Operating

Centrifugal pumps: avoiding cavitation

Cavitation has been identified as one of the leading causes of reduced reliability in centrifugal pumps. Joseph Askew examines the causes of cavitation and discusses real-world solutions to correct them. The same troubleshooting techniques can also be applied at the design stage to prevent cavitation from the outset.

I have the privilege of conducting pumps and pump systems seminars throughout the USA. ‘What can be done about my centrifugal pumps that cavitate?’ is one recurring question that seems to come up quite often. Let’s first review exactly what cavitation is.

NPSH and cavitation

Centrifugal pumps must have a certain amount of absolute fluid energy at the pump inlet/suction to function correctly. We designate this energy, expressed in feet, or metres using the metric system, as the net positive suction head required, or NPSHR. In the USA, NPSHR is determined by the pump manufacturer in their hydraulic laboratory under the guidelines established by the Hydraulic Institute (HI). Above the liquid’s vapour pressure, pumps receive this required absolute energy from the system to which the pump is attached, and we designate this absolute system energy as the net positive suction head available (NPSHA).

When NPSHA does not exceed NPSHR then our system has reached that point where the absolute pressure of the fluid is less than the fluid’s vapour pressure. At that point the fluid begins to experience a change of state from a liquid to a vapour, and begins to vaporize and boil. Vapour bubbles formed within the pump impeller continue through the impeller, moving to areas of higher and higher pressure within the pump until they collapse under sufficient pressure, returning to the liquid state. This change of state is a violent reaction causing small jets of liquid at extremely high localized pressure. The jets impinge on the impeller surfaces like a water jet cutter, blowing small portions of metal from the impeller surface. The implosion of these bubbles happens thousands of times per minute. Each little bubble implosion impinging on the metal causes the metal to fatigue and flake off. The results can be low-frequency vibration and noise (sounding like rocks or marbles in a jar), with damage potential being extensive, including eating holes through impellers, chipping mechanical seal faces and causing bearing failure. This classic phenomenon is called cavitation.

Now that we are experiencing classic cavitation, what can we do to reduce, eliminate or prevent it? This challenge is broken down into the two major categories that cause cavitation, where the system’s NPSHA is less than the pump’s NPSHR. First let’s see what options are available to possibly reduce NPSHR, before considering ways to boost NPSHA.

Plan A: lower NPSHR impeller

Many pump manufacturers will offer optional lower NPSHR impellers for a given pump. These impellers will generally have a larger inlet eye area (Figure 1), thus lowering the absolute energy required to prevent cavitation. Typical installations where we see such impellers used might be vertical turbine hot-well condensate pumps where the first-stage impeller might be a low NPSHR impeller. Another service where we might see a low NPSHR first-stage impeller would be the handling of liquid ammonia or any other high vapour pressure fluids that have a low system NPSHA.

If your existing pump does not offer an optional impeller with a lower NPSHR, then a similar yet more aggressive approach is discussed in Plan B next.

Plan B: larger pump

Consider reducing the NPSHR by installing a larger pump operating at a slower speed, which typically results in a larger inlet eye area that can lower the NPSHR. Albeit a more costly response, many times this can cure your cavitation woes.

Plan C: inducer

Some pump manufacturers will offer an option that will replace the impeller nut (for keyed-on impellers) with a device that looks like a wine corkscrew or a packing puller, known as an inducer. This inducer (Figure 2) is basically a high
suction specific speed axial flow impeller that acts like a small pre-impeller or booster pump at the impeller inlet driving the liquid into the pump, thus reducing the NPSHR. Not every pump manufacturer offers this device but it is worth investigating as an option.

**Option #2 – increase system NPSHA**

The NPSHA is the sum of all absolute energies at the inlet of the centrifugal pump and must be greater than the pump’s NPSHR. This section will outline how to use the NPSHA formula as a troubleshooting diagnostic tool to reduce or eliminate cavitation and maybe even prevent cavitation when designing systems. Let’s first review where this NPSHA comes from and how we define and determine the formula for calculating this value.

### Calculating NPSHA

Absolute energies at the pump inlet come from a variety of system sources. For this discussion we are only interested in what is happening at the inlet of the pump and thus we will focus our attention on the pump suction side of our system. Referring to Figure 3 we will define our system terms:

- \( h_{atm} \) = atmospheric pressure converted to feet of liquid
  - Always an energy credit working for us.
- \( h_p \) = gauge pressure in the suction tank converted to feet of liquid
  - This number will be positive if a positive pressure exists.
  - This number will be negative if a vacuum exists.
  - For an open tank \( h_p = 0 \).
- \( h_{el} \) = static liquid level height, in feet of liquid, relative to the pump suction
  - This number will be positive if the liquid level is above pump suction.
  - This number will be negative if the liquid level is below pump suction.
- \( h_f \) = friction/exit/entrance/all losses incurred in the suction line
  - This negative value at the pump inlet is always an energy loss and is subtracted from our net energies.
- \( h_{vp} \) = vapour pressure of the pumped fluid determined at the pumping temperature
  - This value will always be subtracted from the net available energies because if the net energies equal the vapour pressure we know that the system will cavitate.

The NPSHA is the total sum of all absolute system energies at the pump suction.

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NPSHA = h_{atm} + h_p + h_{el} - h_f - h_{vp}
\]

Note that head in feet = \((\text{psi} \times 2.31)/SG\), where SG is the fluid’s specific gravity at the pumping temperature.

