manager at a municipal water plant, was content. His plant was operating smoothly, and his pumps seemed to be running as designed. He was pleased to see Bob, a pump rep, walk in with a box of doughnuts in hand to talk about the efficiency of the plant's pumps.

"Jim, these are for the guys at the shop. How are the pumps doing?"

"Doing fine, Bob. That spare mechanical seal you sold us is still in my office, ready to go if anything goes bad. But so far—knock on wood—all is well."

"Good to hear, Jim. I must say, we do make good pumps. But I've noticed that it's been a long time since we've done any major repairs for you. Have you checked to see if your pumps are still efficient?"

"They are very efficient. They're pumping water nonstop."

"That's not what I mean, Jim. Do they burn too much energy?"

"Too much energy? I have no idea. All I know is that they run well—no vibration, no leaks, so no trouble for me."

Bob opened the pump catalogue. "See, Jim, these pumps should be nearly 90 percent efficient, according to our books. But it's been a few years now, and these pumps wear. That makes them take more power than they should."

"Really? Just after four years? It's basically clean water we're pumping."

"That's true, Jim. But why not check it anyway? These are 3,000-horsepower (hp) motors. Guess how much it costs you to run them."

"Bob, all I know is that they run all day long and don't fall over. That's all I care about. And whatever we pay to run them, go talk to Charlie in accounting. I have enough to deal with."

Bob pulled out his calculator.

"Okay, but just for kicks, say your 3,000-hp motor runs nonstop. That's about 2,238 kilowatts. If you run them 24 hours for 365 days, you get—let's see— 19,604,880 kilowatt-hours, which, at 10 cents per kilowatt-hour, makes it nearly $2 million!"

Impressed by the amount of money the pump uses but content after two doughnuts and a hot cup of coffee, Jim agreed to allow Bob to measure the pumps' energy consumption using his pumps reliability and efficiency monitoring system (PREMS) technology.

This monitoring system would provide the plant with live, nonstop equipment data at any office computer.

Pulling his car to a main water booster pump, Bob and the plant mechanic, Rusty, attached instrumentation to the device. The vibration and temperature transducers had mag bases and took little time to install on the bearing housing.

For the pressure, they teed off the existing gauges. Flow and power already had output signals on the plant distributed control system (DCS) controllers, and they connected output to that. The system was up and running just before lunch.

"Hey, Jim. My system is collecting data from the instrumentation and will send the gateway signal wirelessly to the cell. From there, our software will transform it into a live pump performance curve and compare it with the original manufacturer curve. I haven't had a chance to analyze it, but if you want, we can take a quick look at it at lunch."

"Sounds good, Bob. Show me what you've got."

At lunch, Bob opened his laptop and pulled up the pump data using the wireless software. Pointing to the solid line that represents expected performance—pump head, power and efficiency curves versus flow—and comparing it with the dashed line representing the pump data gathered that morning, he explained that Rusty asked the operators to throttle the valves to force the pump to run at various flow rates. While the piping system limits the flow to about 40,000 gallons per minute (gpm), the data they took covered the entire flow range.

"Well, that was quick, Bob. You did all that quickly!"

"Sure. Thanks to Rusty, who helped with some wrenches, and the fact that you already have a magnetic flow meter, we simply connected our 4-20 mA leads to your output DCS terminals."

"You are paying about $2 million for this pump running nonstop. Divide $2 million by 100 and you get roughly $20,000 per efficiency point. For 13.5 points, that is more than a quarter of a million dollars wasted per year if you run it nonstop."

While the original curve indicated a best efficiency point (BEP) at 40,000 gpm, the day's data indicated a BEP at 35,000 gpm.

The data also showed lower head, which indicates lost pressure, and increased power.

"Sounds like you might have some wear—maybe rings opened up or some internal rub—which will take more power."

"How much is all that costing?"

"Well, I added a tabulation near the curve there. See, at 40,000 gpm, you should have 255 feet of head, and you've got 227 feet. That is an 11 percent reduction in pressure. The power should be 2,900 hp, and you are actually taking 3,045 hp. Seems like you're running into a motor safety factor. I wouldn't be surprised if your motor starts tripping pretty soon."

"What? Are you kidding? This is almost a brand new motor! You sold it to us about four years ago with the pump!"

"We did, Jim. But we told your engineers at that time to up size the motor a bit—to 3,500 hp instead of 3,000 hp—in case something like this happens. All that aside, your efficiency at 40,000 gpm is 75.3 percent versus the 88.8 percent it should be."

"Really? And?"

"That is a 13.5 percent difference. Remember what I told you? You're paying about $2 million for this pump running nonstop. Divide $2 million by 100 and you get roughly $20,000 per efficiency point. For 13.5 points, that is more than a quarter of a million dollars wasted per year if you run it nonstop."

"But we don't run nonstop. We probably run, on average, about 10 to 12 hours per day."

"That's still $125,000 per year—wasted."

Jim took off his baseball hat and scratched his head.

"Charlie sure won't be happy to hear that. But if I tell him, I know what he will ask: How much would it cost to fix it?"

"Well, based on our previous repair, you'll probably need new wear rings, a new shaft, bearings and maybe an impeller. I'd say that's probably a $100,000 job."

"And that would save us $125,000 a year? So, roughly a one-year payback?"

"That sounds right."

"Interesting. Our budget is tight this year, but let me talk to our guys on this and I'll get back to you. Thanks for coming, Bob." ■

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Read more from Lev Nelik at **pumpsandsystems.com/pumpingprescriptions**.

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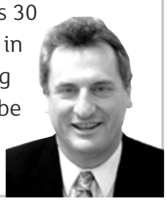


Check the Math: NPSH Problem Corrected to Optimize Pump System

Proper calculations generate additional power.

By **Kristo Naude**
NRG Energy & Turbomachinery Laboratory

The rising cost of electrical power has caused many industrial plants to shift their focus to energy consumption. Plants often run pumping equipment continuously, and much research has pointed to opportunities for cost savings by optimizing pumping equipment.

When evaluating the potential for energy savings, end users cannot consider a pump in isolation. The suitability of the pump for the system within which it operates is vital.

Even the best designed and most efficient equipment offers power-saving potential if it is run off its best efficiency point (BEP) in a system for which it is ill-applied.

Many plants have been in operation for more than 40 years, and their operating philosophies have changed over time. Plant improvements have enabled higher throughput, often increasing production by as much as 125-150 percent.

Unfortunately, little has been done to improve or increase the performance of the support-service pumping equipment, such as cooling water pumps.

As system flow demands increase, the duty point of the pumps is forced to shift far to the right of the BEP, well outside the acceptable operating range (AOR). This causes efficiency and pump reliability to decrease dramatically.

Casting tolerances, surface finishes, and impeller/volute or impeller/diffuser geometry have dramatically improved over the last 40 years. But because many pumps were installed when plants were commissioned, existing pumps were manufactured using techniques that would be considered obsolete today.

The result is higher energy costs and reduced reliability and availability, which often cause production delays.

The Starting Point

Pumps react to changing system conditions. System demand (or system resistance) determines the flow and pressure at which a pump will operate. As system flow demand increases, the flow throughput of a pump also increases, causing it to operate further on the right-hand part of the performance curve.

The system demand is graphically represented by plotting the system resistance curve as a function of flow. This curve enables the end user to quickly determine system flow for a given pump since the pressure and flow are determined by the intersection of the pump performance curve (red) with the system head curve (green). (See Figure 1, page 10.) A process design engineer would ideally select a pump with an operating point that would have coincided with the BEP. This could yield a pump efficiency of 80 percent, also shown in Figure 1.

However, many support pumping systems have exceeded their original design and have much higher flows to support the higher plant production. This is particularly common in cooling water applications, condenser water pumps, descale pumps or any application where water use is proportional to production.

While the original design may have called for two-pump operation, present-day requirements may require 2 ½ pumps online, with two pumps being insufficient and three pumps too many. As flows increase, the result is usually that system requirements have exceeded the AOR of the pumps (see Figure 2, page 11).