Confirm that the NPSHA is sufficiently more than the NPSHR at your pumping conditions, and you are good to go. The ratio of NPSHA to NPSHR is known as the NPSH margin. Many have simply used a margin of 2 ft as safe enough: \(\text{NPSHA} > \text{NPSHR} + 2\) ft. Your safety margin should be determined by the plant process service. The HI’s guide to NPSH margin values suggests that general industrial pumps should have an NPSHA margin of 1.3 \(\times\) NPSHR as a minimum. The HI recommends that high suction energy pumps have margin values as high as 1.6 \(\times\) NPSHR, which can be quite difficult to attain.
Energy, the environment and economics

The MDS Conference will examine the developments within motor driven systems that impact upon energy and the environment and will also address the potential economic implications.

"Delegates will leave with an improved awareness of the benefits of system design and control, the ability to apply this in the real world and see energy savings which equate to cost savings"... STEVE SCHOFIELD Technical Director - BPMA

"This conference comes at a good time with new efficiency regulations for fans and other products about to be released"... MIKE DUGGAN Technical Director - FETA

"The fact that motor driven systems comprise 40% of the world’s total electricity consumption is a strong enough reason to examine what can be done to make energy savings"... STEVE BRAMBLEY Deputy Director - GAMBICA

"Delegates will hear presentations on Legislation, Standardisation, Strategy and Technologies and learn how other industries are tackling the challenges"... CHRIS DEE Executive Director - BCAS

"BEAMA is delighted to be working with the other Trade Associations to provide a comprehensive view of these potentially complex applications."... JOHN PARSONS Project Director - BEAMA
Investigate NPSHA components

We can investigate the NPSHA components to help reduce, eliminate or prevent cavitation by improving system NPSHA. We have five system-related NPSHA components that can cause cavitation. Let us break this into the individual items for a diagnostic tool that will help to reduce, eliminate or prevent centrifugal pump cavitation by improving system NPSHA.

Item #1: investigate $h_{atm}$
There is nothing that we can do to improve atmospheric pressure, $h_{atm}$. What you’ve got is what you’ve got, short of relocating your operating plant to a region of lower elevation on mother earth to gain additional atmospheric pressure.

Item #2: investigate $h_p$
For an open suction tank, the gauge pressure ($h_p$) at the liquid’s surface is 0 psig. If you are in cavitation mode, consider enclosing and pressurizing your tank to some level that will remediate your cavitation problem.

For a closed tank, consider increasing the existing pressure in the tank. Anything you can do to increase this component of the NPSHA should improve your cavitation.

Item #3: investigate $h_{el}$
The height of the liquid level relative to your pump’s suction is a key component to improve NPSHA and reduce cavitation, or the threat of cavitation. Raise the liquid level in your supply tank. In extreme cases where cavitation is severe, I have known facilities to add additional height to their tank to increase the liquid level height.

Item #4: investigate $h_f$
Look hard at your suction piping. Increase the line size to reduce your friction component. Straighten out the line and reduce the number of bends in the suction to reduce the friction. Replace the standard elbows in your suction line with long-radius elbows. Valves in the suction line should be low friction loss valves such as ball valves and not globe valves, which have a high friction loss. Clean out the suction strainers. Do whatever you can to minimize the friction in your suction line.

Item #5: investigate $h_{vp}$
The vapour pressure is the fluid’s internal pressure attempting to change the state from a liquid to a vapour. Vapour pressures are very temperature dependent especially at elevated temperatures. Lowering the

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fluid’s temperature will lower its vapour pressure and improve your NPSHA and thus reduce your cavitation.

Whatever you can do to improve any or several of these components can improve your NPSHA and reduce or eliminate your cavitation problem.

OK, you have done all that you can with your pump to improve its NPSHR and your system has been tweaked to increase the NPSHA, and you still have cavitation with damage to your pump. What now?

**Option #3 – construction materials**

This third option will not help you to eliminate or prevent cavitation but it might help you to reduce the damaging effects of cavitation on your pump. Bronze, cast iron or any other of the softer metals are poor material candidates for cavitating pumps, especially for the impellers. You will want to select harder materials; at the least, use 316 SS impellers, which are available from most pump manufacturers as a standard optional material. Upgrading to 11–13% chrome, CD4MCU, stellite coated, 28% chrome iron or other hard impeller surfaces will better resist cavitation damage. When dealing with very hot liquids, say above ~180°F (82°C), or high vapour pressure liquids, then I will always recommend in the design phase of a project that my clients consider as insurance the hardest material available for the pump in question.

**Conclusion**

Cavitation has been identified as one of the leading causes of reduced reliability in centrifugal pumps. Insufficient absolute system energy at the pump suction (NPSHA), as compared to the energy required by the pump (NPSHR), results in cavitation and reduced pump reliability. Presented here have been two main options to reduce, eliminate or prevent cavitation, with a third option to minimize the effects of cavitation if options 1 and 2 prove unsuccessful. I trust that these diagnostic techniques will help you in your efforts to improve your pumps and pumping systems to make them function better with less maintenance and cost.

**References**


**About the author**

Joe Askew provides fee-based consulting on pump selection, pumping systems analysis, pump system troubleshooting and pump/hydraulics training. He has more than 30 years of pump field experience.