Original Duty Point

The original system design for one processing plant's service water pumps was to have three pumps operating in parallel with an

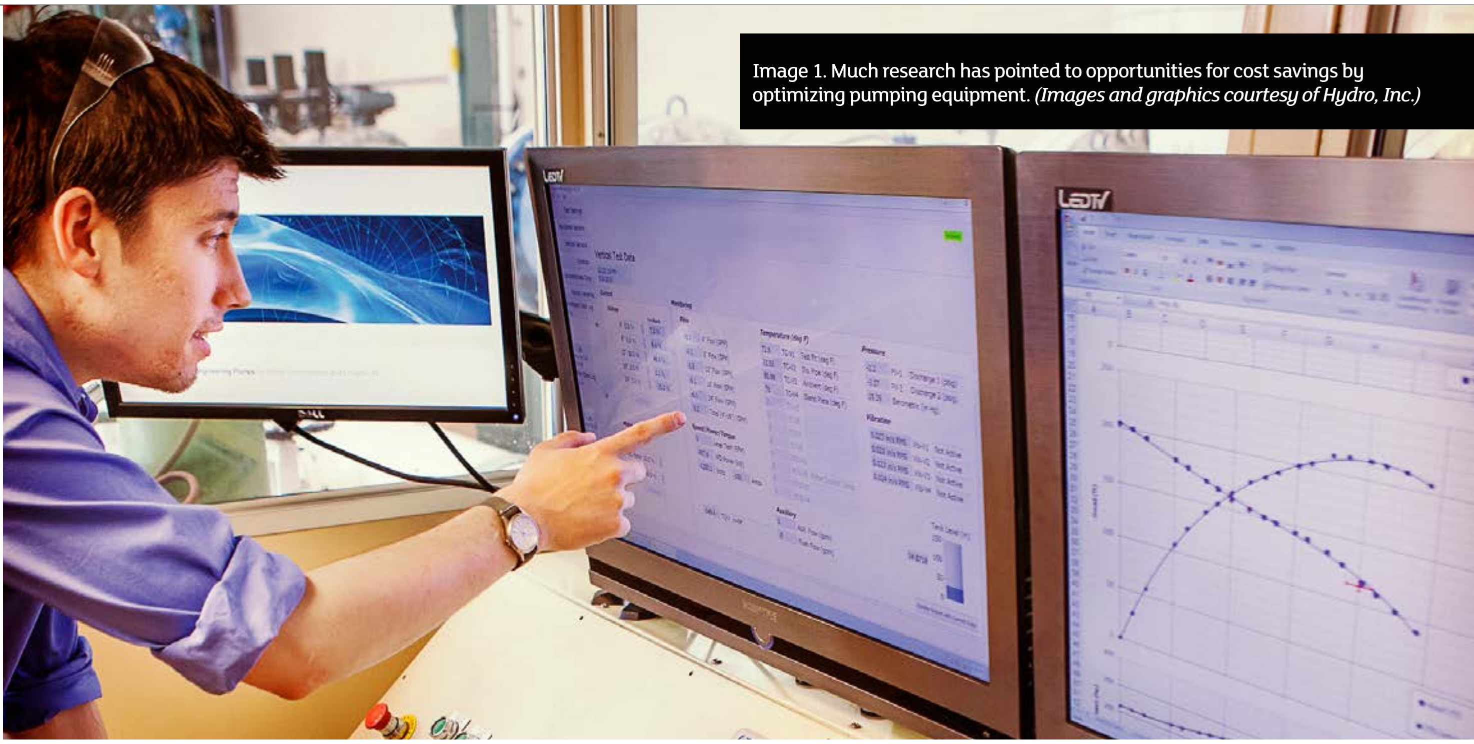


Image 1. Much research has pointed to opportunities for cost savings by optimizing pumping equipment. *(Images and graphics courtesy of Hydro, Inc.)*

installed spare as a standby. The total system requirement was 105,000 U.S. gallons per minute (gpm) (23,864 cubic meters per hour) at a pressure of 190 feet (57.9 meters) total dynamic head (TDH). Each pump was rated for 35,000 gpm (7,955 cubic meters per hour) at 190 feet (57.9 meters) TDH.

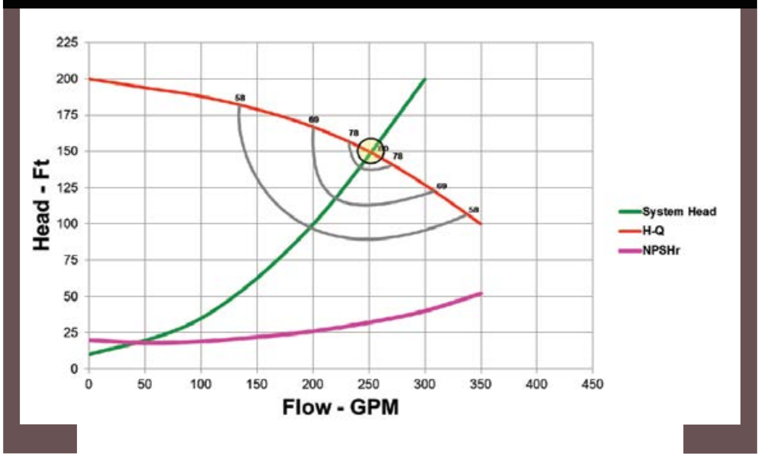
As production increased, more service water was required, causing the existing pumps to operate further to the right of the performance curve.

This caused the net positive suction head required ($NPSH_R$) to exceed the NPSH available ($NPSH_A$), leading to severe cavitation issues.

To reduce cavitation problems, the plant ran four pumps in parallel and throttled each pump to keep the individual pump flows low enough to prevent cavitation.

Over time, the design of the impellers also drifted away from optimal because no testing or verification of performance took place. Cavitation and insufficient service water continued until the pumping station could not keep up with plant demand.

Figure 1. Pump and system curve interaction



As Figure 3 (page 11) shows, field pump assessments and subsequent individual performance tests conducted on the poorly replicated impellers showed that the pump performance had been dramatically compromised.

New Impeller Design

The technological advances made in recent years with reverse engineering, laser digitizing equipment, computation fluid dynamics (CFD) software and the ability to print 3-D foundry molds from computer-aided design/ computer-aided modeling (CAD/ CAM) software has revolutionized the aftermarket industry. Solutions that were cost-prohibitive five years ago are now within the realm of financial feasibility.

The solution helped manufacturers and end users solve their energy optimization difficulties in three ways:

1. **Capture system resistance data and operating conditions.** The plant's pumps operated at different flow conditions. Understanding how these flow requirements matched the system's resistance enabled an optimized design flow to be derived that would ensure that head was not generated by the pump to be dissipated over a control valve, so the number of pumps running was optimized for the demand.
2. **Capture the geometry of the existing impeller using advanced laser-scanning equipment and build a CFD model of this impeller.** This allows design scenarios to be evaluated to get the optimized design for the newly established flow conditions.
3. **Use additive manufacturing in the form of 3-D foundry sand printers and casting simulation software to drastically reduce lead-time and overhead normally associated with pattern/core box sand casting processes.**
   The 3-D printing process directly from the design data ensures that the integrity of the design is completely captured. The high accuracy of sand printing means that vane-to-vane symmetry and vane shape are identical. Sand printing also offers improved casting surface finish. These manufacturing measures alone can lead to a 3 percent efficiency increase.

Tables 1-3 show the before and after energy use, based on projected energy audits. In addition to energy savings, improved reliability and availability translates to extended mean time between repairs, significantly reducing maintenance costs.

Table 1. Original system

Measurement	Per Pump	Per System
GPM	40,000*	160,000*
TDH	185	185
Efficiency	0.74	0.74
Brake horsepower	2,525	10,101
kilowatts (kW)	1,884	7,536
Hours per year	8,400	8,400
kW rate	$0.07	$0.07
Total energy cost per year	$1,107,792.00	$4,431,168.00

* Note: Four pumps online throttle to prevent cavitation

Figure 2. Pump performance curve interaction based on different system requirements

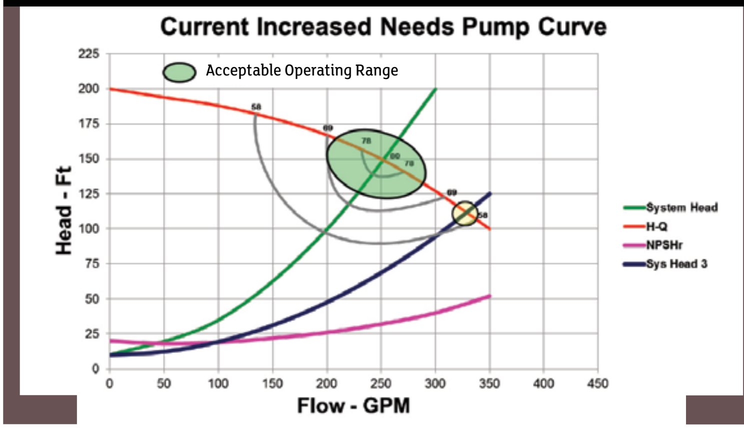


Figure 3. Pump performance test data illustrating performance degradation

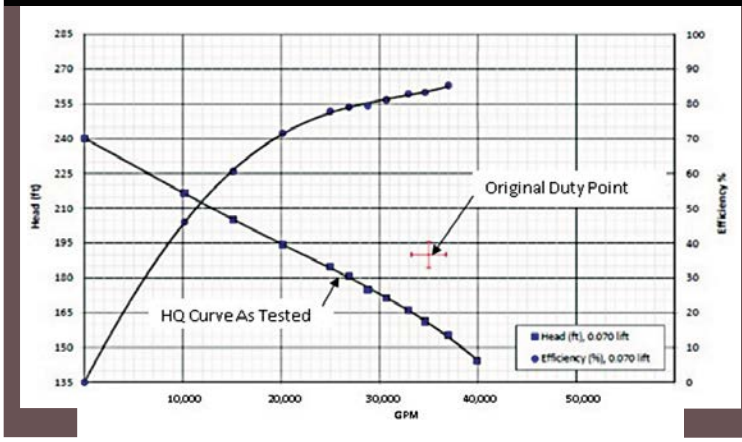


Table 2. Newly designed system		
Measurement	**Per Pump**	**Per System**
GPM	48,333*	144,999*
TDH	160	160
Efficiency	0.89	0.89
Brake horsepower	2,194	6,582
kW	1,637	4,911
Hours per year	8,400	8,400
kW rate	$0.07	$0.07
Total energy cost per year	$962,556.00	$2,887,668.00

* Note: Three redesigned pumps online

Table 3. Total projected energy savings for the system	
Energy Costs - Original (Present)	$ 4,431,168.00
Energy Costs - New Impeller Design	$ 2,887,668.00
Impeller Design and Manufacturing Costs for 4 impellers	$ 390,000.00*
Total Savings	**$ 1,153,500.00**

* Number excludes the regular repair cost(s) normally incurred for this equipment.

With reverse engineering, laser digitizing equipment, CFD software and rapid prototyping coupled with the ability to print 3-D foundry molds directly from CAD/CAM software, the end user is no longer required to limp along with an obsolete pumping system.

Conclusion

Significant energy saving opportunities exist in every manufacturing facility worldwide, particularly pumping systems that:

- Use pumps driven by 200 horsepower (hp) and above
- Are primarily providing cooling water
- Include demands proportional to the plant throughput
- Are used for batch operations
- Have inherent delays or production slowdown
- Use dump valves or bypass lines
- Feature fluctuating system loading

In the past, pump upgrades or rerates tended to lie strictly with the OEM because they were the only party with access to cost-effective cast parts. However, with the technology revolution taking place in the aftermarket, upper tier service centers with on-staff hydraulic engineering support can often provide cost-effective, newly designed impellers or volutes with solutions specifically designed for the application.

With reverse engineering, laser digitizing equipment, CFD software and rapid prototyping coupled with the ability to print 3-D foundry molds directly from CAD/CAM software, the end user is no longer required to limp along with an obsolete pumping system. Solutions are readily available and well within the realm of financial feasibility. ■

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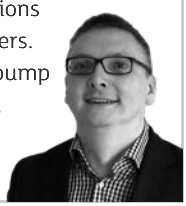

Check the Math: NPSH Problem Corrected to Optimize Pump System

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Editor's Note: This case study is provided by a pump advisor for Turbomachinery Lab at Texas A&M where students are exposed to hands-on experiences, providing them pump training in the field. In this article, students learn the importance of doing the math.

Image 1. Long suction piping from horizontal tank in background. (*Images courtesy Kristo Naude)*

A call came from a regional engineering manager in a Connecticut-based facility two winters ago, inquiring about an operational issue with a No. 2 fuel oil pump feeding a power generation boiler. It would not pump like it should.

The problem had a sudden onset, which coincided with a dramatic flow rate drop, increased vibration, loud noises and overheated pump case.

This was all amid a cold spell, when it was necessary to generate additional power.

After some discussion about the layout and the symptoms, the "why" became clear. The cold weather caused the viscosity of the fuel oil in the long, outdoor suction line to increase until the net positive suction head required (NPSHr) by the pump could no longer be met. It was an NPSH problem.

A site visit was required to assess what to do about this NPSH inadequacy. The problem was evident. Whereas best practices guidelines would contain wording such as "keep the distance between the suction tank and pump as short as possible," this layout was different. Compounding the problem, no source for heat tracing of the 260-foot suction line (electrical or steam) was readily available.

The only practical solution was to either replace the entire suction line with a larger diameter line or to install a second, parallel suction line to reduce the friction head loss.

Both options would carry a price tag of more than $100,000. There was no easy solution. More research was needed.

To determine the appropriate diameters required for each option, the system was modeled using pump and pipe hydraulic modeling software. An unexpected problem arose—despite the increased viscosity and the long suction line, the impact on NPSH available (NPSHa) was still such that the margin (NPSH3) required by the pump could not be met.

Clearly, this was not correct. The team thought a computer error had to be responsible. The calculation was run by hand, and the software output result was confirmed. Then, in researching the behavior of No. 2 fuel oil further, the tendency of the fuel oil to wax, or gel, in extremely cold conditions was discovered.

And that was the real problem. The viscosity did not only increase to the point that friction head losses became excessive, but the exposed pipe wall temperature had dropped low enough to allow the fuel oil to develop wax against the inner pipe wall and propagate radially inward. The slow-flowing liquid in the pipe had lost enough heat to reduce the active hydraulic diameter of the pipe further, to the extent that NPSH3 could no longer be met.

The plan was to increase the suction line capacity to reduce friction losses, which would slow the linear velocity in this line down even further. This would increase fluid residence time even more, and thereby further increase the tendency and opportunity to wax.

A double suction, two-stage pump was used to provide No. 2 fuel oil to the boiler (see Image 2 and 3).

Since the flow rate required by the boiler was low, yet the pump dynamic head required high, the boiler flow rate constitutes an uncomfortable duty for a centrifugal pump—even for pumps with low specific speeds. It was found that the boiler flow rate was the only flow through the pump, at 25 percent best efficiency point (BEP). The minimum flow recirculation (routed back to the fuel oil tank) was essentially inoperative, because a pressure relief valve was ineffective in a flat part of the curve and the activation pressure had been set too high. The preferred option (an in-line flow meter) was not available.

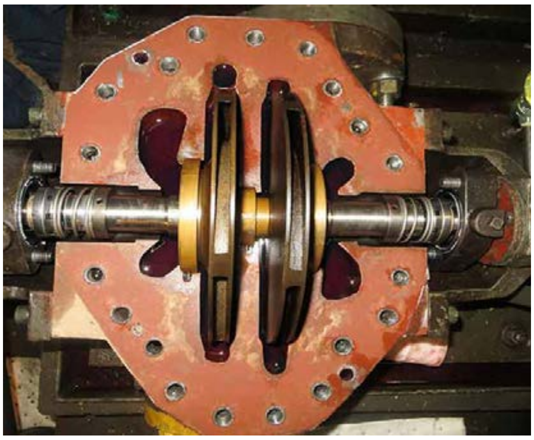

Image 2. Lower half of a double suction, two-stage pump

With the pump operating at only 25 percent BEP and the minimum flow recirculation line inactive, the optimal solution also became apparent.

Contrary to first instinct, the solution was not to increase the suction line diameter and capacity to decrease friction head losses, but the exact opposite: increase the flow rate and linear velocity.

A small modification would be required to activate the minimum flow recirculation by opening a bypass valve to an appropriate setting on a permanent basis to act as a minimum flow orifice. The residence time would be reduced and heat loss to the environment reduced, such that waxing would be delayed.

System modifications in this scenario are not too difficult to implement. The solution would have two-fold benefits: NPSHa will be improved and the operating point on the pump performance curve will improve, and reliability of the centrifugal pump improved as a direct consequence.

Once the math was calculated and the optimal solution determined, a win-win solution was determined:

Residence time in the suction pipe exposed to the cold was reduced, thereby reducing the risk of waxing.

The pump minimum flow recirculation was now activated and functional, such that the pump would run closer to 65 percent BEP. This was a significant improvement over the former 25 percent.

Major reliability improvements were made possible for minimal investment.

It is important to note not only the technical details of this problem and its solution, but also to realize how easy it is to make inaccurate assumptions and to draw incorrect conclusions.

Use facts to draw conclusions. In this case, initial assumptions would have caused the implementation of a modification that would have guaranteed failure.

The major lesson learned here is to do the math. It is less expensive than the results of a mistake, and easier on future career aspirations. ■

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